Key Technologies and Equipment for Contaminated Surface/Groundwater Environment in the Rural River Network Area of China: Integrated Remediation

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Policy brief

Keywords: the rural river network area, environmental remediation, SW-GW interaction, soil remediation, the integrate remediation

DOI: https://doi.org/10.21203/rs.3.rs-73579/v1

Abstract

In eastern China, the rural river network area (RRNA) is an anthropic active area characterized by its rapid economic development and high gross national product. However, the water environmental pollution in these areas is increasingly severe, which has greatly hindered its sustainable development. Especially, the frequent interactions between surface/groundwater (SW-GW) have intensified the pollution migration and transformation in RRNA. Therefore, an integrated remediation in rural river network area project (IR-RRNA) has been launched, funded by the Ministry of Science and Technology of the People's Republic of China, to realize the integrated remediation of SW/GW and soil in RRNA. The IR-RRNA (2019–2022) will apply the related interdisciplinary and methodological knowledge to elucidate the transportation and transformation of pollutants in water and soil during SW-GW interaction, and develop key remediation technologies of surface water, groundwater, and soil suitable for the RRNA. By this way, we attempt to realize the remediation technologies integration for surface/groundwater and soil in RRNA and implementing application demonstration. Meanwhile, a technical guideline will be compiled for the integrated remediation suitable for the RRNA. This project is conducive to addressing the urgent environmental problems of RRNA, and promoting the rural economic revitalization and ecological environment optimization.

1. Introduction

River network is formed by the river mainstreams and their tributaries in the river basin, which is the result from the interaction between the environment and human activity. River networks have both ecological and social benefits for regional development, in particular in the human-modified landscapes. However, in recent decades, river networks have suffered extensive destruction due to the anthropic activities of urbanization and industrialization, and this issue is especially serious in China (Xie et al., 2020; Xu et al., 2019).

Rural areas in plain river network area possess an increasingly important status as they are the main producer of food and other natural resources for urban areas. Urban river system management is considered at an administrative region scale which plays a key role in the economic well-being of people living in both rural and urban areas. Whereas, with the rapid urbanization and industrialization, the rural communities face more pressures and risks from agricultural livelihoods, climate change, new technologies, commodity prices, environmental regulations, and economic conditions. The rural development is hence a hot topic and challenging issue for human beings since the regional development has become more imbalanced between urban and rural in terms of population change, economic development, access to services, and social outcomes (OECD, 2002). Therefore, the strategies to properly manipulate rural development are urgently required to effectively promote the water environment quality in the rural plain river network area.

The Yangtze River Delta (YRD) and the Pearl River Delta are two Chinese regions with the highest river network density (the total length of rivers per square kilometer) (Fig. 1). Specifically, the values of the river density for these two deltas are both above 2.0, and even as high as 6.7 in the YRD (Gu et al., 2011; Wei et al., 2017). Take the YRD for example, is located in the plain river network area where major national city clusters bearing national strategies, but it faces the great challenge of the severe water environment pollution issue (Li et al., 2018; Zhong et al., 2018). The main manifestations of the water environmental pollution are as follows: 1) the river system is seriously divided, leading to poor water connectivity and weak hydrodynamics; 2) the encroachment of river course frequently occurs due to the rapid development of the economy and the high pollution load into rivers; 3) black and smelly water, and eutrophication problems of water bodies are prominent, and the water function areas that meet the national standard rate are few. Indeed, these problems have become the major bottleneck hindering the sustainable development of the plain river network area (Han et al., 2016; Song et al., 2019; Yang et al., 2020). Therefore, efficient control strategies are urgently needed to promote the quality of the water environment in rural plain river network areas.

It should be noted that the boundary zone of surface and subsurface is a complex environmental system where the mass (including pollutant) transformation occurs actively because of the active exchange of surface water and groundwater (Gatel et al., 2016). This situation is especially significant in the plain river network area in China where the underground water tables are generally high at -1 to -3 m (Gu et al., 2011; Yan et al, 2015). Surface water bodies, such as streams, lakes, and reservoirs, frequently interact with groundwater, and their interaction is of great importance in the hydrologic processes of river basins (Guzmán et al., 2016; Conant et al., 2019). Even a small exchange between surface water and groundwater (SW - GW) can deliver a noteworthy contribution of solutes to a groundwater body, causing severe pollution interaction. Moreover, the surface runoff, unsaturated zone movement, and other action can offer the way through which pollutants move from the surface/groundwater to soil (Greene et al., 2004). The soil layer is an important ecosystem that protects both groundwater and surface water from contamination due to its good filtering function, but it can also be contaminated if the pollutant from groundwater or surface water exceeds its carrying environmental capacity. Therefore, if the surface water in plain river network area is contaminated with undesired substances (e.g. heavy metals, organic pollutants), it is likely that these pollutants can move to different environmental compartments, like soil, surface, and groundwater, and ultimately produces great negative impacts on human health, climate change, biodiversity, and food safety. The changing and complex contamination status in RRNA requires the efficient integration of diverse environmental techniques and equipment.

In this context, the Ministry of Science and Technology of the People's Republic of China (MOST) launched “green livable village program”, to improve the rural living environment and to promote the coordination of agricultural production, living condition, and ecological conservation. In the environment monitoring and remediation in rural (EMR-rural) project, one of the projects in “green livable village program”, we proposed a project for the restoration of the contaminated surface water and groundwater bodies to meet the requirements of water environment improvements in the rural river network areas (Chen et al., 2020). The project focus on research and development integrated remediation of key technologies and equipment for contaminated surface/groundwater environment in the rural river network area of China.

The integrated remediation in rural river network area (IR-RRNA) project duration is 38-month (2019–2022), consists of 3 partners from China, including Tongji University, Central South University, and Donghua University. The IR-RRNA will focus on 1) Apply interdisciplinary and methodological knowledge to elucidate the transportation and transformation of pollutants in water and soil during SW-GW interaction; 2) Develop key technologies of surface water, underground water, and soil environmental remediation in rural river network area; 3) Realize the remediation technologies integration for surface/groundwater and soil in rural river network area and implementing application demonstration, and finally 4) Compile technical guidelines for integrated remediation of surface/groundwater and soil suitable for the rural river network area.

2. Current Research Status Of Environmental Remediation In The Rural River Network Area

The Web of Science Core Collection annually collects thousands of journals to provide various records for each publication, including author information, journals, citation, and institutional affiliation, from multiple disciplines for bibliometric analysis. We set different keywords to search and collect publications in the past ten years (2010–2019), the number of environmental remediation publications was shown in Fig. 2.

In the present study, the search for “surface water remediation”, “groundwater remediation” or “soil remediation” all resulted in high numbers of publications and a rapid growth rate. However, only less than 1% of the studies focus on “rural” or “river network” area. Also, the studies aimed to the remediation technologies for combined pollution were only less than 300 in recent 10 years (“Surface water + Groundwater” “Surface water + Soil”, or “Groundwater + Soil”), and there is still a lack of research on integrated Surface water/Groundwater/Soil remediation.

2.1 Current research status of surface water remediation

Surface water pollution has become a severe threat to water resource sustainability and ecological safety in the world (Törnqvist et al., 2011; Wilbers et al., 2014; Pekel et al., 2016; Kumar et al., 2019). However, as surface water has a large amount and widely distribute, it could not be remediated by traditional centralized treatment technology, such as traditional coagulation sedimentation for the polluted surface water (e.g., adsorption, extraction, ion exchange, membrane separation). Moreover, the contaminated surface waters are generally characterized by a relatively low concentration of pollutants compared to that of raw wastewater, e.g., total nitrogen (TN) <10 mg/L and total phosphorus (TP) <1.0 mg/L, so it might be not effective and economic to use the treatment technologies and equipment used for domestic sewage or industrial wastewater treatment (Domagalski et al., 2020). Therefore, it is urgent to develop novel remediation technologies to prevent the deterioration of surface water quality (e.g., eutrophication) and maintain a healthy aquatic ecosystem.

In recent decades, a variety of studies have been carried out to remove contaminants from surface waters, including physical, chemical, and ecological methods (Table 1). Physical methods generally include dredging sediment, mechanical algal removal, aeration, and water diversion, by which surface water pollution can be mitigated temporarily but without persistency effects (Adapa et al., 2016; Wu et al., 2019). Chemical remediation requires chemical agents and adsorbents to change the redox potential and pH in surface water, by which suspended substances and organic matter in surface water, can be adsorbed and precipitated (Sánchez-Martín et al., 2010; Brack et al., 2017; Camacho et al., 2017). The chemical reaction between agents and pollutants will separate and recover harmful substances in water, or convert them into harmless substances. Although the chemical method can quickly function, it needs to add a large number of chemical agents that are expensive and prone to cause secondary pollution. Moreover, the produced chemical sludge requires to be treated in the sewage treatment plants, which brings about a large amount of extra work and troublesome operation of sewage treatment plants.

Ecological remediation is a new in-situ remediation technology that plants and microbes work together to remove environmental pollutants (Wang et al., 2017; Wang et al., 2019; MacArthur et al., 2020). The mechanism of the in-situ ecological remediation is mainly to use the metabolic activities of plants and microbes to absorb, accumulate, or degrade environmental pollutants. In-situ ecological remediation has many advantages when compared to other techniques, such as low costs, less adverse impacts on the environment, and no secondary production of pollutants. Indeed, many in-situ remediation processes, such as ecological floating bed techniques and constructed wetlands, have been developed for the bioremediation of polluted surface water and have exhibited satisfactory results (Irwin et al., 2018; Song et al., 2020).

2.2 Current research status of groundwater remediation

Groundwater and surface water have been managed as an isolated medium for a long time, but actually they are hydrologically connected in terms of both water quantity and quality (Winter, 1999). The physical interactions between groundwater and streams primarily depend on two factors: i) the geological context and permeability degree of an aquifer in comparison to a streambed and ii) the relationship between the river water level and piezometric level in the vicinity of the river. Generically speaking, the interactions between SW and GW take place in three basic ways: i) steams gain water from the inflow of groundwater through the streambed (Gaining stream) (Fig. 3a); ii) streams lose water to groundwater by outflow through the streambed (Losing stream) (Fig. 3b); (iii) do both (i) and (ii), gaining and losing stream. Thus, most of the ground-water contamination in shallow aquifers that are directly connected to surface water (Qin et al., 2017; Lasagna et al., 2016).

Groundwater is a very important source of agricultural irrigation and the domestic supply of drinking water for both human beings and animals in the world (Appelo and Postma, 2005). To ensure the safety and sustainability of groundwater resources, numerous remediation technologies have been developed to remove pollutants from groundwater (Table 2). Pump-treat is one of the earliest groundwater remediation strategies that widely applied previously (Mackay and Cherry, 1989; Chang et al., 2007). However, some factors in terms of the treatable pollutants, cost considerations, cleanup efficiency, and secondary contamination, have become limitations to the successful remediation of the contaminated sites. Therefore, in recent years, the combination of pump-treat with other alternative technologies has been proposed, such as chemical oxidation processes and bioremediation, to enhance the removal efficiency and lower the operational cost (Baciocchi et al., 2014; Levakov et al., 2019). Some novel techniques have also been developed by integrating conventional treatments with modern technologies, such as nano-material technology (Pak et al., 2019). It is reported that permeable reactive barriers (PRBs) with Nano zero-valent iron (nZVI) immobilization and packaging materials have a good capability to improve the decontamination efficiency (Dong et al., 2019; Weil et al., 2019). Additionally, the concept of the in-situ remediation has been widely accepted for decontamination to reduce or eliminate transportation costs.

Table 1
Key techniques for surface water remediation

Remediation technique		Technique principle	Characteristics
Physic method	Artificial aeration	Increase the dissolved oxygen of the water body, reduce the concentration of dissolved pollutants in water, improve the living environment for aquatic organisms	High cost, need to be combined with other methods
	Sediment dredging	Dredging the whole or part of the river with serious deposition to restore the normal function of the river	A large amount of engineering, disrupt existing bio-systems
	Mechanical algal removal	Using ultrasonic wave to make algal cell burst, break algal cell inside the airbag, make it lose float ability and precipitate	Unsustainable method
Chemical method	Chemical precipitation	Adding iron salt or aluminum salt to produces chemical precipitation with inorganic phosphate through adsorption or flocculation, controlling the eutrophication	The addition of chemicals agents raise the cost and introduce secondary pollution
	Enhanced coagulation	Add the appropriate coagulant and the decontamination is carried out by adsorption, chemical precipitation, destabilization flocculation, and adsorption bridging	
	Acid-alkali neutralization	Acidic or alkaline substances are added to the water body to adjust the pH, meet the growing need and species reproduction in the aquatic ecosystem	
	Chemical algal removal	Add chemical algal removal agent, the effect is remarkable	Water table damage, high risk
Ecological method	Constructed wetlands	Simulates natural wetlands by extracting elements from them for artificial enhancement	Large floor space
	Ecological floating bed	Using the principle of soilless cultivation, plants are planted in water and absorb nutrients directly from the water	Generally used to repair small rivers, lakes
	Ecological revetment	Artificially reformed the river revetment to restore or strengthen the ecological capacity of water, which can protect the river bank and purify the water.	Suitable for the long-term ecological remediation process

Table 2
Key techniques for groundwater remediation

Remediation technique		Technique principle	Characteristics
Ex-situ	Pump and treatment	Groundwater is extracted and sent to the sewage treatment system for decontamination.	Suitable for the treatment of soluble pollutants
	Excavation method	The method of soil excavation can be used to treat and remediate the polluted groundwater.	Only suitable for a small range of groundwater pollution.
In situ	Bioremediation	Utilize microorganisms to transform contaminants into less harmful daughter-products.	Long processing time, need the integrated application
	Air sparging	Inject air into the aquifer, and the pollutants in the groundwater move into the vadose zone with the air. Combine with the soil vapor extraction method to treat the pollutants in the groundwater.	Suitable for soil with good permeability and homogeneous quality
	Electrokinetic remediation	The charged ions of the metal undergo directional migration under the influence of the electric field force, and the pollutants eventually gather together for centralized treatment.	Suitable for organic and heavy metal pollution
	Chemical oxidation	Carried out by oxidizing reaction between oxidizing agent and pollutant in groundwater.	Easy to affect the geological and ecological environment
	Permeable reactive barrier	A trench is excavated downstream of the hydraulic gradient of the groundwater to form a reaction wall. When the sewage flows through the reaction wall, the pollutants in the groundwater are adsorbed, oxidized, and biodegraded.	Low cost and large application scope

Table 3
Key techniques for Soil remediation

Remediation technique		Technique principle	Characteristics
Physical-chemical remediation	Vapor extraction	Drive air through the pores of the contaminated soil, thereby entraining VOCs to the extraction system, pumping to the ground, and then collecting and processing.	Suitable for unsaturated areas, sites with strong permeability, and volatile organic pollutants.
	Thermal desorption	The organic pollutants in the soil will accelerate decomposition and volatilization during the heating process, and the contaminated gas is extracted and collected from the soil through the suction system to process.	Suitable for volatile organic matter and semi-volatile organic matter
	Immobilization/ stabilization	Immobilization: encapsulating soil pollutants in a solid material with complete structure; Stabilization: transfer pollutants into a state or form that is not soluble, transportable, or less toxic, reducing the bioavailability of pollutants.	Contaminants cannot be fundamentally removed
	Chemical redox	Add oxidant or reducing agent to contaminated soil, through oxidation or reduction, so that the pollutants in the soil into non-toxic or relatively less toxic substances.	Not suitable for remediation of heavy metal contaminated soil
	Soil washing	The eluent is injected into the contaminated soil, with the help of chemical/biochemical solvents that can promote the dissolution or migration of pollutants, transfer pollutants from the soil phase to the liquid phase. The wastewater from the elution system should be further treated.	Not suitable for soil with a fine (clay/powder) content of more than 25%.
Ecological remediation	Phytoremediation	Use plants for extraction, rhizosphere filtration, volatilization, and fixation to remove, transform, and destroy pollutants in the soil, so that the polluted soil can restore its normal functions.	Long processing time and slow results
	Microorganism remediation	The method of transforming, degrading, and removing pollutants in the environment by using indigenous microorganisms in the natural environment or artificially adding exogenous microorganisms.	Suitable for integrated use with other methods

2.3 Current research status of soil remediation

In the river network area, the riparian zone is the transition area between land and aquatic ecosystems (Fig. 4), and its ability to provide aquatic habitat and process chemical (including contaminants) varied along with the varying water source (Kiel and Cardenas, 2014). Soil filtration in the riparian zones can mitigate the negative effects of non-point source pollution on water quality, and plant absorption is capable of improving interactions between the roots and pollutants (e.g., nitrogen, subordinately phosphorous, and heavy mental) (de Mello et al., 2018). Thus, a better understanding of the riparian zone and create corresponding effective soil remediation technology is significant if the water quality requires to be effectively managing.

Soil pollution could cause profound impacts on crop productivity and human health. Accordingly, investigation of the sources, fate, and occurrence of soil pollution, as well as the induced risks to human health, has been an important topic in the ecological environmental area (Mirsal 2008). The soil remediation techniques can be classified into two categories (i.e. in-situ and ex-situ), and are mainly affiliated to physical-chemical and ecological remediation (Table 3). The selection of the appropriate remediation technology depends on several factors such as the characteristics of the hydrogeological environment, chemical and physical properties, of the contaminants, and financial resources. Due to the occurrence of complex compounds in soil, using the combined remediation technology (more than one) to comprehensively remediate the contaminated soil is often the case (Gidudu and Chirwa, 2020; Rui et al., 2019).

Phytoremediation has been increasingly used for soil remediation in recent years as it has a remarkable co-benefit including providing a plant cover to the soil and reducing the soil erosion(Gerhardt et al., 2009; Liu et al., 2014; Antoniadis et al., 2017). Phytoremediation contains the process of phytodegradation, phytoextraction, phytostabilization, Phyto stimulation, phytovolatilization, and rhizofiltration, to achieve extraction, degradation, or metabolization of toxic substances. The selection of species is an important procedure of phytoremediation and depends greatly on the occurring contamination at the site. The success of phytoremediation approaches ultimately depends on the plant growth and the plant absorbance of the target pollutants. Meanwhile, as a long time required and limited efficiency of phytoremediation, numerous studies have been focused on the development of effective rededication methods assisted phytostabilization, such as bioremediation and chemical immobilization (Passatore et al., 2014; Huang et al., 2018).

For the heavily polluted soil cases, soil washing is an effective remediation approach (Zhai et al., 2018; Feng et al., 2020). This technology combines physical and chemical processes to remove heavy metals from contaminated soil by ex-situ washing soil with the eluent. During the washing process, the polluted soil is excavated from the contamination site and is washed by the injected eluent, during which chemical/biochemical solvents are also added to promote the pollutants dissolution or migration. Thus, pollutions such as heavy metals can be transfered easily from the soil phase to the liquid phase. The remediated soil will be returned to the original site, and the wasted washing effluent will be recycled for the subsequent soil wash processes or discharged to a wastewater treatment facility for disposal. Soil washing is of short duration and can be cost-effective, but not suitable for the soil with a fine (clay/powder) content of more than 25%.

Taken together, selection of the appropriate remediation techniques should consider the contamination condition such as the site environment, pollutant types, and the contamination degree. Due to the complicated scenario of polluted water or soil, single-remediation techniques cannot be suitable for all the contamination situations, and the combined technologies to achieve integrated remediation effects have great potential in future environmental remediation development. Moreover, the urgent reqirement for contamination remediation in multi-media calls us to improve the knowledge on the mechanisms of pollutant transportation and transformation in environmental processes.

3. Planning Progress Of Ir-rrna Project

3.1 Case history and description

The main river network area YRD, located in East China, is one of China's most developed, dynamic, densely populated, and concentrated industrial area. In recent decades, the YRD has grown into an influential world-class metropolitan area and played an important role in China's economic and social development. In general, the boundary of the YRD varies from different perspectives in terms of its culture, economy, or geography. This paper refers to the area composed of Shanghai, Jiangsu, and Zhejiang provinces.

Since 1970, owing to the strong Shanghai's industrial base, the cities along the Yangtze River have caught up in the development of non-agricultural industries through rural collective accumulation. In these rural areas, the "five small industries" (small scale steel, machinery, chemical fertilizer, coal, and cement industries) were allowed and started to grow (Wong, 1980). Since then, those towns with more rural industries became ideal places for farmers to work or do business in the YRD. Without exception, the YRD's rapid industrialization has huge impacts on its natural environment, i.e. water pollution, groundwater levels decline, and soil pollution have become prominent problems. According to the Shanghai Environmental Protection Agency in 2007, Non-point source pollution has become the main factor affecting the stream quality of rural river network area, outpacing industrial point source pollution in the 1990s. Notably, because stream order and catchment boundaries are difficult to delineate in these river networks, the effect of land use on water quality may be quite different than that in other areas (Che et al., 2012; Zhao et al., 2015). Furthermore, the ecological degradation in the YRD is also serious, and the involved issues in terms of land degradation, loss of biodiversity, and serious ecological damage, all have brought serious threats to human survival and sustainable development (Gao et al., 2018).

3.2. Research methodology and Approach

The IR-RRNA project aims to develop effective integrated remediation techniques and equipment for the water environment remediation. It should first clarify the basic information such as the typical pollution in the YRD, the pollution distribution and interactions between water and soil, and the migration and transformation mechanism of pollutants in the water/soil. Accordingly, the literature survey and the typical pollution investigation will be conducted in the RRNA, combined with the collection of the village type and environmental pollution data. A comprehensive analysis will then be conducted to elucidate the distribution of typical pollutants over the RRNA. The scientific principles of ecology, microbiology, and hydrology will be applied to study the process of the pollutant migration and transformation between SW-GW-Soil. Finally, the field pollution survey, experimental methodology, and computer simulation models will be integrated to clarified the migration process of flux between SW/GW, the transformation mechanism of pollutants, and the characteristics of the inner relationship. By this way, we attempt to reveal the regulation principle of surface, soil, and groundwater pollution remediation technology in RRNA.

Based on the above theoretical study, bench-scale and pilot-scale tests will be conducted for polluted surface/groundwater and soil remediation in RRNA. Combining with the theoretical and process analysis, as well as fitness-for-purpose assessment, three key remediation technologies will be formed for three different medium with the advantages of "high efficiency, environmental friendliness, and economy": 1) Aquatic plants and microorganism coupling strengthening remediation technology for surface water; 2) nZVI coupled biochar sustained-release remediation system for groundwater; 3) High efficiency multi-dimensional continuous pollution soil remediation technology using plant-microbial and chemical stabilization. Simultaneously, the outcome of the pilot study will be combined with the theoretical analysis of technology process and pollutant characteristics, to explore the economical, applicable, and easy to hand equipment for the different rural environment remediations. Finally, we will simulate one or two pollution scenarios in RRNA, and systematically study the feasibility of using integrated remediation technology to remediate the contaminated surface/groundwater and soil under different influencing factors, and then establish an efficient and sustainable integrated remediation pilot system.

Considering that the in-situ contaminated environments are complicated and hard to simulate in the laboratory, a field demonstration will be carried out in our project. This field demonstration is characterized by the integrated remediation technique and will be implemented in rural river network areas in Shanghai. In consideration of the natural climate conditions and hydrological characteristics, we will make full use of the spillover effect and carry out integrated remediation in typical pollution sites in RRNA. This platform will take consideration into the complexity of environmental medium and natural biogeochemical processes to form an environmental restoration system that is suitable for the different time and spatial scales, and finally to realize the integrated remediation for contaminated surface/groundwater and soil in RRNA.

3.3. Key technologies and equipment for integrated remediation

The RRNA-remediation project supports the overall target of developing key techniques and devices for rural environmental remediation in RRNA. The selected remediation techniques, such as phytoremediation, microbiological remediation, nZVI/biochar remediation, and chemical stabilization will be combined, regulated, and optimized to effectively restore the polluted water and soil. Afterward, an integrated technical system will be created, including ecological reaction revetment, ecological floating bed, permeable reaction walls, mobile soil leaching device, and plant/roots-microorganism coupling remediation techniques, and ultimately to realize the efficient integrating of the plant, microorganism, and chemical stabilization for the contamination remediation in RRNA (Fig. 6).

River revetment is an important area of the land-water ecotone with comprehensive functions such as safety protection, ecology, and landscape. It also acts as a connection channel between the river ecosystem and the terrestrial ecosystem. However, to accelerate the drainage of rainwater and protect the riverbank from soil erosion, a large number of riverbanks have been cut straight and channelized by constructing revetments in past years (Chen et al., 2016; Yan et al., 2019), resulting in serious damage of the ecological function of these riparian ecosystems. Consideration of improved people's awareness in ecological and environmental protection as well as the preliminary filed investigation in RRNA, our project put forward an in-situ ecological reaction revetment construction plan. The outcome of this project could facilitate the sustainable circulation of SW/GW and river bank ecological restoration.

Eco-restoration materials for concrete revetment, aquatic plants, and PRBs, are the main constitutes of the ecological reaction revetment. The native aquatic plants with a strong tolerance for pollutants will be selected to fix water pollutants via adsorption, accumulation, and degradation reactions. The plants' roots further provide a favorable habitat for microbial reproduction and stimulate the microbial proliferation. Microbial consortia can help to improve the water quality and maintain the stability of river slopes. In the laboratory, we will choose one or two native aquatic plants that with good pollution removal capacity, and examine the plant/microbial interaction effect, based on which we attempt to develop an optimized strategy to effectively promote the mass and energy cycle among water/soil and plants/microorganisms.

The PRBs that consist of nZVI/biochar sustained-release materials will be installed parallel to the revetment, in the path of a plume of contaminated surface and groundwater. Compared with the previous vertical installation method, it can dramatically drive down treatment costs and achieve better interception of pollutants in surface water. As the contaminants move through the nZVI/biochar material, the reaction occurs that transforms the contaminants into less harmful (non-toxic) or immobile species. For instance, nitrates will be reduced to N_2 and/or NH_4^+ by nNZVI and the addition of biochar could be favorable for this process, as NO_3^- can be selectively reduced to N_2 instead of NH_4^+ (Wang et al., 2019). The PRBs are a barrier to the contaminants rather than a barrier to the groundwater. Therefore, PRBs should be designed to be more permeable than the surrounding aquifer materials so that the contaminants are removed as groundwater readily flows through but without significantly altering the groundwater hydrogeology.

Phytoremediation can improve the biological quality of the soil and has been recognized as a benign technology, so it has been selected to our project to degradation, accumulation, or stabilization of contaminants in the polluted aquatic systems. Prior to establishing the demonstration project, we will first select the native plant species that have an extremely high capacity of adsorption of metals, affiliated by the microorganism-based remediation technologies to decompose, transform, and absorb pollutants. For the heavily polluted regions caused by long-term industrial production, the contaminated soil will be moved to a mobile soil washing device (a kind of ex-situ technique), and the contaminants (heavy metals) will be extracted and washed from soils by physical and/or chemical procedures. Meanwhile, a novel ecological floating bed has been proposed in our project that integrates graphene photocatalytic materials, act as a net between ecological floating bed.

The graphene, as a two-dimensional monolayer of sp2-bonded carbon atoms, was used for contaminants removals due to its large specific surface area, good charge transportation, and mechanical strength (Zheng and Kim, 2015). Then, the purification capacity and the stability of the ecological floating bed system can be greatly promoted, which favors flexibly cope with the fluctuation of the water quality of the polluted river.

It should be noted that the integrated remediation system proposed in IR-RRNA project will fully consider the impact of pollution types, pollution levels, and hydrological conditions in different scenarios, and flexibly control the operation of the remediation system. We hope to realize the optimal integration of surface/groundwater/soil remediation in the RRNA in China.

4. Conclusions

In our project, multiple research methods, such as the multi-disciplinary theory application, in situ sampling investigation, lab/pilot-scale experiment, and integrated field determination, will be applied to develop an applicable integrated remediation technique and equipment for complex rural river network. The IR-RRNA project will clarify the key factors affecting the rural environment and address the urgent environmental problems in rural areas, based on which effective integrated remediation techniques will be developed to realize the integrated remediation of surface water/soil/groundwater. Our work highlights the importance of the integrated environment remediation in the rural river network area. The outcome of the project hopes to favor realize the rural economic revitalization and ecological environment optimization.

Declarations

Ethics approval and consent to participate:

Not applicable.

Consent for publication:

All authors agreed to publish the paper.

Avaliability of data and materials:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests.

Funding:

This work was supported by the National Key R&D Program of China (No: 2019YFD1100502).

Authors' contributions:

Han Wang: Conceptualization, Investigation, Writing original draft.

Tianbei Wang: Writing original draft. Gang Xue, Jiang Zhao, Weiwu Ma, Yajie Qian, Min Wu: Conceptualization, Writing- Reviewing and Editing. Zhuoran Zhang: Writing original draft. Jingsong Guo: Conceptualization, Funding acquisition, Supervision. Yayi Wang: Conceptualization, Writing- Reviewing and Editing, Funding acquisition, Supervision.

Acknowledgements:

We appreciate the contribution for all participants.

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Figures

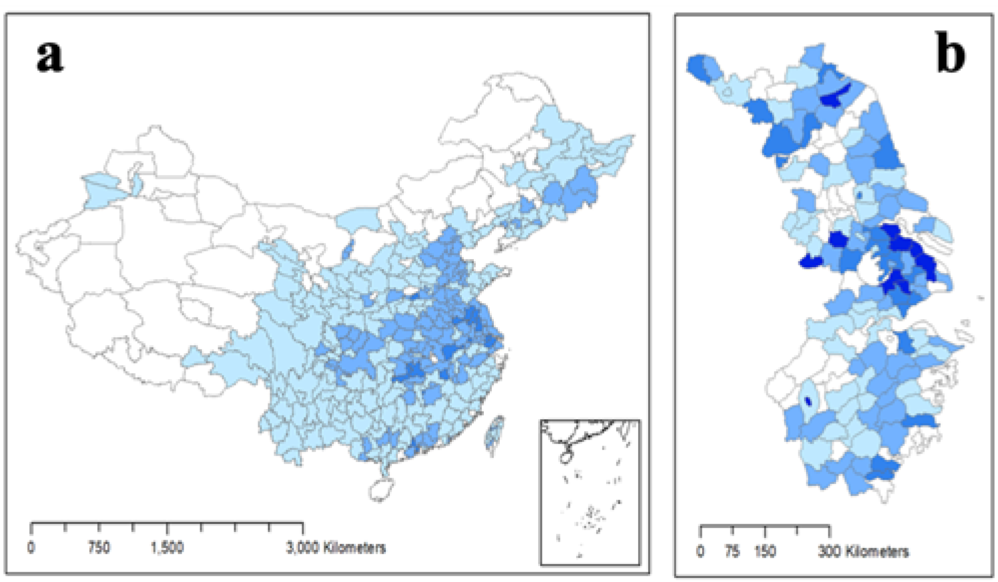

Figure 1

Maps of drainage density (km−1) for the river networks in China (a) and the YRD (b). A density of river networks is the total length of rivers per square kilometer, representing the river distribution density. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

a

Years	Surfacewater	Ground water	Soil
2019	2303	826	5228
2018	2424	925	4677
2017	2250	840	4038
2016	1775	832	3844
2015	1269	721	3179
2014	912	582	2604
2013	873	593	2563
2012	736	562	2330
2011	567	444	1882
2010	489	434	1791
Total	13597	6759	32134

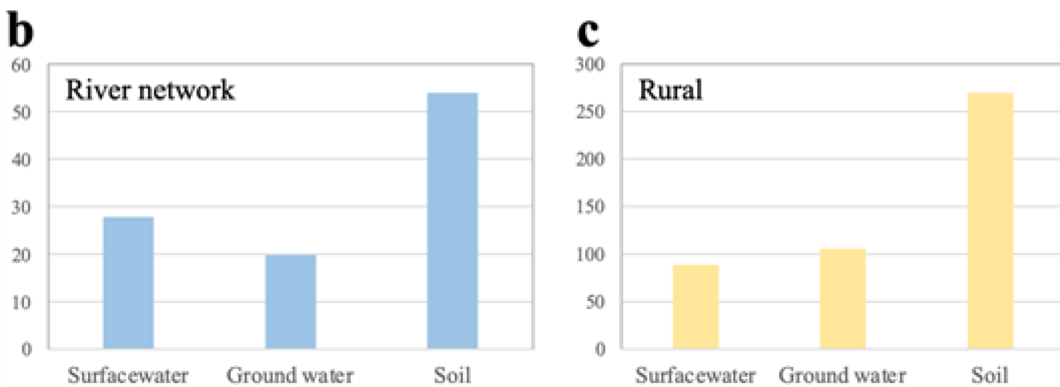

Figure 2

(a) Records for the environmental remediation terms, including surface water, groundwater, and soil, filtered by publication period (2010 to 2019); (b) Records for environmental remediation in river network area; (c) Records for environmental remediation in the rural area.

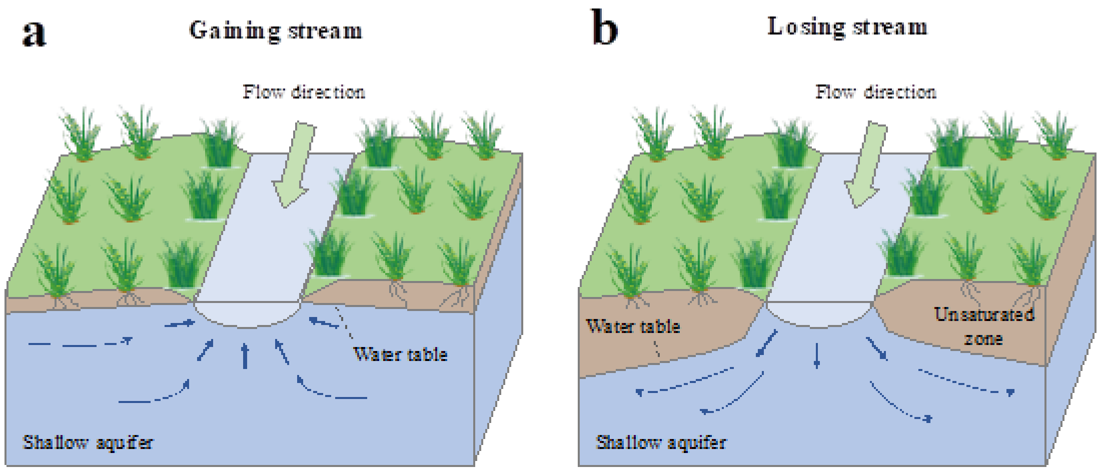

Figure 3

The two type of interactions between SW and GW

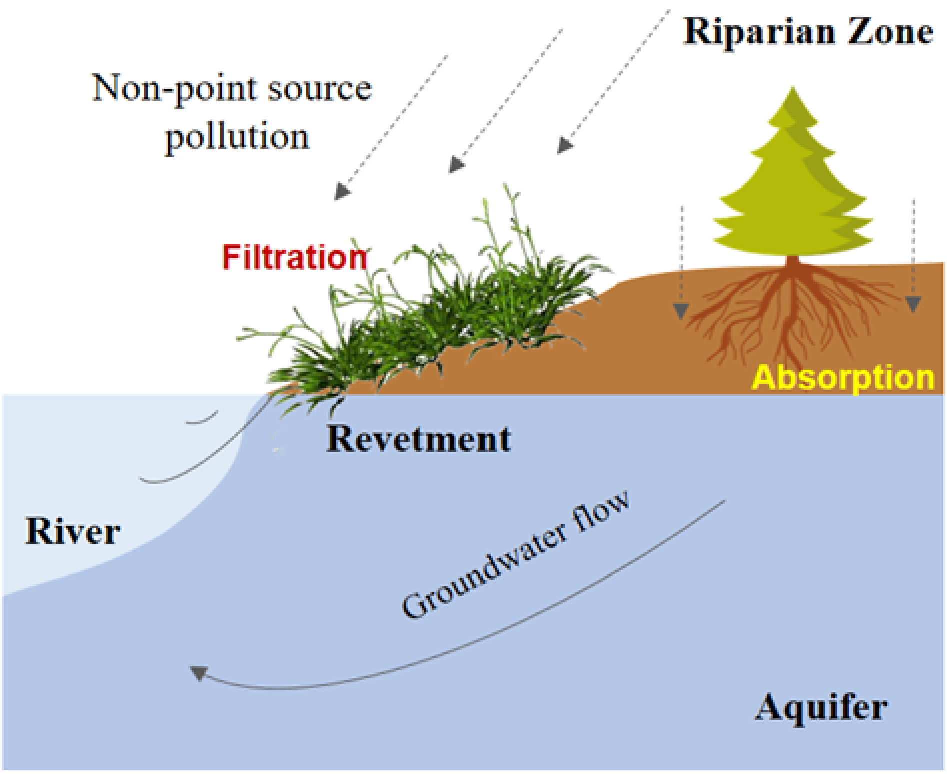

Figure 4

Soil function on pollutant transfer between land and aquatic ecosystems in the riparian zone

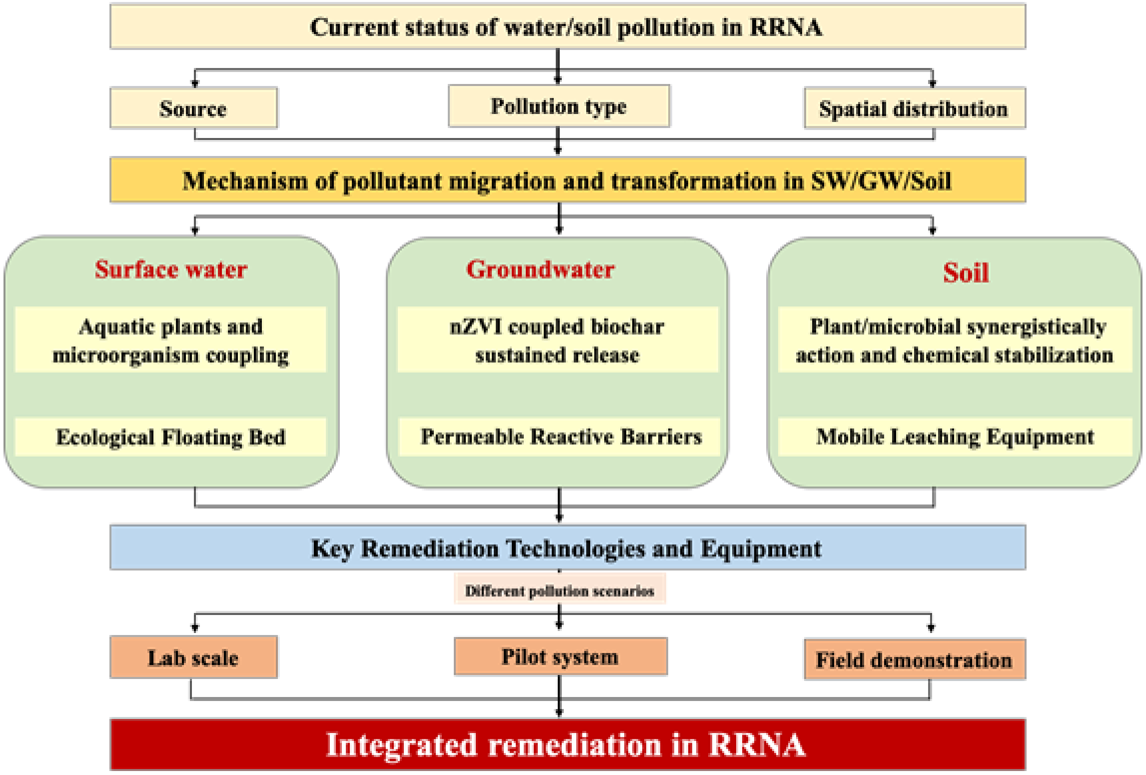

Figure 5

Scheme of the conceptual framework of the IR-RRNA project

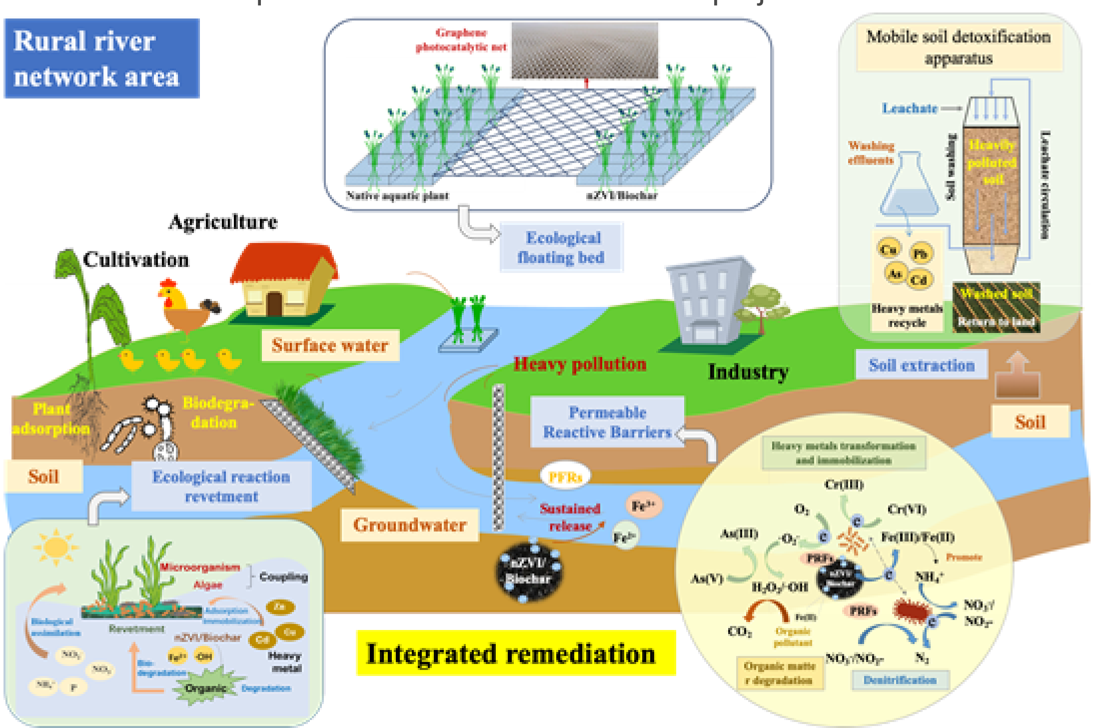

Figure 6

Supplementary Files

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