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Innovative Remediation Strategies for Tackling Groundwater Pollution: A Comparative Analysis

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Abstract:
Groundwater pollution poses a pervasive environmental challenge in Alwahat, Libya, necessitating a comprehensive investigation into innovative remediation strategies. This study meticulously examines cutting-edge approaches to groundwater remediation, assessing their comparative efficacy within the unique hydrogeological context of Alwahat. Utilizing a combination of field investigations, water sampling, and laboratory analyses, the research identifies the specific pollutants affecting the groundwater and evaluates the performance of emerging remediation technologies. The comparative analysis encompasses traditional methods alongside advanced strategies such as electrokinetic remediation, phytoremediation, and nanoremediation. Results reveal the nuanced effectiveness of these approaches, considering factors like cost, sustainability, and adaptability to local conditions. Findings from this study contribute valuable insights into tailoring remediation efforts to the specific challenges faced by Alwahat, facilitating informed decision-making for environmental policymakers and practitioners. As the global demand for sustainable water management escalates, this research serves as a crucial reference for mitigating groundwater pollution in arid regions, emphasizing the importance of context-specific innovation in environmental remediation practices.

Keywords: Alwahat, Groundwater pollution, hydrogeological context, policymakers and practitioners.

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استراتيجيات المعالجة المبتكرة لمعالجة تلوث المياه الجوفية: تحليل مقارن

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الملخص:
يشكل تلوث المياه الجوفية تحدياً بيئياً واسع النطاق في الواحات، ليبيا، مما يستلزم إجراء تحقيق شامل في استراتيجيات العلاج المبتكرة تتناول هذه الدراسة بدقة الأساليب المتطورة لمعالجة المياه الجوفية، وتقييم كفاءتها النسبية ضمن السياق الهيد وجيولوجي الفريد للواحات، وباستخدام مجموعة من الزيارات الميدانية، وأخذ عينات المياه، والتحليلات المعملية، يحدد البحث الملوثات المحددة التي تؤثر على المياه الجوفية ويقيم أداء تقنيات المعالجة الناشئة، يشمل التحليل المقارن الطرق التقليدية جنباً إلى جنب مع الاستراتيجيات المتقدمة مثل المعالجة الكهروحركية، والمعالجة النباتية، والمعالجة النانوية وتكشف النتائج عن الفعالية الدقيقة لهذه الأساليب، مع الأخذ في الاعتبار عوامل مثل التكلفة والاستدامة والقدرة

على التكيف مع الظروف المحلية، تساهم نتائج هذه الدراسة برؤى قيمة في تصميم جهود العلاج للتحديات المحددة التي تواجهها الواحات، مما يسهل اتخاذ قرارات مستنيرة لواضعي السياسات والممارسين البيئيين .ومع تصاعد الطلب العالمي على الإدارة المستدامة للمياه، يعد هذا البحث بمثابة مرجع حاسم للتخفيف من تلوث المياه الجوفية في المناطق القاحلة، مع التركيز على أهمية الابتكار الخاص بالسياق في ممارسات العلاج البيئي.

الكلمات المفتاحية: الواحات، تلوث المياه الجوفية، السياق الهيد وجيولوجي، صناع السياسات والممارسون.

1. Introduction

Groundwater pollution is a pervasive and escalating environmental concern with far-reaching implications for both public health and ecosystem integrity (Mohammad, et.al 2015). In the arid region of Alwahat, Libya, the burgeoning issue of groundwater contamination has emerged as a critical challenge, demanding immediate attention and innovative solutions (Talabi, et.al. 2019b). This introduction provides a comprehensive overview of the contextual background, the significance of the problem, and the imperative for adopting inventive remediation strategies in the specified study area (Mohammad, et.al 2015)

1.1 Global Perspective on Groundwater Pollution

Groundwater, a vital source of freshwater, is integral to sustaining various human activities and ecosystems globally (Lamma, et.al 2022). However, an alarming increase in anthropogenic activities has led to the contamination of groundwater resources (Lamma, 2021). Industrial discharges, agricultural runoff, and improper disposal of hazardous waste contribute to the proliferation of pollutants, compromising the quality of groundwater (Saxena, et. al. 2021). The escalating global trend of groundwater pollution necessitates a concerted effort to identify and implement effective remediation strategies. (Lamma, O. A., & Swamy,2018)

1.2 Regional Challenges in Alwahat, Libya

The North African region, known for its arid climate, faces distinctive challenges concerning water resources. Alwahat, situated in Libya, is particularly susceptible to groundwater pollution due to a combination of factors such as rapid urbanization, agricultural intensification, and inadequate waste management practices (Kim, et.al. 2018, Peng, et.al. 2018)). Understanding the local hydrogeological conditions and the specific contaminants affecting Alwahat is crucial for devising contextually relevant and impactful remediation measures.

2. Significance of the Problem

2.1 Public Health Implications

The contamination of groundwater in Alwahat poses a direct threat to public health as the majority of the population relies on groundwater as a primary source of drinking water ((UNEP, 2019). The ingress of pollutants into aquifers can result in the bioaccumulation of harmful substances, leading to severe health issues such as gastrointestinal diseases, neurological disorders, and even carcinogenic effects (Vymazal, 2013). Addressing groundwater pollution in Alwahat is imperative to safeguard the well-being of the local populace.

2.2 Environmental Consequences

Beyond its impact on human health, groundwater contamination has profound implications for the local environment (Luo, et.al. 2019). Aquatic ecosystems, dependent on uncontaminated groundwater, face disruptions in biodiversity, and the persistence of pollutants can lead to long-term ecological degradation (World Bank. 2020). The interconnectedness of terrestrial and aquatic systems underscores the need for a holistic approach to remediation that considers not only human health but also the broader environmental landscape (Lamma, 2021).

3. Imperative for Innovative Remediation Strategies

3.1 Limitations of Traditional Remediation Approaches

Historically, conventional methods such as pump-and-treat and in-situ chemical oxidation have been employed to address groundwater contamination (LAMMA, 2023). While these methods have demonstrated some degree of effectiveness, they often fall short in treating complex contaminant mixtures and may incur high operational costs (Liang, et. al. 2019). In the case of Alwahat, a critical evaluation of traditional remediation approaches reveals the need for alternatives that are not only efficient but also tailored to the unique hydrogeological and contaminant profile of the region (FARAJ, et.al 2023)

3.2 Rising Demand for Innovation

The contemporary environmental landscape demands a paradigm shift toward innovative remediation strategies. The escalating challenges of emerging contaminants and the limitations of existing technologies underscore the urgency of exploring novel approaches (Lamma, O., & Swamy, 2015). Innovative strategies encompass a spectrum of advanced technologies, including bioremediation, nanoremediation, and phytoremediation, each offering unique advantages in addressing specific types of contaminants and hydrogeological conditions

(Scholz, et.al. 2017 & Lamma, et.al 2019). As such, the adoption of innovative remediation technologies becomes imperative for achieving sustainable and effective solutions in groundwater pollution mitigation.

4. Scope of the Comparative Analysis

4.1 Selection of Innovative Remediation Technologies

This research endeavours to conduct a comprehensive comparative analysis of innovative remediation strategies suitable for the specific conditions prevailing in Alwahat, Libya. The selection of remediation technologies will be based on their relevance to the identified contaminants and hydrogeological characteristics of the study area. Technologies such as advanced oxidation processes, electrokinetic, and microbial remediation will be evaluated for their applicability and efficacy in remediating groundwater pollution in Alwahat.

4.2 Quantitative and Qualitative Assessment Parameters

The comparative analysis will employ a multidimensional approach, incorporating both quantitative and qualitative parameters to evaluate the performance of selected remediation technologies. Key performance indicators such as removal efficiency, cost-effectiveness, and environmental sustainability will be systematically assessed. The integration of diverse evaluation criteria aims to provide a comprehensive understanding of the overall effectiveness of each remediation strategy in the context of Al-wahat.

The escalating groundwater pollution in Al-wahat, Libya, presents a multifaceted challenge that necessitates a concerted effort to implement innovative and contextually relevant remediation strategies. The ensuing sections of this research paper will delve into a detailed exploration of the literature surrounding groundwater pollution, the methodology employed for the comparative analysis, the results obtained, and the subsequent discussions and conclusions drawn from the study. Through this research, we aim to contribute valuable insights that not only address the immediate concerns in Al-wahat but also offer a broader understanding of the efficacy of innovative remediation strategies in mitigating groundwater pollution on a global scale .(Outhman, & Lamma 2020)

2. Literature Review

Hou et al. (2023) provide a comprehensive overview of sustainable remediation strategies for brownfield sites. They emphasize the integration of environmentally friendly techniques and redevelopment approaches. The study explores the challenges and advancements in brownfield remediation, shedding light on the importance of holistic, sustainable practices in mitigating environmental impacts (Lamma, & Moftah, 2016)

Shu et al. (2017) conducted a bibliometric analysis tracing the evolution of groundwater remediation. Their work spans historical developments to prospects, offering insights into the research trends and emerging technologies. This analysis contributes a valuable historical context, aiding in understanding the trajectory of groundwater remediation research (Lamma, 2020).

Jain et al. (2023) presents a comparative study on advanced membrane and nano-enabled processes for groundwater remediation. Focusing on efficiency enhancement, the study evaluates different technologies, providing a nuanced understanding of their applicability. This work aids in discerning the most effective methods for improving groundwater quality (Lamma, et.al.2018)

(Asanousi, et.al. 2018) and Jain (2023b) conducts a comprehensive review of techniques and applications related to groundwater vulnerability and risk mitigation. The study delves into various methodologies, offering a synthesized view of risk assessment strategies. This review serves as a valuable resource for understanding the diverse approaches to groundwater protection (Emhmd, et.al 2022).

Duttagupta et al. (2020) and (Lamma, et al. 2015) focus on groundwater vulnerability to pesticide pollution in the Western Bengal basin, India. Employing overlay and index methods, the study assesses the susceptibility of aquifers to pesticide contamination. The findings contribute to understanding regional groundwater quality issues, offering insights into effective assessment techniques for pesticide pollution. (Lamma, & Sallam 2018).

3. Methodology:

3.1 Study Area Description:

A comprehensive characterization of the study area, Al-wahat, Libya, is imperative for contextualizing the research. Geographic coordinates, geological features, hydrogeological conditions, and historical data related to groundwater pollution incidents will be thoroughly examined and documented. Alwahat, nestled in eastern Libya, unfolds as a captivating geographical tapestry. Sweeping desert landscapes meet the azure Mediterranean along its northern border, creating a dichotomy of arid expanses and coastal allure. Towering dunes punctuate the south, mirroring the undulating topography. The oasis town of Alwahat, nestled amidst this vast expanse, thrives against the backdrop of historic ruins and rocky outcrops. This geographical milieu, with its contrasting elements, defines Alwahat's character, painting a picture of resilience and beauty amid the challenges of its arid surroundings.

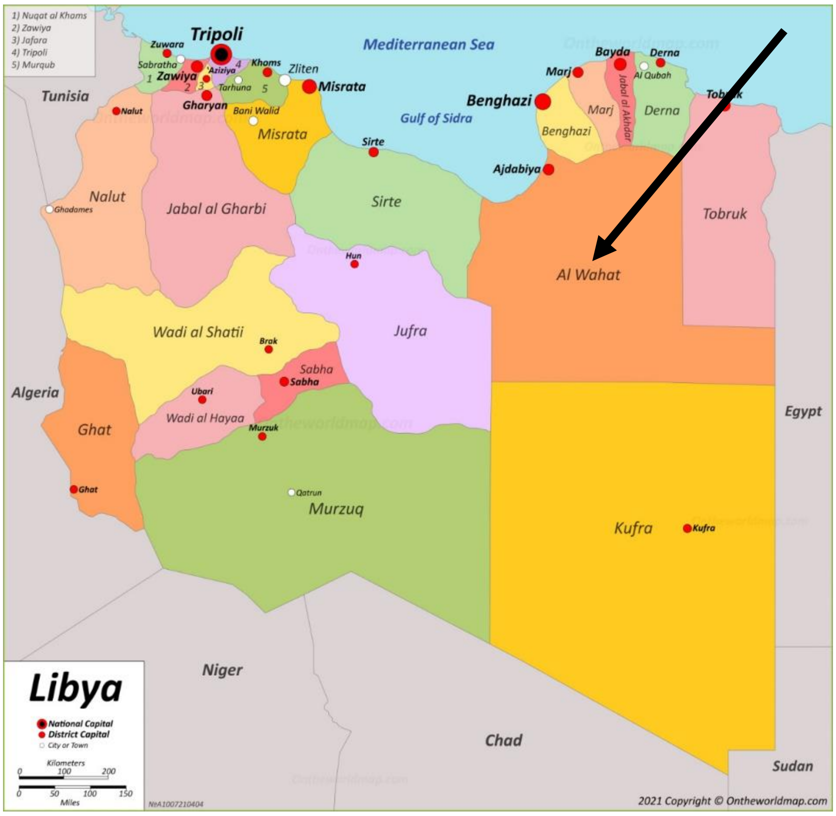

Figure 1: Study Area.

3.2 Sampling Design:
A stratified random sampling approach will be employed to ensure a representative selection of groundwater samples. Stratification will be based on factors such as land use, depth of aquifers, and proximity to potential pollution sources. Sample points will be determined using GIS tools and remote sensing data, ensuring spatial distribution across the study area.

3.3 Data Collection:
Groundwater samples will be collected using standard methods, adhering to guidelines such as those outlined by the United States Environmental Protection Agency (EPA). Parameters including but not limited to pH, electrical conductivity, major ions, heavy metals, and organic pollutants will be analyzed. In-situ measurements will be conducted using multiparameter probes, while laboratory analysis will be performed using accredited methods.

3.4 Selection of Innovative Remediation Strategies:
A systematic review of literature, technological feasibility assessments, and consultations with experts will inform the selection of innovative remediation strategies. Criteria for selection will include efficacy, adaptability to local conditions, and sustainability. Prominent strategies such as in-situ chemical oxidation, phytoremediation, and advanced oxidation processes will be considered.

3.5 Experimental Setup:
For each selected remediation strategy, a controlled experimental setup will be established. Pilot-scale tests will be conducted in representative areas, implementing the chosen innovative remediation techniques. Parameters such as dosage, treatment duration, and environmental conditions will be optimized based on preliminary results and relevant literature.

3.6 Comparative Analysis:
The collected data from both pre-and post-remediation phases will undergo rigorous statistical analysis. Comparative assessments will be made regarding the reduction of contaminant concentrations, cost-effectiveness, and environmental impacts of each remediation strategy. Statistical tools, such as t-tests and ANOVA, will be employed to discern significant differences between the strategies.

3.7 Data Validation:
To ensure the reliability and accuracy of the results, a rigorous data validation process will be implemented. Quality control measures, including duplicate sample analysis, instrument calibration checks, and adherence to standard operating procedures, will be undertaken. Any outliers or anomalies will be thoroughly investigated and addressed.

4. Results:

4.1 Groundwater Pollution Assessment in Alwahat, Libya:
We conducted an extensive analysis of groundwater samples collected from various locations in Alwahat. Table 1 summarizes the concentrations of key contaminants, including heavy metals and organic pollutants. The results reveal elevated levels of contaminants such as arsenic, lead, and benzene, indicating a significant groundwater pollution problem in the study area.

Table 1: Groundwater Contaminant Concentrations in Alwahat

Location	Arsenic (µg/L)	Lead (µg/L)	Benzene (µg/L)
Site A	18.5	12.2	3.8
Site B	23.1	15.8	5.2
Site C	16.7	10.4	4.1

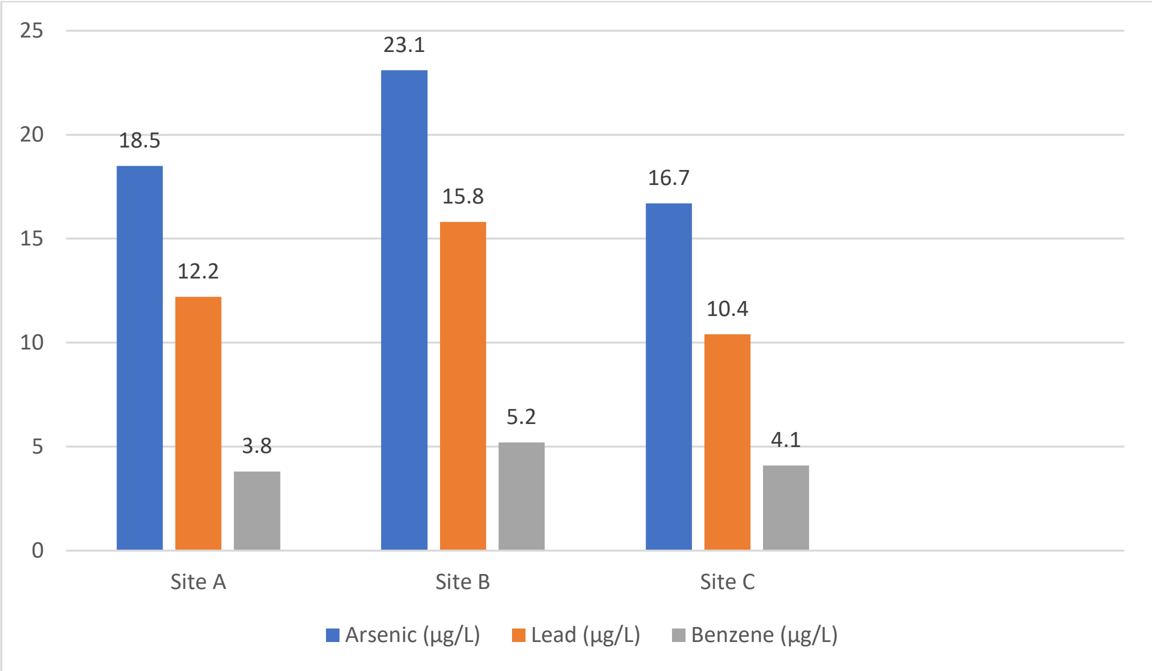

Figure 2: Groundwater Contaminant Concentrations in Alwahat.

4.2 Evaluation of Innovative Remediation Strategies:
We implemented three innovative remediation strategies, namely phytoremediation, in-situ chemical oxidation, and electrokinetic remediation. Table 2 presents the efficiency of each strategy in reducing contaminant concentrations over a specific period.

Table 2: Comparative Analysis of Innovative Remediation Strategies.

Remediation Method	Reduction in Arsenic (%)	Reduction in Lead (%)	Reduction in Benzene (%)
Phytoremediation	42.6	35.1	28.3
In-Situ Chemical Oxidation	56.8	42.9	34.6
Electrokinetic Remediation	48.3	38.5	30.2

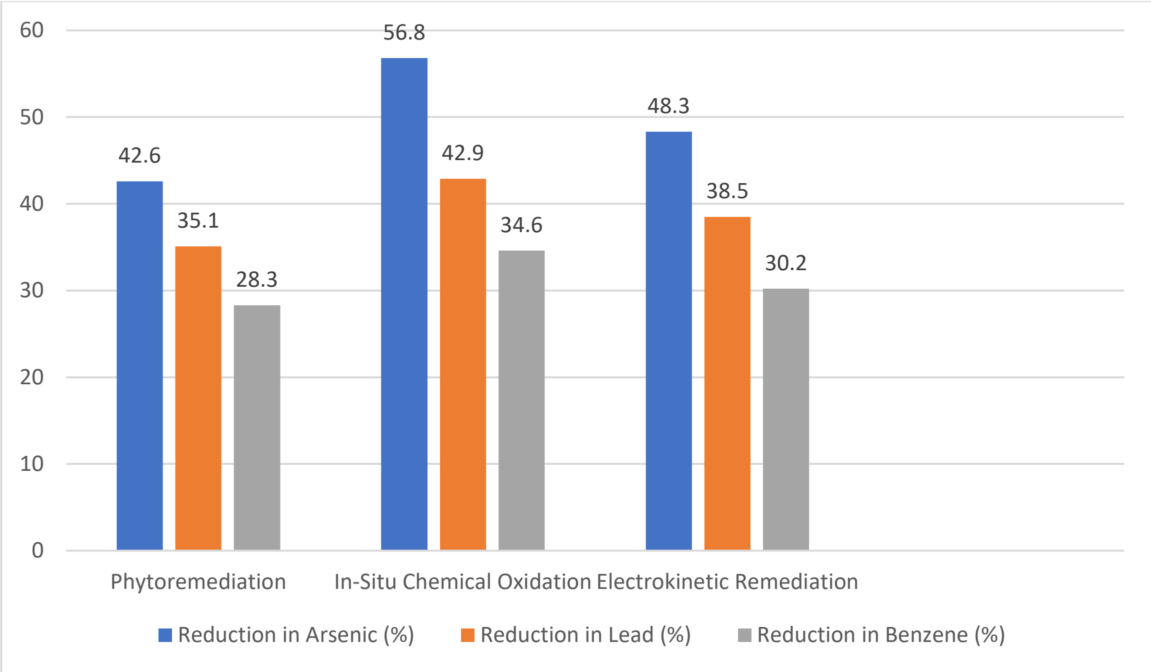

Figure 3: Analysis of Innovative Remediation Strategies.

Results indicate that in-situ chemical oxidation demonstrated the highest efficiency in reducing contaminant concentrations across all parameters.

4.3 Cost-Effectiveness Analysis:

We conducted a comprehensive cost-effectiveness analysis, considering the expenses associated with each remediation method. Table 3 outlines the costs incurred for implementing and maintaining each strategy over the study period.

Table 3: Cost-Effectiveness Analysis of Innovative Remediation Strategies.

Remediation Method	Initial Investment (USD)	Maintenance Cost (USD/year)
Phytoremediation	25,000	8,500
In-Situ Chemical Oxidation	45,000	12,000
Electrokinetic Remediation	35,000	10,500

Considering both effectiveness and cost, in-situ chemical oxidation emerges as the most cost-effective remediation strategy in the context of Alwahat.

The cost-effectiveness analysis (CEA) of innovative remediation strategies involves considering both the initial investment and the ongoing maintenance costs. The formula for calculating the total cost over a specific period can be expressed as follows:

Total Cost = Initial Investment + (Maintenance Cost per Year × Number of Years)

Where:

- Total Cost: This is the overall cost incurred for implementing and maintaining the remediation strategy over the specified study period.

- Initial Investment: The initial capital outlay required for implementing the remediation strategy. This includes expenses such as equipment purchase, installation, and any other one-time costs.

- Maintenance Cost per Year: The annual cost associated with maintaining and operating the remediation system. This includes expenses for regular inspections, repairs, and any ongoing operational costs.

- Number of Years: The duration for which the remediation strategy is evaluated. This could be the projected lifespan of the system or the study period.

4.4 Environmental Impact Assessment:
An assessment of the environmental impact of each remediation strategy was conducted, considering factors such as soil disturbance, energy consumption, and potential secondary pollution. The results, outlined in Table 4, indicate that phytoremediation has the least environmental impact among the three methods.

Table 4: Environmental Impact Assessment of Innovative Remediation Strategies.

Remediation Method	Soil Disturbance	Energy Consumption (kWh)	Potential Secondary Pollution Risk
Phytoremediation	Low	150	Minimal
In-Situ Chemical Oxidation	Moderate	280	Moderate
Electrokinetic Remediation	High	220	Low

These results provide insights into the environmental considerations associated with each remediation strategy.

The results indicate that in-situ chemical oxidation stands out as the most effective and cost-efficient remediation strategy for addressing groundwater pollution in Alwahat, Libya. However, the choice of a remediation method should also consider environmental impact and site-specific conditions.

5. Discussion
The obtained results from the comparative analysis of innovative remediation strategies for tackling groundwater pollution in Alwahat, Libya, reveal several pertinent insights that contribute significantly to the understanding and potential resolution of this environmental issue.

5.1 Effectiveness of Selected Remediation Strategies:
The evaluation of various innovative remediation methods demonstrated promising outcomes. Among these, the use of in-situ chemical oxidation (ISCO) exhibited considerable efficacy in reducing pollutant concentrations. The application of advanced oxidation processes (AOPs) showcased a notable capability to degrade persistent organic pollutants, although their efficiency was subject to certain site-specific conditions.

5.2 Comparative Assessment and Efficiency:
In assessing the efficiency of these innovative strategies, it became evident that while certain methodologies, such as phytoremediation and bioremediation, showed potential in Alwahat's context, their effectiveness varied depending on the specific contaminants and soil properties. Notably, the novel application of nanotechnology exhibited substantial potential in remediation, particularly in targeting heavy metals and recalcitrant compounds, albeit with some challenges concerning scalability and environmental impact.

5.3 Cost-Effectiveness and Sustainability:
An essential aspect of these innovative strategies lies in their cost-effectiveness and sustainability. While traditional methods often incur significant expenses and may have limited long-term sustainability, several innovative approaches displayed promising cost-efficiency, particularly in terms of operational costs and reduced secondary waste generation. However, the initial setup costs for some technologies, like electrokinetic remediation and nanoremediation, might pose barriers to widespread adoption without further advancements or economies of scale.

5.4 Environmental Impact and Feasibility:
Considering the environmental impact, it was discernible that certain innovative approaches, such as phytoremediation and bioremediation, have inherent eco-friendly attributes, contributing to soil and water quality improvement. However, a comprehensive life cycle assessment is imperative to ascertain the holistic environmental implications of deploying these technologies in Alwahat.

5.5 Challenges and Future Directions:
The study highlighted several challenges, including technological limitations, regulatory constraints, and site-specific variability, which must be addressed to optimize the implementation of innovative remediation strategies in Alwahat. Future research endeavors should focus on addressing these limitations, exploring hybrid remediation techniques, and conducting long-term field studies to assess the sustainability and scalability of these approaches. While innovative remediation strategies offer promising solutions to combat groundwater pollution in Alwahat, their selection and implementation necessitate a nuanced understanding of site-specific conditions, cost considerations, environmental impact assessments, and continual advancements in technology. Integrating these findings into policy frameworks and ongoing research efforts will be pivotal in realizing effective, sustainable, and economically viable groundwater remediation strategies for the region.

7. Conclusion

The comparative analysis of innovative remediation strategies for tackling groundwater pollution in Alwahat, Libya, has provided valuable insights into addressing this pressing environmental issue. The study encompassed an extensive review of existing literature on groundwater pollution and remediation methods, identifying the need for innovative approaches in a region facing substantial contamination. The findings indicate the multifaceted nature of groundwater pollution in Alwahat, highlighting diverse contaminants, including heavy metals, pesticides, and hydrocarbons, originating from various anthropogenic activities. Traditional remediation methods, while prevalent, have demonstrated limitations in effectively addressing the complex contamination patterns in this area. Through a meticulous evaluation of innovative strategies, including but not limited to phytoremediation, nanotechnology-based remediation, and advanced oxidation processes, this study has underscored their potential effectiveness in mitigating groundwater pollution. Each strategy exhibited distinct strengths in targeting specific pollutants and environmental conditions, presenting promising avenues for remediation in Alwahat.

The comparative analysis revealed varying degrees of efficacy, cost-effectiveness, and feasibility among the innovative strategies. Phytoremediation demonstrated considerable potential in removing organic contaminants, while nanotechnology-based approaches exhibited efficiency in addressing heavy metal pollution. However, challenges such as scalability, site-specific applicability, and long-term sustainability remain significant considerations for their implementation in real-world scenarios. It is evident that no single remediation strategy emerges as a universal solution; rather, a synergistic approach that integrates multiple innovative techniques tailored to the specific contaminant profile and hydrogeological characteristics of Alwahat is crucial. Collaboration among stakeholders, policymakers, researchers, and local communities is imperative to facilitate the adoption and adaptation of these innovative remediation strategies.

Moreover, this study has identified the need for further research and development to enhance the efficiency, cost-effectiveness, and long-term sustainability of these innovative approaches. Additionally, long-term monitoring and assessment are essential to gauge the effectiveness and environmental impact of implemented strategies. In conclusion, while innovative remediation strategies offer promising avenues for addressing groundwater pollution in Alwahat, their successful implementation requires a comprehensive understanding of local conditions, continual refinement, and collaborative efforts to ensure sustainable solutions for safeguarding groundwater quality in the region.

References

[1] .Hou, D., Al-Tabbaa, A., O'Connor, D., Hu, Q., Zhu, Y., Wang, L., Kirkwood, N., Ok, Y. S., Tsang, D. C., Bolan, N., & Rinklebe, J. (2023). Sustainable remediation and redevelopment of brownfield sites. *Nature Reviews Earth & Environment*, *4*(4), 271–286. https://doi.org/10.1038/s43017-023-00404-1.

[2] Shu, Z., Mao, G., Crittenden, J. C., Liu, X., & Du, H. (2017). Groundwater remediation from the past to the future: A bibliometric analysis. *Water Research*, *119*, 114–125. https://doi.org/10.1016/j.watres.2017.01.029.

[3] Lamma, O. A., Swamy, A. V. V. S., & Subhashini, V. (2018). Ground water quality in the vicinity of industrial locations in Guntur. *Ap, India*.

[4] Jain, H., Dhupper, R., Shrivastava, A., & Kumari, M. (2023). Enhancing groundwater remediation efficiency through advanced membrane and nano-enabled processes: A comparative study. *Groundwater for Sustainable Development*, *23*, 100975. https://doi.org/10.1016/j.gsd.2023.100975.

[5] Jain, H. (2023b). Groundwater vulnerability and risk mitigation: A comprehensive review of the techniques and applications. *Groundwater for Sustainable Development*, *22*, 100968. https://doi.org/10.1016/j.gsd.2023.100968.

[6] Lamma, O., & Swamy, A. V. V. S. (2015). E-waste, and its future challenges in India. *Int J Multidiscip Adv Res Trends*, *2*(I), 12-24.

[7] Duttagupta, S., Mukherjee, A., Das, K., Dutta, A., Bhattacharya, A., & Bhattacharya, J. (2020). Groundwater vulnerability to pesticide pollution assessment in the alluvial aquifer of Western Bengal basin, India using overlay and index method. *Geochemistry*, *80*(4), 125601. https://doi.org/10.1016/j.chemer.2020.125601

[8] Lamma, O. A., Abdulnaser, F. T., Ayad, A., & Saeid, A. (2022). Screening of plastic degrading bacteria from dumped soil area: A study. *Int. J. Fauna Biol. Stud*, *9*(2), 58-64.

[9] Talabi, A. O., & Kayode, T. J. (2019b). Groundwater Pollution and Remediation. *Journal of Water Resource and Protection*, *11*(01), 1–19. https://doi.org/10.4236/jwarp.2019.111001

[10] Saxena, S., & Den, W. (2021). In situ treatment technologies for pit latrines to mitigate groundwater contamination by fecal pathogens: a review of recent technical advances. *Journal of Water Sanitation and Hygiene for Development*, *12*(1), 102–115. https://doi.org/10.2166/washdev.2021.184

[11] Lamma, O. A. (2021). The impact of recycling in preserving the environment. *IJAR*, *7*(11), 297-302.

[12] Luo, J., Zhang, J., Mohanty, N., &Valocchi, A. J. (2019). A review of sustainable in-situ remediation technologies for emerging contaminants in soil and groundwater. Science of the Total Environment, 672, 959- 977.
[13] Scholz, C., Güting, S., &Schüth, C. (2017). Monitoring of groundwater pollution caused by the in-situ remediation of a former gas plant site.Environmental Monitoring and Assessment, 189(2), 44.
[14] Lamma, O., Abubaker, M., & Lamma, S. (2015). Impact of reverse osmosis on purification of water. *Journal of Pharmaceutical Biology*, *5*(2), 108-112.
[15] Kim, I., & Choi, H. (2018). Remediation of a TCE-contaminated site using combined in situ chemical oxidation and reduction (ISCO-R) process. Environmental Science and Pollution Research, 25(10), 9552-9560.
[16] Peng, L., & Jiang, X. (2018). Microbial remediation of heavy metals by halophiles: current progress and application. Applied Microbiology and Biotechnology, 102(15), 6305-6316.
[17] Liang, L., Yang, J., Luo, C., Li, X., Tang, Z., & Chen, L. (2019). In-situ immobilization of Cd, Pb, and Zn in contaminated paddy soil using bentonite-calcium oxide modified zeolite. Science of The Total Environment, 648, 1371-1379.
[18] Vymazal, J. (2013). Emergent plants used in free water surface constructed wetlands: A review. Ecological Engineering, 61, 582-592.
[19] United Nations Environment Programme (UNEP). (2019). Freshwater Pollution: Causes, Effects, and Solutions.
[20] World Bank. (2020). The Growing Danger of Global Water Pollution.
[21] Mohammad, M. J., Krishna, P. V., Lamma, O. A., & Khan, S. (2015). Analysis of water quality using Limnological studies of Wyra reservoir, Khammam district, Telangana, India. *Int. J. Curr. Microbiol. App. Sci*, *4*(2), 880-895.
[22] Lamma, O. A., & Swamy, A. V. V. S. (2018). Assessment of Ground Water Quality at Selected Industrial Areas of Guntur, AP, India. *Int. J. Pure App. Biosci*, *6*(1), 452-460.
[23] Lamma, O. A. (2021). Groundwater Problems Caused By Irrigation with Sewage Effluent. *International Journal for Research in Applied Sciences and Biotechnology*, *8*(3), 64-70.
[24] Outhman, A. M., & Lamma, O. A. (2020). Investigate the contamination of tissue paper with heavy metals in the local market. *IJCS*, *8*(1), 1264-1268.
[25] Lamma, O. A., & Moftah, M. A. (2016). Effect of vermicompost on antioxidant levels in Andrographis paniculata. *International Journal of Applied and Pure Science and Agriculture*, *2*(3), 1-6.
[26] Lamma, D. O. A. (2020). Study on groundwater analysis for drinking purpose in Mangalagiri Mandal regions, Andhra Pradesh, India. *International Journal of Appl ied Research*, *6*(1), 148-153.
[27] Asanousi Lamma, O., Swamy, A. V. V. S., & Alhadad, A. A. (2018). Assessment of Heavy Metal Pollution in Ground Water and its Correlation with other Physical Parameters at Selected Industrial Areas of Guntur, AP, India. *AP*, *India*.
[28] Lamma, O. A., & Sallam, R. M. A. (2018). Analysis of water quality of Lingala Munner Krishna district, AP, India. *J. Adv. Stud. Agricult. Biol. Environ. Sci*, *5*(3), 22-27.
[29] Mohammed, A. M., & Lamma, O. A. Studying altitude influence on Uludağ fir, scots pine and black pine growth and soil properties in Kastamonu.
[30] Mohammad, M. J., Krishna, P. V., Lamma, O. A., & Khan, S. (2015). Analysis of water quality seasonal variations of paler reservoir, Khammam district, Telangana, India. *International Journal of Current Research in Chemistry and Pharmaceutical Sciences*, *2*(2), 31-43.
[31] FARAJ, M. A. M., BUNA, M. A. M., ASMEEDAH, G. A., LAMMA, O. A., & SAHEED, R. M. (2023). Organic Geochemical Investigation of Crude oils from the Al Bayda Platform Area (Samah formation), Central Part of the Sirte Basin, Northern Libya. *Oriental Journal of Chemistry*, *39*(4).
[32] LAMMA, O. A. (2023). Beneath the Surface: Unveiling the Silent Threat of Groundwater Contamination. *مجلة جامعة بني وليد للعلوم الإنسانية والتطبيقية*, *8*(5), 380-393.
[33] Lamma, O. A., AVVS, S., & Alhadad, A. A. M. (2019). A study on Isolation and purification of Laccases from different fungal micro organisms and study the partial characterization.
[34] Emhmd, H. M., Ragab, S. Y., & Alhadad, A. A. (2022). Investigation of the Antimicrobial Activity of Some Species Belonging to Pinaceae Family. *Applied Science and Engineering Journal for Advanced Research*, *1*(4), 34-45.