ISSN 2348-0319 International Journal of Innovative and Applied Research [2023]
(Volume 11, Issue 03)
01-10

Journal home page: http://www.journalijiar.com

INTERNATIONAL JOURNAL
OF INNOVATIVE AND APPLIED RESEARCH

RESEARCH ARTICLE

Article DOI: 10.58538/IJIAR/2014
DOI URL: *http://dx.doi.org/10.58538/IJIAR/2014*

SOIL BIODIVERSITY AS A NATURE-BASED SOLUTION TO CLEAN-UP OF POLLUTED ENVIRONMENTS

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Manuscript Info

Manuscript History
Received: 15 February 2023
Final Accepted: 21 March 2023
Published: March 2023

Keywords:
Polluted Environment, Soil Biodiversity, Clean-Up, Pollutants, Decontamination, Techniques

Abstract

Soils produce 95 percent of the food we consume, healthy soil provides crucial ecosystem services for life, such as water storage, purification and flood regulation, carbon sequestration and consequently climate change mitigation, or nutrient cycling e.t.c. The dangers posed to the environment due to anthropogenic activities necessitate the need for novel strategies for decontamination and clean up. It is challenging to realize and discover the interplay between the biodiversity in polluted environments. The process of clean-up can be done in aerobic or anaerobic systems depending on the microorganisms and the electron acceptors available in the media. This review has examined the sources of pollutants into the environment, mechanism for clean-up, contribution of molecular techniques and how utilization of biodiversity can be an effective technique available for clean-up of polluted sites. Though the idea has a long history, however other relatively new applications are emerging or being developed for optimization of the existing biodiversity - based techniques for clean-up of polluted environments.

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Introduction:-

Soils form the basis for the vast majority of life on earth, yet they are possibly the least understood and appreciated of earth's ecosystems. It is considered to be among the most biologically rich habitats on earth, with greater biodiversity per unit area than that observed aboveground making it a center for biological interaction Nielsen, 2015.

Soils support highly abundant and diverse communities of organisms that show a broad array of life histories and functional traits, and they range in body size from a few micrometers for some bacteria to several meters in length in the case of some earthworms

Soil biodiversity is an important resource that provides ecosystem processes essential to the functioning of natural and global systems. The understanding of the species, their interactions, and effect on processes occurring in the soil food web in natural systems are an important contribution to management of land and its uses. An immediate effect is a decrease in the biological capacity of soils and a change in the regulation of interactions and processes. Knowledge on whether all or a few key taxonomy are important in this regulation of ecosystems processes is a high priority for planning for future sustainability. Wall (2005)

With the increase in human population, it is expected that by 2030, the world population will reach 8.6 billion, (UN 2017). It therefore becomes pertinent that man should respect and protect the natural resources, including soil, water, air, minerals, and biodiversity that support life on Earth, including humanity. Current rates of consumption and inadequate management of resources are putting unprecedented pressure on global systems and it is estimated that one to six billion hectares (up to 30%) of land has been degraded globally (Gibbs, and Salmon, 2015).

Land degradation negatively affects 3.2 billion people, threatens sustained human well-being and is a major contributor to climate change and biodiversity loss (IPBES, 2018). Global initiatives to meet these challenges include the UN 2030 Agenda for Sustainable Development and the UN Convention on Biodiversity's Strategic Plan for 2020. Broadly, these agendas address areas to improve human life and environmental sustainability, rely on the participation of all countries and stakeholders, and will require innovative, timely, and interdisciplinary approaches (Soliveres et al., 2016).

What Is Pollution

Pollution is the introduction of harmful materials into the environment. Pollutants can be natural or as a result of human activity. Pollutants often damage the quality of air, water, and land (NGS, 2022). Environmental pollution has been on the rise in the past few decades owing to increased human activities on energy reservoirs, unsafe agricultural practices and rapid industrialization. Soil pollution is one of the major worry among all because soil contamination can harm the humans by consumption of food grown in polluted soil or it can cause infertility to soil and lower the productivity, Among the pollutants that are of environmental and public health concerns due to their toxicities are: heavy metals, nuclear wastes, pesticides, greenhouse gases, and hydrocarbons.

Pollution load is increasing at an alarming rate as a result of industrialization and population outburst. The industrialization has caused in the utilization and production of chemicals for hi-tech innovations which ensued the generation of non-biodegradable pollutants like xenobiotics, hydrocarbons, heavy metals, etc. (Labie, 2007). These toxic pollutants remain persistent in the environment and pose a serious threat to living organisms.

These toxic pollutants remain persistent in the environment and pose a serious threat to living organisms. Increasing awareness has generated numerous approaches using advanced scientific technology to audit and curtail this arduous global issue. The widely accepted technique for decontaminating a polluted environment in an eco-friendly and sustainable manner is bioremediation (Paul et al., 2005; Raghunandan et al., 2018).

Types of soil pollution

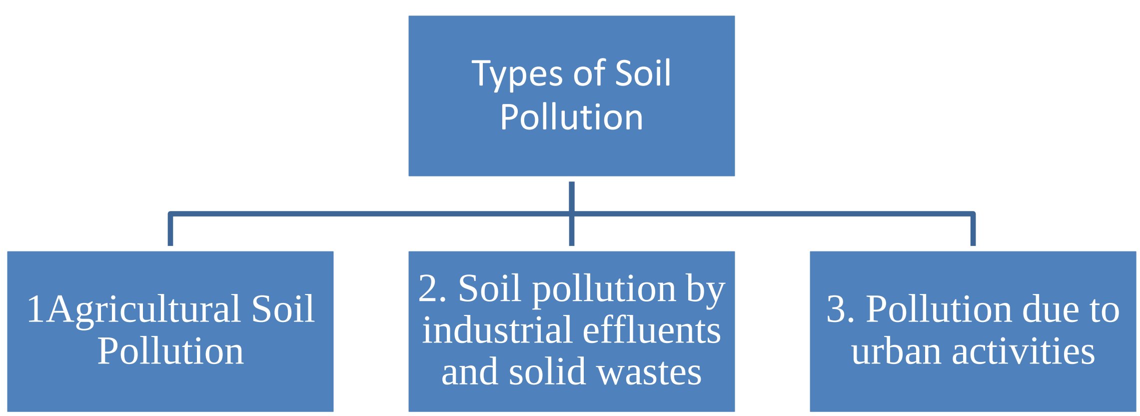

Figure 1:- Different forms of soil pollution.

Sources of soil pollution

The sources which pollute the soil are twofold: Agricultural sources and non-agricultural sources.

i. Agricultural sources

Soil pollution comes from different sources including agriculture and animal husbandry. Some of the agricultural practices lead to soil pollution. They are animal wastes, use of long lived pesticides, herbicides, fungicides, nematocides, etc. fertilizers and some agricultural practices (Fig 1).

ii. Non-agricultural sources

Soil pollution by non-agricultural sources is usually the direct result of urban sprawl caused by rapidly increasing population and a rapidly per capita output of waste related to our modem way of life. Its materials that find their entry into the soil system have long persistence and accumulate in toxic concentration and thus become sources of pollution. Some of those most important soil pollutants are inorganic toxic compounds (Fig 2).

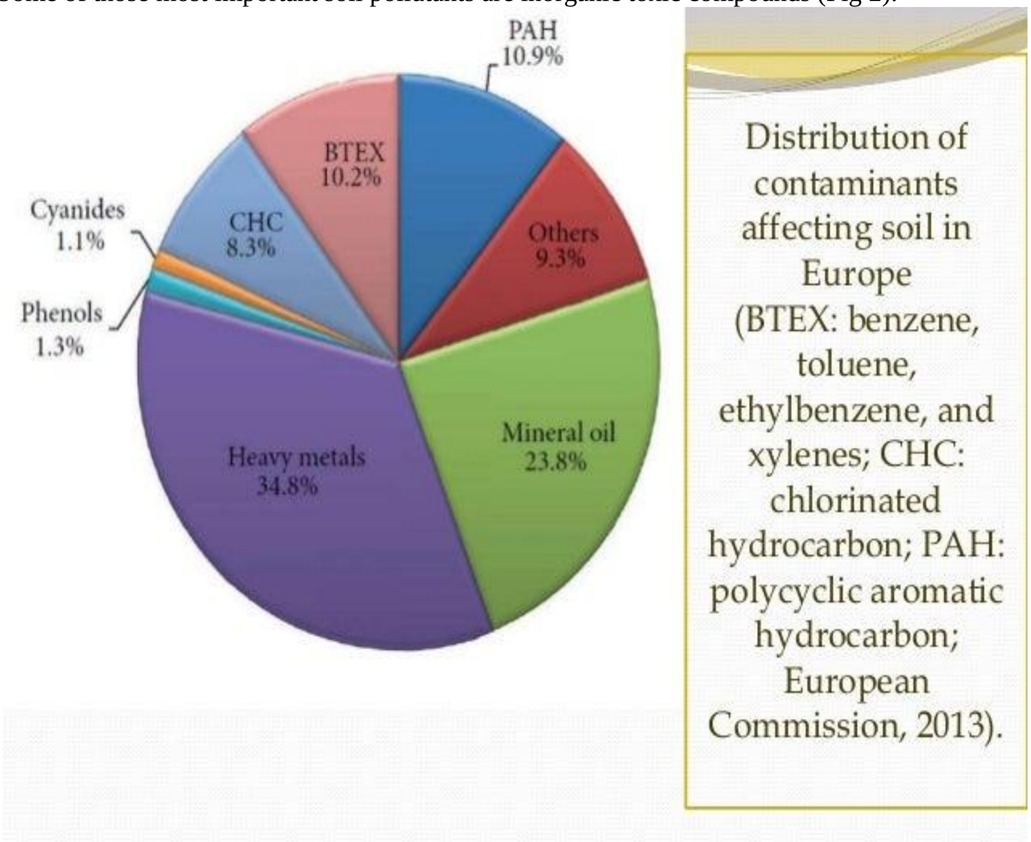

Figure 2:- Distribution of contaminants affecting Soil in Europe Source: European Commission, 2013.

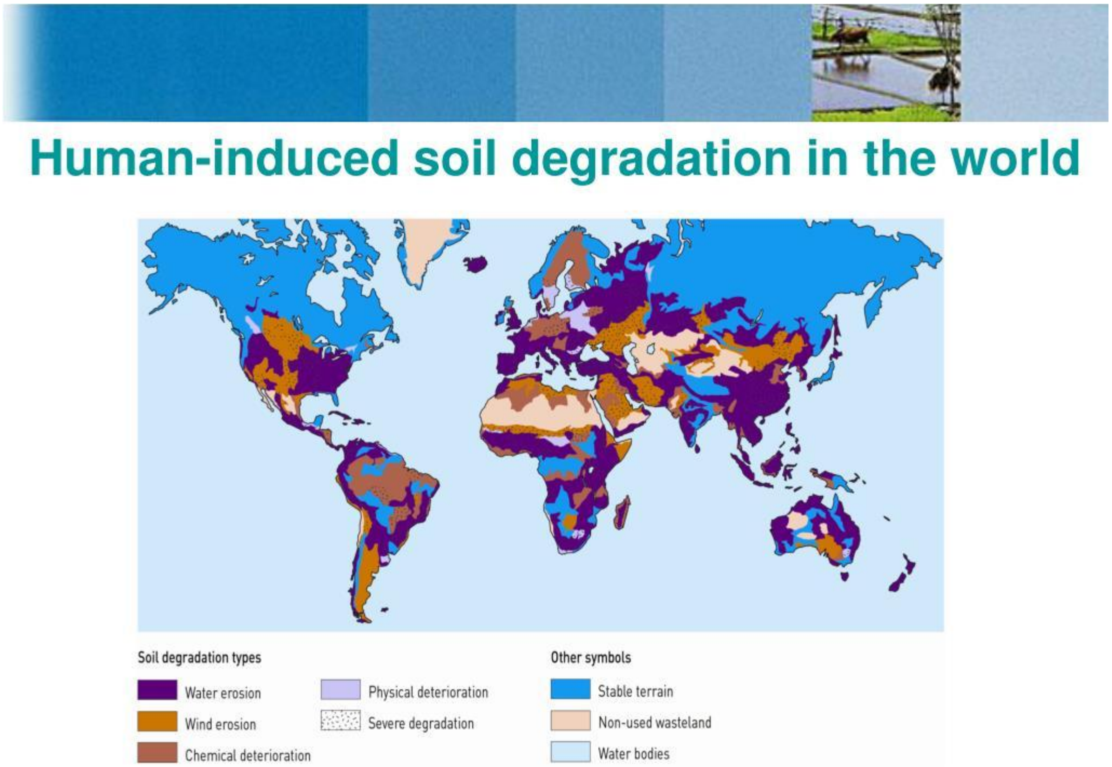

Figure 3:- Human induced Soil Degradation in the World, Source: FAO 2005.

Causes of soil pollution

Soil pollution is caused by the presence of man-made chemicals or other alteration in the natural soil environment. This type of contamination typically arises from the rupture of underground storage links, application of pesticides, and percolation of contaminated surface water to subsurface strata, oil and fuel dumping, leaching of wastes from landfills or direct discharge of industrial wastes to the soil (Fig 3). The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, lead and other heavy metals. This occurrence of this phenomenon is correlated with the degree of industrialization and intensities of chemical usage. A soil pollutant is any factor which deteriorates the quality, texture and mineral content of the soil or which disturbs the biological balance of the organisms in the soil. Pollution in soil has adverse effect on plant growth.

Pollution in soil is associated with;

1. Indiscriminate use of fertilizers Provoost et al. , 2008
2. Indiscriminate use of pesticides, insecticides and herbicides Toccalino and Norman, 2006
3. Dumping of large quantities of solid waste Patterson et al., 2007
4. Deforestation and soil erosion Leon, 2008
5. Pollution due to urbanization Nawrot et al. (2006),
6. Pollution of underground soil FAO (2020)

Soil Biodiversity And Interaction With The Ecosystem

On an economic basis, soil biodiversity has both direct (the organisms themselves and/or their metabolic products) and indirect (the long-term outcome of their activities) uses.

Regardless of any ecological or monetary value, several authors (Hågvar, 1994; McNeely et al., 1995) have stressed ethical and moral reasons why biodiversity should be conserved. Most of the world's religions give intrinsic worth to the natural world, and it is unlikely that this deep-seated notion will disappear, even despite the force of the economic use values placed on biodiversity.

Biodiversity encompasses all living forms including plants, animals and microorganisms, the genes they all contain and the ecosystem they form part of. Biodiversity boosts ecosystem productivity where each species, no matter how small, all have an important role to play. A larger number of plant species means a greater variety of crops. Greater species diversity ensures natural sustainability for all life forms.

Knowledge of the distribution, biogeography, and functional aspects of soil biodiversity is rapidly evolving in part due to the increasing recognition of its substantial role in ecosystem processes and partly because of the benefit of healthy soils to human health and well-being. The continued technological development of molecular methods and equipment, greater sensitivity of analytical equipment and new analytical procedures, and increasingly sophisticated statistical tools (including bioinformatics pipelines) are facilitating the discovery of the true diversity and functional capabilities of the biota (eukaryotes and prokaryotes) found in small quantities of soil. The improved precision of techniques, such as stable isotope analysis, now reveals how small organisms aid the transfer of C and nutrients into the soil food web and helps determine how their functions are affected by soil

Put simply, reduced biodiversity means millions of people face a future where food supplies are more vulnerable to pests and disease, and where fresh water is in irregular or short supply.disturbance (Liu and Yu, 2013)

Since 1751, humankind has emitted over 1.5 trillion tonnes of CO_2 to the atmosphere and it is estimated that between 15% to 40% of all anthropogenic CO_2 will remain in the atmosphere for approximately a thousand years. Hence it is important to not only put a stop to GHG emissions but to also remove carbon from the atmosphere. (Viana, 2021).

Soil and its microorganisms are natural technology that play a major role in climate change adaptation and mitigation. Soil organisms can either contribute to the emission of GHG or aid the absorption of carbon into the soil. How it functions depends on the soil's condition. These organisms have a direct role in the carbon cycle, given that carbon in soil is recycled by microorganisms within the soil food web.

Carbon is naturally found in the atmosphere and in the soil, but the balance of its cycle has been disrupted by human activities, as we put more carbon in the atmosphere and store less. The conversion of natural ecosystems to agricultural use for example, has already released 50 to 100 GT of carbon from soil into the atmosphere, therefore, soil biodiversity is a key instrument to restore the lost balance.

Soil biota fixate carbon into soil through its activities, e.g. by transforming animal and plant debris. Some autotrophic bacteria and archaea can also take CO_2 directly from the atmosphere and fixate that into the soil. But there is also another way in which soil organisms store carbon.

A healthy soil is a biodiverse soil, and it is an essential part of our current ecosystem. Most soils has been significantly impacted by climate change and unsustainable agricultural practices. This decrease in soil biodiversity leads to fewer healthy microbes and has been shown to affect human health. In other words, soil biodiversity can improve human health. (Viana, 2021).

Soil biodiversity (including organisms such as bacteria, fungi, protozoa, insects, worms, other invertebrates, and mammals), supported by SOM pools, enhances the metabolic capacity of soils and plays a crucial role in soil health and ecosystem functioning. The revised World Soil Charter states that soils are a key reservoir of global biodiversity which ranged from microorganisms to flora and fauna. The biodiversity has a fundamental role in supporting soil functions and, therefore, ecosystem goods and services associated with soils. It is thus necessary to maintain soil biodiversity to safeguard these functions.

The quality and quantity of SOC/SOM directly influences soil biodiversity and activities, as it is the main source of energy for their survival and growth. Indirectly, it regulates the soil biodiversity by influencing the habitat properties such as soil aggregates, pore size, and connectivity. The quality and quality of SOM/SOC determines the abundance, diversity, and activities of soil communities, but these are circular interactions, where soil biodiversity also determines the quality and quantity of SOC, and there are multiple interactions which influence the rate and aspects of C cycling and ecosystem functions (Delgado-Baquerizo et al., 2016a, b; Trivedi et al., 2016b; Delgado-Baquerizo et al., 2017a, b). Recent studies provide evidence that soil diversity and functional community diversity are strongly linked to enzymes that degrade SOC, suggesting microbial community regulation of SOC storage (Trivedi et al., 2016a). Soil microbial respiration accounts for 50% (~60 billion tonnes year^{-1}) of the net terrestrial flux while microbes are the main regulators of rate of decomposition (Karhu et al., 2014). However, soil fauna also plays a significant role by manipulating and controlling microbial communities even though they have minor direct contribution via litter fragmentation, partial digestion of litters, and promoting direct contacts between litter and microbial communities (Orgiazzi et al., 2016).

Microorganisms, such as fungi, yeast, and bacteria have been considered to be outstanding organisms for detoxification of pollutants (Zhong and Zhou, 2002; Luciene et al., 2015; Abou Seeda et al., 2017). It assures a cheap, simple, and eco-friendly cleanup method (Lovley, 2003). Microorganisms are nutritionally flexible and have the flair to adapt to extreme environmental conditions. They also possess numerous intracellular and extracellular enzymes which utilize the complex pollutants and convert them into carbon and energy source (Nojiri and Tsuda, 2005; Thakur et al., 2019). They also undergo a rapid genetic transformation which enables them to acquire new metabolic routes for deterioration of xenobiotics (Poirier et al., 2013; Igiri et al., 2018).

Fate of Soil Biodiversity in metal-contaminated sites

The physicochemical properties of metal-contaminated environments tend to inhibit soil-forming processes and affect the area's biodiversity by exerting a strong selective pressure on fungi and plants (Gadd, 1993, Prasad et ai., 2005, Crane et al., 2010, Ceci et al., 2012). Specifically, the bulk metal content of soils and its metal releasability are among the most important edaphic factors determining vegetation composition. Other than metal toxicity, vegetation successions are also retarded by low nutrient status, poorly developed soil structure and water-restricted conditions, (Baker et al., 2010).

In addition, microorganism communities play a significant part in the detoxification of noxious chemicals and in the control of plant growth, (Filip, 2002), and also provide pivotal information about soil metal bioavailability (Saeki et al., 2002). Metalliferous biota is increasingly exploited for the stabilization or active remediation of the metal-contaminated ecosystems and represents an important research topic in the contemporary field of green technology (Adriano, 2001).

It is well-known that a number of plants and fungi are able to survive and actively grow in metal-contaminated soils. For instance, recent studies (Pérez-Tienda et al., 2013) have shown that some arbuscular mycorrhizal fungi from Cu-contaminated soils [Claroideoglomus claroideum (N.C. Schenck and G.S. Sm.) C. Walker and A. Schüßler in association with Imperata condensata Steud. and Rhizophagus irregularis in association with carrot roots] are able to compartmentalize Cu in spores as a survival strategy in polluted environments. Additionally, microfungi are essential in colonizing and detoxifying metal-contaminated soil ecosystems and consequently have environmental and economic significance (Fomina et al., 2007).

Mine dumps cause high selective pressure, enabling bacteria and microfungi to be the first organisms able to re-colonize mine soils, (Novàkovà, 2006). Under this pressure, microfungal communities' change their composition and several resistant strains are selected (Gadd, 2007). In addition, plant communities have established a primary succession on mine wastes (Micò et al., 2006) and can be exploited for biogeochemical prospecting and mine stabilization (e.g., abandoned mines contaminated with arsenic, antimony and tungsten (Prasad et al., 2005).

Restoration of Biodiversity through Application of Molecular technique in Mitigating Environmental Pollution

The widely accepted technique for decontaminating a polluted environment in an eco-friendly and sustainable manner is bioremediation (Paul et al., 2005; Raghunandan et al., 2018).

Microbial treatment methods:

The microbial treatment methods appear to be more promising which can deal with whole range of organic contaminants including phenol, polychlorinated hydrocarbons, oil and oil products, dioxins, etc. There are two different ways of approaching the problems.

1. A community of microbes already existing on the site is collected and cultured in the laboratory.
2. Strains of microbes are developed in the laboratory that is capable of metabolizing particular chemicals.

Excavation of the soil prior to treatment offers the greatest scope for creating optimum conditions. The excavated soil can be placed on thin layers to various depth using standard earth moving techniques and microbes and nutrients applied using standard agricultural techniques such as fertilizing, ploughing, harrowing, etc.

The emergence of genomic technologies has boosted the treatment of contaminated environments in a sustainable manner. The identification of the microbial communities using modern genomic tools has enabled the detection of distinctive microorganisms that were not approachable by culture-based techniques. Gene amplification (using PCR) and sequencing techniques have proven exceptionally useful in evaluating the microbial community (Malik et al., 2008; Rani et al., 2008; Gołebiewski and Tretyn, 2020).

The discovery of a highly conserved and variable gene sequence, 16S rRNA in all microorganisms is considered as the highest quality level for describing phylogenetic similarities among organisms in microbial communities (Lovley et al., 1991; Lovley, 2003). 16S rRNA gene sequence analysis can be used for a complete assessment of microbial diversity by selectively amplifying and sequencing the hypervariable regions of the 16S rRNA gene. It is a highly efficient and cost-effective technology easily accessible by various bioinformatics tools and has become a frequently used technique for profiling intricate microbial communities (Han et al., 2020). It can be used to identify novel, unculturable, and phenotypically unidentifiable microbes (Clarridge, 2004).

The phylogenetic organization of the microbes linked with bioremediation processes can be determined by investigating the 16S rRNA sequences obtained from contaminated environments (Lovley, 2003; Rogers and McClure, 2003). 16S rRNA was used to elucidate the composition of microbial communities and the multifariousness of the dioxygenase genes in the soil of a coal tar mixing plant to study the genetics of PAH degradation (Kumar and Khanna, 2010; Viant and Sommer, 2013; Sakshi Haritash, 2020). Kou et al. (2018) reported 16S rRNA gene amplicon sequencing to study the abundance and diversity of the microbial community in soil polluted with heavy metals like lead, zinc, and copper in Shanghai. 16S rRNA gene sequencing along with membrane fatty acid profile was used to identify soil bacterium Pseudomonas species capable of degrading polyurethane from a site containing an abundance of fragile plastic waste (Cárdenas Espinosa et al., 2020).

An RNA-based stable-isotope probing method was used to identify anaerobic phenol-assimilating bacteria present in activated sludge and used to treat synthetic coke-oven wastewater. Activated sludge was fed with nitrate and 13C-labeled or unlabeled phenol under anaerobic conditions. After the incubation period, RNA was extracted from the activated sludge and separated by isopycnic centrifugation. Bacterial rRNA in each density

The work carried out by Sueoka, Satoh, Onuki, and Mino, (2009), on microorganisms involved in anaerobic phenol degradation in the treatment of synthetic coke-oven wastewater detected by RNA stable-isotope probing' shows that during the anaerobic incubation, simultaneous reduction of phenol and nitrate concentrations and accumulation of nitrite were observed. Their results strongly suggest that bacteria closely related to the genus Azoarcus assimilated phenol anaerobically in the presence of nitrate in an activated-sludge process involving nitrification and denitrification for the treatment of synthetic coke-oven wastewater. In addition, bacteria weakly related to the genera Pelagiobacter, Microbulbifer, Pseudomonas, and Thauera may have been involved in anaerobic phenol degradation by assimilating phenol directly or by assimilating metabolites of phenol.

Conclusion:-

Several approaches to the utilization of biodiversity, particularly physical systems, involve the treatment of aqueous phase pollutants and the distinction between soil and groundwater is of limited practical significance. The molecular approaches have the potency to anticipate microbial metabolism in polluted environments. High-throughput analyses would aid in tracking novel organisms for bioremediation, provide excellent and novel insights into their key biodegradative pathways at the molecular level.

There are other common methods of preventing soil pollution including reforestation and recycling of waste materials. Deforestation often leads to erosion of the soil, which leads to soil pollution due to the loss of fertility of the soil. Thus, utilization of plant biodiversity is an effective method of preventing soil pollution. In addition, reducing the volume of refuse or waste in landfills by recycling materials such as plastics, papers and various other materials is another effective and common method of preventing the phenomenon of soil pollution. Overall study suggested that Pollution is a threat to our health and damages the environment and damage to soils which affects the ability to grow crops. Utilization of both soil, animal and plant biodiversity can help to reduce and control environmental pollution thus providing sustainable soils for future generations.

Conflict of Interest:
Authors hereby state that there is no conflict of interest.

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