


POLICY BRIEF

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The EMR-rural project: key techniques and devices development for rural environmental monitoring and remediation in China

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Abstract

Rural development, as one of the biggest challenges facing human beings recently, has attracted widely attention in the world, among which rural environment protection is essential for sustainable development. In response to the call to build “green livable villages”, the environmental monitoring and remediation in rural project (EMR-rural project) is launched. EMR-rural (2019 to 2022) is funded by the Ministry of Science and Technology of the People's Republic of China (MOST). The project aims to develop key techniques and devices for contamination classification, risk assessment, pollution sources tracing and environmental remediation with regard to soil, underground and surface water quality in rural area. To this end, a new generation of physical, chemical and biological tools is integrated with intelligent management platform. The project follows a problem-oriented approach by in situ investigation, lab/pilot-scale mechanism exploration and field determination. EMR-rural takes advantage of the access to the applicable techniques and devices to investigate and to restore soil and water pollution in river network areas, mountainous areas as well as cold areas of China.

Introduction

Rural, as a supplier of food and natural resources, plays key roles for the economic well-being of people living in rural and urban areas [1]. While along with the urbanization and industrialization, rural communities face increasing pressures and risks from agricultural livelihoods, climate change, new technologies, commodity prices, environmental regulations and economic conditions [2, 3]. The rural development is hence a hot topic and difficult issue for human beings, since the increasing regional imbalances between urban and rural in terms of population change, economic development,

access to services, and social outcomes [4]. Strategies to deal with rural development have aroused widely concerns. Remote regions are taken into consideration, where targeted differentiated approaches are provided [5, 6]. For instance, bottom-up approach, participatory rural appraisal (PRA), rapid rural appraisal (RRA) and working with people (WWP) have been developed and implemented [7]. Agencies and programs, such as International Institute of Rural Reconstruction (IIRR), Technical Center for Agricultural and Rural Cooperation (TCAR), United States Department of Agriculture (USDA) Office of Rural Development and European Network for Rural Development (ENRD) have been established to explore land-intensive natural resources such as agriculture and forestry [8], among which management of natural resources and preservation of ecological balance are perceived today as essential elements of rural

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development. Concerns have grown over the impact of intensive human activities on the rural environment [9]. Consequently, environmental departments are intended not only to reduce the environmental damages resulting from uncontrolled urbanization and industrialization, but also to address ecosystemic degradation in the countryside [10]. The concept of sustainable rural development which characterized by emphasis on natural, landscape and cultural resources protecting and preserving was hence developed [11, 12].

In this context, the Ministry of Science and Technology of the People's Republic of China (MOST) launched a series of projects, namely "green livable village program", to improve the rural living environment and to promote the coordination of agricultural production, living condition and ecological conservation. The program was launched under the direction of the rural vitalization strategy. To build green livable villages, key technologies in the fields of rural cleaning, environmental health, town and village planning, livable housing, green construction materials and clean energy are desired. Thus, platforms on basic research, smart village and ecological construction will be built to promote the construction and development of "green livable villages". Among which rural environment is essential for sustainable rural construction, since a good quality of rural environment can promote sustainable construction [13], while degraded environment may bring negative effects on rural construction [14]. Recently, under pressure from economy and society, more and more synthetic chemicals, such as pesticides, fertilizers, and pharmaceutical and personal care products (PPCPs), are utilized for agriculture, stock farming and livelihoods to support rural development [15–17]. As a result, a large amount of those chemicals are inevitably released into rural areas, which caused serious damages for rural environment and even human health [18]. To address these problems, environmental monitoring and restoration, which are often designed to establish the current environmental status or the trends in environmental parameters, are vital for regulatory agencies [6, 14, 19–21]. Thus, rural environment monitoring and remediation, as one of the major requirements for rural sustainable development, was set as one of the projects in the "green livable village program" for the purpose of healthy environments.

The environment monitoring and remediation in rural (EMR-rural) project is a 38-month project (2019–2022). The EMR-rural consortium consists of 10 partners from different areas of China, including six universities (Chongqing University, Tsinghua University, Tongji University, Central South University, Huazhong Agricultural University and Donghua University), three research institutes (Institute of Applied Ecology, CAS; Institute of

Mountain Hazards and Environment, CAS; Academy of Agricultural Planning and Engineering, MARA) and an instrumental manufacturer (Focused Photonics (Hangzhou), Inc.). EMR-rural will focus on the development of key techniques for (1) analysis of the characteristics of pollutant transportation and transformation under the interference of residents activities; (2) restoration of the contaminated surface water and groundwater bodies to meet the requirements of water environment improvements in river network areas; (3) coordinately restoration of soil and water in mountain areas to challenge the technical difficulties in soil interflow pollution treatments, (4) polluted soil and water remediation during freezing and thawing to support the effectively environment management in cold region; (5) development of rural applicable instruments or sensors to trace pollutant sources, identify key pollutants that induced multi-toxic effects and assess unknown/unexpected risks, and finally (6) establishing an integrated simple, economical and applicable rural environmental monitoring and early-warning platform.

Current research status of environmental monitoring and remediation

Studies on environmental pollution were verified by searching in Web of Science. The environmental pollution-related terms were set as keywords in topic/databases, listed according to their frequency of occurrence. The search period was limited between 2010 and 2019, and the results are summarized in Table 1. In recent decade, rural environmental monitoring and restoration have attracted extensively attention worldwide [21, 22]. Among the research areas, traditional pollutants such as nitrogen, phosphorus, heavy metals, pesticides, and emerging contaminants polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) are still major concerns [23–25]. The research topics have turned from specific pollutants removal and their environmental behaviors to the relationship between pollutants and ecological and health risk [26, 27]. However, studies regarding emerging pollutants are still not adequate since their increasing variety and quantity [28, 29].

The inadequate studies and the existence of unknown/unexpected risks are human major challenges. In the current study, we defined the unknown/unexpected risks as (1) pollutants that have not yet been identified/detected in environments, and their toxic effects to biota and risks are hence unknown; (2) chemicals which were already detected in environments, but their environmental/ecological risks are still unknown and (3) complex environmental mixtures which composed identified and unidentified chemicals, while studies on their fate/risks are still insufficient.

Table 1 Records for the environmental monitoring and restoration terms, filtered by publication period (2010 to 2019), listed according to the frequency of occurrence

Frequency of key words			Burst of key words					
Rank of frequency	Key words	No. of frequency	Time sequence	Key words	Burst intensity	Start	End	2010–2019
1	Heavy metals	324	1	Risk factor	3.15	2016	2019	
2	Drinking water	304	2	Health risk	16.09	2016	2019	
3	Pollution	283	3	PCBs	2.88	2016	2017	
4	Exposure	275	4	Land use	11.00	2016	2017	
5	Soil	239	5	Constructed wetland	10.41	2015	2016	
6	Nitrogen	214	6	Adsorption	7.50	2015	2016	
7	Underground water	203	7	River	7.46	2014	2015	
8	Air pollution	189	8	Wastewater	5.40	2014	2015	
9	Particulate matter	188	9	Form	7.58	2014	2015	
10	Water	180	10	PAHs	6.97	2012	2014	
11	Health	165	11	PM2.5	11.98	2012	2013	
12	Discharge	154	12	PCBs	10.05	2011	2012	
13	Arsenic	150	13	OCPs	3.50	2011	2012	
14	Children	150	14	Particulate matter	9.43	2010	2012	
15	Microelement	147	15	Air	9.35	2010	2011	
16	PCBs	145	16	Rural area	4.57	2010	2011	
17	Pesticides	143	17	Population	2.42	2010	2011	

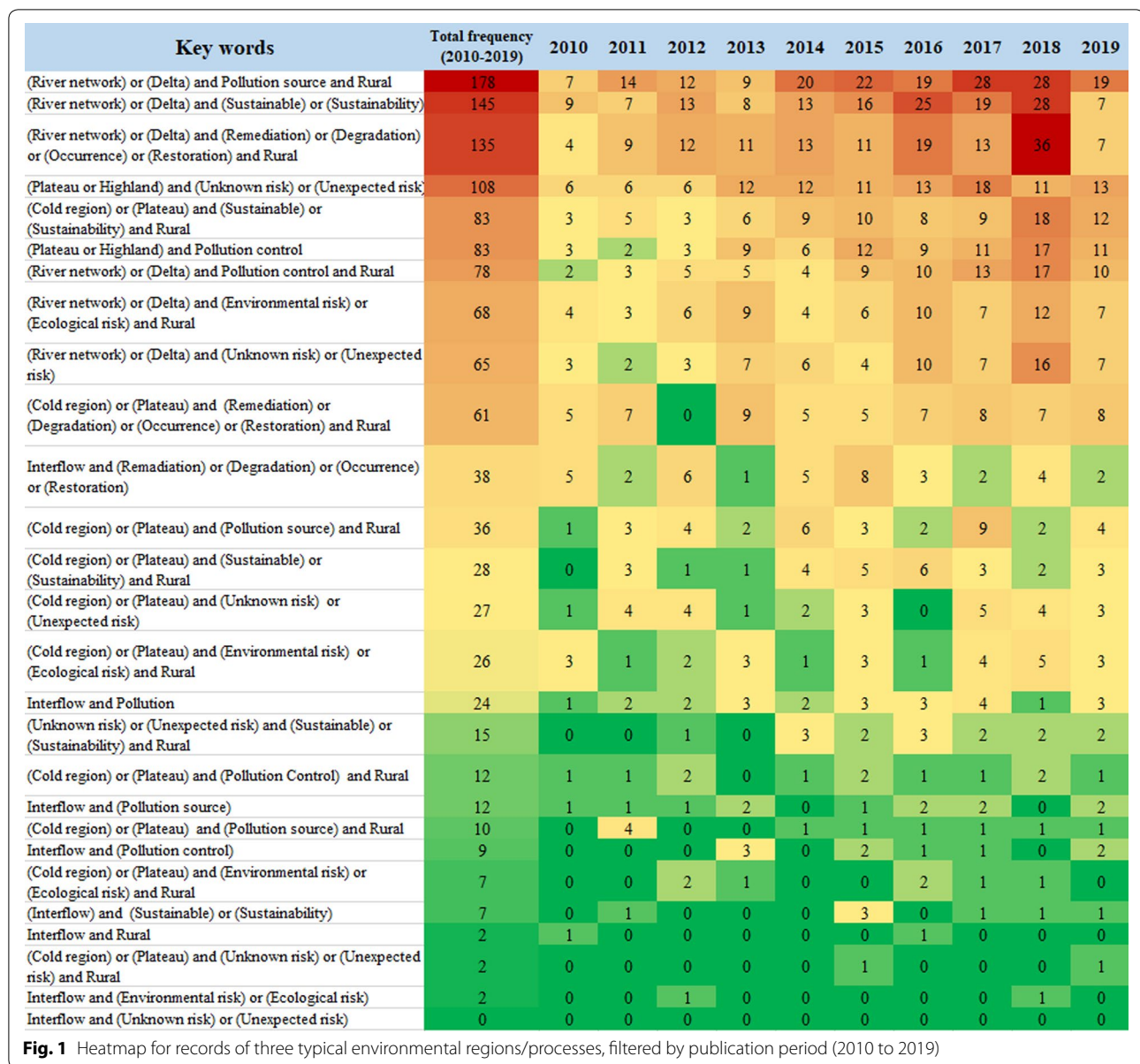
As shown in Fig. 1, researches on pollution control and remediation concentrated in river network areas, whereas the studies in mountainous rural regions and cold areas are rare, in particular for the soil interflow pollution. When it involves unknown/unexpected environmental/ecological risk, the relevant research data are even fewer, regardless of in river network areas, mountainous regimes or cold areas [30]. Studies on environment monitoring and remediation to support effective environmental management in rural area are huge challenges nowadays [27, 31].

In a general term, the technology development trends of environmental monitoring and remediation are as follows: (1) pollutant monitoring has been extending from traditional pollutants to emerging pollutants [32, 33]; (2) specific focus is given to restoration technologies and devices, and (3) integrated technologies are desired [34, 35]. These trends call us to improve the knowledge on the mechanisms of pollutants transportation and transformation in different rural environmental processes. Effective environment monitoring and remediation rely on accurate data and cognition [36], which are the fundamental of technologies and equipment innovation for combined restoration of water and soil. In addition, the economic, intelligent, reliable, practicable monitoring and remediation techniques and devices, such as online intelligent monitoring, and early-warning platform are desired for rural environment management.

Objectives

The EMR-rural project supports the overall aim of developing key techniques and devices for rural environmental monitoring and remediation toward the construction of “green livable village”. The proposed conceptual framework addresses major challenges of rural environment monitoring and renovation. EMR-rural focuses on three research aspects: (1) techniques and devices for pollution classification and risk assessment that are suitable for the characteristics of pollutant transportation/transformation and combined pollution during different biogeochemical processes; (2) environmental remediation techniques and devices that are suitable for the processes of frequent underground/surface water interaction (U/S interaction), alternation of drying and wetting (D/W alternation), and freezing–thawing phase transition (F/T transition) and (3) early-warning platforms and network-monitoring techniques for rural environments.

The U/S interaction, D/W alternation and F/T transition are typical rural natural environmental processes in river network regions, mountainous regions and cold regions, respectively. These biogeochemical processes play important roles for pollutants transportation, transformation, and source-to-sink patterns of pollutants, which may result in variations of hazards in rural environments. EMR-rural intends to explore a technical system for pollution monitoring, classification and risk assessment in rural environments through probing the



dynamics, transformation mechanism of pollutants in various environmental media during different natural biogeochemical processes.

In view of the frequent U/S interaction in river network regions, EMR-rural will first investigate the pollutants' characteristics in groundwater, surface water and soil. Based on these characteristics, remediation techniques, such as phytoremediation, microbiological remediation, zero-valent iron coupled biochar remediation and chemical stabilization will be regulated and optimized to combine restore water and soil effectively. Afterward, an integrated technical system will be created, assembling

plant, microorganism and chemical stabilization for contamination remediation in river network areas.

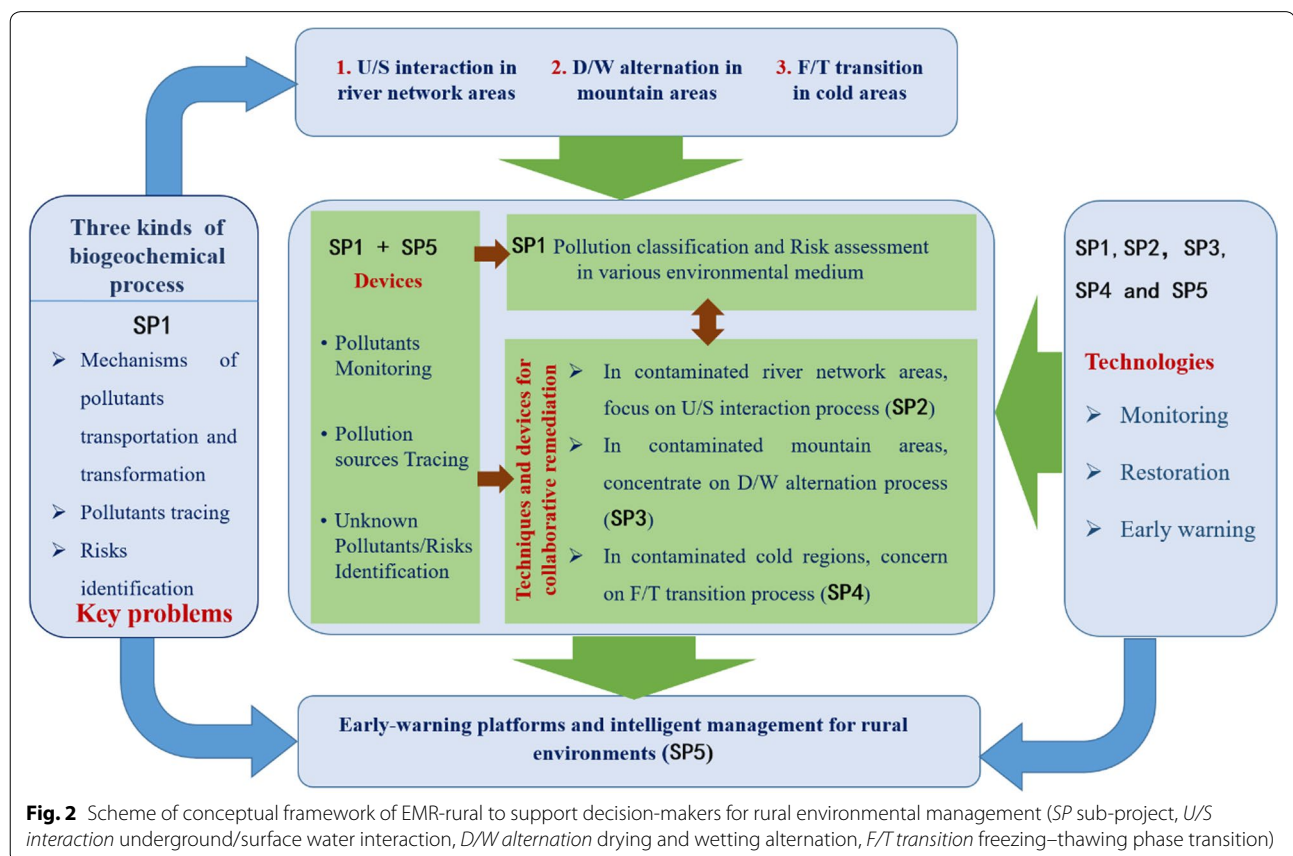
In mountainous region, the interflow often accompanied by soil alternations between drying and wetting is one of key factors for pollutants' source-sink conversion. An ecological reactive barrier will be equipped with techniques of anaerobic ammonia oxidation, denitrification, nitrogen and phosphorus hyper-accumulators, and metallic passivator to remove pollutants. Besides, in consideration of scattered distribution of garbage in mountainous region, a simple landfill will be developed and applied to remediate soil and interflow in situ.

F/T transition is a common phenomenon in cold regions, which always induces redistribution of contamination in water and soil, and may affect the pollutants' transformation efficiency. The low activity of microorganism and its short action period at low temperature challenge on pollution degradation when suffering freezing–thawing stress. EMR-rural will screen specific microorganisms and antifreeze materials, and simultaneously integrate temperature control module to combat multiple disturbance of low temperature. In particular, livestock farms, as typically contaminated places with complex pollutants in rural, will be coupled with bioremediation technology in cold environments.

To provide convenient measurement for pollution monitoring and effective implementation for water/soil remediation in complex rural environments, economical, easy-to-handle and applicable instruments are indispensable parts. EMR-rural plans to exploit an in situ sensor and a dual-mode equipment to trace pollutant sources, a nuclear receptor-based biosensor to ascertain risks, an apparatus to rapid detect and identify heavy metals, and a portable instrument to investigate the acute toxicity of water. In regard to remediation facilities, EMR-rural intends to develop a device for surface water restoration,

an implementor for heavy metals' detoxification, remediation equipment base on interactive fluidized biofilms' technology for interflow, and an integrative system for permafrost pollution in livestock farms.

Therefore, EMR-rural is structured into five subprojects, which will be set according to the workflow illustrated in Fig. 2. Sub-project 1 (SP1) will carry out the occurrence characteristics, ecological risk and fate of pollutants. SP2 focuses on comparative remediation techniques and equipment development for river network areas. In SP2, technologies for water–soil-integrated remediation will be explored by combining biological and chemical methods. SP3 will first quantify the transportation process and flux of pollutants. Then, the transformation mechanism of pollutant source–sink during D/W alternations in soil interflow will be explored. Afterward, a simple landfill instrument equipped pollution control and water–soil remediation techniques will be implemented. A collaborative system for remediation of water–soil with characteristics of interflow will be finally constructed in SP3. SP4 pays close attention to the low activity of soil microorganisms in cold regions and the challenge of freezing–thawing stress imposed to polluted environments. The major work of SP5 is about key



environmental factors on monitoring and supervision, including spectral tracing of pollution sources, environmental risk evaluation with multiple toxic endpoints' investigation, key toxicant pollutants' identification with non-target analysis, and risk screening biosensors' development. Based on the requirements of automated operation, integrative information, intelligent regulation and low maintenance of rural environment management, a monitoring station combining different kinds of sensors will be served to a platform to realize environmental supervision locally. These major products will support an early-warning management platform serving for pollution classification, risk assessment, and environmental monitoring at county scale.

In summary, the outcomes of SP1 on the fate of pollutants in three typical environmental processes (U/S interaction, D/W alternation and F/T transition) will provide basic environmental information and directions for the implementation of the other four sub-projects. The work of SP5 reflects on the SP1 regarding the pollution characteristics and pollutant fate by developing equipment for pollutants' tracing, techniques for unknown contamination identification and integrative system for environmental monitoring and pollution early-warning. SP5 simultaneously supports SP2, SP3 and SP4 to monitor environmental status during/after remediation, and to deepen the precision of technology development. Conversely, SP2, SP3, and SP4 will verify and reflect the theoretical methods and detecting techniques presented in SP1 and SP5. EMR-rural is expected to provide environmental status of specific pollutants in different river basins or regions, and to assist abatement options in rural.

Approach

Mechanism explanation with multi-disciplinary integration

In consideration of the complexity of environments, EMR-rural will apply interdisciplinary and methodological knowledge to elucidate the interfacial behaviors, transportation and transformation of pollutants in water and soil during U/S interaction, D/W alternation and F/T transition processes. Because environmental problems originate from a wide variety of sources (natural and man-made) and occur in various forms including biological, chemical, particulate or even energy. To parse pollution mechanism, studies must be done with different aspects, from understanding how the environment has evolved and how it functions, to the direct and indirect interactions [37]. Thus, the in situ pollution investigation, literature research, data analysis, and expert interviews will be integrated to expound characteristics of pollutants' distribution and transport flux. The project will make multivariate approaches to explain pollution

mechanisms regarding source–sink conversion, essential transformation processes, and regulation principles in rural environments.

Pilot studies for remediation techniques' exploration

Pilot studies are preliminary studies that are often carried out before large-scale quantitative research, in an attempt to avoid time and money being used on an inadequately designed project [38]. Due to the uncertainty and the large number of associated variables in field implementation, pilot studies are frequently applied to evaluate the feasibility, adverse events, and improve upon the study design before a full-scale research project [39]. In particular for environmental remediation, a pilot study can serve as an effective screening tool in efficiency evaluation, approaches selection and process designing [40]. EMR-rural will construct three types of pilot systems to explore and evaluate remediation techniques and equipment. Three typical processes (U/S interaction, D/W alternation and F/T transition) will be settled in pilot systems to simulate natural conditions in river-network region, mountainous region, and cold region, respectively. Pilot studies in EMR-rural will hence take on the responsibility to verify the transportation and transformation mechanisms of pollutants in rural environments. They are particularly important for the effective remediation approach development. In addition, in view of the advantage of pilot experiments on providing large amount of initial information, pilot studies will be applied to evaluate the efficiency of remediation techniques, and to collect technical parameters for optimization of field-scale remediation [9]. Finally, the results of pilot study will be combined with the theoretical analysis of technology process and pollutants' characteristics to explore economical, applicable, and easy-to-handle techniques and equipment for rural environment remediation.

Spectrum or biosensor-based portable detectors' development

Spectrum technology has been intensely used in recent decades in the water quality monitoring programs for the dissolved organic matter analysis in water to evaluate the quality of various aquatic environments, such as sewage [41], oil [42] or pesticides [42]. Due to the capabilities of fluorescence spectroscopy, it has been suggested for pollution source identification [43]; while the in situ fluorescence experiments have been trapped to the limitation of proper portable instrumentation [44]. Moreover, the fixed excitation and emission wavelengths allow only the measurement of the specific chemicals [44]. EMR-rural will develop a portable dual-mode spectral detector based on concave flat-field raster and array photoelectric coupling technology with the technique of pollution

source tracing and the full-spectrum-based multi-parameter probe. A special dual-mode chemical reagent which is prepared according to the principle of chromogenic reaction and precipitation reaction will be applied in this detector. Afterward, the observed data will be analyzed by convolutional artificial neural network algorithms. According to the spectral database that obtained by the extensive investigation of rural samples, we can rapidly and accurately detect the rural-specific pollutants and trace the pollution sources.

As required by environmental monitoring programs, the portability, applicability and economics of detecting devices for a wide range of pollutants are essential for rural environment managements. The chemical sensors-based measuring devices are frequently applied in environmental detection with optical and/or electrochemical transduction [45]; for instance, volatile organic compounds' sensors [46], heavy metal ion sensors [47, 48], and pesticide and residual pesticide sensors [49]. These devices could only be optimized to interact with a specific analysis, which may not be appropriate for complex rural environment monitoring. While biosensors measure or monitor the occurrences of substances with the response of bio-materials, which provides the possibility on measuring pollutants in complex matrices with minimal sample preparation [50]. These methods have been hence encouraged for environmental mixture quality assessment [51]. EMR-rural will develop a biosensor integrated with a nuclear receptor affinity column for endocrine-disrupting effects' investigation and endocrine-disrupting compounds' identification, which could purify risk chemicals and test biological activity simultaneously.

Effect-directed analysis (EDA) for unknown pollutants' identification

Most environmental quality standards are established to address risk priority chemicals and other specific pollutants in monitoring programs. While the targeted chemical monitoring only for priority/specific chemicals cannot account for the presence of unknown chemicals and their transformation products [52]. Besides, environmental chemicals which are presented below guideline/standard values may still induce significant toxic effects since they are actually existed as mixtures in environments [53]. Numerous studies have indicated that substance-by-substance environmental monitoring could not reveal the real environmental effects, and target chemical analysis alone may lead to environmental pollution underestimation [54]. Effect-directed analysis (EDA) combines bioassays, fractionation and chemical analysis to identify bioactive chemicals in complex mixtures, which is designed to meet the challenge of reducing mixture

complexity. EMR-rural will apply EDA for unknown pollutants' identification in rural water and soil/sediment samples. EMR-rural will start with biotesting for environmental organic extracts. If significant effects are detected, the complexity of the environmental sample is sequentially reduced by fractionation. Finally, the isolated toxic fractions are subjected to high-resolution mass spectrometry for key toxicants' identification [55].

Field demonstration

Numerous studies show that in situ works always fail when they equipped with new techniques or devices, even they have been successfully applied in both lab-scale and pilot-scale experiments. Field demonstration is necessary and particularly important, since it combined the complexity of in situ environments that are difficult to simulate and cover in laboratory. Thus, field demonstration will follow the lab experiments and pilot studies to validate the monitoring and remediation techniques and devices in EMR-rural. In consideration of the distinction of natural climate conditions and hydrological characteristics in different areas, field demonstration will be implemented in river network areas, mountainous regions and cold areas, respectively. To obtain applicable monitoring and remediation techniques in rural, technical parameters and processes' combinations will be optimized through demonstration. In addition, an intelligent monitoring platform, which equipped with pollution detection, classification, tracing and restoration, will be involved. This platform will take into consideration of the complexity of environmental medium and natural biogeochemical processes to form an environmental restoration system that is suitable for different spatial scales.

Conclusion

Given the goals of "the green livable village" construction, EMR-rural will provide techniques and devices for environmental monitoring and remediation with regard to soil, and underground and surface water quality in rural area. Based on the multi-disciplinary integration studies, in situ investigation, lab/pilot-scale experiment will be combined with field determination in EMR-rural to develop applicable tools for complex rural environments. This project will not only benefit to address the urgent rural environment problems, but also serve for the construction of rural revitalization and eco-environment improvement.

Abbreviations

EMR-rural: Environmental monitoring and remediation in rural project; PRA: Participatory rural appraisal; WWP: Working with people; IIRR: International Institute of Rural Reconstruction; CTA: Technical Center for Agricultural and Rural Cooperation; USDA: United States Department of Agriculture; ENRD: Office of Rural Development and European Network for Rural Development;

MOST: Ministry of Science and Technology of the People's Republic of China; MARA: Ministry of Agriculture and Rural Affairs of the People's Republic of China; CAS: Chinese Academy of Sciences; PPCPs: Pharmaceutical and personal care products; PCBs: Polychlorinated biphenyls; PAHs: Polycyclic aromatic hydrocarbons; U/S interaction: Underground/surface water interaction; D/W alternation: Alternation of drying and wetting; F/T transition: Freezing–thawing phase transition; SP: Sub-project; EDA: Effect-directed analysis.

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Authors' contributions

JGS was responsible for the general design of the review and wrote the first draft of the manuscript. ZLC, FF and YS drafted the manuscript; JLL and YXJ supported data interpretation; YYW, MHZ, ZQG and MH contributed to supported the writing of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

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

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors agreed to publish the paper.

Competing interests

The authors declare that they have no competing interests.

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