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Several major issues concerning the environmental transmission and risk prevention of SARS-CoV-2

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Abstract Coronavirus disease 2019 (COVID-19) is the most serious infectious disease pandemic in the world in a century, and has had a serious impact on the health, safety, and social and economic development of all mankind. Since the earth entered the "Anthropocene", human activities have become the most important driving force of the evolution of the earth system. At the same time, the epidemic frequency of major human infectious diseases worldwide has been increasing, with more than 70% of novel diseases having zoonotic origins. The review of several major epidemics in human history shows that there is a common rule, i.e., changes in the natural environment have an important and profound impact on the occurrence and development of epidemics. Therefore, the impact of the natural environment on the current COVID-19 pandemic and its mechanisms have become scientific issues that need to be resolved urgently. From the perspective of the natural environment, this study systematically investigated several major issues concerning the environmental transmission and risk prevention of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). From a macroscopic temporal and spatial scale, the research focus on understand the impact of the destruction of the natural environment and global changes on the outbreak of infectious diseases; the threat of zoonotic diseases to human health; the regularity for virus diffusion, migration and mutation in environmental media; the mechanisms of virus transmission from animals and environmental media to humans; and environmental safety, secondary risk prevention and control of major epidemics. Suggestions were made for future key research directions and issues that need attention, with a view to providing a reference for the prevention and control of the global coronavirus disease 2019, and to improving the ability of response to major public health emergencies.

Keywords SARS-CoV-2, Environmental transmission, Risk prevention, Zoonotic diseases, Ecological security

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1. Introduction

Coronavirus disease 2019 (COVID-19) is the most serious infectious disease pandemic to occur globally in a century. Human society has been plagued by infectious diseases at various stages in its development. The history of human development itself is a history of human struggle against infectious diseases. The occurrence and development of major infectious diseases in human history has an inherent regularity and is affected by a variety of factors. Looking

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back at past pandemics of infectious diseases in human history, it is apparent that the natural environment has an important and profound impact on their development (Jones et al., 2008; Waits et al., 2018; Wu, 2020). Human safety and health depend on a large extent on thriving, natural, and harmonious ecosystems (Whitmee et al., 2015). After the outbreak of "Severe Acute Respiratory Syndrome (SARS)" in 2003, many researchers stressed the need to ensure the safety of the natural environment (Song et al., 2004). Unfortunately, this important issue has not attracted enough attention in the human response to pandemics of infectious diseases.

In fact, viruses are important members of the earth's ecosystem. As a unique life form, they participate in various material, energy, and ecological processes (Hochella et al., 2019). The occurrence, survival, spread, and extinction of viruses must follow the objective laws of the earth's ecosystem. Theoretically, in a healthy and balanced natural ecosystem, various life forms, including viruses, microorganisms, plants, animals, and humans, can coexist dynamicly. Unfortunately, when the natural ecosystem is disturbed or even destroyed, the ecological equilibrium is broken. Ecological and environmental risks greatly increased. As a result, the possibility of human contact with infectious diseases also increased, especially zoonotic diseases. Studies of the occurrence and spread of viruses are therefore critical for the establishment of environmental security (Jiao et al., 2021; Wang et al., 2022).

Facing COVID-19 and other major epidemics that may occur in the future, we need to re-examine the role of the natural environment for the improvement on the national public health emergency system. By carefully considering the impact of the natural environment on the occurrence and development of COVID-19 (Priyadarsini et al., 2020), we will attain a deeper understanding of the generation, mutation, and environmental transmission of the new coronavirus, and develop an effective risk prevention system. Based on the concept of One Health between humans and nature, we took interaction between the natural environment and human infectious diseases as the base line, and identified the key nodes at each stage of the epidemic development (including the generation and spread of the virus, epidemic management, secondary risks, etc.) (Figure 1). From the perspectives of environmental attribution, environmental traceability, environmental transmission, and environmental risks, four issues that need to be focused on are proposed and discussed below.

2. Several major issues that need attention

2.1 Is there any connection between the destruction of the natural environment and the outbreak of human infectious diseases?

Recent studies of global environmental changes have shown that the earth has entered a geological era dominated by humans, i.e., the Anthropocene. The establishment of the Anthropocene marks a fundamental change in the relationship between humans and the earth. Human activities have become the unique most important driving force of global changes (Lewis and Maslin, 2015). Human activities emit large amounts of greenhouse gases, including carbon dioxide, leading to global warming. According to the fifth assessment report of the Intergovernmental Panel on Climate

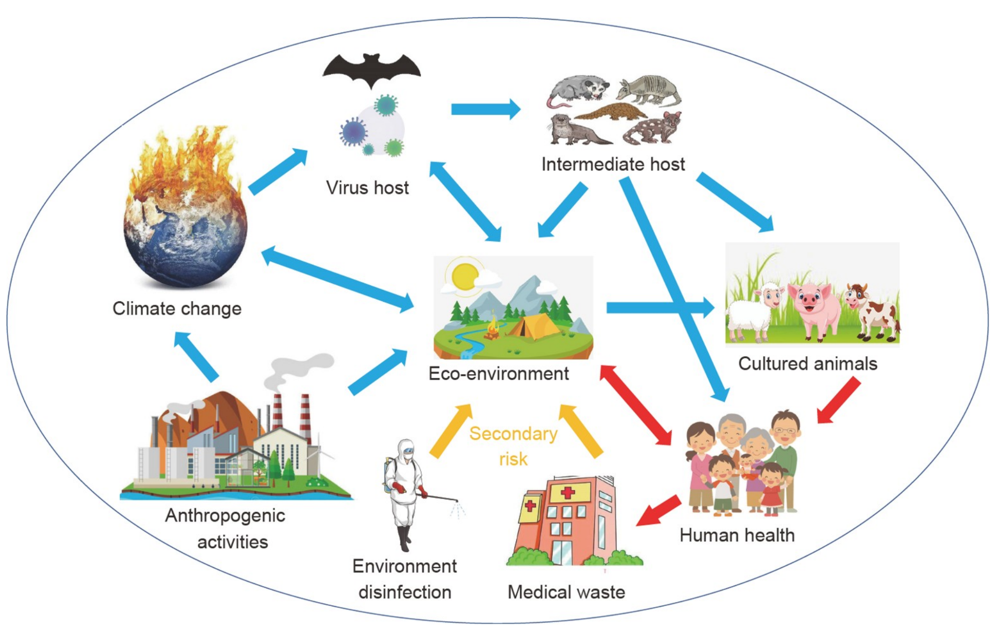

Figure 1 Conceptual diagram of the outbreak of a human infectious disease.

Change (IPCC, 2013), the average global surface temperature has increased by 0.76°C since 1850. It is estimated that the global temperature increase will be as high as 1.1 to 6.4°C by the end of the 21st century. Human activities also have serious impacts on the structure and function of the earth's ecosystem (Liski et al., 2003), causing major ecological and environmental crises, such as an abnormal climate, the loss of biodiversity, ecosystem function degradation, and species extinction (Butchart et al., 2010). Global climate change has changed the pattern and scope of the habitats for natural or intermediate host of existing viruses. As a result, promoted the spread of new infectious diseases, and posed a serious threat to human health, including the outbreak of major global pamdemic (McMichael et al., 2006; Jones et al., 2008).

The pathogens responsible for human infectious diseases mainly originate from nature. Human activities are increasingly having an impact on natural ecosystems, including ecological degradation, environmental pollution, and climate change. Under the stress of natural environment changes, microorganisms such as viruses will break through interspecies barriers and search for new host animals and/or vectors. The probability of mutations and the emergence of new pathogens have increased substantially over time, paving the way for the outbreak of human infectious diseases. Looking back on the severe epidemics occurred in human history, it has been shown a clear connection between those epidemics with the destruction of the natural environment (Waits et al., 2018; Priyadarsini et al., 2020).

The number of new human infectious diseases is increasing rapidly, and most of them have a natural foci. Currently, three or more new virus species that can affect human health are discovered every year (Woolhouse et al., 2012). Emerging infectious diseases have become a major burden on the global economy and public health. The incidence of emerging infectious diseases has increased significantly over time, with most (71.8%) being zoonotic diseases that originate from wild animals. The origin of infectious diseases is significantly related to ecological and environmental factors (Jones et al., 2008).

The impact of the natural environment on the occurrence and development of new infectious diseases is a complex process. During the different stages of the development of an epidemic, the natural environment plays different roles (Wu, 2020). From a macro-scale perspective, human activities have an important impact on global climate change and the structure and function of ecosystems, which directly or indirectly affect the occurrence, spread, and changes of infectious diseases (Shakil et al., 2020; Wang Y et al., 2020). As early as 2005, the World Health Organization (WHO) listed nine infectious diseases as climate-sensitive diseases in the field of public health, including influenza, malaria, and dengue fever. WHO also proposed an early warning system framework for climate-sensitive diseases. The framework integrates vulnerability assessment, early warning and detection, control response and post-epidemic assessment. A framework for an early warning system for climate-sensitive diseases was established (WHO, 2005). Liu et al. (2020) found that in the winter of 2017–2018, large-scale influenza outbreaks in densely populated areas in the mid-latitudes of the northern hemisphere were closely related to rapid weather changes in the early autumn. Wu et al. (2014) reported that climatic conditions limited the geographic and seasonal distribution of infectious diseases, while environmental and meteorological factors may affect the time and intensity of disease outbreaks. Climatic and meteorological factors also had an impact on the spread of SARS-CoV-2 (Baker et al., 2020). In the early stage of the SARS-CoV-2 outbreak, due to the general susceptibility of most people, the impacts of climate, meteorology, and natural environment factors on the spread of SARS-CoV-2 were limited. To prevent the spread of SARS-CoV-2 further, strong human intervention was required. With the development of the epidemic and the increasing level of herd immunity, seasonal characteristics of the spread of SARS-CoV-2 have gradually emerged (Carlson et al., 2020). Huang et al. (2020) and Liu et al. (2021) found that 60% of patients with COVID-19 live in areas where the temperature is between 5–15°C. The infectivity and lethality of COVID-19 are higher in cold seasons, and there is an obvious seasonality of COVID-19 in high latitudes, which further explained the impact of temperature on the disease. These studies provide an important reference for countries around the world, enabling them to formulate more scientific, reasonable, and targeted epidemic prevention and control strategies.

Due to global land use changes caused by human activities, pathogenic microorganisms and their host animal habitats have become fragmented, forcing the migration of virus host habitats. This has resulted in changes in their community structure, sometimes with the loss of organisms that originally had natural disease control effects. The disappearance of these ecological barriers will result in a "coevolution effect" locally, which will accelerate the increase in the diversity of pathogenic microorganisms, thereby increasing the probability of the spread of infectious diseases across species (Zohdy et al., 2019). Gislason (2015) found that human encroachment on the forest habitat of bats and other wild animals is an important factor in the spread of the Ebola virus. Jones et al. (2008) studied the spatial distribution characteristics of the global relative risk of emerging infectious diseases caused by wild animal pathogens. It is found that the relative risk in some areas of China is high and needs attention. In addition, some disease outbreaks have obvious temporal and spatial distribution characteristics. For example, besides the long-term upward trends and short-term fluctuations, China's historical epidemics have also displayed seasonal differences. Epidemics are most prevalent in the relatively warm and wet summer and autumn seasons. In the past 2200 years, the cumulative number of epidemic years in China has displayed a gradual decrease from the southeast to the northwest. It is consistent with the spatial pattern of the country's physical geographic zones (Gong et al., 2020).

The natural environment has an important impact on emerging infectious diseases. However, the mechanism by which the occurrence of infectious diseases and changes in the natural environment interact is still unclear. To reduce the risk of emerging infectious diseases (especially zoonotic diseases) effectively, there is a need to first consider the problem from the perspective of the natural environment, i.e., "take preventive measures". From the perspective of the natural environment, it is important to study the evolution, transmission, and spread of pathogens, including viruses, and their key influencing factors. This will be helpful to predict the occurrence and development of potential new infectious diseases and their temporal and spatial characteristics. To achieve an early warning and prevention system, there is a need to build an ecological barrier as an initial firewall to prevent major human epidemics. This would substantially reduce the impact of epidemics on human society.

2.2 How can the threat of zoonotic diseases to human health be effectively prevented?

As mentioned above, the earth has entered the Anthropocene, and human activities have an important impact on the earth's ecosystem. Due to global changes and changes in the structure and function of the earth's ecosystems, the habitat of wild animals has been severely damaged. The chances of human contact with wild animals has greatly increased, which in turn leads to a greatly increased risk of zoonotic diseases, i.e., "zoonotic spillover". Hence, we have also entered a pan-epidemic Anthropocene (Lucey et al., 2017).

Allen et al. (2017) found that most of the new and recurring infectious diseases are zoonotic diseases, including atypical pneumonia, avian influenza, and rabies. The natural and intermediate hosts of the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV) that caused the "SARS" epidemic in 2003 were likely to have been wild animals, such as bats, monkeys, and civet cats. The virus was transmitted to humans through human capture, and the subsequent transportation, sale, and consumption of animals (Wang et al., 2006). In 2012, there was an outbreak of Middle East Respiratory Syndrome (MERS) in the Kingdom of Saudi Arabia. The pathogen was Middle East Respiratory Syndrome Coronavirus (MERS-CoV). In 2014, the Swine Acute Diarrhea Syndrome Coronavirus (SADS-CoV) caused a serious level of fatality in pigs, destroying livestock production in Qingyuan, Guangdong, China (Ding et al., 2020). It should be noted that SARS-CoV, MERS-CoV, and SADS-CoV, are all coronaviruses, while another new type of coronavirus (SARS-CoV-2) caused COVID-19. Coronaviruses are widespread in nature. They can infect various domestic animals, birds, wild animals, and humans, resulting in diseases affecting the respiratory tract, gastrointestinal tract, liver, genitourinary tract, and nervous system (Chafekar and Fielding, 2018). Bats are considered to be particularly important hosts of coronaviruses. Genome sequencing studies have shown that there are at least 30 types of coronaviruses in bats, while bats that have not been sequenced may carry many more types of coronaviruses (Wong et al., 2019).

The destruction of the natural environment caused by human activities leads to changes in the behavior of wild animals, making it easier to spread pathogenic microorganisms to domestic animals and humans, and increasing the risk of outbreaks of infectious diseases (Karesh et al., 2012). It was estimated that between 1968 and 2005, the population of China nearly doubled (from 790 million to 1.3 billion), while the number of pigs raised increased nearly 100 times (from 5.2 million to 508 million heads) during this period (Osterholm, 2005). With the changes in agricultural production and human lifestyles, the number, type, and scale of domesticated, reared, and utilized animals has greatly increased, which has greatly increased the chances of human contact with host animals. As a result, the potential risk for outbreaks of epidemics also increased (Daszak et al., 2000). During the COVID-19 epidemic, Danish mink was infected with SARS-CoV-2, which led to the infection of farm workers. This is a common situation, with numerous examples of viruses infecting humans through both wild and farmed animals.

In addition, it should be noted that rapid urbanization had a profound impact on global health problems. There is a need to carefully examine the relationship between epidemics and urbanization (Tian et al., 2018; Gu, 2019). The frequent outbreaks of global infectious diseases indicate that cities have become the centers of the spread of epidemics. More importantly, most developing countries have not yet completed the transition of healthy lifestyles alongside urbanization, and infectious diseases are still the leading cause of mortality and morbidity in developing countries (Alirol et al., 2011).

The rapid global urbanization process has objectively created convenient conditions for "zoonotic spillover". Some factors have led to a high risk of disease transmission in large cities, such as the spatial proximity of the urban population, the heterogeneity of residents' health, frequent mutual contact, and high population mobility. Cities have become incubators of infectious diseases (Qin et al., 2021). In addition, compared with natural ecosystems, in highly artificial urban ecosystems, the population, structure, and function of animals, plants, and microorganisms have undergone drastic changes, which has increased the risk of urban infectious diseases occurring and spreading. For example, the prevalence of Leishmaniasis, an increasingly serious zoonotic disease in Latin American cities, is closely related to urbanization. Animals such as chickens, pigs, and dogs raised in cities have become breeding grounds for Leishmania. Poor sanitary conditions and changes in the vector ecosystem have caused Leishmania to multiply and infect humans through various routes of contact, leading to the spread of Leishmaniasis (Marcondes and Day, 2019).

Historically, there have been attempts to understand the occurrence of infectious diseases through the interaction between a single host and a single parasite. However, in many situations, new infectious diseases are often embedded in a complex network of interactions between multiple hosts and carriers. Therefore, traditional one-to-one biomedical methods may not be effective for determining the occurrence of new diseases (Johnson et al., 2015). It should be noted that our understanding of viruses and other microorganisms is still very limited. It has been estimated (Anthony et al., 2013) that there are more than 320,000 different viruses that can cause mammalian infections in nature, of which more than 200 can infect humans (Woolhouse et al., 2012). However, due to the lack of rapid, accurate, and reliable detection and diagnosis technology, only a very limited number of known pathogens (0.07% of all viruses) can currently be detected and diagnosed (Kiselev et al., 2020).

How many kinds of viruses exist in nature, how they exist, how they spread, and whether they pose a threat to human health are urgent questions that need to be answered. Therefore, it is necessary to carry out systematic investigations and research on pathogenic microorganisms, including viruses in the environment. Such studies should consider their types, hosts, genomes, pedigrees, mutations, and distribution characteristics. Based on these studies, we could continuously establish and improve database resources. For example, virus resource databases, natural epidemic-borne virus comprehensive application databases, and zoonotic disease virus databases. On this basis, it may be possible to use efficient mathematical algorithms in the future, including machine learning, to compare the genome of an unknown virus with all available viral genomes and predict its possible characteristics, including its pathogenic potential (Kiselev et al., 2020). This would provide scientific and technological support for the response to unknown human infectious diseases.

In addition, the spread of viruses by birds and other long-distance migratory animals cannot be ignored. For example, Altizer et al. (2013) reported that birds carrying avian influenza viruses may be responsible for the long-distance or even intercontinental transmission of the virus through migratory behavior. In addition, the spread of viruses by the migration of aquatic animals is also worthy of attention. These concerns have also provided guidance for studying the environmental transmission of SARS-CoV-2, and have sounded the alarm for the global prevention and control of COVID-19.

There is a need to consider human health and disease from a macro and more inclusive perspective. Human health is closely related to the health of the earth's ecosystem and its animals. Humans cannot be independent of the earth's ecosystem. There is a need to use a collaborative, multi-sectoral, and interdisciplinary approach to re-evaluate the relationships between humans, animals, and the natural environment at local, regional, national, and global levels. By reducing the interference of human activities to protect the diversity of wild animals, the possibility of outbreaks of zoonotic diseases will be reduced in the future, thereby protecting human health and wellbeing (Jones et al., 2008).

2.3 Can environmental media become the media for virus transmission?

As a unique nanoparticle or substance, viruses participate in environmental biogeochemical cycles and various ecological processes. Environmental media (water, air, soil, etc.) play an important role in the various transmission and migration pathways of viruses. The mechanism of virus transfer and interaction in environmental multi-media has become a hot spot in the field of environmental science research (Bofill-Mas and Girones, 2003; Wu, 2020; Yao et al., 2020; Yeo et al., 2020). Many recent studies have confirmed that SARS-CoV-2 can spread through a variety of environmental media. For example, aerosol, droplet, and contact transmission have been confirmed to be the transmission route of SARS-CoV-2. Ma et al. (2021) collected the exhaled condensate of patients with COVID-19 and conducted a reverse transcription polymerase chain reaction (RT-PCR). The results showed that COVID-19 patients emitted a large number (several million per hour) of SARS-CoV-2 particles through their breath. In addition to aerosol transmission, many viruses, including SARS-CoV-2, can survive in environmental media, such as surface water (Wang Y et al., 2020), sewage (Wigginton et al., 2015), groundwater (Li R et al., 2020), and the floor of the wards of COVID-19 patients (Ong et al., 2020). This may cause human infection and, therefore, needs to be taken seriously.

Researchers from many countries have detected SARS-CoV-2 in sewage samples from wastewater treatment plants. This discovery has provided a new way to monitor the prevalence of COVID-19 (Michael-Kordatou et al., 2020). As an infectious virus, it takes a certain amount of time for humans to develop symptoms from the time they are infected with SARS-CoV-2. There are even asymptomatic infections, which present great challenges to the prevention and control of the disease. To monitor the prevalence of COVID-19, various forms of monitoring have been conducted worldwide, including: clinical monitoring, key population screening, symptom monitoring, serum antibody monitoring, and molecular epidemiological monitoring. Monitoring of the aquatic environment has occurred through wastewater monitoring, and can be used as an important supplement to the monitoring of COVID-19. Through sewage epidemiological monitoring, SARS-CoV-2 can be detected 3–7 days earlier than the detection of the infected person, which can provide sufficient time for COVID-19 prevention and control.

The Netherlands began to monitor the nucleic acids of SARS-CoV-2 in sewage samples from wastewater treatment plants as early as February 2020. The detection of the nucleic acids of SARS-CoV-2 in sewage samples started with the emergence of cases, and the latest detection was more than three days before the occurrence of a local case. More than 300 Chinese wastewater treatment plants have incorporated routine sewage monitoring into the national COVID-19 monitoring program. Australia and other countries are also actively conducting sewage monitoring to provide support for COVID-19 prevention and control. China's COVID-19 prevention and control response has become routine, in which sewage monitoring can help to detect COVID-19 in a timely, rapid, and accurate manner, especially in key locations such as hospitals and isolation areas. Therefore, it is recommended that China should monitor sewage as an epidemiological approach and include such monitoring as part of its standard prevention and control measures.

Soil is also a virus reservoir, whose role in the process of virus transmission cannot be ignored (Yoshimoto et al., 2012; Wang, 2017). Various pathogens in the soil, including viruses, may also cause animal and human infections, leading to severe epidemics of infectious diseases (Wu et al., 2020). A large number of unknown pathogenic bacteria and viruses are dormant in the soil environment. Global warming may promote the activation and release of these microorganisms, some of which can directly infect humans and animals, having the potential to cause a pandemic. For example, *Bacillus anthracis* hides in the soil in the form of endospores. They can be inhaled by humans or animals under extreme weather conditions, causing the infection with anthrax (Qian et al., 2021). Kupferschmidt (2013) found that humans may be infected with MERS-CoV through contact with soil contaminated by bat feces. It was indicated that Hepatitis A can survive in soil for 13 weeks at 37°C (Parashar et al., 2011). The hepatitis A virus was detected in 19.1% of 403 soil samples collected near the Sam River in India. Humans may be infected through contact with these virus-contaminated soils.

Studies of the traceability and transmission of SARS-CoV-2 are continuing, and it has not been ruled out that animals or humans may be infected by soil contaminated by SARS-CoV-2 (Steffan et al., 2020). In addition to the direct exposure to soil contaminated by the virus, the virus stored in the soil may also cause more widespread transmission through surface runoff or infiltration contaminated groundwater. Viruses, pathogens, and microorganisms in soil play a vital role in ecosystem health, human health, and even planetary health. They need to be taken seriously and given more attention (Zhu et al., 2019).

In addition to the environmental media, the researchers also detected SARS-CoV-2 on the surface of a variety of objects and analyzed its survival time and influencing factors. Doremalen et al. (2020) found that under a temperature of 21–23°C and a relative humidity of 65%, SARS-CoV-2 can only survive in aerosols for 3 h, while under low temperature (21–23°C) and low humidity (40%) conditions, SARS-CoV-2 survived on copper, cardboard, stainless steel, and plastic surfaces for 8, 24, 48, and 72 h, respectively. Recently, SARS-CoV-2 has been detected in the outer packaging of a variety of imported cold chain foods in many places in China. A variety of viruses other than SARS-CoV-2 can survive on the surfaces of inert objects for a certain period of time, which needs to be considered in the formulation of prevention and control measures (Yang et al., 2020).

On November 8, 2020, Chinese government issued the "Preventive and comprehensive disinfection work plan for imported cold chain food". This plan is applicable to the disinfection of vehicles used in imported cold chain food during loading and transportation, as well as the internal and external packaging of products. On the basis of the testing of imported cold-chain food for SARS-CoV-2, consideration should be given to the effect of disinfection on SARS-CoV-2, which could effectively prevent the risk of contracting SARS-CoV-2 from imported cold-chain food. In addition, there have been incidents of human infections caused by contact with containers contaminated by SARS-CoV-2. As the COVID-19 epidemic has progressed, people have developed a deeper understanding of the factors controlling the spread of SARS-CoV-2. China's prevention and control strategy has also changed from "preventing infection from people to people" to "preventing infection from people and objects to people jointly". With the continuous expansion of research, the prevention and control strategies of China and other countries will be further improved in the future.

2.4 How can turn effectively the secondary environmental risks caused by COVID-19 into safety?

As mentioned earlier, there are complex interactions between viruses and environmental media. Environmental media are an important carrier of virus transmission. Meanwhile, Environmental media are also a major receptor for the secondary environmental risks and ecological damage caused by COVID-19. Establishment on a coordinated control system for COVID-19 prevention and control with secondary environmental risks management, will be of important practical and long-term significance for disease prevention and control, as well as environmental safety guarantees. It will improve the national public health emergency management system, and the country's capability to handle major public health incidents (Wu, 2020).

(1) Medical waste may result a risk of secondary spread of the virus. Improper disposal of medical waste may also generate potential secondary risks in response to the COVID-19 epidemic. On January 21, 2020, the Ministry of Ecology and Environment issued the "Notice about attention matters in the Environmental Management of Medical Wastes in the COVID-19 Epidemic", and subsequently issued the "Technical Guidelines for the Emergency Disposal and Management of Pneumonia Epidemic Medical Waste Caused by the COVID-19 Epidemic (Trial Implementation)", to guide all localities in the safe and standardized handling of medical waste. To prevent effectively the risk of COVID-19 passing through the medical waste collection and transfer stage, it is necessary to ensure that all medical wastes are collected and processed in a centralized manner. This will also be helpful to avoid secondary disasters caused by COVID-19 and secondary pollution caused by medical waste. Various health departments have introduced individual medical waste-related management plans, which have effectively blocked the transmission of SARS-CoV-2 through medical waste. However, there are still some urgent problems that need to be solved, such as the lack of research regarding the methods used to assess secondary risks, lack of environmental biosafety control standards in medical waste collection facilities, insufficient understanding of medical waste management by grassroots personnel, and imperfect medical waste emergency management systems (Luo et al., 2020).

(2) Large amounts of disinfectant entering the natural environment can present serious secondary contamination risks. During the COVID-19 epidemic, due to the excessive disinfection rates by concerned urban residents (Li X N et al., 2020), various disinfectants were applied in large quantities. Disinfectants entering soil, water, and other environmental media will inevitably have potential impacts on the natural environment (Zhu et al., 2020). On February 18, 2020, the National Health Commission issued the "Guidelines for the Use of Disinfectants" to guide the public use disinfectants correctly, and ensure the effective role of disinfectants. It was clearly stated that, "Carry out large-scale disinfection of the outdoor environment was not recommended." However, a large amount of disinfectant still enters environmental media. During the COVID-19 epidemic, chlorine-containing disinfectants (e.g., sodium hypochlorite) were used in large or even excessive quantities throughout the country. Residual chlorine will inevitably enter environmental water bodies and then generate a variety of toxic by-products (neurotoxicity, cytotoxicity, genotoxicity, etc.), causing long-term potential secondary risks. In addition, residual chlorine can cause the loss of nitrifying microorganisms and affect the natural water nitrogen cycle. It can also reduce the self-purification ability of the water, and cause harm to the aquatic environment and aquatic organisms (Chu et al., 2020; Zhang et al., 2020).

On January 31, 2020, the Ministry of Ecology and Environment issued the "Emergency Surveillance Plan for Responding to the COVID-19 Epidemic", which stated that, "During the COVID-19 prevention and control period, except for the routine monitoring of drinking water sources, the monitoring of the characteristics of COVID-19 prevention and control, such as residual chlorine and biological toxicity, need to be conducted. If there is any abnormal situation, measures should be taken timely to ensure the safety of the people's drinking water." Researchers have conducted studies of the secondary risks to the water environment under the enhanced disinfection of sewage treatment plants. It was recommended to monitor and evaluate the microorganisms and disinfection by-products in the water of key epidemic areas. In addition, the receiving water bodies of sewage treatment plants should be monitored to prevent ecological damage.

Studies of the secondary risks during and after the epidemic are still very limited. In particular, there have been few reports of the type, concentration, migration and transformation, and ecological toxicity of disinfection by-products in soil and other environmental media. There is still a lack of in-depth and systematic research on the extent, scope, and mechanism of secondary risks. During sewage treatment, air purification, municipal waste treatment, and environmental disinfection, excessive use of anti-COVID-19 chemicals may produce poisonous by-products. Hence, there is an urgent need to conduct research on poisonous by-products prevention and control mechanisms. There is also a need to achieve a coordinated approach to the safe inactivation of viruses and the blocking of secondary environmental risks. All of these will provide a scientific basis for formulating effective, economic, and safe prevention and control countermeasures.

3. Suggestions

Currently, COVID-19 is still spreading globally, which will have a huge impact on both human health and economic and social development. In the face of COVID-19, there is a need to adhere to scientific prevention and control, implement precise control policies, and maintain a respect for nature to ensure the harmonious coexistence of humans and nature. To solve the current crisis and those posed by future epidemics, in addition to the development of vaccines and drugs, there is also an urgent need to provide scientific, effective, and sustainable solutions based on earth system science and the integrated protection and control of the environment and health (Wu, 2020). The following are suggestions for ways to achieve this goal.

(1) Carry out multidisciplinary joint research. Multi-disciplinary studies will enable the integration of natural factors (e.g., climate, geography, geology, ecology, environment, etc.) and socioeconomic factors. Such studies will combine the advantages of environmental science, ecology, biology, chemistry, botany, zoology, and other disciplines, and conduct integrated and in-depth research on phenomena, mechanisms, and processes. Key scientific issues could potentially be resolved, such as the mechanism by which the evolution of natural ecosystems affects the production and mutation of SARS-CoV-2 and related viruses in the context of global climate change. This will inform both national and global efforts to prevent and control COVID-19. In particular, consideration must be given to the important roles of earth science and environmental science. From the perspective of the formation and evolution of the earth system, using the methodologies adopted in the disciplines of earth science and environmental science will help to detect new viruses and the epidemics in a timely manner, enabling the provision of early warning systems. This will change the way humans respond to and deal with public health emergencies, from a "passive response" to an "active defense".

(2) Conduct in-depth research on virus identification and transmission in environmental media. To deal effectively with the environmental spread of SARS-CoV-2, it is necessary to conduct in-depth research to determine rapid and accurate detection methods for SARS-CoV-2 in various environmental media, such as air, water, soil, and garbage, and to develop quantitative identification techniques to assess the survival of SARS-CoV-2. There is also a need to determine how SARS-CoV-2 passes through single-, cross-, and multi-medium transmission channels, and its associated activity changes; and to clarify the mechanisms of key factors, such as environmental temperature, humidity, physicochemical media, and biological properties on the survival ability and transmission flux of SARS-CoV-2.

(3) Gradually establish and improve the environmental emergency response and management mechanisms for major human epidemics. Environmental emergency management during major epidemics is a key feature of the modern environmental governance system, which should be improved rapidly and significantly. It is recommended to incorporate the environmental emergency management of epidemics into relevant laws and regulations. This will provide a legal basis for environmental emergency management. The linkage with the health department needs to be strengthened, with a focus on environmental emergency management in public health incidents. There is also a need to construct basic environmental emergency response capabilities, improve the ability of environmental emergency response teams. In addition, the monitoring of biological indicators should be incorporated into the scope of daily and emergency monitoring of the environment, and develop relevant instrument and equipment. This will ensure that the role of environmental monitoring in the response, monitoring, and early warning of public health emergency are fully utilized.

(4) Carry out a comprehensive assessment of the secondary risks for the natural environment during major epidemics and determine related prevention and control strategies. Carry out in-depth research on the mechanism by which environmental secondary risks and ecological damage are caused by drugs and chemicals during major epidemics. Explore the concentrations and factors affecting the migration and transformation of typical drugs, chemicals, and their secondary products in different environmental media. Dosages and control methods should be optimized for anti-epidemic drugs and chemicals in major epidemics. In response to the COVID-19 epidemic and other possible major epidemics in the future, there is an urgent need to build a multi-scale systemic risk assessment method covering factors such as viruses/anti-epidemic chemicals, multi-media/multi-channel transmission, environmental pollution, and ecological damage. It is urgent to develop predictive models for the accumulation, outbreak, and prevention of the environmental secondary risks of major epidemics. In addition, strategies for environmental security and secondary risk control should be established based on big data, artificial intelligence, and other technologies. All of these measures could effectively serve the national epidemic prevention and control system.

(5) Exploit the comprehensive advantages of environmental science to perfect the construction of a national public health emergency system. The important factor, namely the natural environment, should be considered in China's emergency response system. The management should be applied in the whole process, namely before, during, and after public health emergencies. It is necessary to strengthen natural environmental protection and the routine investigations of biological pollution. Additionally, there is a need to develop monitoring techniques and equipment for viruses and pathogens in environmental media, and improve the early warning system. It is also necessary to strengthen the study of virus survival and transmission behavior, prevent secondary environmental risks, and evaluate the risks of viruses in the environment to human health. It is then necessary to prevent another outbreak of an epidemic, improve the emergency response system for public health emergen-

cies, and therefore achieve sustainable development. Environmental research should play a significant role in the response, monitoring, and early warning of public health incidents.

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