PHYTOREMEDIATION: PLANTS IN ENVIRONMENTAL POLLUTION MONITORING: A REVIEW

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***ABSTRACT*:** Phytoremediation is a new technique for cleaning up polluted areas that is cost-effective, has cosmetic benefits, and can be used for a long time. The technology entails the effective use of plant species to naturally eliminate, detoxify or immobilise toxins in a growth matrix (air, water, soil, and sediments). The current concern is soil and water pollution, as well as erosion, which are serious issues from both an environmental and agriculture standpoint. A quantity of toxic heavy metals that entails serious toxic effects on all life forms Changes in soil properties and biological activity are caused by organisms. Environmental contamination is being caused by anthropological practices such as the use of organic fertilisers, pesticides, and rapid industrialization. These actions contaminate and degrade the soil, air and water. These practices have an effect on plant growth and production. The emphasis of this study was on how different forms of toxins, such as heavy metals and pesticides, pollute the atmosphere. Phytoremediation is a safe and sustainable way to remove toxins from the atmosphere.

***Key words*:** Phytoremediation, Environment**,** Anthropogenic, Pollution.

INTRODUCTION:

Phytoremediation (Phyto – herb, remediation – clean) is the process of removing contaminants from a polluted area using green plants. Phytoremediation has a number of benefits. Basically, it's an autotrophic system with a lot of biomass that needs a lot of energy. The addition of a small amount of nutrient, which is easy to handle and widely accepted, Because of its artistic beauty and environmental sustainability, it is favoured by society. (Mahajan et al,2018). Phytoremediation is cost effective and environmentally safe method for removal of heavy metal. Nature in the form of soil is one of the most important resources for a wide range of living species, whether unicellular and multicellular, that are partly or completely reliant on it. Soil is a source of both vital and non-essential nutrients, and it plays an important part in the rotation of nutrients through many interactions (Ahemad, 2013). Because of rapid industrialization and urbanisation, which pollutes the atmosphere, soil pollution has become a major and difficult environmental issue all over the world. (Li,2018). Due to geogenic, anthropogenic, human culture, and industry operations, soil biodiversity has been disrupted by the addition of toxins, resulting in noticeable improvements in the metabolism of living species

(Swain et al,2013). Heavy metals are an interesting group of trace elements (TEs), The presence of TEs in the environment may be caused by either natural or by anthropogenic activities. (Eqani et al,2016. Muszy ´nska et al,2017). Heavy metals such as aluminium (Al), arsenic (As), antimony (As), barium, caesium, cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), molybdenum (Mb), nickel (Ni), zinc (Zn), tin, indium, plutonium, ruthenium. (Ahemad, 2012; Liu et al,2013; Waterlot et al,2013; Chodak et al,2013). Owing to their long-term survival, extreme toxicity, and bioaccumulation properties across the food chain, only a few heavy metals are harmful to living species (Ahemad and Malik, 2011; Ali et al, 2013; Ahemad and Kibret et al, 2013;). Some heavy metal toxins affect illness in animals through having a stronger impact on the immune system, making them more susceptible to pathogens or adjustments (Auffret et al, 2002; Gagne et al, 2008).

New molecular strategies are needed in light of today's task of feeding nine billion people in the near future, including the most economically vulnerable). (Godfray et al, 2010). To clean up metal-contaminated soils, a variety of high-tech equipment has been created (Hashim et al,2011). High-end/conventional methods, on the other hand, are more costly and time-consuming to apply in order to decontaminate the soil and affect its fertility and texture (Rajkumar et al,2010). Bioremediation, or biological exploitation methods for the clean-up of degraded lands, is a promising and environmentally sustainable solution to chemical technology in terms of preservation and environmental ethics (Hashim et al, 2011; Gillespie and Philp, 2013). Phytoremediation (extract contaminant metal contaminants from plants) is gaining popularity among bioremediation methods because it is inexpensive and environmentally friendly. But the procedure is time intensive, and elevated levels of metals reduce plant remediation performance (Ali et al, 2013). Furthermore, interactions between plants and metal-resistant bacteria have improved not only Phyto stabilization and phytoextraction of metal substrates, but have also accelerated plant growth production (Khan et al,2009).

Heavy metal is a non-biodegradable, long-lasting environmental chemical contaminant that may cause significant cytotoxicity, genotoxicity, and mutagenicity among all living things. Heavy metals are typically absorbed by plants from tainted soil or other toxic sources (air/water). As a result, there are two types of metals: important micronutrients (Fe, Mn, Cu, Zn, Mg, Mo, and Ni) and non-essential micronutrients (cd, Sb, Cr, Pb, As, Co, Ag, Se, and Hg) with undefined biological and physiological roles (Flora et al, 2008; Rascio et al, 2011; Schutzendubel et al, 2002; Tangahu et al, 2011; Zhou et al, 2014). These metals have been functionalized as catalysts for biochemical reactions in cells, enzyme stability, gene regulation, and osmosis pressure regulation for cell membranes. The formation of enzymes and proteins in plants relies heavily on vital micronutrients. They are needed in small amounts by plants for metabolism, growth, and development. When metal concentrations exceed normal requirements, plant growth can be slowed or stopped (Zengin et al, 2005). As heavy metal exceeds toxic levels, it can disrupt the normal functions of plants' metabolic and protein synthesis pathways, causing them to malfunction. The formation of bonds between heavy metals and sulfhydryl groups causes this (Hall et al, 2002), hindering functional groups of important cell membrane (Hossain et al, 2012), disrupting functionality of essential elements in biomolecules such as carbohydrates, proteins, lipids, nucleic acids, and enzymes (Ali et al, 2013), and negatively affecting the integrity of the cytoplasmic membrane (Farid et al, 2013), resulting in repression of important events in plants such as photosynthesizing (Hossain et al, 2012). The different types of heavy metal elements extracted by phytoremediation of contaminated soils and water around the world are described in this study.

There have been several methods to tackle the issue of environmental heavy metal emissions. Many researchers have been drawn to the bioremediation approaches used to reduce the number of heavy metals in the atmosphere. Plants, bacteria, fungi and algae are used suitably for heavy metal bioremediation. (Malik. A, 2004).

Aluminium (Al^{3+}) metal:

Extremely acidic soils cover around a third of the earth's total land area, and up to half of the world's potentially arable land is acidic (von Uuexkull et al,1995). The tropics and subtropics have vast areas of acid soils, which are important food-producing regions. After the two most abundant elements in the earth's crust, oxygen (O) and silicon (Si), aluminium is the third most abundant element (Foy et al,1978). On acidic soils, an ionic aluminium [Al^{3+}] metal severely restricts plant growth and yield. Where the most phytotoxic type of Al^{3+} is revalent, and particularly in areas where food security is still a major concern as the world's population grows to nine billion people. Although there is no established or confirmed biological function for Al^{3+} in plants, some researchers have suggested that low levels of Al^{3+} can stimulate plant growth (Kidd et al,2000). Most plants are known to be harmed by a 2-3 gg1 Al^{3+} threshold in soils with a pH below 5.5 (Pahlsson et al, 1990). The rhizotoxic/phytotoxic type of Al^{3+} species is solubilized in Al^{3+} polluted soil, inhibiting root growth and function (Jones et al, 2006). and making plants more susceptible to abiotic stresses and mineral nutrient deficiencies [Jones et al, 2006]. Roots are the primary target of Al3+ toxicity, with the accumulation of Al^{3+} causing root growth inhibition in minutes or hours (Ma et al,2001). Al^{3+} can cause lateral roots to thicken and turn brown (Mossor et al,2001). as well as a reduction in root respiration and disruptions in sugar phosphorylation enzymatic control (Rout et al,2001). The attachment of Al^{3+} to carboxylic groups of pectin's in root cells (Lidon et al,2002). as well as other molecular events, may be responsible for Al^{3+}-induced root depression. or the inhibition of cell division in roots by Al ions binding to DNA, resulting in increased double helix structural rigidity in DNA and cell wall (Foy. CD, 1992). The effects of Al^{3+} toxicity stress on aerial sections of plants is negative, especially as a result of initial root damage (Stiener et al,2012). which impairs root nutrient uptake, resulting in nutritional deficiency (Silva et al,2012). but the symptoms are not as obvious as those seen in roots (Bian et al, 2013). The root transition zone contains the most unmethylated pectin, resulting in the highest Al sensitivity (Li et al,2016). Plants have evolved both Al^{3+} tolerance and Al^{3+} avoidance mechanisms to cope with Al^{3+} stress in most cases (Kochian et al,2005). Internal mechanisms enable plants to deal with Al^{3+} toxicity in the root cell wall and/or detoxify Al^{3+} that enters root cells by forming nontoxic organic acid anions such as malate, citrate, and oxalate chelate (OA)–Al^{3+} complexes in the cytosol and/or sequestering Al^{3+} in subcellular compartments such as vacuoles (Ma et al,1997; Shen et al,2002; Huang et al,2012). Exudation of Al^{3+}-chelating OAs into the rhizosphere, where the OAs form nontoxic OA–Al^{3+} complexes that do not reach the root, is the primary mechanism for avoiding Al^{3+} in the rising root apex/tips. Plants have been established as having several primary cellular/molecular components for both Al^{3+} tolerance and exclusion mechanisms over the last decade (Xia et al,2010; Yamaji et al,2009; Huang et al,2009; sasaki,2004; magalhaes,2007; Yokosho et al,2011; Tovkach et al,2013). Al^{3+} binding to the pectic matrix of the cell wall and the apoplastic face of the plasma membrane in the root apex, which is particularly sensitive to Al^{3+}, can inhibit root elongation (Horst et al, 2010; Blancaflor et al,1998; Jones et a,.2006). Furthermore, Al^{3+} has been shown to inhibit calcium channel activity as well as damage and peroxide membrane lipids and the cytoskeleton (Jones et al,1995). Al also decreases the efficiency of $NO3^{-}$ NH4 +conversion (Zhao and Shen et al, 2018). Root hair growth is interrupted, root tips swell, and roots stop developing as a result (Panda et al,2009). Stunting leaves, discoloration (purple) on leaves, stems, and leaf veins accompanied by chlorosis (yellowing), rolling young leaves and dead leaf tips, rising points, or petioles are some of the symptoms of Al^{3+} induced stress on shoots, which are close to other nutritional elements (phosphorus, calcium) deficiency (Wang et al,2006; Bian et al,2013). Tiny necrotic spots on the border of young leaves, as well as chlorosis in the margins and middle of older leaf laminas, are other obvious signs of aluminium toxicity (Steiner et al,2012). Al^{3+} toxicity has also been linked to a decrease in stomatal aperture and photosynthetic activity (Vardar et al,2007). According to Bhalerao and (Prabhu et al, 2013). Al^{3+} toxicity in plants like Zea mays and sorghum may disrupt the absorption and transportation of key nutrients like P, K, Ca, and Mg. When crop plants are exposed to various levels of Al^{3+}, they display a variety of morphological and physiological responses. (Hossain et al,2006). Researchers looked at two wheat cultivars that differed in their response to Al^{3+} stress discovered that the length of root in the Al^{3+}-sensitive cultivar was noticeably shorter. Furthermore, Al^{3+} stress increased the amount of some cellular substances like pectin and hemicelluloses, particularly in sensitive cultivars. (Batista et al,2013). It was discovered that leaf sheaths of corn plants treated with various doses of Al^{3+} had underdeveloped epidermal and cortical cells, as well as a reduction in the diameter of the metaxylem and protoxylem in the vascular bundle. Al stress causes changes in chromatin configuration in the nucleus as well as an increase in the size and frequency of nucleolar vacuoles at the ultrastructural stage (Bennet et al, 1985). Al is poisonous to plants in a number of ways, Al ions stop root cell expansion and elongation in the short term, but they also stop cell division in the long term. As result, root growth is slowed (Kochian et al.2015).

Arsenic (As):

withstand weathering and bio weathering processes. Covalent bonds between arsenic and sulphur, coordination bonds between iron and arsenic or sulphur, and van-der-Waals forces between molecular units stabilise the structure of Arsenic metal (O' Day et al, 2004; Mullen and Nowicki, 1972). Many of these elements exist in close proximity to other metals like Au, Ag, Cu, Cd, Fe, Pb, and Ni. These metals are found in hydrothermal and magmatic ore deposits and are generally rare. Arsenides have covalent chemical bonds, similar to sulphides. The most significant is that in structural arrangements of common sulphides, these elements often form solid solutions with each other and with sulphide minerals (e.g., pyrite, pyrrhotite, marcasite, galena). The introduction of As into the atmosphere by natural processes (such as weathering of As-rich minerals in the Earth's critical zone and volcanic activity) or anthropogenic activities (such as the use of wood preservatives, mining, and smelting, and the overuse of As-based fertilisers and industrial pesticides, as well as irrigation of As-contaminated groundwater (Khalid.S.et al,2017. Chandrakar et al,2016. Rehman et al,2014). As's metabolic pathway includes many oxidative state modifications, as well as oxidative methylation, which results in four metabolites. Inorganic As (iAs) is metabolised by oxidative methylation to monomethylated As (MMA), further reduction to trivalent MMA, and final methylation to dimethylated As (DMA) (Vahter,2002). Arsenic enters plants primarily in the inorganic forms of As(III) or As(V) via transporter proteins, which is likely governed by the As concentration gradient between growth media and plant cells. According to our understanding, (Ghosh et al,2015).In living organisms, multiple transferase genes control metabolism. As-methyltransferases (MeT) and glutathione S-transferases have been linked to these gene classes (GSTs). In As methylation, both the oxidative and reductive metabolic pathways of As (III) methyltransferase (As3MT) are essential. GST is a detoxifying enzyme that works in tandem with glutathione (GSH) to detoxify xenobiotics, and it's been proposed that polymorphic variants could have different capacities to metabolise arsenic (Wood et al,2006. Tseng,

2009. Engstrom et al, 2009). The most effective strategies to tackle the harm impacts of As appear to be major As pollution in phytoremediation of crops that can be grown in polluted environments without suffering from and accumulating As in edible pieces. These methods necessitate a thorough understanding of As absorption, toxicity, and detoxification mechanisms (Tripathi et al, 2007). The distribution and speciation of As elements in plants are critical factors in this direction. The most common types of As in aquatic and terrestrial environments are inorganic arsenate [HAsO4 22 or As (V)] and arsenite [H2AsO3 2 or As (III)]. As contamination isn't just confined to water sources. As pollution of soil has become a major environmental concern, particularly in agricultural areas (Mishra et al,2014. Farooq et.al,2016).

As pentavalent (AsV) is normally taken up by plants through phosphate transporters (Asher and Reay, 1979; Meharg and Macnair, 1990; (Isayenkov and Maathuis, 2008; Ma et al, 2008). and As (III) through nodulin26-like intrinsic aquaporins (Isayenkov and Maathuis, 2008; Ma et al, 2008). As (V) is easily reduced to As (III) within the cell by As(V) reductase, which uses reduced glutathione (GSH) as a reductant (Duan et al,2005. Bleeker et al, 2006). The thiol ligands are then complexed with As (III) through GSH and phytochelatins (PCs; Schmoger et al,2000). HPLC was used in conjunction with element-specific (inductively coupled plasma-mass spectrometry [ICP-MS]) and molecule-specific (electrospray ionization-mass spectrometry [ESI-MS]) detectors for the first time to demonstrate complexes of PCs in plant extracts. This approach provides data on the ligand diversity and As species present in plants. Objects during sample preparation, such as ligand exchange for previously weakly bound metals due to cell and subcellular compartment breakage during plant extraction, cannot be ruled out. The majority of As was accumulated in the pinnae, probably in vacuoles, according to studies in the hyperaccumulator Pteris vittata (Lombi et al,2002; Hokura et al,2006; Pickering et al,2006). Using either fragmented or sectioned dry rice grains (Meharg et al,2008; Lombi et al, 2009; Moore et al,2010).or whole fresh rice grains(Carey et al,2010, 2011), high-resolution techniques such as synchrotron-based microscopic-X-ray fluorescence (m-XRF) and secondary ion mass spectrometry were used in rice grains. However, little is known about the distribution of As in non-hyperaccumulator plants at the cellular or subcellular level. (Moore et al, 2011). used nano-secondary ion mass spectrometry to investigate the subcellular distribution of As and silicon in rice roots (Kopittke et al,2012). Using m-XRF and sequential computed tomography, researchers investigated the spatial distribution of arsenic in hydrated, fresh cowpea roots and discovered variations in As distribution in plants exposed to As(V) or As(V) (III). The distribution of As in aquatic plants was recently recorded by (Xue et al,2012). However, there is still a lack of knowledge about As speciation and distribution in plant sections, as well as its relationship to toxicity in non-hyperaccumulator plants. As heavy metal toxicity treatment is successful. The use of bacteria such as bacillus is one example (Bacillus subtilis), which uses a chemical process to reduce Cr (VI) to a less toxic form Cr(III) and biochar, which is charcoal, are renewable materials. Used to increased soil productivity and boot soil pH to make it more fertile for dangerous metals are less bioavailable for plant uptake. (Chibuike G. et al,2014).

Cadmium metal (Cd):

Cadmium (Cd) is a non-essential trace element that is found in abundance in nature. Cd concentrations in soils and groundwater can be elevated by both geogenic and anthropogenic causes, which is vital for preserving stable food supplies and clean drinking water and Humans are carcinogenic at high doses of Cd. Anthropogenic and natural sources of cadmium enrichment in soil have been weathering of rocks is the most common natural source of Cd pollutants.

while agrochemicals, processing, vehicular emissions, Wastewater, smelting, mining and irrigation are the most common anthropogenic sources of Cd. (Khan et al,2015. Nawab et al, 2015). Cadmium in the soil enters plants through transporters for essential elements (such as calcium, iron, and zinc) for growth and development. The effects of Cd toxicity in plants are various. The use of phosphate fertilizers, which contain Cd as an impurity, is a common cause for elevated Cd concentrations in soil and groundwater. (Bigalke et al,2017). Cd enters result of the Cd, tissues are damaged, causing changes in subcellular structures as well as physiological and molecular processes (Kramer, 2010; Mendoza-Cozatl et al,2011). Cd may alter the structure of cell walls and cause cellular organelles such as chloroplasts and mitochondria to degenerate (Van Belleghem et al,2007). Ionic Cd^{2+} can compete for transporters with nutrient cations (e.g. Ca^{2+}, Fe^{2+}, and Zn^{2+}), resulting in reductions in these essential elements and disturbances in plant ionic homeostasis (Rodriguez-Serrano et al,2009). Due to competition for iron transporters between Cd^{2+} and Fe^{2+}, cadmium exposure can cause iron deficiency in plants (Besson-Bard et al, 2009; Wu et al,2012). Plants exposed to Cd often experience photosynthesis repression as a result of damage to the photosynthetic apparatus (Cunha et al, 2008). This has the potential to change carbohydrate concentrations in all plant tissues (He et al, 2011). In plants, Cd can cause an oxidative burst by inducing hydrogen peroxide (H_2O_2) and superoxide (O_2 c–) (Rodriguez-Serrano et al, 2009). Furthermore, Cd exposure can cause differences in gene expression in plants that are involved in both Cd transport and scavenging reactive oxygen species (ROS) (Kupper and Kochian, 2010). Cadmium concentrations in biomass ash can exceed 30 mg/kg, providing an additional method for growing Cd levels in soil, as such ash is commonly used as a fertiliser. Due to an ash-induced pH increase, the bioavailable pool of Cd remains low. (Kapanen et al,2005; Li et al, 2016). Cadmium can impact plant output from the subcellular up to the ecosystem level at various levels of biological organisation. At the mobile stage, when plants experience Cd stress, a spectrum of ROS is increased. the ROS is toxic until rapidly removed. (Chen et al,2014; Alikhani et al,2019).

Plants have developed a variety of Cd detoxification strategies. First, since Cd^{2+} binds to polyuronic acids and pectin in plant cell walls and stimulates increased lignification (Conn and Gilliham, 2010). the apoplast acts as a barrier to Cd entry (Schutzendubel et al,2001; Elobeid et al,2012). Second, Cd chelates in the cytosol and sequestration in vacuoles can detoxify Cd entry into the symplast. Reduced glutathione (GSH) and phytochelatins (PCs) will bind to ionic Cd^{2+} in the cytosol, forming Cd ligands that are then transported to vacuoles, where Cd can be sequestered (Conn and Gillham,2010; Park et al,2012). Finally, Cd stress stimulates many biochemical defences, including antioxidative enzymes and GSH synthesis, resulting in root or leaf transcriptome reprogramming (Herbette et al,2006. Mendoza-Cozatl et al,2008; Rodriguez-Serrano et al,2009. Xu et a, 2012).

Cd toxicity and detoxification have primarily been studied in Arabidopsis (Arabidopsis thaliana), Arabidopsis halleri, and Thlaspi caerulescens, which are herbaceous plants (Kramer, 2010. Mendoza-Cozatl et al, 2011). Herbaceous plants' small biomass, on the other hand, limits their use for phytoremediation on a wide scale. Because of their rapid development, deep root system, and relatively high Cd accumulation in some genotypes, poplars (Populus spp.) have been suggested for phytoremediation (Merkle, 2006; He et al,2013). High levels of Cd in algae have been shown to have a detrimental impact on nitrate, phosphate, and sulphate assimilation (Clarke et al,2002; Codex et al,2009; Grant et al,2008; Archambault et al,2001). photosynthesis (Knox et al, 2009). carbohydrate metabolism (Weibe et al,2010). and plant- Similar effects have been observed in the cyanobacterium Synechocystis, where the breakdown of photosynthetic apparatus appears to provide nutrients for the synthesis of Cd resistance proteins

(Varshney et al,2005). Cd transported to cereal shoots prior to anthesis accumulates in a decreasing gradient in the leaves and stems towards the developing spike (Gerger et al,2004; Yoneyama et al,2010; Liu et al,2007). As a result, there are numerous sources of Cd (multiple shoot organs and roots) that could be remobilized to the grain. During grain filling, plants may continue to absorb Cd from the soil, transporting it directly to the grain through the stem. Similarly, during grain filling, rice grown in hydroponic culture continued to absorb Cd from the nutrient solution and translocate it to the shoots (Rodda et al,2011). Differences in Cd accumulation ratios inside shoot organs such as flag leaf and grain have been interpreted in several studies as evidence of Cd remobilization from the vegetative portion to the reproductive organ grain (Gerger et al,2004. Liu et al,2007].

Chromium (Cr):

Chromium is found in rocky soils and volcanic dust as a naturally occurring element. In the earth's mantle, it is the 17th most abundant element. (Auvdainayagam et al, 2003). For every kilogramme of soil, natural soil usually contains 10 to 50 mg of chromium. Chromium toxicity has an effect on seed germination. Photosynthesis and plant development. In small amounts, chromium is beneficial to humans because it is involved in the action of insulin (Arun K et al, 2005). Chromium (III) is essential in the diet in trace amounts because it regulates glucose metabolism in the human body (Ali et al, 2013). Cr(VI) and Cr(III) are the most stable forms of Cr in the environment. On the basis of bioavailability in soil and translocation to different sections of plants, Cr(VI) is stated to be more toxic than Cr(III). (Shahid.M.et al,2017; Choppala. et al,2018). Reduced seed germination, reduced growth, decreased yield, inhibition of enzymatic activities, oxidative and nutrient imbalances, and photosynthesis are all consequences of Cr toxicity in plants.

Chromium (Cr) influences all components of the food chain, including soil microorganisms, plants, animals, and humans (Baath, 1989; Jordao et al, 1999; Turkdogan et al, 2003; Liu et al, 2009). Cr is the most popular heavy metal on the planet as a result of human activity. Steel alloy fabrication, plated product fabrication, nonferrous alloy metal fabrication, textile, leather industries, and the manufacture of green varnishes, inks, paints, and glazes, as well as ceramics, all use Cr compounds. With fertilisers or waste material used for soil development, a large amount of Cr reaches the soil (Ghosh et al, 2003; Dampare et al, 2006; Shams et al, 2010).

Different Cr derivatives enter the natural environment depending on the source. Cr has oxidation numbers ranging from -2 to +6 in the atmosphere. The oxidation number III is the most stable, according to Cr oxidation state. The oxidation numbers Cr hexavalent (VI) and Cr trivalent (III) are the most common types of Cr in the natural environment (Fendorf, 1995). Cr (VI) and Cr (III) have different physiochemical properties and, as a result, different behaviours in living organisms. In most aquatic environments, Cr trivalent (III) and Cr hexavalent (VI) species coexist. Since Cr (III) has the potential to form complexes with organic ligands, its concentration in water is lower than that of Cr (VI) (Banks et al, 2006; Kimbrough et al, 1999). Many factors influence the equilibrium between these two modes of Cr. pH, reducer concentrations (Fe (II), organic compounds), oxidising mediators (O2, manganese oxides), and complexing agents are among these variables (Kotas and Stasicka, 2000). On living organisms, the Cr (VI) ions (dichromats/chromate) have extremely toxic effects. Cr (VI) has a high redox potential, mobility, and capacity to penetrate biological membranes, all of which contribute to its high toxicity.

Cr is an important element found in all plant tissues, which means that both a lack of it and an abundance of it will damage plants (Shanker et al, 2005). Its absence can cause problems with plant growth and photosynthesis, as well as reduce plant resistance to pathogens (Bartlett and Klmble, 1976). Cr added to soil, on the other hand, can boost plant yields (Wyszkowski and Radziemska, 2010). Excess Cr, on the other hand, causes toxic symptoms in plants, such as wilting leaves, chlorosis of young leaves, and damage to the growth apex and roots (Pederno et al, 1997). Many studies have shown that Cr compounds have a harmful impact on plants, but most of them focus on Cr (VI) compounds (Srivastava et al, 1999. Cervantez et al, 2001. Shanker et al, 2005; Banks et al, 2006; Wyszkowski and Radziemska, 2010, 2013). Because of the differences in their impact on plants and soil, the two types of Cr should be studied separately, according to the above studies. The aim of this research was to see how soil contamination with tri- and hexavalent Cr affected the mass of oats and the content of nitrogen compounds in different parts of the crop (grain, straw, and roots), as well as how added compost, zeolite, and calcium oxide affected the impact of Cr on plants. Minerals are obtained by aquatic plants from both aquatic and sediment reservoirs. The absorption of metallic compounds by macrophytes is influenced by the chemical shape of ions as well as the life form of the plants themselves: floating, emergent, submerged, well-rooted, or rootless (Malec et al, 2011). There are macrophytes that effectively strip Cr pollutants from aquatic ecosystems, such as Eicchornia crassipes, Polygonum hydropiperoides, Nymphaea spontanea, and Leersia hexandra (Choo et al, 2006; Qian et al, 1999; Zayed and Terry, 2003; Zhang et al, 2007). Since root–shoot Cr translocation is small, Chromium levels in aquatic species' shoots are typically lower than in roots, similar to terrestrial plants (Zayed and Terry, 2003). For example, when Borreria scabiosoides is treated with Cr (III), the element accumulates preferentially in cell walls and some vacuoles of the cortical parenchyma (Manga Beira et al, 2006). Furthermore, due to the increased contact area with the natural environment, species submerged in water can have a higher accumulation potential than floating or emergent species (Rai et al, 1995). As a result, these species hold a lot of promise for phytoremediation. Cr impact, we have recently found that inoculation with highly effective nitrogen-fixing bacteria reduces the toxic effects of chromium (IV) on P. sativum. Protection results included an increase in the length of time. The shoots and the mass of the roots of the plant and the improved levels of Chlorophylls, carotenoids, and anthocyanins relative to Impact of chromium on inoculated pea plants. (Stambulska U.Y,2017).

Nickel (Ni):

Nickel is a transitional material which is widely distributed in soil, air, water and air. It may come from natural and anthropogenic sources. Although nickels are omnipresent in the world, they have never functioned as a trace factor for animals and humans. Still acknowledged. The industrial use of liquid and solid fuels as well as municipal waste are contaminating the environment by nickel. (Giuseppe Genichi et.al,2020). Nickel is important and has vital roles in a number of morphologic and physiologic roles including sprouting and productivity when the plant is properly grown and developed. (Sreekanth et al,2013) Nickel is used in a wide range of metallurgical processes for the manufacture of nickel-cadmium batteries in the modern metallurgy and as a catalyst in the chemical and food processes such as alloys, electroplating. Products at all processing, recycling and disposal stages high distribution eventually contributes to nickel and secondary environmental contamination by storing this metal. (Song X et al,2017).

Nickel has long been regarded as a vital trace factor for both human and animal health. The WHO recommends a Nickel allowable maximum of 10mg/kg in plants. Originally, the term hyperaccumulator applied to plants capable of accumulating more than 1 mg g1 Ni (dry weight) in the shoot, an extremely high heavy metal concentration given that Ni toxicity in most plants' vegetative organs ranges from 10 to 15 g g1. Threshold values were provided for each heavy metal, based on its particular phytotoxicity, in order to identify hyperaccumulation. More than 75% of taxa hyperaccumulate Ni, while Cd, one of the most toxic heavy metals, has a small number of hyperaccumulators (only 5 species to date) (Rascio N and Navari-Izzo, 2011). High concentration of nickel modifies plant metabolic activity in the production of enzymes, electron photosynthesis and chlorophyll biosynthesis at high levels. (Sreekanth et al,2013).

Zinc (Zn):

Zinc is an essential trace factor that plays an important role in many organisms' physiological and metabolic processes. The structural element of Zn is the only metal ion that is present in all six classes of enzymes (Gupta et al, 2016). Nonetheless, higher zinc concentrations can be harmful to the body. It is a metal that plays an important role in protein synthesis and has a relatively low concentration in surface water due to its limited mobility from rock weathering or natural sources. Zinc is a necessary component of all plants, with a mean concentration of 66 lg/g in normal plants (aboveground tissues) (Outridge and Noller, 1991) The toxic level is greater than 230 lg/g (Borkert et al, 1998; Long et al, 2003). S. barbata and S. Orientalis had the highest levels of Zn (329.3 lg/g) and (1,208.3 lg/g) in the aboveground and underground tissues, respectively (Nouri et al, 2009). The presence of metal concentrations higher than toxic levels in certain plants suggests that, in addition to their exclusion strategies, these plant species may have internal metal detoxification tolerance mechanisms (Taylor and Crowder, 1983).

Lead (Pb):

Pb was one of the first anthropogenic contaminants to enter the setting (Nriagu, 1998). Pb is a soft, easy-to-process metal with numerous applications. Due to its poor solubility at pH values greater than 5 and close contact with organic matter, Pb is highly persistent in soils and hardly bioavailable under most conditions. Mining, smelting, and battery production continue to release it into the environment. Because of the long-term use of leaded fuel, massive amounts are still present in the atmosphere (Landrigan et al, 2002). The natural variation in Pb accumulation by crops has not been examined as well as it should have been. While there is obviously variation (19, 132), there is little information on genotype effect. However, data from a recent rice survey (Norton et al, 2014) suggests that Pb has a much smaller impact than As and Cd. The majority of the difference seems to be due to environmental factors such as the effects of mining. Still less is known about Hg and methylmercury; as previously mentioned, researchers have only recently begun to investigate accumulation in crops grown near Hg mining and smelting. (Rothenberg et al, 2014; Huang et al, 1997) The use of chelates in Pb-contaminated soils to increase Pb accumulation in plants was investigated, and it was discovered that lead concentrations in corn and pea shoots were greatly increased. The most effective chelate in increasing Pb desorption from soil into the soil solution was ethylenediaminetetraacetic acid (EDTA), which also significantly increased Pb translocation from roots to shoots by preventing cell wall retention. However, there's a chance that adding EDTA to soil could mobilise heavy metals, which could then be leached into the subsoil or into land- or surface waters, necessitating metal-leaching prevention steps. It may be appropriate to use chelate solutions to meet plant water needs and tile drains to trap leachate (Cooper et al, 1999; Vangronsveld et al,1995, 1996) used beringed, a by-product of coal refuse burning, to immobilise heavy metals in polluted soil, reducing their phytotoxic impact (Pulford and Watson, 2003). Monocotyledonous species had higher Pb concentrations in their roots than in their shoots, according to (Fitzgerald et al, 2003).

Copper (Cu^{2+}):

Copper(cu) is a redox-active transition metal that is essential for plant growth. It comes in two forms: (Cu2+) and Cu+. Since soil solution concentrations generally range from 10-6 to 10-9 M, plants typically find a variable supply of Cu in the soil (Marschner, 1995). It is considered an important micronutrient for all living organisms at low concentrations (Muhammed et al,2015). Cu content in plant tissue averages 10 g g-1 dry weight (Baker and Senef, 1995). Cu is essential in photosynthetic and respiratory electron transport chains, as well as ethylene sensing and cell wall metabolism in plants. Molybdenum cofactor biogenesis and defence from oxidative stress (Inmaculada, 2009). Cupper stress caused significant damage to the metabolic pathway, disrupted photosynthesis and biosynthesis of chlorophyll contents, and consequently reduced plant productivity (Hegedus et al, 2001). Several anthropogenic sources include smelting and mining activities, inorganic and organic fertiliser applications, liming procedures, improper use of Cu-containing fungicides and pesticides, sewage sludge, and wastewater irrigation systems (Herawati et al, 2000). (Rebecca, 2011). Copper toxicity causes plant growth retardation, leaf chlorosis, and root growth reduction. The higher level of Cu decreases the root-to-shoot transport of Fe, Mg, K, P and Ca and thus may lead to changes both in morphology and in physiological processes, such as exchanged gases, photosynthesis and water homeostasis, as these elements are essential for cellular metabolism to work properly. (Souza et al,2017).

Iron (Fe^{2+}):

In the lithosphere, iron is the fourth most abundant element. All living organisms need iron as a micronutrient (Zargar et al, 2015). Plants cannot produce chlorophyll without iron, for example, and iron is required for respiration, photosynthesis, and DNA synthesis. Iron also activates a number of metabolic pathways. Iron is needed for the synthesis of chlorophyll in plants, as well as the maintenance of chloroplast structural function Iron is a prosthetic group made up of a variety of enzymes. (Gyana et al, 2015). Plants with a deficiency in Fe develop extreme chlorosis on their leaves, which reduces plant growth and yield efficiency. Because of the poor solubility of the oxidised ferric form in aerobic conditions, iron is the third most limiting nutrient for plant growth and metabolism (Zuo and Zhang ,2011; Samaranayake et.al, 2012). The absorption of manganese by plants is reduced when there is an excess of iron.

Magnesium (Mg^{2+}):

Magnesium is a macronutrient that is needed for plant growth and development. (Gransee and Fuhrs, 2013). Mg is needed for the normal structure of chloroplasts and is involved in the biosynthesis of chlorophyll. Magnesium is involved in photosynthesis because it is the central atom of four nitrogen atoms in the chlorophyll. Many enzymes are activated by magnesium. Mg2+ is needed for the activation of all phosphorylases and kinases. It's needed for basic energy transfer processes including photosynthesis, glycolysis, and respiration. (Bo Yan et al, 2018) Magnesium is consumed as the ion Mg2+, and it moves from older to younger leaves in plants.

Mg is essential for SOD, CAT, and POD activities, as well as plant growth and development and enzyme activities. Magnesium deficiency reduces root development, reduces enzyme activities (Mg dependent enzymes), inhibits sucrose transport, and disrupts electron transfer and ROS activities. (Farhat et al,2016).

CONCLUSION:

This paper examines the causes of heavy metal emissions, heavy metal contamination of soil and its harmful effects, phytoremediation methods, and plants used for various purposes. Worldwide attention has been paid to toxic effects of heavy metals on biosphere to find an appropriate solution for removal of these contaminants Out of the surroundings. Since there are many physical and biological factors, Strategies were established and plant remediation is extremely reliable and effective metal removal solution. As a chronic pollutant in our atmosphere, heavy metals must be fully eliminated. A completely rehabilitative goal Phytoremediation appears to be a less disruptive choice. Clean-up equipment that is both cost-effective and environmentally friendly. The most important thing is to choose the right plant is a crucial aspect of phytoremediation. Phytoremediation is an alternative green technology for treating heavy metal polluted environments. Several plants have a high potential as heavy metals bio accumulators and can be used in heavy metal phytoremediation process.

References:

[1] Ahemad, M. Kibret, M.2013. Recent trends in microbial biosorption of heavy metals: a review. Biochemistry Molecular Biology, 1:19–26.

[2] Ahemad, M. Malik, A. 2011.Bioaccumulation of heavy metals by zinc resistant bacteria isolated from agricultural soils irrigated with wastewater. Journal of Bacteriology, 29:12–21.

[3] Ali, E. K., & Sajad, M. A. 2013.Phytoremediation of heavy metals concepts and applications. Chemosphere, 91(7) : 869–881.

[4] Alikhani, Abbaspour, H.2019. Effects of methyl jasmonate and cadmium on growth traits, cadmium transport and accumulation, and allene-oxide cyclase gene expression in wheat seedlings. Revista de Agricultura Neotropical. Cassilândia MS,6: 20-29.

[5] Archambault, D.J. Marentes, E. Buckley, Clarke, J. Taylor, G.J. 2001. A rapid, seedling-based bioassay for identifying low cadmium-accumulating individuals of durum wheat (Triticum turgidum L.) Euphytica, 117:175–182.

[6] Arun, k. Shanker. Carlos Cervantes. Herminia Loza-Tavera. S. Auvdainayagam. 2005.Chromium toxicity in plants. Environment International.31:739-753.

[7] Asher, C.J. Reay, P.F. 1979.Arsenic uptake by barley seedlings. Australian Journal of Plant Physiology, 6: 459–466.

[8] Auvdainayagam, S. Megharaj, M. Owens, G. Kookana, R.S. Chittleborough, D. and Naidu, R. 2003.Chemistry of chromium in soils with emphasis on tannery waste sites. Review of environmental contamination and toxicology,178 : 53-91.

[9] Baath,1989. E. Effects of heavy metals in soil microbial processes and populations: a review. Water, Air, and Soil Pollution, 47(3/4):335–379.

[10] Baker, D.E. Senef. 1995. Cooper Heavy Metals in soil. Blackies Academic and Professional London.

[11] Banks, M.K. Schwab, A.P. and Henderson, C. 2006.Leaching and reduction of chromium in soil as affected by soil organic content and plants. Chemosphere, 62:255–264.

[12] Bartlett, R.J. and Klmble, J.M. 1976.Behaviour of chromium in soils. I. Trivalent forms. Journal of Environmental Quality, 5(4); 383–389.

[13] Batista, M.F. Moscheta, I.S. Bonato, C.M. Batista, M.A. de Almeida, O.J.G. and Inoue, T.T.2012. Aluminium in corn plants: influence on growth and morpho-anatomy of root and leaf. Revista Brasileira de Ciencia do Solo, 37(1):177–187.

[14] Bennet, R.J. Breen, C.M. and Fey, M.V.1985. Aluminium induced changes in the morphology of the quiescent center, proximal meristem and growth region of the root of *Zea mays.* South African Journal of Botany, 51(5) : 355–362.

[15] Besson-Bard, A. Gravot, A. Richaud., Auroy. Duc, C. Gaymard, Taconnat, Renou, J.P. Pugin, A., Wendehenne, D.2009. Nitric oxide contributes to cadmium toxicity in Arabidopsis by promoting cadmium accumulation in roots and by up-regulating genes related to iron uptake. Plant Physiology, 149;1302-1315.

[16] Bhalerao, S.A.and Prabhu, D.V. 2013.Aluminium toxicity in plants—a review. Journal of Applicable Chemistry, 2(3) ; 447–474.

[17] Bian, M. Zhou, D. Sun and Li, C.2013. Molecular approaches unravel the mechanism of acid soil tolerance in plants. The Crop journal 1(2); 91-104.

[18] Bigalke, M. Ulrich, A. Rehmus, A. Keller, A. 2017. Accumulation of cadmium and uranium in arable soils in Switzerland. Environmental Pollution, 221; 85–93.

[19] Blancaflor, E.B. Jones, D.L. Gilroy, S. 1998.Alterations in the cytoskeleton accompany aluminium-induced growth inhibition and morphological changes in primary roots of maize. Plant Physiology, 118;159–172.

[20] Bleeker, P.M. Hakvoort, H.W.J. Bliek, M., Souer, Schat,H.2006. Enhanced arsenate reduction by a CDC25-like tyrosine phosphatase explains increased phytochelatin accumulation in arsenate-tolerant *Holcus lanatus*. The Plant Journal, 45;917–929.

[21] Bleeker, P.M. Schat, Vooijs, R. Verkleij, J.A.C. Ernst, W.H.O. 2003.Mechanisms of arsenate tolerance in Cytisus striatus. New Phytologist, 157;33–38.

[22] Bo Yan. And Ying Hou. 2018.Effect of soil magnesium on plants: a REVIEW". Earth and Environmental Science,170;01-08

[23] Borkert, C.M. Cox, F.R. Tucker, M.R. 1998.Zinc and copper toxicity in peanut, soybean, rice and corn in soil mixtures. Communications in Soil Science and Plant Analysis, 29(19.2); 2991–3005.

[24] Carey, A.M. Norton, G.J. Deacon, C. Scheckel, K.G. Lombi, E. 2011.Phloem transport of arsenic species from flag leaf to grain during grain filling. New Phytologist, 192; 87–98.

[25] Carey, A.M. Scheckel, K.G. Lombi, E. Newville, M. Choi, Y. Norton, G.J. Charnock, J.M. Feldmann, J. Price, A.H. Meharg, A.A. 2010.Grain unloading of arsenic species in rice. Plant Physiology, 152;309–319.

[26] Cervantez, C. Campos-Garcia, J. Devars, S. Gutierrez-Corona, F. Loza-Tavera, H. Torres-Guzman, J.C. 2001.Interactions of chromium with microorganisms and plants. Microbiology Reviews, 25;335–347.

[27] Chandrakar, V. Naithani, S.C. Keshavkant, K.. 2016.Arsenic-induced metabolic disturbances and their mitigation mechanisms in crop plants: A review. Biologia Plantarum, 71;367–377.

[28] Chen, C. Zhou, Q. Cai, Z. 2014.Effect of soil HHCB on cadmium accumulation and phytotoxicity in wheat seedlings. Ecotoxicology, 23; 1996–2004.

[29] Chibuike, G. U. Obiora, S.C. 2014.Heavy metal polluted soils: effect on plants and bioremediation methods. Applied Environmental Soil Science, 1−12.

[30] Chodak, M. Gołe-biewski, Morawska-Płoskonka, J. Kuduk, K. Niklin´ska, M.2013. Diversity of microorganisms from forest soils differently polluted with heavy metals. Applied Soil Ecology, 64;7–14.

[31] Choo, T.P. Lee, C.K. Low, K.S. Hishamuddin, O.2006. Accumulation of chromium (VI) form aqueous solutions using water lilies (Nymphaea spontanea). Chemosphere, 62;961–967.

[32] Choppala, G, Kunhikrishnan, A. Seshadri, B. Park, J.H. Bush, R. Bolan, N. 2018.Comparative sorption of chromium species as influenced by pH, surface charge and organic matter content in contaminated soils. Journal of Geochemical Exploration, 184;255–260.

[33] Clarke, J.M. Norvell, W.A. Clarke, F.R. Buckley, W.T.2002. Concentration of cadmium and other elements in the grain of near-isogenic durum lines. Canadian Journal Plant Science, 82;27–33.

[34] Codex Alimentarius Commission.2009. General Standard for Contaminants and Toxins in Food and Feed. CODEX STAN 4;193–1995.

[35] Conn, S. Gilliham, M. 2010.Comparative physiology of elemental distributions in plants. Annals of Botany, 105; 1081–1102.

[36] Cooper, E.M. Sims, J.T. Cunningham, S.D. Huang, J.W. Berti, W.R.1999. Chelate assisted phytoextraction of lead from contaminated soils. Journal of Environmental Quality, 28;1709–1719.

[37] Cunha, K.P. do Nascimento, C.W.A. Pimentel, R.M.D. Ferreira, C.P.2008.. Cellular localization of cadmium and structural changes in maize plants grown on a cadmium contaminated soil with and without liming. Journal of Hazards Materials, 160;228–234.

[38] Dampare, S.B. Ameyaw, Y. Adotey, D.K. Osae, S. Serfor- Armah, Y. Nyarko, B.J.B. 2006.Seasonal trend of potentially toxic trace elements in soils supporting medicinal plants in the eastern region of Ghana. Water, Air, and Soil Pollution, 169;185–206.

[39] Duan, G.L. Zhu, Y.G. Tong, Y.P. Cai, C. Kneer, R.2005. Characterization of arsenate reductase in the extract of roots and fronds of Chinese brake fern, an arsenic hyperaccumulator. Journal of Plant Physiology, 138;461–469.

[40] Elobeid, M. Gobel, C. Feussner, I. Polle, A.2012. Cadmium interferes with auxin physiology and lignification in poplar. Journal of Experimental Botany, 63;1413–1421.

[41] Engstrom, K., Nermell, B. Concha, G. Stromberg, U. Vahter, M. Broberg, K.2002. Arsenic metabolism is influenced by polymorphism in genes involved in one-carbon metabolism and reduction reactions. Mutation Research, 667;4–14.

[42] Eqani, S. Kanwal, A. Bhowmik, A.K. Sohail, M. Ullah, R. Ali, S.M. Alamdar, A. Ali, N. Fasola, M. Shen, H. 2016.Spatial distribution of dust-bound trace elements in Pakistan and their implications for human exposure. Environmental Pollution, 213;213–222.

[43] Farhat, N. zorrig. W. salhi.T. abdelly.C. smaoui. A. Rabhi.M. 2016.Do medium- and long-term magnesium deficiencies affect potassium and calcium nutrition in Sulla carnosa? Acta Physiologlae plantarum 38 (6);145,

[44] Farid, M. Shakoor, M.B. Ehsan, A. Ali, S. Zubair, M. and Hanif, M.S.2013. Morphological, physiological and biochemical responses of different plant species to Cd stress. International Journal of Chemical and Biochemical Sciences, 3;53–60.

[45] Fendorf, S.E. 1995.Surface reactions of chromium on soils and waters. Geoderma, 67;55–71.

[46] Fitzgerald, E.J. Caffrey, J.M. Nesaratnam, S.T. McLoughlin, P. 2003.Copper and lead concentrations in salt marsh plants on the Suir Estuary, Ireland. Journal of Environmental Pollution, 123(1);67–74.

[47] Flora, S.J.S. Mittal, M. Mehta, A. 2008.Heavy metal induced oxidative stress & its possible reversal by chelation therapy. Indian Journal of Medical Research, 128(4);501–523.

[48] Foy, C.D.1992. Soil chemical factors limiting plant root growth in limitations to plant root growth. Advances in soil Sciences, 19;97-149.

[49] Ghosh, U.C. Dasgupta, M. Debnath, S. and Bhat, S.C.2003. Studies on management of chromium (VI)-contaminated industrial waste effluent using hydrous titanium oxide (HTO). Water, Air, and Soil Pollution, 143;245–256.

[50] Gillespie, I.M.M. Philp, J.C.2013. Bioremediation, an environmental remediation technology for the bioeconomy. Trends in Biotechnology, 31(6);329-32.

[51] Giuseppe Genichi. Alessia Carracci. Graziantonio Lauria. Maria Stefania Sinicropi. and Alessia Catalano.2020. Nickel: Human Health and Environmental Toxicology. International Journal of Environmental Research Public Health, 17:679.

[52] Gransee, A. Fuhrs, H.2013. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Journal of Plant Soil, 368;5–21.

[53] Grant, C.A. Clarke, J.M. Duguid, S. Chaney, R.L.2008. Selection and breeding of plant cultivars to minimize cadmium accumulation. Science of the Total Environment, 390;301–310.

[54] Greger, M. Lofstedt, M. 2004.Comparison of uptake and distribution of cadmium in different cultivars of bread and durum wheat. Journal of Crop Science, 44;501–507.

[55] Gupta, N. Ram, H. and Kumar, B.2016. Mechanism of Zinc absorption in plants: uptake, transport, translocation and accumulation. Reviews in Environmental Science Biotechnology. 15;89–109.

[56] Gyana, R. Rout. and Sunita Sahoo. 2015.Role of iron in plant growth and metabolism: A review in Agriculture Science,3;1-24.

[57] Hall, J.L.2002. Cellular mechanisms for heavy metal detoxification and tolerance. Journal of Experimental Botany, 53(366) ;1–11.

[58] Hashim, M.A. Mukhopadhyay, S. Sahu, J.N. Sengupta, B.2011. Remediation technologies for heavy metal contaminated groundwater. Journal of Environmental Management, 92;2355–2388.

[59] He, J.L. Ma, C.F. Ma, Y.L. Li, H., Kang, J.Q. Liu, T.X. Polle, A. Peng, C.H. Luo, Z. B.2013. Cadmium tolerance in six poplar species. Environmental Science Pollution Research,20;163–174.

[60] He, J.L. Qin, J.J. Long, L.Y. Ma, Y.L. Li, H. Li, K. Jiang, X.N. Liu, T.X. Polle, A. Liang, Z.S.2011.Net cadmium flux and accumulation reveal tissue specific oxidative stress and detoxification in Populus 3 canescens. Physiologia Plantarum, 143;50–63.

[61] Hegedus, A. Erdei, S. & Horvath, G. 2001.Comparative studies of H2O2 detoxifying enzymes in green and greening barley seedings under cadmium stress. Plant Science,160;1085–1093.

[62] Herawati, N Suzuki, S. Hayashi, K., Rivai, I. F. & Koyoma, H.2000.Cadmium, copper and zinc levels in rice and soil of Japan, Indonesia and China by soil type. Bulletin of Environmental Contamination and Toxicology, 64;33–39.

[63] Herbette, S. Taconnat, L. Hugouvieux, V. Piette, L. Magniette, M.L.M. Cuine, S. Auroy, P. Richaud, P. Forestier, C. Bourguignon, J.2006.Genome-wide transcriptome profiling of the early cadmium response of Arabidopsis roots and shoots. Biochimie, 88;1751–1765.

[64] Hoang, T.H. Ju-Yong.K. Sunbaek, B. Kyoung-Woong, K.2001.Source and fate of as in the environment. Geosystem engineering, 13;35–42.

[65] Hokura, A. Omuma, R. Terada, Y. Kitajima, N. Abe, T. Saito, H. Yoshida, S. Nakai, I.2006. Arsenic distribution and speciation in an arsenic hyperaccumulator fern by x-ray spectrometry utilizing a synchrotron radiation source. Journal of Analytical Atomic Spectroscopy, 21;321–328.

[66] Horst, W.J. Wang, Y. Eticha, D.2010.The role of the root apoplast in aluminium-induced inhibition of root elongation and in aluminium resistance of plants: A review. Annuals Botany, 106;185–197.

[67] Hossain, A.K.M.Z. Koyama, H. and Hara, T.2006..Growth and cell wall properties of two wheat cultivars differing in their sensitivity to aluminium stress. Journal of Plant Physiology, 163(1);39–47.

[68] Hossain, M.A. Piyatida, P. da Silva, J.A.T. and Fujita, M.2012. Molecular mechanism of heavy metal toxicity and tolerance in plants: central role of glutathione in detoxification of reactive oxygen species and methylglyoxal and in heavy metal chelation. Journal of Botany,2(2012)37.

[69] Huang, C.F. 2009.A bacterial-type ABC transporter is involved in aluminium tolerance in rice. Plant Cell, 21(2); 655–667.

[70] Huang, C.F. Yamaji, N. Chen, Z. Ma, J.F.2012.A tonoplast-localized half-size ABC transporter is required for internal detoxification of aluminium in rice. Plant journal 69(5);857-867.

[71] Huang, J.W. Chen, J. Berti, W.R. Cunningham, S.D. 1997.Phytoremediation of lead contaminated soils: role of synthetic chelates in lead phytoextraction. Environmental Science and Technology, 31;800–8005.

[72] Inmaculada Yruela. 2009. Cupper in plants: Acquisition, transport and interactions. A review Functional Plant Physiology,36;409-430.

[73] Isayenkov, S.V. Maathuis, F.J.M.2008.The Arabidopsis thaliana aquaglyceroporin AtNIP7;1 is a pathway for arsenite uptake. FEBS Letters, 582;1625–1628.

[74] Jones, D.L. Blancaflor, E.B. Kochian, L.V. Giloy, S.2006. Spatial coordination of aluminium uptake production of reactive oxygen species, callose production and wall rigidification in maize roots. Plant cell Environment, 29;1309-1318.

[75] Jones, D.L. Kochian, L.V.1995.Aluminium Inhibition of the Inositol 1,4,5-Trisphosphate Signal Transduction Pathway in Wheat Roots: A Role in Aluminium Toxicity? Plant Cell, 7;1913–1922.

[76] Jordao, C.P. Pereira, J.L. Jham, G.N. and Bellato, C.R.1999. Distribution of heavy metals in environmental samples near smelters and mining areas in Brazil. Environmental Technology, 20;489–498.

[77] Kapanen, A. Lodenius, M. Tulisao, E. Hartikainen, H.2005. Effects of different wood ashes on the solubility of cadmium in two boreal forest soils. Boreal Environmental Research, 10;135–143.

[78] Khalid, S. Shahid, M. Niazi, N.K. Rafiq, M. Bakhat, H.F. Imran, M. Abbas, T. Bibi, I. Dumat, C. 2017.Arsenic behaviour in soil-plant system: Biogeochemical reactions and chemical speciation influences. In Enhancing Clean-up of Environmental Pollutants; Springer,3;97–140.

[79] Khan, M.S. Zaidi, A. Wani, P.A. Oves, M. 2009.Role of plant growth promoting rhizobacteria in the remediation of metal contaminated soils. Environmental Chemistry Letters, 7;1-19.

[80] Khan, S. Munir, S. Sajjad, M. Li, G. 2016.Urban park soil contamination by potentially harmful elements and human health risk in Peshawar City, Khyber Pakhtunkhwa, Pakistan. Journal of Geochemical Exploration, 165;102–110.

[81] Kidd, P.S. and Proctor, J.2000. Effects of aluminium on the growth and mineral composition of Betula pendula Roth. Journal of Experimental Botany 51(347);1057-1066.

[82] Kimbrough, D.E. Cohen, Y. Winer, A.M. Creelman, L. and Mabuni, C.A2006. critical assessment of chromium in the environment. Environmental Science and Technology, 2;1–46.

[83] Knox, R.E. Pozniak, C.J. Clarke, F. R. Clarke, J.M. Houshmand, S. Singh, A.K.2009. Chromosomal location of the cadmium uptake gene (Cdu1) in durum wheat. Genome, 52;741–747.

[84] Kochian, L. V. Pineros, M. A. Liu, J. and Magalhaes, J. V.2015. Plant adaptation to acid soils: the molecular basis for crop aluminium resistance. Annul Review Plant Biology. 66;571–598.

[85] Kochian, L.V. Hoekenga, O.A. Pineros, M.A.2005. How do crop plants tolerate acid soils? Mechanisms of aluminium tolerance and phosphorous efficiency. Annual Review Plant Biology 55(1);459-493.

[86] Kopittke, P.M. de Jonge, M.D. Menzies, N.W. Wang, P. Donner, E. McKenna, B.A. Paterson, D. Howard, D.L. Lombi, E.2015. Examination of the distribution of arsenic in hydrated and fresh cowpea roots using two- and three-dimensional techniques. Plant Physiology, 159;1149–1158.

[87] Kotas, J. and Stasicka, Z.2000. Chromium occurrence in the environment and methods of its speciation. Environment Pollution, 107;263–283.

[88] Kramer, U. Metal hyperaccumulation in plants. Annual Review of Plant Biology, 61(2010)517–534.

[89] Kupper, H. Kochian, L.V.2010. Transcriptional regulation of metal transport genes and mineral nutrition during acclimatization to cadmium and zinc in the Cd/Zn hyperaccumulator. Thlaspi caerulescens (Ganges population). New Phyto logia, 185;114-129.

[90] Landrigan, P.J. Schechter, C.B. Lipton, J.M. Fahs, M.C. Schwartz, J. 2002.Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. Environment and Health Perspect, 110;721–28.

[91] Li, X. Li, Y. Qu, M. Xiao, H. Feng, Y. Liu, J. Wu, L. Yu, M. 2016.Cell wall pectin and its methyl-esterification in transition zone determine al resistance in cultivars of pea (Pisum sativum). Frontiers in Plant Science, 7;39.

[92] Li, X.X. Rubaek, G.H. Sorensen, P.2016. High plant availability of phosphorus and low availability of cadmium in four biomass combustion ashes. Science of the Total Environment, 557;851–860.

[93] Li, F. 2018.Heavy metal in urban soil: Health risk assessment and management. Heavy Metals, 337.

[93] Lidon, F.C. and Barreiro, M. G. 2008.Aluminium toxicity in maize hybrids during germination. Bulgarian journal of Plant physiology, 28(3-4); 96-112.

[94] Liu, H. Chen, LP. Ai, X.Y. Yu, Y.H. and Zuo, Y.B.2009.Heavy metal contamination in soil alongside mountain railway in Sichuan, China. Environmental Monitoring and Assessment, 152;25–33.

[95] Liu, J. Qian, M., Cai, G. Yang, J. Zhu, Q. 2007.Uptake and translocation of Cd in different rice cultivars and the relation with Cd accumulation in rice grain. Journal of Hazard Materials, 143;443–447.

[96] Liu, M. Huang, B. Bi, X. Ren, Z. Shenga, G. Fu, J. 2013.Heavy metals and organic compounds contamination in soil from an e-waste region in South China. Environmental Science: Process and Impacts, 15;919–929.

[97] Lombi, E. Zhao, F. Fuhrmann, M. Ma, L.Q. McGrath, S.P. 2002.Arsenic distribution and speciation in the fronds of the hyperaccumulator Pteris vittata. New Phytologist, 156(2);195–203.

[98] Long, X.X. Yang, X.E. Ni, W.Z. Ye, Z.Q. He, Z.L. Calvert, D.V. Stoffella, J.P. 2003.Assessing zinc thresholds for phytotoxicity and potential dietary toxicity in selected vegetable crops. Communication in Soil Science and Plant Analysis, 34;1421–1434.

[99] Ma, J.F. Ryan, P.R. Delhaize, E. 2001.Aluminium tolerance in plants and the complexing role of organic acids. Trends in Plant Science, 6(6);273-278.

[100] Ma, J.F. Hiradate, S. Nomoto, K. Iwashita, T. Matsumoto, H.1997. Internal detoxification mechanism of Al in hydrangea (Identification of Al form in the leaves). Plant physiology 113(4);1033-1039.

[101] Ma, J.F. Yamaji, N. Mitani, N. Xu, X.Y. Su, Y.H. 2008.Transporters of arsenite in rice and their role in arsenic accumulation in rice grain. PROC NATL ACAD SCI 105(29);9931–9935.

[102] Magalhaes, J.V. 2007. A gene in the multidrug and toxic compound extrusion (MATE) family confers aluminium tolerance in sorghum. Nature Genetics, 39(9);1156–1161.

[103] Mahajan, P. Kaushal, J.2018. Role of phytoremediation in reducing cadmium toxicity in soil and water. Journal of Toxicology, 4864365;1–16.

[104] Malec, P. Mysliwa-Kurdziel, B. Prasad, M.N.V. Waloszek, A. Strzalka, K.2011. Role of aquatic macrophytes in biogeochemical cycling of heavy metals, relevance to soil-sediment continuum detoxification and ecosystem health. In: Sherameti I, Varma A (eds) Detoxification of heavy metals. Springer, Berlin, 345–368.

[105] Malik, A.2004. Metal bioremediation through growing cells. Environment International,30;261–278.

[106] Marschner, H.1995. Mineral nutrition of higher plants. (Academic Press: London.

[107] Meharg, A.A. and Macnair, M.R.1990. An altered phosphate uptake system in arsenate-tolerant Holcus lantus L. New Phytologist, 116(1);29–35.

[108] Meharg, A.A. Sun, G. Williams, P.N. Adomako, E., Deacon, C.2008. Inorganic arsenic levels in baby rice are of concern. Environment Pollution, 152;746–749.

[109] Mendoza-Cozatl, D.G. Butko, E. Springer, F. Torpey, J.W. Komives, E.A. Kehr. Schroeder, J.I.2008. Identification of high levels of phytochelatins, glutathione and cadmium in the phloem sap of Brassica napus. A role for thiol-peptides in the long-distance transport of cadmium and the effect of cadmium on iron translocation. The Plant Journal, 54;249–259.

[110] Mendoza-Cozatl, D.G. Jobe, T.O. Hauser, Schroeder, J.I.2011. Long distance transport, vacuolar sequestration, tolerance, and transcriptional responses induced by cadmium and arsenic. Current Opinion in Plant Biology, 14(;554–562.

[111] Merkle, S.A.2006. Engineering forest trees with heavy metal resistance genes. Sylvie Genet, 55;263–268.

[112] Mishra, B.K. Dubey, C.S. Shukla, D.P. Bhattacharya, P. Usham, A.L. 2009.Concentration of arsenic by selected vegetables cultivated in the Yamuna flood plains (YFP) of Delhi, India. Environmental Earth Science. 72;3281−3291.

[113] Mishra, S. Srivastava, S. Tripathi, R.D. Trivedi, P.K. 2008.Thiol metabolism and antioxidant systems complement each other during arsenate detoxification in Ceratophyllum demersum L. Aquatic Toxicology, 86;205–215.

[114] Mishra, S. Wellenreuther, G. Muttusch, J. Stark, H.J. and Kupper, H. 2013.Speciation and distribution of arsenic in the no hyperaccumulator macrophytes *Ceratophyllum demersum*. Plant Physiology, 163;1396-1408.

[115] Moore, K.L. Schroder, M. Lombi, E. Zhao, F.J. McGrath, S.P. Hawkesford, M.J. Shewry, P.R. Grovenor, C.R.2009..Nano SIMS analysis of arsenic and selenium in cereal grain. New Phytologist, 185;434–445.

[116] Moore, K.L. Schroder, M. Wu, Z., Martin, B.G. Hawes, C.R. McGrath, S.P. Hawkesford, M.J. Feng Ma, J. Zhao, F.J Grovenor, C.R.2011. High-resolution secondary ion mass spectrometry reveals the contrasting subcellular distribution of arsenic and silicon in rice roots. Plant Physiology, 156;913–924.

[117] Mossor-Pietraszewska, T. 2001.Effect of aluminium on plant growth and metabolism. Acta Biochemica Polonica, 48(3);673-686.

[118] Muhammad, A. Farooq, A. Faisal Islam A. Basharat Ali, A, B. Ullah Najeeb. Bizeng Mao. 2016.Arsenic toxicity in plants: Cellular and molecular mechanisms of its transport and metabolism. Environmental and Experimental Botany, 132;42-52.

[119] Muhammad, A. Shafqat, A. Muhammad, R. Muhammad, I. Farhat, A. Mujahid, F. Saima, A.B.2015. The effect of excess copper on growth and physiology of important food crops: A review. Environmental Science and Pollution Research, 22(11);8148–8162.

[120] Mullen, D.J.E. Nowacki, W. 1972.Refinement of crystal-structures of realgar, AS's and orpiment, As2S3. Zeitschrift Fur Kristallographie,136;48–65.

[121] Muszy ´nska, E. Hanus-Fajerska, E. Piwowar, B. Augustynowicz, J. Ciarkowska, K. Czech, T. 2017.From laboratory to field studies–the assessment of Biscutella laevigata suitability to biological reclamation of areas contaminated with lead and cadmium. Ecotoxicology and Environmental Safety, 142;266–273.

[122] Nawab, J. Khan, S. Aamir, M. Shamshad, I. Qamar, Z. Din, I. Huang, Q.2016. Organic amendments impact the availability of heavy metal (loid) s in mine-impacted soil and their phytoremediation by Pennisetum Americanum and Sorghum bicolour. Environmental Science and Pollution Research, 23;2381–2390.

[123] Nouri, J.N. Khorasani, N. Lorestani, B. Karami, M. Hassani, A.H. and Yousefi, N. 2009.Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. Environmental Earth Science,59;315–323.

[124] Nriagu, J.O. 2008.Tales told in lead. Science, 281;1622–23.

[125] O'Day, P.A, Vlassopoulos, D., Root, R., Rivera, N. 2009.The influence of sulfur and iron on dissolved arsenic concentrations in the shallow subsurface under changing redox conditions. Proc. Natl. Acad. Sci. U. S. A. 101;13703–13708.

[126] Outridge, P.M. and Noller, B.N. 1991.Accumulation of toxic trace elements by freshwater vascular plants. Reviews of Environmental and Contamination Toxicology, 121;1–63.

[127] Pahlsson, A.M.B.1990. Influence of aluminium on biomass, nutrients, soluble carbohydrates and phenols in beech (*Fagus sylvatica*). Physiologia Plantarum, 78 (1);79-84.

[128] Panda, S.K. Baluska, F. Matsumoto, H. 2009.Aluminium stress signalling in plants. Plant Signal Behaviour, 4;592–597.

[129] Park, J. Song, W.Y. Ko, D. Eom, Y. Hansen, T.H. Schiller, M. Lee, T.G. Martinoia, E. Lee, Y.2012. The phytochelatin transporters AtABCC1 and AtABCC2 mediate tolerance to cadmium and mercury. Plant Journal, 69;278–288.

[130] Pederno, N.J.I. Gomez, R. Moral, G. Palacios, J. and Mataix, J. 1997. metals and plant nutrition and development. Recent Research Developments in Phytochemistry, 1;173–179.

[131] Pickering, I.J. Gumaelius, L. Harris, H.H. Prince, R.C. Hirsch, G. Banks, J.A. Salt, D.E. George, G.N.2006. Localizing the biochemical transformations of arsenate in a hyperaccumulating fern. Environmental Science and Technology, 40;5010–5014.

[132] Pozniak, C.J. Clarke, J.M. Clarke, F.R.2012. Potential for detection of marker-trait associations in durum wheat using unbalanced, historical phenotypic datasets. Molecular Breeding,1537–1550.

[133] Pulford, I.D. and Watson, C.2003. Phytoremediation of heavy metal-contaminated land by trees—a review. Environment International, 29;529– 540.

[134] Qian, J.H. Zayed, A. Zhu, Y.L. Yu, M. Terry, N.1999. Phytoaccumulation of trace elements by wetland plants: III. Uptake and accumulation of ten trace elements by twelve plant species. Journal of Environment Quality, 28;1448–1455.

[135] Rahman, M.A. Hogan, B. Duncan, E. Doyle, C. Krassoi, R. Rahman, M.M. Naidu, R. Lim, R.P. Maher,W. Hassler, C. 2014.Toxicity of arsenic species to three freshwater organisms and biotransformation of inorganic arsenic by freshwater phytoplankton (Chlorella sp. CE-35). Ecotoxicology and Environmental Safety, 106;126–135.

[136] Rai, U.N. Sinha, S. Tripathi, R.D. Chandra, P.1995.Wastewater treatability potential of some aquatic macrophytes: removal of heavy metals. Ecological Engineering, 5;5–12.

[137] Rajkumar, M. Ae, N. Prasad, M.N.V. Freitas, H. 2010.Potential of siderophore-producing bacteria for improving heavy metal phytoextraction. Trends in Biotechnology, 28;142–149.

[138] Rascio, N. and Navari-Izzo, F.2011. Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting? Plant Science, 180(2); 169–181.

[139] Rebecca, R.C. 2011.Copper: Inorganic and coordination chemistry. Encyclopaedia of Inorganic and Bioinorganic Chemistry, John Wiley and Sons, Ltd. USA..

[140] Rodda, M.S. Li, G. Reid, R.J. 2011.The timing of grain Cd accumulation in rice plants: the relative importance of remobilisation within the plant and root Cd uptake post-flowering. Plant Soil, 347;105–114.

[142] Rodriguez-Serrano, M. Romero-Puertas, M.C. Pazmino, D.M. Testillano, P.S. Risueno, M.C. Del Rio, L.A. Sandalio, L.M. 2009.Cellular response of pea plants to cadmium toxicity: cross talk between reactive oxygen species, nitric oxide, and calcium. Plant Physiology, 150;229–243.

[143] Rothenberg, S.E. Windham-Myers, L. Creswell, J.E.2014. Rice methylmercury exposure and mitigation: a comprehensive review. Environmental Research, 133;407–23.

[144] Rout, G.R. Samantaray, S. and Das, P.2001. Aluminium toxicity in plants: a review. Agronomie, 21(1);3-21.

[145] Samaranayake, P. Peiris B.D. and Dissanayake, S. 2012.Effect of excessive ferrous (Fe 2+) on growth and iron content in rice (Oryza sativa). International Journal of Agricultural Biology, 14;296-298.

[146] Sasaki, T.2004. A wheat gene encoding an aluminium-activated malate transporter. Plant Journal, 37(5);645–653.

[147] Schmoger, M.E.V. Oven, M. Grill, E.2000. Detoxification of arsenic by phytochelatins in plants. Plant Physiology, 122;793–801.

[148] Schutzendubel, A. and Polle, A.2002. Plant responses to abiotic stresses: heavy metal-induced oxidative stress and protection by mycorrhization. The Journal of Experimental Botany, 53(372);1351–1365.

[149] Schutzendubel, A. Schwanz, P. Teichmann, T. Gross, K. Langenfeld-Heyser, R. Godbold, D.L. Polle, A. 2001.Cadmium-induced changes in antioxidative systems, hydrogen peroxide content, and differentiation in Scot's pine roots. Plant Physiology, 127; 887–898.

[150] Shahid, M. Shamshad, S. Rafiq. Khalid, S. Bibi, I. Niazi, N.K. Dumat, C. Rashid.2017. Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: A review. Chemosphere, 178;513–533.

[151] Shams, K.M. Tichy, G. Fischer, A. Sager, M. Peer, T. Bashar, A.2010. Aspects of phytoremediation for chromium contaminated sites using common plants Urtica dioica, Brassica napus and Zea mays. Plant and Soil, 328;175–198.

[152] Shanker, A.K. Cervantes, C. Loza-Tavera, H. Auvdainayagam, S.2005.Chromium toxicity in plants. Environment International, 31;739–753.

[153] Shen, R. Ma, J.F. Iwashita, T.2002. Compartmentation of aluminium in the leaves of an Al-accumulator, *Fagopyrum esculentum* Moench. Planta 215(3);394-398.

[154] Silva,2002. Aluminium toxicity targets in plants. Journal of Botany. Articles ID 219462, 8.

[155] Sneller, F.E.C. van Heerwaarden, L.M. Kraaijeveld-Smit, F.J.L.1999. Toxicity of arsenate in *Silene vulgaris*, accumulation and degradation of arsenate-induced phytochelatins. New Phytologist, 144(2);223–232.

[156] Song, W.Y. Park, J. Mendoza-Cozatl, D. Suter-Grotemeyer, M. Shim, D. Hortensteiner, S. Geisler, M. Weeder, B. Rea, P. Rentsch, D. Schroder, J. Lee, Y. Martinoia, E. 2010.Arsenic tolerance in Arabidopsis is mediated by two ABCC-type phytochelatin transporters. Proc Natl Acad Sci USA. 107;21187–21192.

[157] Song, X. Kenston, S.S.F. Kong, L. Zhao, J. 2017.Molecular mechanisms of nickel induced Toxicity and chemoprevention. Toxicology, 392;47–54.

[158] Souza, V.L. Almeida, A.A.F. Manga Beira, P.A.O. Silva, D.C. de Jesus, R.M. Valle, R.R. 2017.Morphophysiological, ultrastructural, and nutritional changes induced by Cu toxicity in young Erythrina fusca plants. International Journal of Phytoremediation, 19;621–631.

[159] Sreekanth, T.V.M. Nagajyothi, P.C. Lee, K.D. Prasad, T.N.V.K.V. 2013.Occurrence, physiological responses and toxicity of nickel in plants. International Journal of Environmental Science and Technology, 10;1129–1140.

[160] Srivastava, S. Mishra, S. Tripathi, R.D. Dwivedi, S. Trivedi, P.K. and Tandon, P.K.2007. Phytochelatins and antioxidant systems respond differentially during arsenite and arsenate stress in Hydrilla verticillate (L.f.) Royle. Environmental Science and Technology, 41(8);2930–2936.

[161] Srivastava, S. Prakash, S. and Srivastava, M.M.1999. Chromium mobilization and plant availability—the impact of organic complexing ligands. Plant and Soil, 212;203–208.

[162] Stiener, T. Zoz, A.S. Junior P. Castagnara, D.D. and Dranski, J.A.L. 2012.Effects of aluminium on plant growth and nutrient uptake in young physic nut plants. Semina: Ciencias Agrarias 33(5);1779-1788.

[163] Swain, H. and Abhijita, S.2013. Nitrogen fixation and its improvement through genetic engineering. Journal of Global Bioscience, 2;98–112.

[164] Tangahu, B.V. Abdullah, S.R.S. Basri, H. Idris, M. Anuar, N. Mukhlisin.2011.A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. International Journal of Chemical Engineering. Article ID 939161, 31 pages.

[165] Taylor, G.J. Crowder, A.A.1983. Uptake and accumulation of heavy metals by Typha latifolia in wetlands of the Sudbury, Ontario region. Canadian Journal of Botany, 61(1);63–73.

[166] Tovkach, A.2013.Transposon-mediated alteration of TaMATE1B expression in wheat confers constitutive citrate efflux from root apices. Plant Physiology 161(2);880–892.

[167] Tripathi, R.D. Srivastava, S. Mishra, S.2013.Arsenic hazards: strategies for tolerance and remediation by plants. Trends in Biotechnology, 25(4);158–165.

[168] Tseng, C.H.2009. A review on environmental factors regulating arsenic methylation in humans. Toxicology and Applied Pharmacology, 235;338–350.

[169] Turkdogan, MK. Kilicel, F. Kara, K.2003. Heavy metals in soil, vegetables and fruits in the endemic upper gastrointestinal cancer region of Turkey. Environmental Toxicology and Pharmacology, 13;175–179.

[170] U.Y. Stambulska.2017. Effect of symbiotic nitrogen-fixing bacteria and xenobiotics on physiological and biochemical parameters of pea plants," Dissertation, Chernivtsi National University named after Yu. Fed'kovych, Chernivtsi, pp. 190.

[171] Vahter. M. 2002. Mechanisms of arsenic biotransformation. Toxicology, 181– 182;211–217.

[172] Van Belleghem, F. Cuypers, A. Semane, B. Smeets, K. Vangronsveld, J. d'Haen, J. Valcke, R.2007. Subcellular localization of cadmium in roots and leaves of Arabidopsis thaliana. New Phytologist, 173; 495–508.

[173] Vangronsveld, J. Colpaert, J.V. Van Tichelen, K.K.1996. Reclamation of a bare industrial area contaminated by non-ferrous metals: physico-chemical and biological evaluation of the durability of soil treatment and revegetation. Environmental Pollution, 94;131–40.

[174] Vangronsveld, J. van Assche, F. Clijsters, H.2006. Reclamation of a bare industrial area contaminated by non-ferrous metals: in situ metal immobilization and revegetation. Environmental Pollution, 87;51 –59.

[175] Vardar, F. Unal, M. 2007Aluminium toxicity and resistance in higher plants. Advances in Molecular Biology, 1;1–12.

[176] Varshney, R.K. Graner, A. Sorrells, M.E.2005. Genomics-assisted breeding for crop improvement. Trends in Plant Science, 10;621–630.

[177] von Uexküll, H.R. Mutert, E.1995. Global extent, development and economic-impact of acid soils. Plant Soil journal 171(1);1–15.

[178] Wang, J.P. Raman, H. Zhang, G.P. Mendham, N. and Zhou, M.X. 2006.Aluminium tolerance in barley (*Hordeum vulgare* L.): physiological mechanisms, genetics and screening methods. Journal of Zhejiang University. Science. 7(10);769–787.

[179] Waterlot, C. Bidar, G. Pelfrene, A. Roussel, H. Fourrier, H. Douay, F. 2008.Contamination, fractionation and availability of metals in urban soils in the vicinity of former lead and zinc smelters, France. Pedosphere, 23;143–159.

[179] Wiebe, K. Harris, N.S. Faris, J.D. Clarke, J.M. Knox, R.E. Taylor, G.J. Pozniak, C.J.2010. Targeted mapping of Cdu1, a major locus regulating grain cadmium concentration in durum wheat (Triticum turgidum L. var durum). Theor Appl Genet, 121;1047–1058.

[180] Wood, T. Salavagionne, O. Mukherjee, B. Wang, L. Klumpp, A. Thomae, B. Eckloff, B. Schaid, D. Wieben, E., Weinshilboum, R. 2000.Human arsenic methyltransferase (As3MT) Pharmacogenetics gene resequencing and functional genomics studies. Journal of Biological Chemistry, 281; 7364–7373.

[181] Wu, H.L. Chen, C.L. Du, J. Liu, H. Cui, Y. Zhang, Y. He, Y.J. Wang, Y.Q. Chu, C.C. Feng, Z.Y.2012. Co-overexpression FIT with AtbHLH38 or AtbHLH39 in Arabidopsis-enhanced cadmium tolerance via increased cadmium sequestration in roots and improved iron homeostasis of shoots. Plant Physiology, 158; 790–800.

[182] Wyszkowski, M. and Radziemska, M.2010. Effects of chromium (III and VI) on spring barley and maize biomass yield and content of nitrogen compounds. Journal of Toxicology and Environment Health,73(17); 1274–1282.

[183] Wyszkowski, M. and Radziemska, M. 2013.Influence of chromium (III) and (VI) on the concentration of mineral elements in oats (Avena sativa L.). Fresenius Environmental Bulletin, 22(4);979–986.

[184] Xia, J. Yamaji, N. Kasai, T. Ma, J.F.2010. Plasma membrane-localized transporter for aluminium in rice. Proc Natl Acad Sci USA 107(43);18381–18385.

[185] Xu, J. Sun, J. Du, L. Liu, X. 2012.Comparative transcriptome analysis of cadmium responses in Solanum nigrum and Solanum torvum. New Phytologist, 196;110–124.

[186] Xue, P. Yan, C. Sun, G. Luo, Z.2012. Arsenic accumulation and speciation in the submerged macrophyte Ceratophyllum demersum L. Environmental Science and Pollution Research, 19;3969–3976.

[187] Yamaji, N. 2009.A zinc finger transcription factor ART1 regulates multiple genes implicated in aluminium tolerance in rice. Plant Cell 21(10);3339–3349.

[189] Yokosho, K. Yamaji, N. Ma, J.F. 2011. An Al-inducible MATE gene is involved in external detoxification of Al in rice. Plant Journal 68(6);1061–1069.

[190] Yoneyama, T. Gosho, T., Kato, M. Goto, S. Hayashi, H. 2010.Xylem and phloem transport of Cd, Zn and Fe into the grains of rice plants (Oryza sativa L.) grown in continuously flooded Cd-contaminated soil. Journal of Soil Science and Plant Nutrition, 56;445–453.

[191] Zargar, S.M. Agrawal, G.K. Rakwal, R. Fukao, Y.2015. Quantitative proteomics reveals role of sugar in decreasing photosynthetic activity due to Fe deficiency. Frontiers in Plant Science, 6;592.

[192] Zayed, A.M. and Terry, N. 2003.Chromium in the environment: factors affecting biological remediation. Plant Soil, 249(1);139–156.

[193] Zengin, F.K. and Munzuroglu, O.2005. Effects of some heavy metals on content of chlorophyll, proline and some antioxidant chemicals in bean (*Phaseolus vulgaris* L.) seedlings. Acta Biologica Cracoviensia Series Botanica, 47(2);157–164.

[194] Zhang, X.H. Liu, J. Huang, H.T. Chen, J. Zhu, Y.N. Wang, D.Q.. 2007.Chromium accumulation by the hyperaccumulator plant Leersia hexandra Swartz. Chemosphere, 67;1138–1143.

[195] Zhao, X. Q. and Shen, R. F.2018. Aluminium-nitrogen interactions in the soil-plant system. Frontiers in Plant Science, 9;807.

[196] Zhou, B. Yao, W. Wang, S. Wang, S. and Jiang, T. 2014.The metallothionein gene, *TaMT3*, from *Tamarix androssowii* confers Cd2+ tolerance in Tobacco. International Journal of Molecular Sciences, 15(6); 10398–10409.

[197] Zuo, Y. and Zhang, F. 2011.Soil and crop management strategies to prevent iron deficiency in crops. Plant Soil, 339; 83-95.