Research status on soil and water pollution remediation and environmental impact of nanomaterials

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Abstract. Nanomaterials are a new type of materials, which have been widely used in many fields. In the field of environmental governance and restoration, nanomaterials are highly concerned by scholars all over the world. Due to the small particle size, strong reducing ability, high surface activity and large specific surface area, nanomaterials have obvious advantages in the rehabilitation and treatment of contaminated soil and water. At the same time, due to the characteristics of small particle size, low solubility and weak degradation ability, nanomaterials will have adverse effects on the ecological environment. In this paper, through literature research, the application of nanomaterials in soil and water pollution remediation and treatment is summarized, and the repair mechanism and influencing factors are briefly described. At the same time, the impact of nanomaterials on ecological environment is also summarized. On this basis, this paper points out that further research on measures to reduce the impact of nanomaterials on ecological environment should be carried out in the aspects of soil and water pollution rehabilitation and treatment.

1. Introduction

In recent years, industry has been developing rapidly all over the world. With the rapid development of economy and industry, a large amount of air, soil and water has been seriously polluted. In the stage of seeking to repair soil and water pollution, people found that nanomaterials have the advantages of small particle size, strong reducing ability, high surface activity and large specific surface area, which can be used to repair and control the polluted soil and water. Through theory and practice, nanomaterials have full advantages in environmental pollution control. However, when using nanomaterials to control the environment, whether nanomaterials themselves will cause harm to the environment and whether they can be fully degraded are also worth paying attention [1]. Since the 21st century, famous journals such as Science and Nature have published a large number of papers on the impact of nanomaterials on the environment and ecology [2]. Based on the existing literature research results, this paper introduces the main nanomaterials used for pollution remediation and their remediation mechanism, summarizes the impact of nanomaterials on the environment, and proposes measures to reduce the impact of the remediation process on the environment.

2. Nanomaterials are commonly used in soil and water restoration

With the rapid development of industry, a great deal of soil and water has been polluted, which has caused great harm to the environment and soil and water resources. However, traditional methods of
soil and water restoration are inefficient, cost-effective and have problems such as secondary pollution. Therefore, more effective treatment schemes are needed. When the particle size of nanomaterials decreases, the ratio of the number of atoms on the surface to the total number of atoms increases rapidly. This property can make the surface have a large number of active sites, and the more active sites there are, the stronger the adsorption property will be. Therefore, nanomaterials are suitable for the treatment and rehabilitation of polluted soil and water [3]. With the development of nanotechnology, practice shows that using nanomaterials to repair polluted soil and water can achieve both economic and efficient purposes. At present, the nanomaterials used for soil and water pollution restoration and treatment are mainly zero-valent metal materials, carbonaceous nanomaterials, metal oxides, semiconductor materials, nanoscale minerals, nanoscale polymers and so on [4]. As for modified zero-valent nano iron, although it can repair cadmium pollution, it needs to be modified due to its disadvantages such as easy passivation, easy agglomeration and difficult recovery. The modified nanomaterials can not only solve the defects, such as easy deposition in water and soil and difficult recovery, but also increase the contact area between nanomaterials and pollution sources, minimize or avoid their harm to the environment, and even enhance the electronic transfer between nanomaterials and pollutants in the reaction [5]. For example, due to its strong reducibility, the principle of removing Cr (VI) is to reduce Cr (VI) to Cr (III) through redox reaction and electron transfer between Cr (VI) and Cr (VI), so as to reduce its pollution and achieve the purpose of remediation and treatment.

Besides, different types of nanomaterials are suitable for different repair objects and repair mechanisms. For iron-based nanomaterials, the repair mechanism mainly includes redox reaction, coprecipitation and adsorption. For carbon-based nanomaterials, the main repair mechanism includes Van der Waals force, electrostatic interaction and adsorption. For metal oxide nanomaterials, the main repair mechanism includes complexation, intermolecular force (Van der Waals force), chemical coordination bond, electrostatic interaction and so on. For each kind of nanomaterials, the repair mechanism of each kind of nanomaterials is different. For example, the repair mechanism of nano zero-valent iron is mainly redox reaction, adsorption and co-precipitation, while the repair mechanism of iron oxide is Van der Waals force and electrostatic interaction.

3. Factors influencing the repair effect of nanomaterials
The purpose of soil and water restoration is to remove or reduce the toxicity of soil and water. Studies have shown that the repair effect of nanomaterials is related to the pH, illumination time, heavy metal concentration, adsorption time, temperature, addition number of nanomaterials, addition time of nanomaterials, types of polluters and other factors.

Due to different pH values of water and soil, nanomaterials have different effects on pollution repair and their repair mechanisms are also different. Generally speaking, when the pH value of water and soil increases, the trend of potential development of nanomaterials is the electronegativity will increase gradually. If the pH of the water and soil is just near the equipotential point of the nanomaterial, the electrostatic repulsion of the nanomaterial will be the least, and the most unstable and prone to aggregation [6]. For example, when H⁺ concentration is high, with the increase of humic acid concentration, for iron oxide nanomaterials, the humic acid thickness on them increases, and the other iron oxide is more likely to be charged and neutralized, making it easier to sink [7]. The effects of the same nanomaterials on the repair and treatment of heavy metal ions are different at different concentrations. Studies have shown that with the increase of Cr (VI) concentration under the same conditions, the repair rate of the composite nanomaterials of zero-valent iron and carbon nanotubes decreases. For nano zero-valent iron to remove the Cu²⁺, pH value has a great influence on the adsorption effect. The repair rate will increase with the increase of pH. It indicates that acidic conditions are not conducive to the adsorption of heavy metal ions by nanomaterials. When the concentration of H⁺ increases, H⁺ occupies more adsorption sites of some nanomaterials and reduces the probability of metal ions being absorbed. Therefore, it will reduce the adsorption effect.

The research also showed that the repair effect of nanomaterials would increase with the increase of the adding time of nanomaterials and the increase of the adding number of nanomaterials. The adsorption
rate of nanomaterials would increase with the increase of adsorption time. At the same time, the increasing trend of adsorption rate would gradually slow down with the increase of time and finally reach a fixed value [8].

The optimum temperature for different nanomaterials to treat different pollutants is different. For example, Guo Jingjing found that when treating Cu²⁺ pollution, the adsorption rate and removal effect of nano zero-valent iron would be the highest at 25°C. When the temperature increased or decreased, the adsorption rate would decrease. When Pb²⁺ was repaired and treated by nano zero-valent iron, the adsorption rate reached 98% at 45°C [9]. The effect of temperature on the adsorption effect of nanomaterials is mainly reflected in two aspects: first, increasing temperature can accelerate the effective collision of active molecules, thus speeding up the reaction rate. Second, when the temperature increases, the thermal motion of molecules will also speed up, which is not conducive to the adsorption between nanomaterials and pollutants. Therefore, in the case of different materials, different sources of pollution, the optimal temperature is different.

4. Environmental hazards of nanomaterials and their influencing factors

Although nanomaterials have great advantages in soil and water conservation, nanomaterials have negative effect and potential harm to the environment. Therefore, it is worth paying attention to whether the restoration process will have an impact on the environment.

Metal nanomaterials and metal oxide nanomaterials have certain toxicity to environment and biology. Through biological enrichment and environmental transmission, heavy metals eventually invade the bodies of animals and plants, damaging the organisms [10]. For example, nanoscale SiO₂ material will cause certain damage to some immune organs of the organism, which will lead to a large number of lymphocyte and macrophage aggregation of the organism and activation, and eventually lead to enlargement of spleen, lymph node and other phenomena. Nano SiO₂ also has certain damage to the non-specific immunity of organisms, mainly by disturbing the normal biological functions of macrophages, and eventually forms certain immune system toxicity [11]. Van [12] et al. showed that the activity of macrophages decreased with the increase of exposure dose and exposure time. It is suggested that the dose and exposure time of nanomaterials can affect the biotoxic effect. Nano TiO₂ material not only has immunotoxic effect, but also has some biological toxicity effect, which has certain harm to the environment and ecology. In addition, Bermudez [13] et al. conducted air exposure experiments of nano TiO₂ particles on mice, and the final experimental results showed that it had certain harm to the lung tissues of mice. In addition, nano TiO₂ particles will also do some harm to genetics. It not only causes oxidative damage to DNA, but also promotes its unwinding and even fracture, and then affects the structure and expression of DNA, transcription and translation [14]. Other studies have shown that polystyrene nanomaterials can harm the killifish, invade its body, and damage mitochondria, cell membrane, etc [15]. At the same time, some relevant scholars have shown that nano ZnO also has certain harm to bacteria, which can inhibit the growth of bacteria. Yamamoto et al. [16] found that the toxic effects of lower ZnO with different particle sizes on Escherichia coli and staphylococcus aureus were different. When the particle size of nano ZnO decreases, its toxicity increases and it is very sensitive to the size effect.

Carbon nanomaterials have certain effects on the ability of bioenrichment of organic compounds. The study found that the effect of carbon nanotubes on the uptake of pyrene by earthworms. The study results showed that the toxicity effect was related to the concentration of carbon nanotubes. When the concentration was low, it had no significant effect on the enrichment and uptake ability of earthworms. However, when the concentration was increased to 3mg/g, the enrichment and uptake ability of earthworms to pyrene was significantly reduced [17]. In addition, Zhu et al. [18] showed that carbon nanotubes could inhibit the growth of mussel sphinx cells and show some biological toxicity. However, the main mechanism of inhibition was that carbon nanotubes damaged the macronucleus and membrane of mussel spinneret cells, leading to the impairment of their normal biological functions. Besides, it was found that when the concentration of carbon nanotubes increased, the degree of cell damage was also deepened.
The environmental effects of nanomaterials are influenced by exposure time, light intensity, material properties, biological species, particle size and concentration. Generally speaking, the environmental negative effects of nanomaterials will increase with the increase of exposure time, and when the exposure time increases, the biological toxicity and environmental negative effects will increase. At the same time, when the particle size of nanomaterials decreases, due to the size effect, its biological toxicity also increases, and increases with the increase of concentration.

5. Suggestions on rehabilitation of polluted soil and water
Due to the immunotoxicity and biological toxicity of nanomaterials, relevant measures should be taken to prevent or reduce the environmental harm of nanomaterials when they are used to repair polluted soil and water bodies.

5.1. Control the dosage and time of adding nanomaterials
In the process of restoration, the addition of nanomaterials should be controlled, so as to realize the restoration of polluted soil and water as far as possible, and reduce the negative effects on the environment as far as possible. At the same time, the cost and cost-performance ratio of restoration and treatment can be improved. In addition, the addition time of nanomaterials will not only affect the repair and governance effect, but also affect their negative effects on the environment. Therefore, it is necessary to control the addition time of nanomaterials.

5.2. Reasonable selection of nanomaterials for repair
For different types of pollution, the repair effects of different nanomaterials are different. Meanwhile, under specific ecological environment and biological conditions, the biological toxicity and environmental negative effects of different nanomaterials are also different. Therefore, reasonable remediation materials should be selected to not only achieve the effect of pollution remediation, but also avoid or reduce its impact on the environment.

5.3. Properly control the particle size of nanomaterials
Particle size of nanometer material not only has significant influence in the repair process, and its biological toxicity and environmental negative effect is influenced by the significant. Therefore, we should choose appropriate particle size of nanometer materials, not only ensure the repair and the size effect of pollution at the same time, but also avoid risk to reduce its harmfulness to the environment as much as possible.

5.4. Modification of nanomaterials used for repair
The size and shape of nanomaterials are artificially controlled by surface modification. Through modification, the biotoxicity of nanomaterials can be reduced and the biocompatibility of nanomaterials can be improved, so as to avoid risk and reduce their harmfulness to the environment.

5.5. Synthesis of non-toxic or low-toxic nanomaterials
In the synthesis of nano materials, in order to reduce its biological toxicity, it can be processed from the source. When preparing nanomaterials, metals with low toxicity can be used as catalysts without affecting the synthesis quality and repair effect. At the same time, the usage of metal catalyst is reduced as far as possible, so as to avoid its harm to the environment.

6. Conclusion
(1) Nanomaterials are widely used in the rehabilitation of polluted soil and water with obvious advantages.

(2) The immunotoxicity and biological toxicity of nanomaterials will cause harm to the environment and the research on the impact of nanomaterials on the environment should be strengthened.
(3) In view of the impact of nanomaterials on the environment, appropriate measures should be taken to reduce the harm to the environment when repairing the polluted soil and water.

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