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PLANTS AND THEIR ROLES IN COMBATING CONTEMPORARY GLOBAL CHALLENGES

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ABSTRACT

This paper examined some aspects of contemporary global challenges that have mostly been occasioned by anthropogenic factors which have uncoupled ecological equilibria. These have been made more severe by pressure from the rapidly increasing human population. Some of these global challenges include deforestation, climate change, pollution of air and soils, ground and surface water scarcity/contamination, food shortages, decreased food quality, extreme poverty and decreased overall health and wellbeing. Plants provide a veritable resource for mitigation of these challenges if they are sustainably exploited to provide qualitative food, raw materials, medicine and ecosystem services. The paper also examined the trends and impacts of these global challenges and concluded that it is imperative for research and development efforts to be directed at the restoration of ecosystem balances, where stability has been disrupted, and to maintain such stability in pristine environments.

Key words: Plants; global warming; climate change; food systems; green house
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INTRODUCTION

The *Cambridge Dictionary* defines contemporary as something current, the word *global* relates to the whole world, while *challenge i*s anything that requires great mental or physical effort in order to be done successfully, or the situation of facing this kind of effort. Dealing with *global challenges* means that you are handling more coercive problems than *global issues*. Also, dealing with global challenges requires not only mental efforts but physical actions.

Kirsten Gelsdorf defines global challenge as any major trend, shock or development that has the potential for serious global impact. These challenges result from uncontrolled production, consumption, pollution, population growth and pressure on the ecosystems. These impact on the environment, the economy, technology, human health, social systems, cohesion and peace in a complex and interwoven manner. The paper examines some of the contemporary global challenges and the role of plants and plant-based systems in mitigating these challenges on human societies.

DEFORESTATION, GLOBAL WARMING AND CLIMATE CHANGE

Deforestation

This is the removal of trees and the surrounding ecosystems which make up forests. Deforestation is a particular problem in tropical forests, which are disappearing rapidly due to human influence. The forest landscape is cleared for farms and pastures, for the harvesting of timber for construction and fuel, and for roads, housing and commercial use.

Deforestation has profound and often devastating consequences including loss of biodiversity, loss of carbon sinks, increasing carbon dioxide in the atmosphere, interruption of water cycles and destruction of water quality. It may also cause social conflict, loss of livelihoods and loss of food sources from forests and rivers. The

The National Aeronotic and Space Administration (NASA) conducts research on tropical forests using space-based and ground-based observations.

Global Warming and Climate change

Solar energy in the form of radiation reaches the earth, where two-thirds of it is absorbed by the planet's surface. The rest is reflected into the atmosphere where greenhouse gases operate. These gases reflect the energy back to earth where it again converts to heat – this process keeps the planet habitable. This phenomenon is called the greenhouse effect. Naturally, with the increasing amount of greenhouse gases in the atmosphere, this effect intensifies, leading to global temperature rise. Excessive temperature rise due to human activity is called global warming. Figure 1: presents the trends on global warming up to recent times.

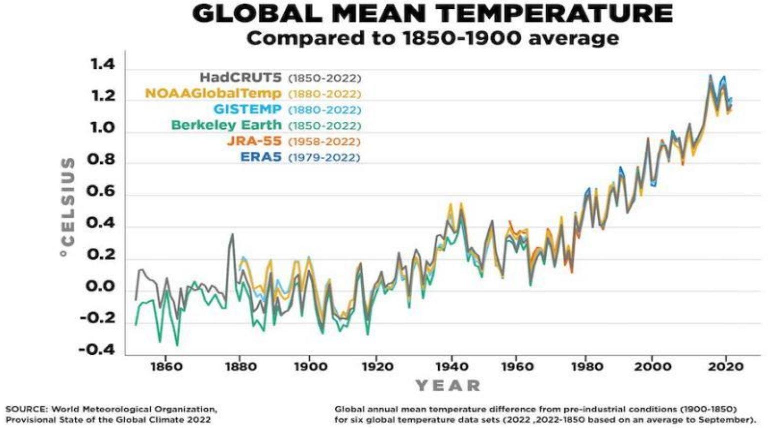

Figure 1: Global mean Temperatures 1850-2020

Climate and weather are two different phenomena that are closely related. While weather refers to short-term conditions that can change quickly, climate determines the long-term character of a given place, for instance, whether it is temperate or tropical. The relationship between weather and climate is crucial: the former is subordinate to the latter. Climate determines temperatures, weather diversity, the traits of winters, rainfall totals, as well as the nature of meteorological phenomena such as the severity of storms. It is due to this delicate relationship that we are facing both temperature rises and more frequent weather extremes and natural disasters as a result of climate change.

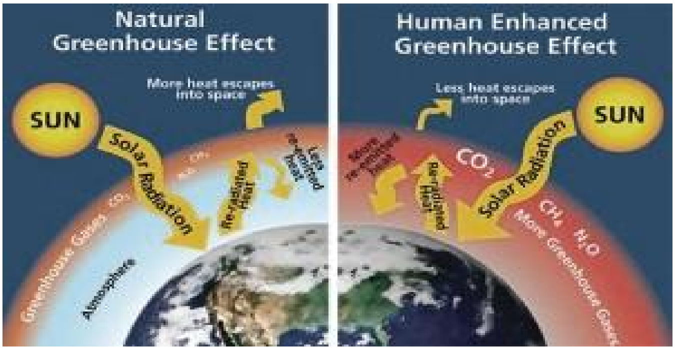

Figure 2: The Greenhouse effect and Climate change

Climate change is arguably the most severe challenge facing our planet during the 21st century. Human interference with the climate system mainly through the emission of green-house gases and changes in land use has increased the global and annual mean air temperature at the Earth's surface by roughly 0.8°C since the 19th century (IPCC, 2013). This trend of increasing temperatures will continue. By 2100, the globe could warm by another 4 °C or so if emissions are not decisively reduced within the next decades (IPCC, 2013). There is broad consensus that a warming of this magnitude would have profound impacts both on the environment and on human societies (IPCC, 2014), and that climate change mitigation must be achieved to prevent the worst of these impacts (IPCC, 2014).

In its sixth report in 2022, the International Panel of Climate Change (IPCC) outlined a series of near-term, mid-term and long-term risks. If global warming reaches 1.5°C in the near term (2021-2040), it would cause "unavoidable increases in multiple climate hazards," as well as "multiple risks to ecosystems and humans." In the long term, climate change will present major health issues, premature deaths, risks to cities and settlements and other dangers. Therefore, mitigation is desperately and urgently needed.

The role of plants in mitigation and adaptation to climate change

Reforestation is an important and increasingly more well recognised solution to our global environmental and climate change crisis. In recent years much effort has been given to estimate a rough figure of how many trees the world would need to plant in order to offset all of the carbon that has and will contribute to global warming in the coming decades as we strive to decarbonise our energy use. One of the strongest advocates for reforestation who quantified how many trees the Earth currently has versus how many more trees would be needed, 1.2 trillion, was Dr. Thomas Crowther (Corbett, 2019). As an anchor and integral part of the carbon cycle, forests have the ability to sequester enormous amounts of carbon and potentially have the ability to offset most of the carbon dioxide already emitted by humans. As a rough average, a single tree is capable of removing 48 pounds of carbon per year; over a 40-year lifespan, that tree can remove and store 1 ton of carbon. Currently, it is estimated that the world's forests absorb approximately 40 per cent of man-made carbon. A further 6 billion tons is offset each year by reforestation efforts: however, this is canceled out by the nearly 10.8 billion tons of carbon released by deforestation. The role plants play in the global carbon cycle is critical to climate change mitigation and adaptation solutions. Atmospheric carbon sequestration, its storage in plant tissues such as branches, stems and roots take place via photosynthesis and subsequent addition to soil via decomposition (Volk *et al*., 2023).

Plant-based climate change mitigation measures generally involve reducing, preventing or removing greenhouse gases from the atmosphere through the protection of high-carbon ecosystems that hold or increase carbon storage (particularly in soils and in plant-rich landscapes such as forests), practice of agroforestry (incorporating trees and shrubs in crops and pastureland) to improve soil health, ecological diversity and increased land productivity; use of sustainable agricultural approaches that decrease dependency on high-input field production; breeding of crop varieties for improved carbon sequestration such as crops with increased deep root biomass or for biological nitrification inhibition; and developing urban landscapes that minimise water use and sequester carbon.

Plant-based adaptation to the negative impacts of climate change involves making the needed adjustments to predicted changes or novel conditions. Some plant-based adaptations include maintenance of diverse forest habitats that offset extremes in temperature and moisture; selection of biological diverse cropping systems to retain productivity as a result of a wide range of environmental responses; identification, development and growing a diversity of food plants and agricultural crops; selection and production of crops that reduce the need for inputs and reduce waste at all stages: on the farm, during processing and storage, and by the consumer. Some of the approaches for plant-based mitigation and adaptation to the negative consequence of climate change include:

1. Agroecology, agroforestry and forest ecosystems

Agroforestry as a sustainable land-use system incorporates trees and shrubs into cropland and pastureland. It conserves biodiversity, sequester carbon, block wind and provide food sources (Mbow *et al*., 2014, Abbas *et al*., 2017). Agroecological strategies to adapting to climate change include crop diversification/biodiversity, maintenance of local genetic diversity, soil organic matter management and water conservation. This includes agroforestry systems that incorporate perennial plants that both capture carbon and provide shade (Altieri *et al*., 2015) or methods that incorporate landscape biodiversity can increase resilience to climate-related shocks and disturbances that affect productivity (Queiroz *et al*., 2021). Biodiversity enhances resilience because crops and cultivars differ in their environmental responses, thus occupying different niches in changing conditions (Vandermeer *et al*., 1998). Forest ecosystems sequester carbon within woody plants and in healthy organic matter- rich soils (Udawatta *et al*., 2022). These forest ecosystems absorb 15 to 20% of annual human carbon emissions, and thus play an important role in climate change mitigation (Le Quéré *et al*., 2018; Case *et al*., 2021). Water is also retained in high-quality soils, thereby promoting additional plant growth and reducing the occurrence of wildland fires. Forest ecosystems help buffer the environmental extremes that could be experienced in a changing climate. Shade and moisture-rich microclimates caused by evapotranspiration reduce extreme temperature fluctuations that might occur (De Frenne *et al*., 2021).

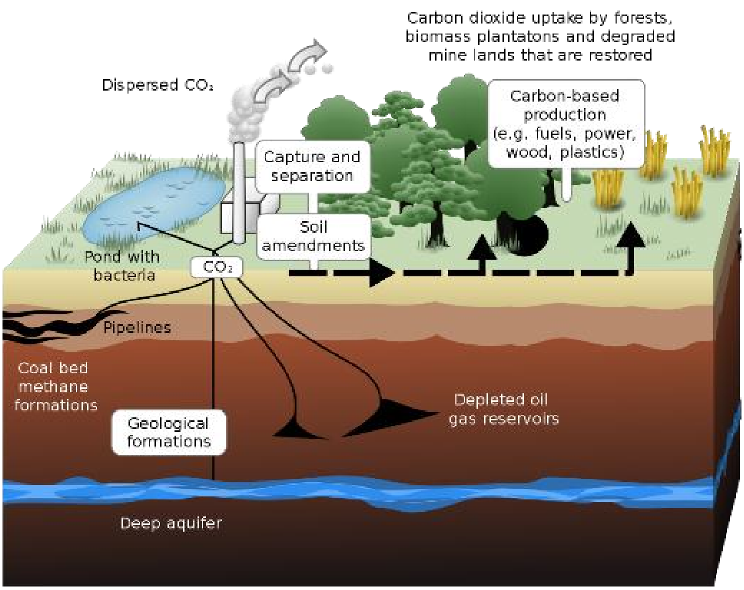

Figure 3: General process of carbon sequestration in agroforestry systems

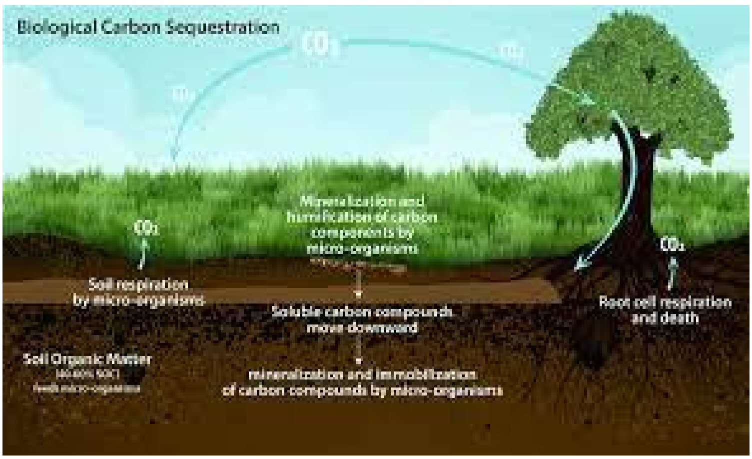

Figure 4: Biological carbon sequestration

2. Agricultural Production

Agricultural production methods are keys to climate change mitigation and adaptation. Important climate change mitigation strategies include adoption of agricultural practices that apply specifically targeted fertilisation regimes to single-crop cultivated systems can reduce inputs, decrease water waste, fossil fuels, and unharvested products, which in turn reduce emissions and increase net productivity (McPherson *et al*., 2005; Hartin *et al*., 2014; Turner-Skoff and Cavender, 2019). Breeding of new crops with deep root systems that can sequester carbon (van der Pol *et al*., 2022), and the choice of plant-based protein sources (such as pulse crops) instead of animal-based proteins reduces agricultural greenhouse gas emissions by reducing methane released in animal production.

Incorporating climate adaptation action in agriculture aligns with sustainable agriculture practices and can enhance these efforts by considering climate vulnerabilities and potential future threats. For example, organic agriculture practices support soil fertility and pest management and can also enhance the resilience of farms to climate changes. The United Nations Climate-Smart Agriculture programme is an example of one approach to develop actions to ensure food security under climate change (Loboguerrero *et al*., 2019). It aims to develop synergies between climate mitigation, adaptation and food security, particularly for small farms in developing countries, but it also has implications for large-scale agriculture. The goals of the United Nations Climate-Smart Agriculture programme are to sustainably and equitably increase agricultural productivity and incomes; help food systems and family livelihoods to be more resilient; and to minimise agricultural greenhouse gas emissions.

3. Urban Forests and gardens
Gardens and urban forests are important for both mitigating and adapting to climate change. In urban areas, sustainable gardening and landscaping helps minimise water use and sequesters atmospheric carbon both above and below ground (McPherson *et al*., 2005; Hartin *et al*., 2014; Turner-Skoff and Cavender, 2019). The Grow Green Guide is a sustainable gardening resource designed for people living in the Metro Vancouver area of Canada. This resource provides over 100 garden designs and information on over 300 plant selections based on criteria including native range, pollinator-friendliness, ability to provide food, water-wise, etc.

4. Developing Resilient Food Systems
A food system refers to the network of activities connecting people to their food. A resilient food system occurs when people produce and access nutritious and culturally acceptable food over time and space in the face of disturbance and change (Schipanski *et al*., 2016). There are increasing efforts to identify and understand important qualities of resilient food systems. Worstell and Green (2017) presented eight qualities common to ecologically resilient food systems namely Complementary diversity; Conservative innovation and flexibility (open to new ideas); Ecological integration (working with nature); Modular connectivity (among farmers, marketers and suppliers); Locally self-organised; Periodic transformation: Reorganising, reforming, embracing disturbance; Physical infrastructure and accumulating reserves; and Responsive redundancy or back-ups.

Resilient food systems depend on access to diverse plant genetic resources that are made available through conservation efforts. Agricultural production using biodiversity strategies improves ecosystem function because the diversity of species acts as a buffer against failures caused by environmental fluctuations. If one species fails, others can compensate, thus improving the overall health and productivity of the ecosystem (Altieri *et al*., 2015).

Additional strategies for improving food system resilience includes educational gender-equity and women's empowerment, which influences family dietary choices, human nutrition, and can minimise food waste; utilising ecological, multi-crop systems rather than single-crop production based on intensive external inputs; improving regional food distribution networks; and linking human nutrition and food production policies (Schipanski *et al*., 2016)

WATER, AIR AND SOIL CONTAMINATION
Increase in population, urbanisation, advances in agriculture and other industrial processes have resulted in an increase in contaminants polluting surface and underground waters as well as soils and the air. This leads to the destruction of biodiversity, depletion of the quality of the air, soils and aquatic ecosystems, unbridled proliferation of phytoplankton in water bodies, eutrophication, contamination of the food chain, decreased potable water (in quality and quantity), water-borne diseases, contamination of agricultural soils and infant mortality.

The reports from the WHO (2023) shows that more than 1.5 m people have died globally as a result of contaminated water and related diseases in the year 2023. Statistics from the OECD (2023) show that globally, 2.5 billion people are facing high water stress (severe water scarcity in at least half of a year); an additional 280 billion tons of groundwater is being polluted every year; oceans cover 71 per cent of the planet and are home to 80 per cent of life on Earth. But they are also fragile ecosystems threatened by massive overfishing and pollution: By 2050, world oceans could contain more plastic than fish; the world could run out of freshwater by 2040.

Human activities have been implicated for the increase in heavy metal concentrations in many environments (Maine *et al*, 2004; Bako *et al*., 2008; Tanimu *et al*., 2013; Wei *et al*., 2021). Potentially Toxic

Elements (PTEs) are important components of agro-allied products such as pesticides, herbicides, fertilizers, and other synthetic products such as paints and batteries (USDA, 2000). Mining activities, industrial, municipal and domestic wastes are important sources of PTE pollution to the environment (Bako *et al*., 2005; Mathews-Amune and Kakulu, 2013; Ombugadu *et al*., 2014; Monaci *et al*., 2020).

Aquatics have shown an excellent capacity to clean up contaminated aquatic ecosystems across the world over the years (Gorito *et al*., 2017). These plants (macrophytes, algae and fungi) have a structure that enables them to collect contaminants in their roots and shoots (Ali *et al*., 2020). As a green technology, aquatic plant treatment of contaminated waters promotes long-term growth and utilises microbial natural resources, lowers degradation of the environment, safeguards ecosystems, and improves lives and livelihoods.

Similarly, ruderal plants provide a naturally occurring gene pool for the selection of pollution- tolerant species that have adapted to growth and development under less than ideal environments. Depending on their effectiveness, such plants may be exploited either in their natural state or after genetic modification, as an alternative clean-up strategies of metal-polluted soils/sites. Examples of ruderals with tolerance of heavy metals include *Biscutella laevigata* (Pošćić *et al*., 2015), *Agrostis canina* (Bech *et al*., 2012a, 2012b), *Agrostis capillarys* (Teodoro *et al*., 2020) and *Lotus hispidus* (Matanzas *et al*., 2021). Others include *Salix leadermanii, Ceruana pratensis, Polygonum lanigerum, Physalis angulata, Polygonum limbatum, Cymbopogon giganteum, Heliotropium indicum, Croton lobatus, Hypoethes cancellata* and *Mimosa pigra* (Bako *et al*., 2023).

Both organic and inorganic contaminants are effectively treated by plants, using multiple mechanisms such as phytoaccumulation, phytodegradation, phytotransformation, phytovolatilisation, or phytoextraction.

Plant-based remediation technology has the advantage of being simple to maintain and it is less expensive than the traditional technologies for chemical and physical treatment (Abdullah *et al*., 2020).

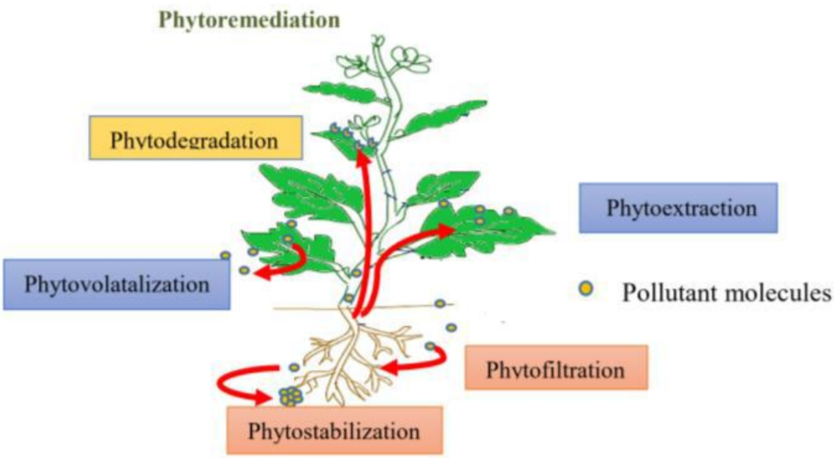

Figure 5: The general mechanisms in plant pollution remediation

The treatment procedures for plants can be split into three categories: (i) pollutant degradation, (ii) suppression, and (iii) extraction, or a combination of these three categories (Mohebi and Nazari, 2014). The processes used by plants to remove or detoxify contaminants can also be categorised. Extraction of contaminants from groundwater or soil, as well as contamination levels in plant tissue, biotic and abiotic mechanisms that degrade contaminants, volatile pollutant evaporation or transpiration from the plant into the air, and contaminant immobilisation in the root zone are examples of these mechanisms (Abdullah *et al*., 2020).

The plant's capability to absorb and transfer large volumes of groundwater in phytoremediation is known as the process of hydraulic monitoring of contaminated sites. This hydraulic control can be managed to prevent horizontal movement and vertical leaching contaminants. During the evaporation and transpiration of water absorbed by the plant, dissolved organic and inorganic compounds enter the plant and may also enter other phytoremediation processes. The subsequent uptake and evaporation of volatile compounds through the leaves is known as plant volatilisation (Figure 5) (Mohebi and Nazari, 2014). Organic compounds introduced into the plant can be degraded by plant enzymes, which is called plant degradation. Plant accumulation is the absorption and accumulation of minerals in plant tissues. The combined anaerobic and phytoremediation systems were used to evaluate their potential and efficiency for sanitary wastewater treatment. The results revealed that using a hybrid method of anaerobic and phytoremediation systems resulted in COD and TSS removal rates of up to 80% apiece and turbidity and BOD removal rates of up to 90%. Total coliform and intestinal nematode eradication efficiency were 99.99 and 100%, respectively. According to international effluent irrigation regulations, the treated wastewater quality was adequate (Mohebi and Nazari, 2014). These are the plants with submerged roots and floating leaves.

Several aquatic plants have long been known for their capacity to remove metals from polluted environments: water hyacinth (*Eichhornia crassipes*) (Gunathilakae *et al*., 2018), water ferns (*Salvinia minima*) (Iha and Bianchini, 2015), duckweeds (*Lemna minor* or *Spirodela intermedia*) (da-Silva *et al*., 2017; Daud *et al*., 2018), water lettuce (*Pistia stratoites*) (Abbas *et al*., 2019), and watercress (*Nasturtium officinale*) (Shi *et al*., 2020). These plants have shown capacity to remediate wastewater with out-of-range BOD, COD, Fe, Zn, oil, grease, colour, Cl, Cu, Ti, TDS, PO_4, NH_4 and Pb (Mohebi and Nazari, 2014).

HUMAN HEALTH PROBLEMS

Health problems have always been a challenge for humanity. Science has progressed and therapies of many diseases have been discovered. Despite improvements, there are still many health challenges. For Instance, one billion people do not have access to health-care systems in the 21st century.The WHO listed communicable diseases, non-communicable diseases, epidemics and pandemics, shortage of food supply due to plant diseases, inequality in the availability of healthcare and healthcare in war zones as the top six healthcare challenges of the 21st century. Environment factors influence global health in a variety of ways. Some scientists believe the virus that causes COVID-19 originally crossed over from a wild animal, partly because of human encroachment on what was once a wilderness. Ebola and HIV also emerged from animals in crossover infections. As people spread more into formerly wild areas and come into contact with previously isolated animals, new infectious diseases may emerge. Thus, protecting the wilderness from development can also protect human beings. Environmental pollution also impacts human health, and pollution released by one country can spread across national borders. Polluted air causes illness and millions of early deaths each year, especially in urban areas of Asia.

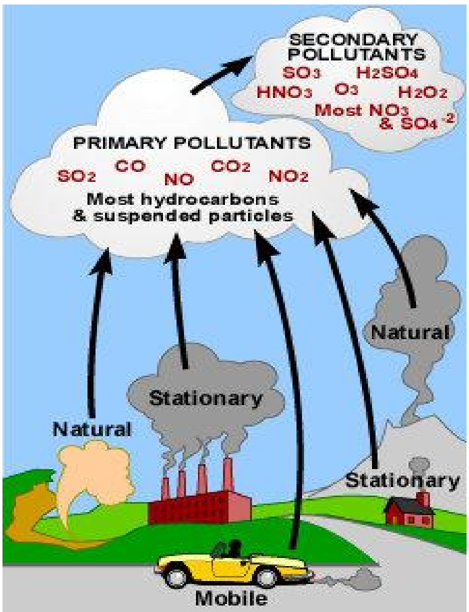

Figure 6: Source air pollution

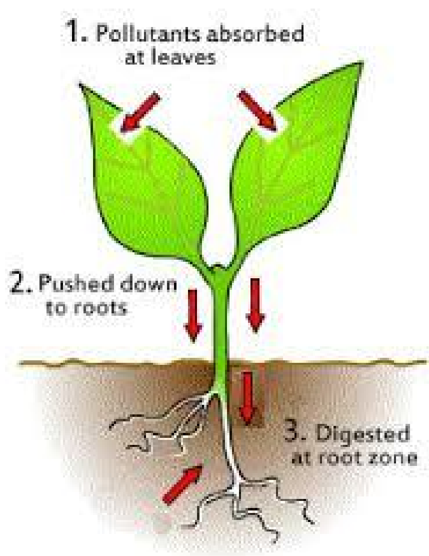

Figure 7: How plants remove air pollutants from the environment

There is also cross-specialty research into the health impacts caused by climate change. As temperatures rise, tropical diseases are reaching new areas, impacting the health of patients in areas once free of diseases. Plants have been used in healthcare since time immemorial. Globally, studies have been carried out that have verified their efficacy and some of the findings have led to the production of plant-based medicines. The global market value of medicinal plant products exceeds $100 billion per annum (Sofowora *et al*., 2013).

POVERTY ALLEVIATION/ ERADICATION

Extreme poverty is defined as living below $2.15 per person per day. It has been calculated based on 2017 Purchasing Power Parities (PPPs) and it replaces the $1.90 poverty line. Based on these definitions, 30.9% of Nigerians are extremely poor, which is higher than the 20% global average (World Bank, 2023). Economic inequalities between people and states is a serious problem that leads to wars and acts of terrorism. This is the reason poor people are taken advantage of in the name of incentives for their votes during elections. It may be the root of the grudge held by the poor (people or states) against the rich and super-powers.

Plants and plant-based products are potent ways out of extreme poverty either through agricultural production, food processing, packaging, distribution, and retail of other valuable non-timer forest products (NTFPs) such as fibres, resins, fruits, spices, vegetables, snails, honey and oils. Research has shown that NTFPs significantly alleviate poverty among peasants (Ambrose-Oji, 2003).

HUNGER AND STARVATION/ FOOD SECURITY

The United Nations Hunger Report (2017) describes the term hunger as the period when a population experiences severe food insecurity. It is the situation where people continue their lives without eating all day long due to lack of money, lack of access to food or other reasons (FAO, 2017). When defining hunger, some commonly accepted key terms are:

(i) Hunger is a problem caused by a lack of food. Lack of food or malnutrition is less than 1,800 calories per day.

(ii) Nutritional deficiencies are used to indicate deficiencies in energy, protein and/or essential vitamins and minerals; nutritional deficiencies go beyond calories.

(iii) Malnutrition refers to both undernutrition and overfeeding (problems with unbalanced diets) (FAO, 2017).

According to Sorunu *et al*. (2022), 821 million people in the world do not have enough food to live a healthy active life. This number means that approximately one in nine people in the world are hungry. Majority of hungry people in the world live in developing countries; about 12.9 per cent of the world's population is malnourished. Asia is the region with the highest hunger, two-thirds of the total continent are starving. The rate in South Asia has declined in recent years, but slightly increased in West Asia. Sub-Saharan Africa is the region of hunger with the highest hunger rate (as a percentage of the population). In this region, one in four people is malnourished. As a result of malnutrition, one in five children born every year dies. In other words, almost half (45%) of 3.1 million children die. In developing countries, one in six children die from starvation (around 100 million in number). A quarter of the world's children do not show enough physical development (or stay dwarf). In developing countries, this rate goes up to one-third. Out of 66 million children of primary school age each year, 23 million join the hunger class only between Africa and developing countries. The World Food Programme (WFP) has calculated that 3.2 billion USD is needed annually to reach 66 million school-aged hungry children. According to the 2022 Global Report on Food Crises, which is produced by the Global Network against Food Crises, the number of people in crisis or worse is the highest that has been in six years since the report has existed. Close to 193 million people experienced acute food insecurity in 2021, which is an increase of almost 40 million since 2020. This represents a staggering 80% increase since 2016. Causes include "economic shocks," like an increase in global food prices. Domestic food price inflation in low-income countries also rose Weather-related disasters are also a big driver. For 15.7 million people in 15 countries, it was the primary driver of acute food insecurity.

Plants provide over 80% of the food consumed by humans and are the primary source of nutrition for livestock. Current estimates suggest that there are at least 7,039 edible plant species, in a broad taxonomic sense, which includes 7,014 vascular plants. This is in striking contrast to the small handful of food crops that provide the majority of humanity's calorie and nutrient intake. Most of these 7,039 edible species have additional uses, the most common being medicines (70%), materials (59%), and environmental uses (40%). Species of major food crops display centres of diversity, as previously proposed, while the rest of edible plants follow latitudinal distribution patterns similar to the total plant diversity, with higher species richness at lower latitudes. The International Union for Conservation of Nature Red List includes global conservation assessments for at least 30% of edible plants, with ca. 86% of them conserved *ex situ.* However, at least 11% of those species recorded are threatened. We highlight multipurpose NUS of plants from different regions of the world, which could be key for

a more resilient, sustainable, biodiverse, and community participation-driven new "green revolution (Ulian *et al*., 2020).

CONCLUSION

A rapidly increasing human population has exerted profound pressure on the natural equilibria in the erstwhile stable ecosystem, on which humans depend for sustenance. This has constituted a threat to human existence by precipitating global challenges, including climate change, ground and surface water scarcity/contamination, food shortages, decreased food quality, extreme poverty and decreased overall health and wellbeing. Plants provide a veritable resource for mitigation of these challenges if they are sustainably exploited to provide qualitative food, raw materials, medicine and ecosystem services. Therefore, it is imperative that research and development efforts should be directed at the restoration of ecosystem balances where stability has been disrupted and maintaining such stability in pristine environments.

REFERENCES

Abbas, F., Hammad. H. M. and Fahad, S. (2017). Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. *Environmental Science and Pollution Research,* 24:11177-11191. DOI: 10.1007/s11356-017-8687-0

Abdullah, S. R., Al-Baldawi, I. A. Almansoory, A. F., Purwanti, I. F., Al-Sbani, N. H. and Sharuddin, S.N. (2020). Plant-assisted remediation of hydrocarbons in water and soil: Application, mechanisms, challenges and opportunities. *Chemosphere,* 247:125932. doi: 10.1016/j. *Chemosphere*.2020.125932

Ali, S., Abbas, Z., Rizwan, M., Zaheer, I.E,. Yavaş, İ., Ünay, A., Abdel-Daim, M.M., Bin-Jumah, M., Hasanuzzaman, M. and Kalderis, D. (2020). Application of Floating Aquatic Plants in Phytoremediation of Heavy-Metals-Polluted Water: A Review. *Sustainability,* 12:1927. doi:10.3390/su12051927.

Altieri, M., Nicholls, C.I., Henao, A. and Lana, M.A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development,* 35:869-890. DOI: 10.1007/s13593-015-0285-2

Ambrose-Oji, B. (2003). The contribution of NTFPs to the livelihoods of the 'forest poor': evidence from the tropical forest zone of south-west Cameroon. *International Forestry Review,* 5 (2), 2003.

Bako, S. P., Funtua, I.I. and Ijachi, M. (2005), Heavy metal content of some Savanna plant species in relation to air pollution. *Water, Air and Soil Pollution*,161(1-4): 125.

Bako, S.P., Odiwo, J.E. and Ezealor, A.U. (2008). Plant diversity in relation to anthropogenic Trace Metals in oils of selected sites in Nigeria's Guinea Savanna. *International Journal of Environmental Pollution: Special issue on Biogeochemistry of toxic trace metals in Water, Soil and Plant,* 33 (2/3):185-194.

Bako, S.P., Ezealor, A.U. and Tanimu, Y., (2023). Potentials of ruderal plants in the remediation of potentially toxic metal-contaminated sites in Kaduna metropolis, Northwestern Nigeria. *The Bioscientist Journal* Vol. 11(2):106-113, March 2023 Available online at https://www.bioscientistjournal.com

Bech, J., Duran, P., Roca, N., Poma, X., Sanchez, I., Roca-Perez, L., Boluda, R., Barcelo, J. and Poschenrieder, C. (2012a). Accumulation of Pb and Zn in *Bidens triplinervia* and *Senecio* sp. spontaneous species from mine spoils in Peru and their potential use in phytoremediation. *Journal of Geochemical Exploration*, 123: 109–113.

Bech, J., Duran, P., Roca, N., Poma, W., Sanchez, I., Barcelo, J., Boluda, R., Roca-Perez, L. and Poschenrieder, C. (2012b). Shoot accumulation of several trace elements in native plant species from contaminated soils in the Peruvian Andes. *Journal of Geochemical Exploration*, 113, 106–111.

Case, M.J., Johnson, B.G., Bartowitz, K. J. and Hudiburg, T. W. (2021). Forests of the future: Climate change impacts and implications for carbon storage in the Pacific Northwest, USA. *Forest, Ecology and Management,* 482:118886. DOI: 10.1016/j.foreco.2020.118886

Corbett, J. (2019). Global Effort to Plant a Trillion Trees 'Overwhelmingly' Among Most Effective and Cheapest Solutions to Climate Emergency: Study. Common Dreams https://www. jessicacommondreams.org.

da-Silva, C.J., Canatto, R. A., Cardoso, A.A., Ribeiro, C. and Oliveira, J.A. (2017). Arsenic-hyperaccumulation and antioxidant system in the aquatic macrophyte *Spirodela intermedia* W. Koch (Lemnaceae). *Theoretical and Experimental Plant Physiology*. 29:203-213.

Daud, M., Ali, S., Abbas, Z., Zaheer, I.E., Riaz, M.A., Malik, A. and Zhu, S.J. (2018). Potential of Duckweed (*Lemna minor*) for the Phytoremediation of Landfill Leachate. *Journal of Chemistry,*1-9.

De Frenne, P., Lenoir, J., Luoto, M., Scheffers, B.R., Zellweger, F., Aalto, J. and Ashcroft, M.B. (2021). Forest microclimates and climate change: Importance, drivers and future research agenda. *Global Change Biology,* 27:2279-2297. DOI: 10.1111/gcb.15569.

Food and Agriculture Organisation (FAO) (2017). The State of Food Security and Nutrition in the World 2017. Building Resilience for Peace and Food Security. Retrieved from http://www.fao.org/state-of-food-security-nutrition/en/

Gorito, A.M., Ribeiro, A.R., Almeida, C.M.R. and Silva, A.M. (2017). A review on the application of constructed wetlands for the removal of priority substances and contaminants of emerging concern listed in recently launched EU legislation. *Environmental Pollution,* 227:428-443.

Gunathilakae, N., Yapa, N. and Hettiarachchi, R. (2018). Effect of arbuscular mycorrhizal fungi on the cadmium phytoremediation potential of *Eichhornia crassipes* (Mart.) Solms. *Groundwater for Sustainable Gevelopment,* 7:477-482.

Hartin, J., Geisel, P., Harivandi, A. and Elkins, R. (2014). Sustainable landscaping in California. University of California. Division of Agriculture and Natural Resources Publication 8504. Available from: escholarship.org/uc/item/2xg41968

Iha, D. S. and Bianchini-Jr. I. (2015). Phytoremediation of Cd, Ni, Pb and Zn by *Salvinia minima*. *International Journal of Phytoremediation,*17:929-935.

IPCC, Climate Change (2013). The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,1535 p.

IPCC, Climate Change (2014). Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edenhofer, O., Pichs-

Le Quéré, C., Andrew, R.M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P.A. and Korsbakken, J.I. (2018). Global Carbon Budget 2018, *Earth System Science Data,* 10:2141-2194. DOI: 10.5194/essd-10-2141-2018.

Loboguerrero, A.M., Campbell, B.M., Cooper, P.J.M., Hansen, J.W., Rosenstock, T. and Wollenberg, E. (2019). Food and earth systems: Priorities for climate change adaptation and mitigation for agriculture and food systems. *Sustainability,* 11:1372. DOI: 10.3390/su11051372

Maine, M.A., Sune, N.L. and Lagger, C. (2004). Chromium bioaccumulation: comparison of the capacity of floating aquatic macrophytes *Water Research,* 38: 1494-1501.

Matanzas, N., Afif, E., Díaz, T. E. and Gallego, J.R. (2021). Phytoremediation Potential of Native Herbaceous Plant Species Growing on a Paradigmatic Brownfield Site. *Water, Air and Soil Pollution,* 232:290 https://doi.org/10.1007/s11270-021-05234-9.

Mathews-Amune, O.C. and Kakulu, S. (2013). Investigation of heavy metal levels in roadside agricultural soil and plant samples in Adogo, Nigeria. *Academic Journal of Environmental Science*,1(2):31-35.

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P.A. and Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability,* 6:61-67. DOI: 10.1016/j.cosust.2013.10.014.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E. and Xiao, Q. (2005). Municipal forest benefits and costs in five US cities. *Journal of Forestry,* 103:411-416. Available from: fs.usda.gov/research/tree search/45956.

Monaci, F., Trigueros, D., Mingorance, M.D. and Rossini-Oliva, S. (2020). Phytostabilisation potential of *Erica australis* L. and *Nerium oleander* L.: A comparative study in the Riotinto mining area (SW Spain). *Environmental Geochemistry and Health*, 42: 2345–2360.

Mohebi, Z. and Nazari. M. (2021). Phytoremediation of wastewater using aquatic plants, A review. *Journal of Applied Research in Water and Wastewater,* 8:50-58.

OECD (2023). Environmental Outlook to 2050. https://read.oecd-ilibrary.org/environment/oecd-environmental-outlook-to-2050_9789264122246-en#page210

Ombugadu, A., Mwansat, G.S., Manu, S.A., Chaskda, A. A., Ottosson, U., Njila, L.H, Karau, S. D. and Leventis, A. (2014). Comparison on bioaccumulation of heavy metals in birds and plant species in Amurum Forest Reserve and the Nigerian National Petroleum Corporation (NNPC) Refinery Area of Kaduna, Nigeria. *International Journal of Advanced Studies in Engineering and Scientific Inventions*, 2(1):26-36.

Pošćić, F., Fellet, G., Vischi, M., Casolo, V., Schat, H. and Marchiol, L. (2015). Variation in heavy metal accumulation and genetic diversity at a regional scale among metallicolous and non-metallicolous populations of the facultative metallophyte *Biscutellala evigata* subsp. *laevigata*. *International Journal of Phytoremediation*, 17(5): 464–475.

Qin, T.F. D., Plattner, G.K., Tignor, M., Allen, S.K., Boschang, J., Nauels, A., Xia, Y., Bex, V. and Midgely, P.M. (Eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 p.

Queiroz, C., Norström, A.V. and Downing, A. (2021). Investment in resilient food systems in the most vulnerable and fragile regions is critical. *Nature Food* 2:546-551. DOI: 10.1038/s43016-021-00345-2.

Shi, J., Xiang, Z., Peng, T., Li, H., Huang, K., Liu, D. and Huang,T. (2020). Effects of melatonin-treated *Nasturtium officinale* on the growth and cadmium accumulation of subsequently grown rice seedlings. *International Journal of Environmental Analytical Chemistry* pp.1-9. https://doi.org/10.1080/03067319.2019.1700972.

Schipanski, M.E., Macdonald, G.K., Rosenzweig, M., Chappell, M.J., Bennett, E.M., Kerr, R.B. and Blesh, J. (2016). Realising resilient food systems. *Bioscience,* 66:600-610.

Sofowora, A., Ogunbodede, E. and Onayade, A. (2013). The Role and Place of Medicinal Plants in the Strategies for Disease Prevention. *African Journal of Traditional, Complementary and Alternative Medicine* 2013; 10(5): 210–229. Published online 2013 Aug 12. doi: 10.4314/ajtcam.v10i5.2 10.1093/biosci/biw052.

Sorunu ve Dünya Açlık, Bu Sorunu Çözmeye, Yönelik Yeni Bir, Model Önerisi Ramazan Kılıçs (2022). The Problem of Hunger in the World and a New Model Proposal to solve This Problem *Balkan Sosyal Bilimler Dergisi,* 2022 11 (21): 63-68.

Tanimu, Y., Bako, S.P. and Tiseer, F.A. (2013). Effect of sewage pollution on water quality of Samaru stream, Zaria, Nigeria. In: Fernando Sebastian Garcia Einschlag and Luciano Carlos (Eds). *Waste Water: Treatment Technologies and Recent Analytical Developments*, INTECH Publishers, Rijeka, Croatia, pp189 - 195.

Teodoro, M., Hejcman, M., Vitkova, M., Wu, S. and Komarek, M. (2020). Seasonal fluctuations of Zn, Pb, As and Cd contents in the biomass of selected grass species growing on contaminated soils: Implications for *in situ* phytostabilisation. *Science of the Total Environment* 703,134710. https://doi.org/10.1016/j.scitotenv. 2019. 134710.

Turner-Skoff, J.B. and Cavender, N. (2019). The benefits of trees for livable and sustainable communities. *Plants, People & Planet,* 1:323-335. DOI: 10.1002/ppp3.39.

Udawatta, R.P., Walter, D. and Jose, S. (2022). Carbon sequestration by forests and agroforests: a reality check for the United States. *Carbon Footprints,* 1:8. DOI: 10.20517/cf.2022.06.

Ulian, T., Mauricio, D., Samuel, P. S., Padulosi, U. L., Lee, D., Melanie-Jayne, R., Howes, J. S., Borrell, I. O. O. S. and Pérez-Escobar, A. (2020). Unlocking plant resources to support food security and promote sustainable agriculture. *Plants, People & Planet*, 2:421–445. DOI: 10.1002/ppp3.10145.

van der Pol, L.K., Nester, B., Schlautman, B., Crews, T.E. and Cotrufo, M.F. (2022). Perennial grain fields have higher particulate organic carbon at depth than annual grain fields. *Canadian Journal of Soil Science,* 102:1005-1009. DOI: 10.1139/CJSS-2022-0026.

Vandermeer, J., van Noordwijk, M., Anderson, J., Ong, C. and Perfecto, I. (998). Global change and multi-species agroecosystems: *Concepts and issues. Agriculture, Ecosystems & Environment,* 67:1-22. DOI: 10.1016/S0167-8809(97)00150-3

Volk, G.M., Byrne, P.F. and Moreau, T.L. (2023). Importance of plants for mitigating and adapting to the effects of climate change. In: Volk, G. M., Moreau, T. L., Byrne, P. F. Conserving and Using Climate-Ready Plant Collections. Fort Collins, Colorado: Colorado State University. Availablefrom:https://colostate.pressbooks.pub/climatereadyplantcollections/chapter/importance-of-plants/

Wei, Z., Van Le, Q., Pen, W., Yang,Y., Yang, H., Gu, H., Shiung Lam, S. and Sonne, C. (2021). A review on phytoremediation of contaminants in air, water and soil. *Journal of Hazardous Materials*, 403:12, 36-58. https://doi.org/10.1016/j. jhazm at. 2020. 123658.

Worstell, J. and Green, J. (2017). Eight qualities of resilient food systems: Toward a sustainability/resilience index. *Journal of Agriculture, Food Systems and Community Development,* 7:23-41. DOI: 10.5304/jafscd.2017.073.001.

World Bank (2023). Understanding Poverty. https://data.worldbank.org/country/nigeria?view=chart

WHO (2023). Global Health Issues, Challenges and Trends. https://www.aucmed.edu/about/blog/global-health-issues