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EFFICIENCY OF NANOTECHNOLOGY IN ENVIRONMENTAL POLLUTION CONTROL BY SOIL AND GROUNDWATER REMEDIATION

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ABSTRACT

The role of soil and water is crucial in the formation of the environment and for the existence of living beings. In recent years, soils have been contaminated with volatile organic compounds (VOCs), heavy metals and other chemicals. Soil contamination is closely related to groundwater contamination and has a long-term impact. Furthermore, this problem is closely associated with human health and socio-economic activities. Therefore, it is evident to find a solution for decontamination. To find viable and sustainable restoration methods, coordination between science and engineering is a must. Nanotechnology is getting popular for restoring the environment through waste management and pollution control. This paper reviews the use of nanotechnology in soil and groundwater remediation. Different methods that are used in these processes are discussed and compared.

Keywords: *Nanotechnology, Environmental Pollution Control, Soil Remediation, Water Resource Management*

1. INTRODUCTION

The term ‘Environmental pollution’ is defined as the introduction of harmful materials into the environment (National Geographic Society). It has become one of the biggest challenges humankind has ever faced. The result of ignoring the environmental aspects in the process of industrialization, development and progress can now be observed as their ramifications such as environment pollution, particularly soil and groundwater (Zhang, M., 2019). In addition, with growing population, unsustainable urbanization, and technology advancement, the pollution is increasing at an alarming rate putting the lives of the present as well as the coming generations at stake. The main sources of this waste are municipal enterprises, industry, clinical laboratories, hospitals, household waste and farms, from where a heavy amount of untreated sewage sludge, toxic heavy metals, radionuclides, and organic matter are discharged. Agriculture is also another major source of soil and groundwater contamination due to harmful chemicals present in pesticides, fertilizers, herbicides and many more which through leaching flows to groundwater ultimately contaminating the drinking water and other water sources. Therefore, it is high time for a technology that will help reduce these problems. Nanotechnology is being analyzed to implement new solutions to purify the environment and improve the performance of traditional technologies.

Nanotechnology can be defined as the technology that is implemented at the nanoscale and has real world applications. The term "nanotechnology" was defined by Professor Norio Taniguchi of Tokyo University of Science. The scope of nanotechnology has widened to various fields of study such as medicine, food, agriculture, and environment. Recently, it is becoming one of the most promising revolutionary approaches for environmental remediation. In the past few years, nanoscale particles have attracted great interest in the immobilization of heavy metals in soil and groundwater (R. Ibrahim et al., 2016). Due to its large surface area and high surface energy nanoparticles can absorb large amounts of contaminants and catalyze the reaction much faster. This reduces energy consumption during decomposition and prevents the release of pollutants. (Mehndiratta et al., 2013). With more research, it might be the ultimate tool for soil and groundwater remediation.

Remediation is the process of removing or reducing pollutants from the environment using chemical or biological means. With recent advances, control of pollutants in soil, sediments, and water have become the biggest environmental challenge. As it is near impossible to get to the previous situation through traditional pollution control techniques, researchers are inventing innovative things to reduce the rate of pollution in soil and groundwater through remediation. Soil remediation is a process of soil revitalization in which harmful contaminants are removed from soil to restore it to its natural state. The process of removing or transferring contaminants to harmless products to treat contaminated groundwater is known as groundwater remediation. Although it has a huge scope, there is still a lack of more research due to the need for a large amount of investment and controversial perception on nanotechnology.

Having a lack of resources and comparing methods, we have selected only seven articles in this review paper for comparison. However, this study can go a long way, if there are plenty of resources with a handful of analysis methods. Perhaps, this article can be a beginning as the startup for future study in soil and groundwater remediation in developing and underdeveloped countries in southern asia, and middle east countries as well.

In this review article, efficiency of some selected methods of nanotechnology for soil and groundwater remediation will be determined, based on their limitations and future scope, in order to find out the most effective one among them. On top of that, some recommendations will be added at the end for the embellishment of nanoscale research for environmental remediation in upcoming days.

This paper aims to present a review comparing some existing methods of nanotechnology used in soil and groundwater remediation and to find out the future scope of nanotechnology in environmental pollution control.

2. PRESENT SCENARIO OF NANOTECHNOLOGY IN DIFFERENT PARTS OF THE WORLD

With the high rate of soil and groundwater pollution in recent decades, most of the developed countries have been using various technologies for remediation. Physical remediation consists of techniques such as soil cleaning, vitrification, electrokinesis, encapsulation, and permeable barrier systems. Chemical methods include solidification, precipitation, ion exchange and biological methods use plants that help to remove heavy metals. More recently, there is a shift towards nanotechnology, which requires less energy and investment. Innovative approaches such as passive soil and groundwater treatment technologies have been developed. For instance, pump -and treat, despite being effective and widely used for the remediation and transformation of a variety of environmental contaminants, due to high cost and lengthy operating periods for remedies, ex situ groundwater treatment technologies are decreasing. On the other hand, the number of actual applications of non zero-valent iron nanoparticles is increasing rapidly (Karn et al. 2009).

However, it is beyond imagination for most of the underdeveloped and developing countries like Nepal and Bangladesh. Mostly physical and biological methods of remediation are used which is energy and budget draining. Nanotechnology application requires proper training, knowledge and systematic approach which significantly lack in developing and underdeveloped countries. Nevertheless, developing countries like India and some of the African countries have initiated the use of nanotechnology. Therefore, there is a possibility of use of nanotechnology in areas like medicine, agriculture, engineering applications and environmental pollution control in developing and underdeveloped countries as well.

3. IMPORTANCE OF NANOTECHNOLOGY

Nanotechnology is a "breakthrough" technology and has the potential to offer several benefits that are not offered by other conventional technologies; their high surface-area-to-volume ratio imparts unique physiochemical properties, including versatile functionalities and enhanced reactivity or selectivity. It is one of the most promising revolutionary approaches for environmental remediation. The fusion of nanotechnology with water science and technology has led to innovative advances in water treatment, desalination and recycling technologies (Savage and Diallo 2005; Shannon et al. 2008; Diallo and Brinker 2011).

As nanotech has been used in different sectors of both agriculture and engineering, various methods have been identified and innovated for better performance. Some available methods are listed below

4. AVAILABLE METHODS IN NANOTECHNOLOGY FOR SOIL AND GROUNDWATER REMEDIATION

The most investigated nanomaterials for the use of mitigation of heavy metals and organic contaminants covers carbon nanomaterials (especially carbon nanotubes), metal oxide nanomaterials (such as $Fe3O4$, $TiO2$ and ZnO), zero-valent iron nanoparticles (ZVI) (Qian et al., 2020).

Nanomaterials such as carbon nanotubes (CNTs), zeolites, zero-valent iron nanoparticles (ZVI), and nanosorbents are used in water treatment. Likewise, silver nanoparticles, carbon-based nanoparticles, polymer-based nanoparticles and oxide metal nanoparticles show a great impact on the removal of wastewater contaminants which supports nanotechnology as an effective medium for solving water-related problems of quality and quantity (Soni et al., 2020). Similarly, photocatalysts such as zinc oxide (ZnO), titanium dioxide ($TiO2$) and tungsten oxide are used to oxidize organic pollutants into harmless substances. Among these, titanium dioxide is the most favored due to its high photostability, high photoconductivity, easy availability, low-cost, and non-toxic properties. In addition, a new technology known as nanofiltration can be used in water treatment in homes, offices, and industries. Molybdenum disulphide ($MoS2$) nonporous membrane is used for energy efficient water desalination which does five times higher effective filtration than the conventional ones.

On the other hand, nanozeolite, nanomagnet, nanosensors, polymers, clays, zeolites, nanomembranes play an important role for soil remediation. Despite their advantages, nanoparticles may undergo transformations, such as growth, dissolution, aggregation, and aging, changing the micro or nano environment surrounding the individual soil nanoparticles. Furthermore, nanoparticles also depend on environmental factors like temperature, pH, solubility, etc. Hence if these factors are altered, it may alter the function of nanoparticles. Therefore, more research is needed to understand their properties (Tarafdar and Adhikari, 2015).

5. METHOD OF COMPARISON

In this case study, it has been found what methodologies have been adopted in the selected research papers, what was their findings and what steps may be taken in the future to overcome the limitations as well. This review will find out their limitations, compare the methods used, and find out the best and most effective method among the for a particular soil condition.

All the steps of this case study can be summarized in a flow chart given below (Figure 1)

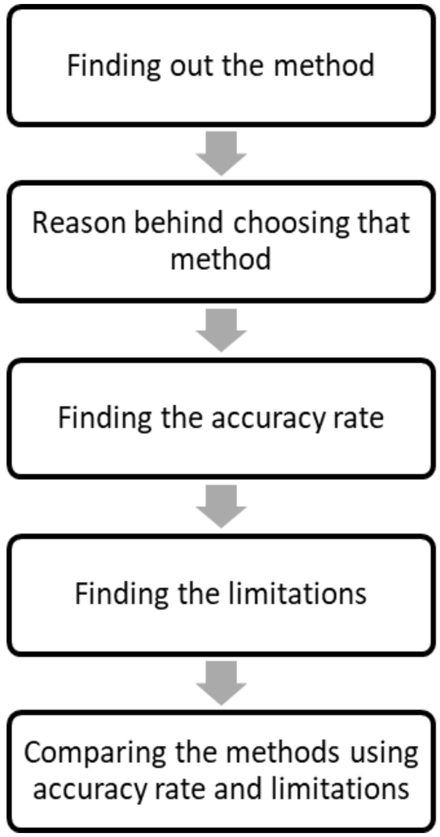

Figure 1: Flow chart of method of comparison

There are various advantages of nanotechnology in soil and groundwater. In the past, various methods had been introduced and reviewed as well; like carbon nanotube, nano clays/zeolites, in situ chemical oxidation, nZVI, and nano sorbents.

Carbon nanotubes are especially popular for pollution detection and sensing. They are used as nanoscale chemical sensors and electrochemical sensors. Also, oxidized and hydroxylated carbon nanotubes are good adsorbers for metals. In spite of being popular for removal of organic contaminants in water, they have much lower specific surface area limiting the potential as organic contaminants adsorbents. However, KOH -activated carbon nanotubes have improved specific surface area and micropore volume. However, it is well known that carbon nanotubes can be deposited in biological tissues and cause serious toxic effects. This needs more research to better understand this aspect and advance the potential applications and environmental impact of carbon nanomaterials (Zhu et al., 2010).

In situ chemical oxidation (ISCO) is a technology used in soil and groundwater remediation to convert contaminants into less harmful products by application of strong chemical oxidants. It has advantages such as robustness in nature, less time in implementation, availability of a variety of oxidants and diverse activation and delivery approach, and so on. Nevertheless, this method needs a large amount of chemicals and properly trained and equipped workers.

Nano clay/ zeolites play an important role in transportation of minerals. In an article entitled,' Effects of vermiculite, nanoclay and zeolite on ammonium transport through saturated sandy loam soil', Mazloomi and Jalali had reported that zeolite and nanoclay showed the highest effect on decreasing NH4-N transport in the sandy loam columns, which prevents the leaching and ultimately contamination. This investigation suggests that application of inorganic amendments could be a beneficial technique to decrease leaching of NH4-N fertilizers in the light-textured sandy soils.

Nano sorbents due to having large surface area and a high substance specificity can quickly and specifically remove or recover target contaminants such as cadmium (Cd2+) and cobalt (Co2+) ions from aqueous solution.

Nano-scale zero-valent iron particles (NIP) have a greater reduction rate initially and a reduction of the total number of moles of pollutants per mole of iron than the permeable reactive barrier technology (PRB) because of its infinitesimally small size (nm) and high reactivity. Although, despite its superiority over permeable reactive barrier technology (PRB), the delivery of nano-scale zero-valent iron particles (NIP) into the contaminated subsurface soils and groundwater for in-situ applications is **limited due to quick aggregation and settling characteristics of NIP.** Therefore, lactate-modified NIP was developed that has potential to be used for safe and effective in-situ remediation and to maintain their stability (Reddy, 2010).

According to Bakshi and Abhilash, 2019, despite the plethora of possibilities of nanotechnology in soil remediation, there is little evidence which indicates this might lead to some uncertainties and risk. Therefore, appropriate long-term evaluation of large-scale ecosystem studies should be conducted to prevent any potential adverse environmental impacts they may cause.

Moreover, some important parameters should be prioritized before conducting any operation in nanoscale. Although the technology is obviously an efficient replacement of current practices for site remediation, potential risks are not taken into account thoroughly. More research is needed for understanding the mechanisms affecting the fate and transport of manufactured nanoparticles in water, soil, and sediments; their interactions with each other; and how these interactions are influenced by different environmental variables; and last but not least, how these nanoparticles may affect human health (Karn et al. 2009).

6. ANALYSIS AND COMPARISON OF THE EFFICIENCIES FOR DIFFERENT METHODS

In this case study, five different methods have been identified, depending on their used nanoscale particles and implementable field of area, and have been compared based on those two parameters as well. The findings can be summarized as given in Table 1.

Table 1: Different Methods used in Soil and Ground Remediation

Method Name	Carbon Nanotube	Nano clays/zeolites	*In situ* chemical oxidation	nZVI	Nano sorbents
Properties	1. Reduce the interparticle' spacing, which will improve the mechanical properties of the soil. 2. Remove almost all three types of pollutants, i.e., organic, inorganic and biological pollutants	1.Decrease the leaching of NH4-N	1. Remediation of organic compounds	1.Nanoscale zero-valent iron is the most studied nanomaterials for facilitating the phytoremediation due to its successful engineering applications in treating contaminated soil and groundwater	1. Remove Cd^{2+} and Co^{2+} ions from aqueous solution.

The above table can illustrate the overall outcomes of the five studied methods. However, more study is required to find out the most of these methods.

7. CONCLUSION AND RECOMMENDATIONS

Nanotechnology can contribute significantly in soil and groundwater remediation. Nanoremediation has the potential not only to bring the contaminated soil and groundwater to its original state but also to reduce the rate of overall pollution in the future. In addition, though there are myriads of methods for remediation, five methods have been considered in this review; carbon nanotube, nano clays/zeolites, in situ chemical oxidation, phytoremediation, and nanosorbents. Among these methods, it is found that the best method for soil and groundwater remediation is phytoremediation or the use of nanoscale zerovalent iron (nZVI) based on accuracy rate and limitations. However, in the case of removal of organic, inorganic and biochemical pollutants Carbon nanotubes can effectively be used. While nanotechnology has huge scope in controlling the environment, it also can be deleterious for the human health and environment though, if it's not used properly. This is a vast area of research and most of us still are unaware about the various possibilities of nanotechnology. Therefore, further study is required to find out the best possible method with higher accuracy rate.

CONFLICT OF INTEREST

The Authors declare that there is no conflict of interests regarding the publication of this paper.

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