



Biosorption Potential of Dry Biomass of *Parthenium Hysterophorus*, and *Euphorbia Helioscopia* from Heavy Metal Solution in a Column Method

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Abstract

The study was carried out to determine the biosorption capacity of three wild plants *Euphorbia helioscopia* (Sun spurge), and *Parthenium Hysterophorus* (Gajar buti) by using column method. The experiment was conducted in Environmental biotechnology lab of University of Okara, located in Renala Khurd, District Okara, Pakistan. The plants biomass was treated with tap water, 10 ppm, 20 ppm and 30 ppm chromium solution. The experiment was repeated three times within three weeks and average data was collected. The metal analysis was done by using AAS (Atomic Absorption Spectrophotometer). The results analysed that *Parthenium Hysterophorus* had greater capacity (25.060 mg g^{-1}) to absorb chromium metal as compared to *Euphorbia helioscopia* (5.0300 mg g^{-1}) at 30 ppm chromium concentration and with increasing the metal ion concentration the rate of biosorption increased. The results concluded that plant *Parthenium Hysterophorus* has the highest potential to accumulate chromium.

Keywords: *biosorption capacity, column method, environment, biomass treatment, chromium accumulation potential.*

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Introduction

Environment is the most important constituent of life for living as well as non-living organisms. Therefore, environment should be clean and clear but now a day's environmental pollution is the serious problem we are facing on our planet (Muralikrishna and Manickam). The substances that cause pollution are called as pollutants (heavy metals, sulphonic compounds, industrial waste etc.) and these are coming into environment due to natural (volcanic eruption, wild fire, fossil fuel emissions) as well as human activities like deforestation, industrialization, agriculture waste, material, fertilizers, radiations etc.) (Verma, & Prakash, 2020; Niaz, et al., 2022; Naqvi, et al., 2024; Bartowitz, et al., 2022).

Air pollution, soil pollution as well as water pollution are main types of pollution. Air pollution is mainly caused by the automobile waste, industrial waste, volatile organic compounds VOC, volcanic eruption etc. Air pollution causes serious damage to human health like asthma, lungs cancer, Chronic Obstructive Pulmonary Diseases (COPD) (Kwon, et al., 2024). Acidic rain is the main impact of air pollution (Manoj Kumar, et al., 2013). The acidic rain causes serious damage to buildings and human health. The utilization of domestic waste water, fertilizers, pesticides, herbicides and livestock manure on large scale led to contamination the soil of agricultural area. Soil pollution destroys the agricultural land, the ultimate results of soil pollution is the disturbance of food chain (Singh, & Singh, 2020; Ghosh, et al., 2022).

The types of metals include precious metals (Platinum, silver, gold), the toxic metals (copper, cadmium, nickel, lead, arsenic, chromium) and radioactive metals (uranium etc.) (Jagaba, et al., 2024). The sources of heavy metals are mainly agriculture waste and wastewater coming from various industries (fertilizers, mining, food, steel, pharmaceutical, leather tanning, paint, nuclear power stations etc.). The heavy metals cause serious diseases to human like cancer, asthma, urinary tract diseases, neurotoxicity, cardiovascular diseases and diabetes (Jomova, et al., 2024). Heavy metal can also bind with proteins and prevent DNA replication so that cell division does not occur, and the complete cell cycle stops (Mukherjee, et al., 2022).

To avoid the hazardous effects of heavy metals it is most important to remove metals from ruin water before its disposal to water sources. There are many physical and chemical methods to remove metals like chemical separation from solution, lime clotting, solvent ejection, membrane leaching, opposite diffusion and ion conversion. These processes have their own merits and demerits. But due to incomplete metal removal, high reagent needs, large amount of energy usage and generation of very toxic waste these methods are not commercially used (Qasem, Mohammed, & Lawal, 2021). It's necessary to use the biological methods like bioremediation, phytoremediation, adsorption and biosorption because these are environmental amiable and inexpensive process for heavy metals diminution (Saxena, et al., 2020).

Parthenium Hysterophorus (Gajar buti) that is commonly called as Gajar buti is a wild plant that is mainly present along the bank of river, road sides, and bare lands as well as agricultural land and along railway tracks etc. Parthenium is a widely spread plant belongs to family Asteraceae it mainly presents during dry and hot days. It has thick stem short, dull green and star like leaves and its average height is mainly 1.5 to 2.0 m. One plant can produce 2500 seeds. Parthenium is allelopathic plant that show competition in growth with other commercially important plants and it cause allergic reactions to human. It is very important to cease the growth of Parthenium for the best growth of other plants (Kumar, et al., 2021).

Euphorbia Helioscopia (Sun spurge) is a weed that ranges from herb, shrub to woody plant belongs to family Euphorbiaceae that is present word wide that secrete white milky exudate. Its containing lush green ranged leaves from end, bushy stem that is branched further, roots are slender threadlike, and flowers are yellow green, hermaphrodite (Schmidt, & Evans, 1980). The euphorbia plant causes cancer, skin allergy, asthma, hay fever, tumors in humans and various diseases to animals (Ali, et al., 2016). This plant also has various pharmaceutical activities like the seeds are used in the treatment of cholera, the leaves



have anti-cancer activities. And its milky sap is applied to gust skin. Aims and objectives of this experimental study are:

- To determine the biosorption capacity of dry biomass of Parthenium Hysterophorus (Gajar buti) and Euphorbia Helioscopia (Sun spurge) for heavy metal chromium (Cr^{+2}) from aqueous solution.
- Comparison between dry biomass of different plant Parthenium Hysterophorus (Gajar buti) and Euphorbia Helioscopia (Sun spurge) for the remediation of chromium (Cr^{+2}) metal.

Materials and Methods

Selection of Plants

Following plants were selected.

- Parthenium Hysterophorus (Gajar buti)
- Euphorbia Helioscopia (Sun spurge)

Essential reason for selection these plants was that these were easily available in bulk amount and these were also wild plants that were abundantly present all over the world. Comprehensive description and key characteristics of selected plant species are shown in Table 1.

Table 1. Description of Selected Plants

Sr. no.	Vernacular name	Scientific name	Family	Picture
1	Sun spurge	Euphorbia Helioscopia	Euphorbiaceae	
2	Gajar buti	Parthenium Hysterophorus	Asteraceae	

Storage of Biomass

All the selected plant species were collected from University of Okara as well as from adjacent areas from Renala city. Pieces of plants were dried in an open air for elimination of all moisture content. All plants were crushed and milled into powdered biomass with the help of mortar and pestle and electrical grinder. The biomass was sieved by the 1 mm sieve to obtain fine powdered biomass. After sieving the biomass was preserved in the polythene bags. 30.64 g and 40.74 g of plant P1 and P2 biomass was measured with the help of physical balance. Where, P6= P1 (Euphorbia Helioscopia) and P7= P2 (Parthenium Hysterophorus).



Determination

The required chromium metal concentration from salt was determined by using following formula.

$$1 \text{ gram Cr} = \frac{\text{Molecular of potassium chromate}}{\text{Atomic mass of chromium}} \quad (1)$$

Atomic mass of potassium = 39.1 u, atomic mass of chromium = 51.99 u, and atomic mass of oxygen = 16 u. The 3.73 g of chemical (potassium chromate) was measured by using analytical balance.

Preparation of Stock Solution

1000 ppm stock was prepared by dissolving 3.73 gram of potassium chromate salt in small amount de-mineralized water then the volume of 1000 ml³ flask was filled up to mark by adding de-mineralized water. Stock solution was stored in the glass cylinders.

1000 ml of tap water and metal solutions from drips were allowed to fall down drop wise into the columns. The effusion of solution from all drips started at the same time by keeping the drops number also same i.e., 15 drops per minute.

Digestion of Leachate

25 ml of the filtered leachate after treatments was taken into 250 ml conical flask. The acid nitric acid HNO³ (50%) and per chloric acid HClO⁴ (50%) was taken and prepared 1:1 acid mixture. After that the 3ml acid mixture was added into the flask and flasks are heated at hot plate at 280 °C within fume hood. When the solution was reduced in volume then 25 ml of distilled water was added in digesting leachate and allowed to reduce again this process was repeated again and again until the transparent and cleaned solution was obtained. Then the flasks were taken off from hot plate and allowed to cool down.

The control samples of biomass and treated samples of biomass were also digested in fume hood. 1g of biomass was measured with the help of balance and then poured into the 250 ml conical flask. 10ml of acid mixture (50% HNO³+ 50% HClO⁴) was added into flask with the help of funnel and the flasks were placed on the hot plate in fume hood and start heating at 280 °C. Distilled water was added to adjust volume and allowed to digest until the transparent and cleaned solution was obtained. After that flasks are allowed to cool. Then the solutions were filtered and 25 ml volume was attained in volumetric flask by adding distilled water.

Analysis of Heavy Metal Concentration

All the digested samples were tested for detection of concentration of heavy metal chromium by using (AAS) Atomic Absorption Spectrophotometer. The Atomic Absorption Spectrophotometer (Hitachi Polarized Zeeman AAS, Z-8200, Japan) hitac Lab, university of Agriculture Faisalabad was used. Before running the apparatus, the gas, pressure the flame accuracy and other conditions of AAS was checked carefully. And then apparatus was standardized by blank solutions and standard solutions. After that, the samples were loaded, and the graphs and readings were obtained from the computer.

The uptake of metal ions was determined by comparing the metal concentration of control samples with the treated samples. Data computation and calculations was executed on Microsoft Excel and statistical analysis was done by using statistical software (STATISTICA).



Results

Graphical representation of concentration of chromium (mg g^{-1}) in leachate collected from Euphorbia Helioscopia (Sun spurge) absorbent in a column method (Figure 1). Concentration of chromium (mg g^{-1}) in leachate collected from Euphorbia Helioscopia (Sun spurge) absorbent using a column method is shown in Table 2. Where, T0 = biosorbent treated with tap water. T1= biosorbent treated with 10ppm chromium. T2 = biosorbent treated with 20 ppm chromium. T3 = biosorbent treated with 30 ppm chromium. And P1= Euphorbia Helioscopia (Sun spurge) as biosorbent.

Table 2. Concentration of Chromium (mg g^{-1}) in Leachate Collected from Euphorbia Helioscopia (Sun spurge) Absorbent in a Column Method

Source	<i>df</i>	<i>ss</i>	<i>ms</i>	<i>f</i>	<i>p</i>
Treat	3	50.0484	16.6828	111219**	0.0000
Error	8	0.0012	0.00020		
Total	11	50.0496			
Grand Mean 2.3817 CV 0.51					

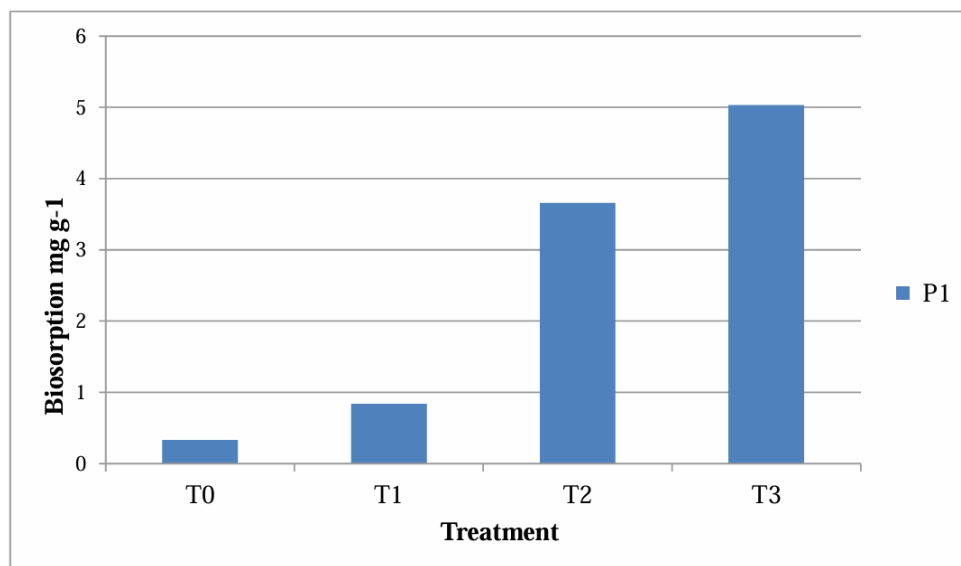


Figure 1. Euphorbia Helioscopia (Sun spurge) Absorbent in a Column Method

Concentration of chromium in leachate obtained from treated biomass of Euphorbia Helioscopia (Sun spurge) collected from the fields of university of Okara, and adjacent areas of Renala khurd, Okara presented in Table 3 and Figure 2. Data was statistical analyzed. ANOVA results showed that chromium (Cr) concentration in leachate samples were high significantly ($P \leq 0.05$) different as confront to control.

Table 3. Concentration of Chromium (mg g^{-1}) in Leachate Collected from Parthenium Hysterophorus (Gajar buti) Absorbent in a Column Method

Source	<i>df</i>	<i>ss</i>	<i>ms</i>	<i>f</i>	<i>p</i>
Treat	3	1182.82	394.272	5604**	0.0000
Error	8	0.56	0.070		
Total	11	1183.38			
Grand Mean 8.1817 CV 3.24					



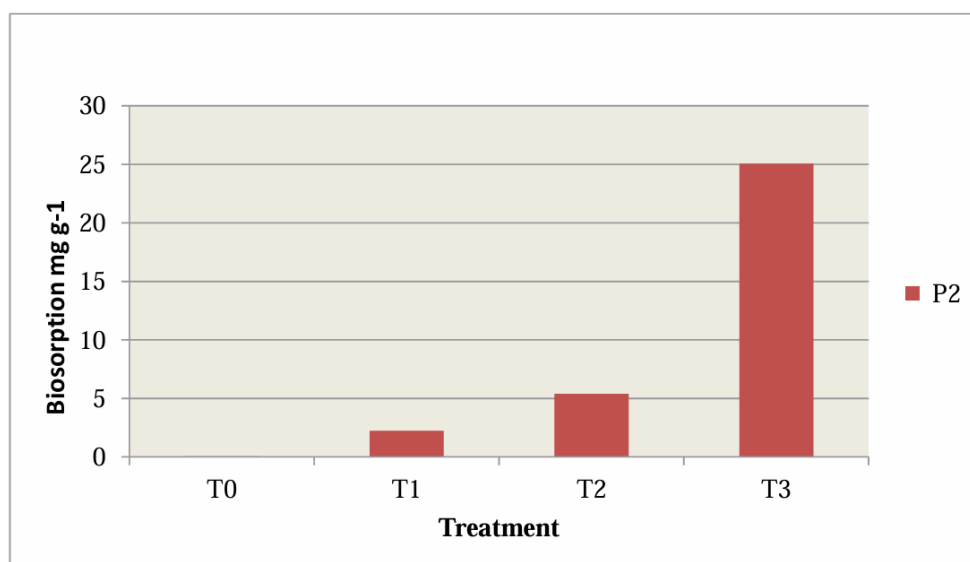


Figure 2. Graphical Representation of Concentration of Chromium (mg g⁻¹) in Leachate Collected from Parthenium Hysterophorus (Gajar buti) Absorbent in a Column Method

Here, P2= Parthenium Hysterophorus (Gajar buti) as biosorbent. The concentration of Cr was found in leachate collected from Euphorbia Helioscopia (Sun spurge) biosorbent was in following corresponding order $0.33 > 0.8367 > 3.6567 > 5.03$. Results have been showed that increase in Cr concentration increased the biosorption capacity in Euphorbia Helioscopia (Sun spurge). The highest significant biosorption occurred in treatment T3 (30 ppm) as compared to control.

Comparison

Comparison among Concentration of chromium (mg g⁻¹) in leachate collected from Euphorbia heliscopia (Sun spurge) and Parthenium Hysterophorus (Gajar buti) absorbent in a column method (Table 4 and Figure 3).

Table 4. Comparison among Euphorbia Heliscopia (Sun spurge) and Parthenium Hysterophorus (Gajar buti) Absorbent in a Column Method

Treatments	Cr (mg g ⁻¹) P1	Cr (mg g ⁻¹) P2
T0	0.33±0.004 d	0.0467±0.05 d
T1	0.8367±0.83 c	2.2300±2.22 c
T2	3.6567±5.02 a	5.3900±5.18 b
T3	5.0300±3.64 b	25.060±25.05 a
LSD	0.0231	0.4994
F value	111219	5604

Concentration of chromium in leachate collected from treated biomass of Euphorbia heliscopia (Sun spurge), Parthenium Hysterophorus (Gajar buti) and Cirsium arvense (Kandyari) collected from University of Okara, and adjacent areas of Renala khurd presented in Table 4 and Figure 3. Data was statistical analyzed. ANOVA results showed that chromium (Cr) concentration in all leachate samples were high significantly ($P \leq 0.05$) different as confront to control. Comparatively results revealed that increase in Cr concentration increased the biosorption capacity in Euphorbia heliscopia (Sun spurge), Parthenium Hysterophorus (Gajar buti) and Cirsium arvense (Kandyari). According to table 8



Parthenium showed high absorption values as compared to chatri dodak and kandyari. Kandyari showed lowest absorption capacity. Hence results indicated that: $P2 > P1 > P3$.

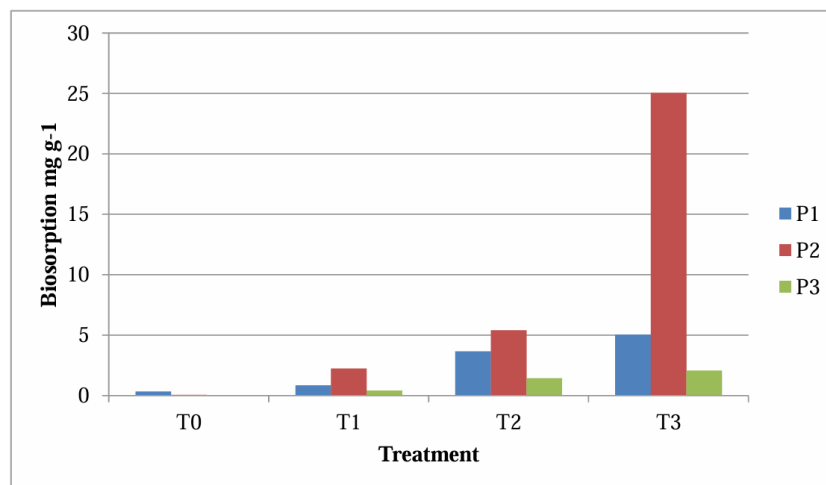


Figure 3. Graphical Representation of Comparison among Euphorbia Heliscopia (Sun spurge), Parthenium Hysterophorus (Gajar buti) and Cirsium Arvense (Kandyari)

Discussion

The presence of undesirable substance & dangerous chemicals in the natural environment is considered as pollution. Environmental pollution is a global issue that have drafted effect on all organisms especially humans. It has been reported that progress in modern technology and increasing trends in industrialization is a primary cause of environmental pollution (Kraemer, Ramachandran, & Perron, 2019). Among various kinds of pollution, the water pollution is widespread and remain for long time (Al-Taai, 2021). Contaminated water is a by-product of agricultural, industrial and commercial activities.

Hazardous metals like arsenic, arsenic, mercury, lead, cadmium and chromium are non-biodegradable in nature (Jadaa, & Mohammed, 2023; Sall, et al., 2020). Some heavy metals are trace metals like chromium (Cr) and lead (Pb) are essential for living organisms but in higher concentration they are toxic for them (Bánfalvi, 2011; Rahman, & Singh, 2019). Heavy metals can interfere in many processes of plants like gaseous change, photosynthesis and nutrient absorption (Rai, Agrawal, & Agrawal, 2016). These heavy metals are needed to be removed from environment and there are different methods for this purpose that are very expensive. In liquid medium heavy metals are in the form of mobile ions, soluble salt with legends that cannot be separated by common physical ways of separation.

Chromium is the very first element of the group VI with atomic number 24 and atomic mass 51.996. Chromium does not exist freely in nature and always found in chromite form. There are two states of chromium (Cr), (Cr III) trivalent chromium & (Cr VI) hexavalent chromium. Trivalent chromium is insoluble & hexavalent chromium is soluble in water. Trivalent form is essential for human body only in trace amount (Ukhurebor, et al., 2021). Its deficiency enhanced the chances of diabetes. While hexavalent form of chromium is very toxic for both animals & plants and its removal from aqueous solution is consider as essential (Kapoor, et al., 2022). Both form of chromium reduced the content of chlorophyll and immediately retard the growth of plant.

To keep in view water contamination, researchers took step to mitigate these contaminants through biosorption method. This mechanism is more valuable when selected material as a biosorbent is available



in bulk amount and commercially display low cost (Vijayaraghavan, & Balasubramanian, 2015; Aksu, 2005). The objective of recent study was to know the biosorption potential of *Euphorbia helioscopia* (Sun spurge) and *Parthenium Hysterophorus* (Gajar buti) plants biomass treated with different concentration of chromium metal and to check the ability which wild plant has greater absorption capacity than other plants.

The biosorption capacity of *Euphorbia Helioscopia* (Sun spurge) biosorbent was in following corresponding order $T_0 (0.33) < T_1 (0.8367) < T_2 (3.6567) < T_3 (5.03)$. Results have been showed that increase in Cr concentration increased the biosorption capacity in *Euphorbia Helioscopia* (Sun spurge). The highest significant biosorption occurred in treatment T_3 (30 ppm) as compared to control. Husnain et al. (2013) reported 0.25 mg g^{-1} biosorption of chromium ions by *Euphorbia Helioscopia* (Sun spurge) weed when it was grown in chromium treated waste water as well as *Euphorbia Helioscopia* could also be used as biosorbent of other heavy metals like lead, cadmium, iron etc. The results of this research were somehow matched with that study.

In *Parthenium Hysterophorus* (Gajar buti) biosorption was in following corresponding order $T_0 (0.0467) < T_1 (2.23) < T_2 (5.39) < T_3 (25.06)$. Results demonstrated that increase in Cr concentration increased the biosorption capacity in *Parthenium Hysterophorus* (Gajar buti). The highest significant biosorption occurred in treatment T_3 (30 ppm) as compared to control. 24.5 mg g^{-1} chromium was remediated by *Parthenium* at optimized conditions. According to the wild plant *Parthenium Hysterophorus* remediate 11.47 mg g^{-1} lead metal from aqueous medium.

Results clearly revealed that increase in Cr concentration increased the biosorption capacity in *Euphorbia helioscopia* (Sun spurge) and *Parthenium Hysterophorus* (Gajar buti). *Parthenium Hysterophorus* (Gajar buti) showed highest absorption value (25.060) as compared to *Euphorbia helioscopia* (Sun spurge) (5.030) at same concentration of Chromium metal treatment. Conclusively, it was found that selected plants (Sun spurge and parthenium) biomass can be used effectively for metal elimination from liquid medium.

Conclusion

This study highlights the significant potential of selected wild plant species—*Euphorbia helioscopia* (Sun Spurge), and *Parthenium Hysterophorus* (Gajar Buti)—for biosorption of chromium from aqueous solutions. As the concentration of chromium increased, so did the biosorption capacity of these plants, with *Parthenium Hysterophorus* (Gajar Buti) demonstrating the highest absorption capacity. These findings suggest that *Parthenium Hysterophorus* is particularly effective in removing chromium compared to *Euphorbia helioscopia*. The results align with previous studies on the biosorption capabilities of these plants for other heavy metals, underscoring their potential as cost-effective and sustainable biosorbents for environmental cleanup, particularly in water contaminated with hazardous metals like chromium. This research reinforces the utility of using plant biomass for metal remediation, offering a viable alternative to expensive conventional methods for mitigating water pollution. For future research, exploring the optimization of biosorption conditions, such as pH, temperature, and contact time, as well as investigating the potential of these plants to remove a broader range of heavy metals, would be valuable to enhance their practical applications in environmental remediation.

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Conflict of Interests

No conflict of interest.

References

- Abdel-Shafy, H. I., & Mansour, M. S. M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*, 27(4), 1275–1290. <https://doi.org/10.1016/j.ejpe.2018.07.003>
- Ali, B., Sohail, Y., Toome-Heller, M., & Mumtaz, A. S. (2016). *Melampsora pakistanica* sp. nov., a new rust fungus on *Euphorbia helioscopia* (Sun spurge) from Pakistan. *Mycological Progress*, 15, 1285–1292. <https://doi.org/10.1007/s11557-016-1244-2>
- Al-Taai, S. H. H. (2021, June). Water pollution: Its causes and effects. In *IOP Conference Series: Earth and Environmental Science* (Vol. 790, No. 1, p. 012026). IOP Publishing.
- Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences*, 115(25), 6506–6511. <https://doi.org/10.1073/pnas.1711842115>
- Bartowitz, K. J., Walsh, E. S., Stenzel, J. E., Kolden, C. A., & Hudiburg, T. W. (2022). Forest carbon emission sources are not equal: Putting fire, harvest, and fossil fuel emissions in context. *Frontiers in Forests and Global Change*, 5, 867112. <https://doi.org/10.3389/ffgc.2022.867112>
- Eze, J. I., & Chukwu, O. (2011). Small scale poultry farming and its effects on livelihood of rural farmers in Nasarawa State, Nigeria. *PAT*, 7(2), 82–91.
- Ghosh, A., Manna, M. C., Jha, S., Singh, A. K., Misra, S., Srivastava, R. C., ... & Singh, A. K. (2022). Impact of soil-water contaminants on tropical agriculture, animal and societal environment. *Advances in Agronomy*, 176, 209–274. <https://doi.org/10.1016/bs.agron.2022.07.006>
- Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., ... & Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science*, 327(5967), 812–818. <https://doi.org/10.1126/science.1185383>
- Jadaa, W., & Mohammed, H. (2023). Heavy metals—Definition, natural and anthropogenic sources of releasing into ecosystems, toxicity, and removal methods—An overview study. *Journal of Ecological Engineering*, 24(6). <https://doi.org/10.12911/22998993/162955>
- Jagaba, A. H., Lawal, I. M., Birniwa, A. H., Affam, A. C., Usman, A. K., Soja, U. B., ... & Yaro, N. S. A. (2024). Sources of water contamination by heavy metals. In *Membrane technologies for heavy metal removal from water* (pp. 3–27). CRC Press.
- Jomova, K., Alomar, S. Y., Nepovimova, E., Kuca, K., & Valko, M. (2024). Heavy metals: Toxicity and human health effects. *Archives of Toxicology*. <https://doi.org/10.1007/s00204-024-03903-2>
- Kraemer, S. A., Ramachandran, A., & Perron, G. G. (2019). Antibiotic pollution in the environment: From microbial ecology to public policy. *Microorganisms*, 7(6), 180. <https://doi.org/10.3390/microorganisms7060180>
- Kumar, D., Thakur, C., Bhardwaj, D., Sharma, H., Sharma, N., Sharma, P., & Sharma, A. (2021). Key factor of invasion and control measures of major exotic weed species in subtropical and temperate forest of North Western Himalaya. *International Journal of Current Microbiology and Applied Sciences*, 10, 2529–2541. <https://doi.org/10.20546/ijcmas.2021.1001.293>
- Kwon, E., Jin, T., You, Y. A., & Kim, B. (2024). Joint effect of long-term exposure to ambient air pollution on the prevalence of chronic obstructive pulmonary disease using the Korea National Health



- and Nutrition Examination Survey 2010–2019. *Chemosphere*, 358, 142137. <https://doi.org/10.1016/j.chemosphere.2024.142137>
- Manoj Kumar, M. K., Abhradip Pal, A. P., Joginder Singh, J. S., Shashank Garg, S. G., Madhu Bala, M. B., Ashish Vyas, A. V., ... & Pachouri, U. C. (2013). Removal of chromium from water effluent by adsorption onto *Vetiveria zizanioides* and *Anabaena* species. *Current Research Journal of Biological Sciences*, 5(1), 36–41.
- Mukherjee, A. G., Wanjari, U. R., Renu, K., Vellingiri, B., & Gopalakrishnan, A. V. (2022). Heavy metal and metalloid-induced reproductive toxicity. *Environmental Toxicology and Pharmacology*, 92, 103859. <https://doi.org/10.1016/j.etap.2022.103859>
- Naqvi, S. L. H., Nadeem, M., Ayub, F., Yasar, A., Naqvi, S. H. Z., & Tanveer, R. (2024). Social and environmental impacts in textile production. In *Dye pollution from textile industry: Challenges and opportunities for sustainable development* (pp. 423–453). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-5341-3_19
- Niaz, A., Kader, M. S., Khan, S., Jia, Y., Shoukat, M. U., Nawaz, S. A., ... & Niaz, I. (2022). Environment friendly hybrid solar-hydro power distribution scheduling on demand side. *Polish Journal of Environmental Studies*, 32(1), 215–224. <https://doi.org/10.15244/pjoes/152810>
- Parashar, S., & Hait, S. (2021). Plastics in the environment: A review of sources, occurrence, and methods for plastic waste management. *Environmental Technology & Innovation*, 24, 102064. <https://doi.org/10.1016/j.eti.2021.102064>
- Pruss-Ustun, A., Wolf, J., Corvalan, C., Bos, R., Neira, M., & Rehfuess, E. (2016). *Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks*. World Health Organization.
- Qasem, N. A., Mohammed, R. H., & Lawal, D. U. (2021). Removal of heavy metal ions from wastewater: A comprehensive and critical review. *NPJ Clean Water*, 4(1), 1–15. <https://doi.org/10.1038/s41545-021-00127-0>
- Sall, M. L., Diaw, A. K. D., Gningue-Sall, D., Efremova Aaron, S., & Aaron, J. J. (2020). Toxic heavy metals: Impact on the environment and human health, and treatment with conducting organic polymers: A review. *Environmental Science and Pollution Research*, 27, 29927–29942. <https://doi.org/10.1007/s11356-020-09354-3>
- Saxena, G., Purchase, D., Mulla, S. I., Saratale, G. D., & Bharagava, R. N. (2020). Phytoremediation of heavy metal-contaminated sites: Eco-environmental concerns, field studies, sustainability issues, and future prospects. In *Reviews of Environmental Contamination and Toxicology* (Vol. 249, pp. 71–131). Springer. https://doi.org/10.1007/398_2019_24
- Schmidt, R. J., & Evans, F. J. (1980). Skin irritants of the sun spurge (*Euphorbia helioscopia* L.). *Contact Dermatitis*, 6(3), 204–210. <https://doi.org/10.1111/j.1600-0536.1980.tb05599.x>
- Singh, S. P., & Singh, M. K. (2020). Soil pollution and human health. In *Plant responses to soil pollution* (pp. 205–220). Springer. https://doi.org/10.1007/978-981-15-4964-9_13
- Verma, A. K., & Prakash, S. (2020). Impact of COVID-19 on environment and society. *Journal of Global Biosciences*, 9(5), 7352–7363. <https://ssrn.com/abstract=3644567>
- Wilson, D. C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis, C., ... & Simonett, O. (2012). *Global waste management outlook*. United Nations Environment Programme.
- Zhang, H., & Wang, Z. (2020). Economic and environmental impacts of global agricultural trade. *Journal of Environmental Management*, 265, 110500. <https://doi.org/10.1016/j.jenvman.2020.110500>

