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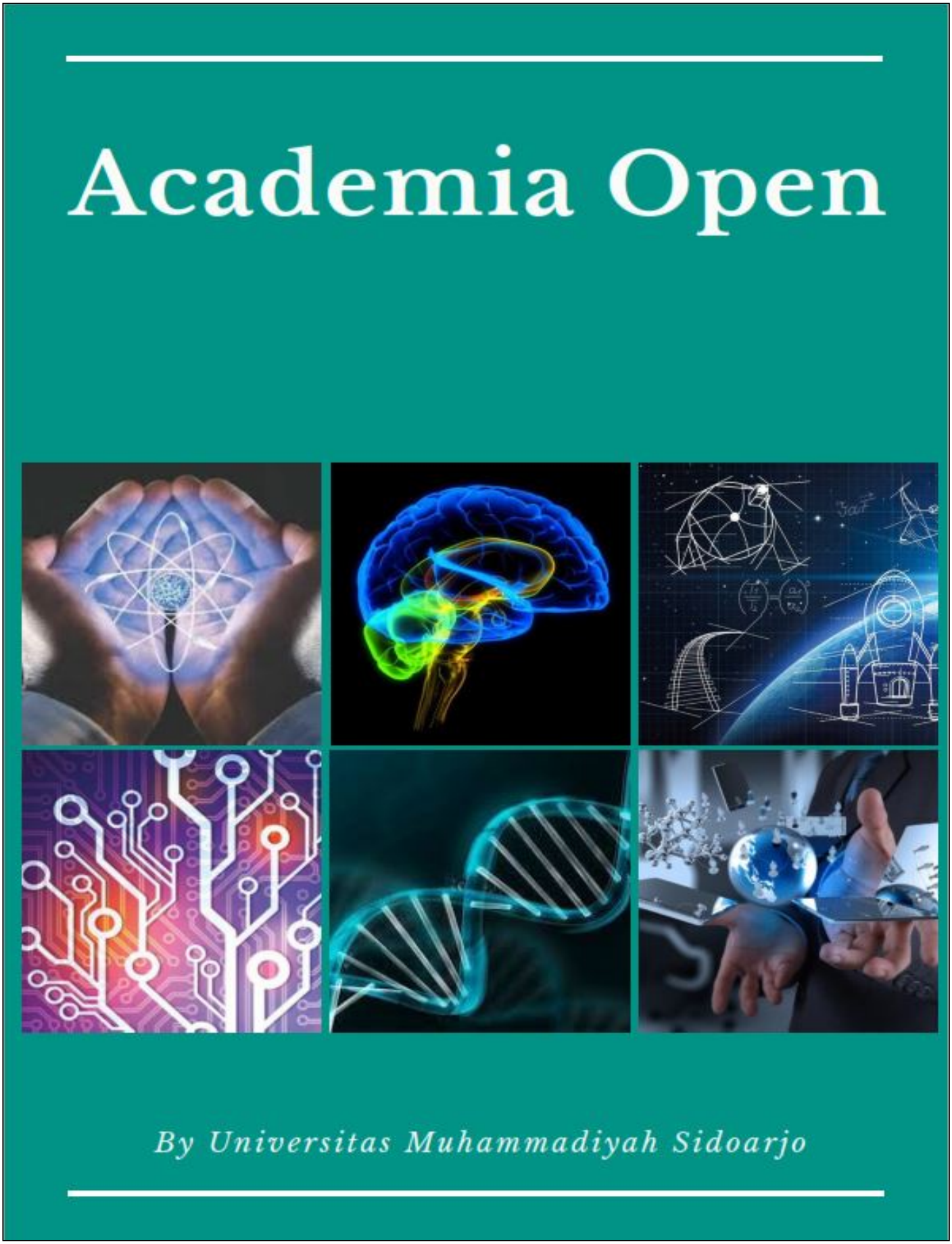

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Iraq's hydrocarbon crisis demands integrated remediation solutions

Krisis hidrokarbon Irak menuntut solusi remediasi terpadu

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Abstract

Petroleum hydrocarbon contamination in Iraq's oil-bearing areas significantly impacts the environment and public health. This study reviews contamination sources, such as oil spills and industrial disposal, and outlines the identification and quantification methods using GC-MS and FTIR. Various remediation strategies, including bioremediation, phytoremediation, chemical oxidation, thermal remediation, and physical removal, are discussed. The review highlights challenges in implementation due to technological, financial, regulatory, and community engagement issues. An integrated adaptive management approach is recommended to mitigate risks and ensure sustainable development of Iraq's oil sector.

Highlight:

- Hydrocarbon identification and quantification using GC-MS and FTIR.
- Combined remediation: bioremediation, phytoremediation, chemical oxidation, thermal remediation, physical removal.
- Challenges: technological, financial, regulatory, and community engagement issues.

Keyword: Petroleum hydrocarbon contamination, Iraq, GC-MS, FTIR, remediation strategies

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Pendahuluan

Petroleum hydrocarbon pollution is another concern in the environment, and it is a major concern in oil and gas producing countries where production is rife and companies have numerous industrial activities. Being a member country of the group of the largest oil producers, Iraq experiences peculiar difficulties in the regulation of the consequences of the anthropogenic dangerous impact in connection with pollution by hydrocarbons. The exploration, production and refining of crude oil in the country has reached its expected potential, with obvious effects on the land and water resources in the country. This contamination not only creates dangerous threats to the environment but also affects society's health and revenues of certain firms [1]. The shore sources of petroleum hydrocarbon contamination in oil-producing regions of Iraq include the following. Leakages of pipelines and storage tanks, micro leakage in refineries, and poor disposal of drilling waste are other sources of pollution. These events emit several hydrocarbons into the environment in form of alkanes, aromatic hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs) all of which, though may differ in their toxicity and persistence in the environment. Therefore, to prevent the harm of these contaminants to natural resources and the people of Iraq, it has become paramount to fully comprehend them [2]. PHCs identification and categorization involves complex analytical procedures that can more precisely identify as well as enumerate all the hydrocarbon species present. Techniques like GC-MS, coefficients of variation of crude oil samples as well as FTIR essentially assist in an enhanced understanding of the types and concentrations of contaminants for efficient and proper means of remediation. These remedies involve removal and treatment of the contaminants, and the unique behavior of each of these contaminants due to factors such as their chemical nature and reaction with their environment puts them in a category that requires specific methods of remedial action [3].

Dispersal of petroleum hydrocarbon pollution in Iraq is riddled with a myriad of challenges. These are technological constraints, cost considerations and fluctuations in the regulations that make it cumbersome to remediate pollutants at affected locations. Furthermore, the involvement of local stakeholders and their consequent participation in redevelopment processes is also important for such projects. The contamination of hydrocarbons is complex and consequently the remediation requires the use of several processes since some at times may not be sufficient [4].

Petroleum Hydrocarbon Contamination in Iraq

Contamination by petroleum hydrocarbons in Iraq is one of the most critical environmental problems caused basically by large oil production and related activities within the country. Sources of contamination include a variety of issues: from accidental oil spills to continuous industrial activity and improper methods of waste management. The country is on the list of major oil-producing countries; as such, there are serious concerns regarding handling and mitigating the environmental impacts of hydrocarbon contamination [5]. The significant sources contributing to petroleum hydrocarbon contamination in Iraq include ruptures of pipelines and storage facilities, refineries, and the petrochemical industry, together with the improper disposal of drugs and produced water from oil wells. These sources directly disseminate hydrocarbons into terrestrial and aquatic systems, particularly within all oil-producing areas of the country. Consequently, this will accumulate the effect of these various sources, causing persistent contamination and affecting terrestrial and aquatic ecosystems [6]. Regarding types of contaminants, petroleum hydrocarbons represent a diverse group of organic chemicals derived from crude oil. In Iraq, these include alkanes in the form of saturated hydrocarbon chain lengths from methane to higher molecular weight compounds, including octane and upward. Besides saturated hydrocarbons, aromatic hydrocarbons like BTEX—benzene, toluene, ethylbenzene, and xylenes—are significant contaminants, as they can form part of crude oil and cause adverse environmental impact at deficient levels [7].

Another class of compounds of concern in the hydrocarbon contamination profile of Iraq is PAHs. They are byproducts during incomplete combustion of organic materials and exist in significant amounts in crude oil and all its petroleum derivatives. PAHs have been identified to be potentially persistent, carcinogenic, and mutagenic to both human health and ecological systems [8]. Characterization of contaminants within the Iraqi environment and water systems relies on high-end analytical techniques, such as GC-MS and FTIR. The outcome provides the environmental scientist or regulator with the exact identification and quantification of hydrocarbons necessary for understanding the nature and extent of contamination and planning remediation strategies. Contamination by petroleum hydrocarbons in Iraq's producing regions should be fully understood concerning sources and types. State-of-the-art characterization approaches must go together with local conditions targeting applied remediation technologies under environmental and regulatory settings if such challenges are to be addressed effectively. It is through this that Iraq shall strive to reduce the environment and health risks from hydrocarbon contamination while at the same time promoting sustainable development in that critical area [9].

Metode

Characterization Techniques

Characterization techniques for petroleum hydrocarbon contamination in the soil and water systems can, at various

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dimensions, be applied to ascertain the nature and extent of the contamination within Iraq. Physical-Chemical Methods: This kind of methodology represents the bond between both physical and chemical analyses, leading to the identification and quantification of hydrocarbons in environmental samples. The physical methods primarily include visual inspections, where the presence of oil sheens or discoloration in soil or water may indicate the presence of contamination. Chemical methods, on the contrary, make use of analytical instruments such as Gas Chromatography-Mass Spectrometry, High-Performance Liquid Chromatography, and Fourier Transform Infrared Spectroscopy [10]. GC-MS can separate and identify individual hydrocarbons, studying their molecular weight and fragmentation pattern to obtain details on petroleum mixture composition. Functional groups in hydrocarbons were characterized with FTIR spectroscopy, providing a use for qualitative and semi-quantitative analyses of contamination levels. All these techniques permit accurate profiling of the characterization of hydrocarbon contaminant activities in Iraqi soil and water for stakeholder decision-making on remediation efforts. Biological Methods: Biological techniques complement the tradition of information on petroleum hydrocarbon contamination through assessment of their impact on microbial communities or by using organisms for remediation. Techniques for microbial analyses, with DNA sequencing and studies from cultures of microorganisms, show the presence of hydrocarbon-degrading bacteria and fungi in contaminated environments [10].

Biodegradation depends mainly on these microorganisms that help break hydrocarbons down to less harmful substances using metabolic pathways. Biomarker analysis, which includes measuring enzymatic activities such as dehydrogenase and catalase, presents indicators for microbial activity and degradation potential in contaminated sites. In addition, various bioassays with plants and invertebrates as test organisms will be performed to evaluate hydrocarbon toxic contamination and eventually assess their induced ecological risk. Biological techniques need to be combined with physico-chemical analyses for an integrated understanding of the dynamics of contamination in Iraqi environments. This will help develop sustainable remediation strategies using natural processes that allow for effective cleanup [12].

Hasil dan Pembahasan

Remediation Challenges

Remediating petroleum hydrocarbon contamination in Iraq will be an extremely challenging task, mirroring both in complexity and dimension the environmental impacts in oil-producing nations. First, the major challenge is that sources of contamination are pervasive and varied, including not only accidental spills but also chronic leaks and legacy pollution from decades of extraction and processing of oils, which contribute to the widespread contamination of soils and water systems, hence making clean-up efforts targeting specific areas particularly complicated [13]. Another critical challenge is the persistence of hydrocarbon contaminants in the environment. Because of their low dissolution and relatively poor microbial degradability, petroleum hydrocarbons can persist for an extended period under certain conditions in soils and groundwaters. This persistence not only prolongs environmental risks but also requires long-term monitoring strategies and remediation efforts to ensure cleanup and prevent recontamination. Technological and resource limitations further complicate the remediation challenges in Iraq. The availability of sophisticated remediation technologies, such as in-situ chemical oxidation, bioremediation, and thermal treatment methods, may be limited in some regions, and their use for adopting efficient cleanup strategies may be consequently restrained. Besides, the huge expenses to be incurred for implementation and maintenance make such technologies financially unaffordable, especially in areas whose economic resources are already overstretched [14]. Both environmental and regulatory complexities are crucial in setting the tone for remediation efforts. For example, environmental legislation and enforcement vary across Iraq, making it a significant challenge to create uniformity regarding cleanup standards. In addition, geopolitical factors—security concerns at times of conflict—may disrupt remediation activities and thus cause undue delays in progress toward the checking of contamination issues [15]. Community stakeholder engagement is another dimension to the challenges related to hydrocarbon contamination remediation. In Iraq's oil-producing regions, these local communities generally face the worst impacts of environmental and health contamination. Therefore, transparent communication capacity building and collaborative approaches to remediating contamination become critical. Addressing social and cultural considerations will be important in building trust and thus ensures that the long-term sustainability of remediation efforts promotes good environmental stewardship throughout generations [4]. The remediation of petroleum hydrocarbon contamination in Iraq will involve technical, environmental, regulatory, financial, and social problems. Integrated approaches will be required to overcome such challenges, considering scientific rigor, technological innovation, community engagement, and policy coherence. This would ensure that sustainable solutions to safeguard the health and well-being of affected populations and ecosystems are implemented [1].

Complexity of Contaminants

The complexity of petroleum hydrocarbon contaminants in Iraq's soil and water systems is multilevel, posing significant challenges to environmental management and remediation efforts. Such pollutants have very diverse sources within the oil industry: crude oil spills, leakages from pipelines and storage facilities, and discharges from refineries and petrochemical plants. Each source introduces a different blend of hydrocarbons into the environment, which differs in composition, volatility, and toxicity [5]. This broad grouping of petroleum hydrocarbons includes simple alkanes and aromatic hydrocarbons through diverse polycyclic aromatic

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hydrocarbons (PAHs). The saturated alkanes, which include methane, ethane, and propane, are saturated hydrocarbons; they are relatively innocuous but tend to persist in the environment because of low water solubility. These include BTEX—benzene, toluene, ethylbenzene, and xylene—all aromatic hydrocarbons that are more water-soluble, posing severe threats to human health and ecosystems due to their carcinogenic and neurotoxic properties. The degree of solubility generally defines the extent or degree of natural attenuation of a compound in an aquifer [11]. PAHs are products of incomplete combustion of organic material and in high amounts in crude oil and all by-products. These chemicals, therefore, are recalcitrant to soil and aquatic systems, resistant to degradation, and bioaccumulating in marine organisms, thereby posing long-term environmental and human health risks. The existence of PAHs complicates efforts aimed at remediation because they comprise a heterogeneous group of hydrocarbons with complicated chemical structures and different levels of toxicity, thus requiring unique methods for effective cleanup [10]. The complexity is further added to by the composition and distribution of petroleum hydrocarbon contaminants in environmental matrices. Contaminants can exist in this free phase as oil, dissolved in groundwater, absorbed onto soil particles, or residual compounds in sediments and biota. In these regards, heterogeneity within contamination across different environments—from arid landscapes to marshlands and coastal areas—may entail specially tailored assessment and remediation strategies that would consider geology, hydrology, and ecological sensitivities [9].

The persistence of hydrocarbon contaminants over time is also a challenge to environmental management. Climate, temperature, soil pH, and microbial activity all act to either raise or lower the degradation rates for hydrocarbons. Indeed, some compounds may persist as viable contaminants for decades under the most favorable conditions. This, therefore, calls for long-term monitoring with adapted managerial strategies that will be relevant in assessing the effectiveness of remediation and preventing secondary contamination [9]. The complexity of the petroleum hydrocarbon contaminants in Iraq underscores the need for fully integrated characterization, risk assessment, and remediation approaches. Advanced analytical techniques and emerging remediation technologies will be necessary to accomplish this goal, as well as interdisciplinary collaboration between scientists, engineers, policymakers, and local communities. Considerable attention must be dedicated to understanding and negotiating the intricacies involved in hydrocarbon contamination if Iraq is going to achieve the avoidance of environment-related impacts, protection of public health, and sustainable development in its oil-producing regions [13].

Environmental Health Risks

The environmental and health risks associated with petroleum hydrocarbon contamination in Iraq are profound and different, affecting ecosystems and human communities within areas where the production of oil is taking place. Crude oil spills, refinery discharge, and pipeline leaks diffuse into the soil and water systems, resulting in wide-scale ecological degradation. Hydrocarbons are exceptionally high in the more toxic aromatic compounds, such as benzene, toluene, ethylbenzene, and xylene (BTEX), which pose high risks to flora and fauna. These chemicals can act as endocrine disruptors in plants, cause reproductive impairment in wildlife, and bio-accumulate in the food chain, which may lead to long-term ecological imbalances [11]. These petroleum hydrocarbons enter the water body and create acute and chronic toxic effects on aquatic life. Fish, amphibians, and invertebrates are amongst the groups that become victimized quite quickly; at high concentrations, hydrocarbons can cause immediate mortality, while lower levels may result in sublethal effects like changed growth, altered behavior, and decreased fertility. Moreover, these risks are exacerbated by the persistence of polycyclic aromatic hydrocarbons in sediments, which are degradation-resistant compounds that can source contamination for years and, hence continue to impact benthic organisms and overall aquatic health [5]. Human health risks are equally important, especially for communities living near the contaminated sites. Exposure can occur through direct contact with contaminated soil and water, by inhalation of volatile compounds, and via ingestion of food and contaminated water. Skin and eye irritation, respiratory complaints, headache, and dizziness are symptoms of acute exposure to high concentrations of hydrocarbons [1].

Even at lower concentrations, as might be expected with compounds such as benzene and after long-term exposure, there are still very significant health risks associated, including the potential development of cancers like leukemia and other chronic diseases such as liver and kidney damage and neurologic disorders [12]. The socio-economic dimensions of hydrocarbon contamination are equally significant. Land and water resources can be deprecated, agriculture and fishery yields decrease, while drinking water quality is also affected, thus directly hitting the means of livelihood and welfare of the local communities. Psychological stresses from living in a polluted environment and potential health impacts further decrease the quality of life and increase social inequalities. The mitigation of those environmental and health risks is therefore called for through comprehensive strategies in the assessment and management of risks. Protecting ecosystems and human health depends on the effective remediation of contaminated sites combined with rigorous regulatory frameworks, enhanced environmental monitoring, community sensitization on the risks involved, and building resilience within the affected populations [5]. It is through addressing the multifaceted risks associated with petroleum hydrocarbon contamination that Iraq gets to protect its natural resources and promote health and well-being in the oil-producing regions.

Remediation Strategies

Strategies to remediate petroleum hydrocarbon contamination in Iraq include the many restoration techniques for petroleum-contaminated soil and water systems. Such a strategy should be designed with intrinsically site-specific differences relative to environmental conditions and types of hydrocarbons that could exist in oil-producing regions

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characterized by varied and extensive contamination [6]. Bioremediation is one of the best and most environmentally friendly approaches to dealing with hydrocarbon contamination. This strategy uses microorganisms like bacteria and fungi, which can degrade petroleum hydrocarbons into less harmful compounds. These indigenous microbes or specially selected and introduced microbial strains metabolize hydrocarbons enzymatically while turning them into CO_2, water, and biomass. Techniques on bioremediation include in-situ bioremediation, wherein treatment is done directly at the contaminated site, and ex-situ bioremediation, whereby the contaminated material must be excavated elsewhere for treatment. The factors that should be optimized to increase the activity and efficiency of microbes include nutrient availability, oxygen level, and pH [3]. Phytoremediation is when plants absorb, accumulate, and degrade hydrocarbons from soils and water. Some plant species are competent in taking up and metabolizing petroleum compounds via their roots and associated rhizosphere microbial communities. This technique has proved to work well in large, less highly contaminated regions where other conventional means of decontamination may become impractical or too money-consuming. One of the significant benefits of phytoremediation is that it is a sustainable way to enrich the structure of the soil, adding other ecological values like habitat and restoration and carbon sequestration. Chemical oxidation is applied in another broad strategy by injecting chemical oxidants into contaminated media. Oxidants react with hydrocarbons, cleaving them into non-toxic compounds. The approach is specifically effective for treating groundwater contamination and can be combined with other methods to enhance the overall effectiveness of remediation. However, this calls for careful management in dosage, together with monitoring, to avoid secondary impacts on the environment [6]. One of these thermal remediation techniques involves the application of heat to volatilize and finally destroy hydrocarbon contaminants. Depending on the degree of contamination and site conditions, what is used here includes techniques such as soil vapor extraction, thermal desorption, and incineration. SVE uses a vacuum system to extract volatile hydrocarbons from the soil, while thermal desorption heats the soil to release and capture contaminants for further treatment [2]. Incineration is quite expensive, however, and might raise a few air-quality concerns; because of this, it usually is held as a last resort. Methods of containment and physical removal are utilized when contamination poses immediate risks to human health and the environment. Containment measures prevent the spreading of contaminants through various means, such as barriers or impermeable liners. On the other hand, physical removal includes excavating contaminated soil or pumping out polluted groundwater for subsequent treatment. Mono application is often combined with other remediation techniques to handle any complex contamination scenarios.

Most frequently, all these strategies together can be foreseen as integrated remediation strategies for effectively managing variable hydrocarbon contaminants in Iraq. For instance, combining bioremediation and phytoremediation will have additive treatment efficiency by working on microbial and plant-based degradation processes, respectively. In a similar approach, chemical oxidation will integrate very well with bioremediation to proactively accelerate contaminant breakdowns for improved long-term site recoveries. Implementation of such remediation strategies in Iraq requires some solid regulatory frameworks, adequate funding, and a committed stakeholder participation process. Planning and implementing remediation projects will require local communities, government agencies, industry stakeholders, and environmental organizations to work jointly. Capacity-building programs, like training, can enable local communities to participate in remediation efforts actively. Only if holistic and adaptive approaches are impressed on remediation will Iraq be able to combat effectively petroleum hydrocarbon contamination and foster environmental sustainability for its oil-producing regions [6].

Simpulan

The petroleum hydrocarbon pollution of these oil-producing regions within Iraq presents a significant challenge to the environment and public health. Characterization and remediation will have to account for multiple sources of contamination and complex hydrocarbon compounds. Advanced analytical techniques should be used in identifying these contaminants appropriately and quantifying them as the conditions and nature of the hydrocarbons adopts effective remediation measures. Bioremediation and phytoremediation offer viable, environmentally beneficial strategies for handling contamination by natural degradation of hydrocarbons. Chemical oxidation and thermal remediation provide heavyweight tools in cases in which contamination is immediate and severe, though requiring management that minimizes secondary impacts. Containment and physical removal remain central to acute risk scenarios and preventing the spread of contaminants. Therefore, there are significant challenges to be overcome in implementing these strategies in Iraq related to technological limitations, financial constraints, variability in regulatory stances, and community engagement. This could be so because several different methods brought under one integrated approach can work successfully to remedy varied contamination profiles. After all, robust regulatory frameworks laying down guidelines and standards, adequate funding, and good collaboration among stakeholders have to come together for the successful execution of remediation projects. In sum, central environment and health risks associated with its oil industry can be reduced in Iraq through an integrated adaptive management approach to petroleum hydrocarbon contamination. This will not only protect the health and well-being of local people but also ensure sustainable development of the country's critical oil sector. Further research, innovation, and cooperation will help surmount challenges and achieve long-term environmental sustainability within Iraq's oil-producing regions.

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