Analysis of the Current Situation and Countermeasures of China's Soil Contamination

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***Abstract*—Soil contamination directly concerns the safety of food, ecological environment, public's health and capacity of social sustainable development. According to China's official report, the overall status of China's soil environment is not good, about 16.1% of China's soil, 19.4% of its arable land, 10.4% of grassland, 10% of forest land and 34.9% of brownfields are polluted by heavy metals and pesticides and far beyond national pollution standards. It's an urgent issue for China to curb continual deterioration of soil pollution and remediate contaminated soil as soon as possible to decrease harm on people's health and ecological environment. In fact, China has also already accelerated related legislation, increased capital investment and technical development to remediate soil contamination and achieved some progress. However, due to all sorts of the constraints, whether soil management system or technical capacity for decontamination in China is relatively outdated, so there remains a lot of work need to be done. It isn't unique to China, other developing countries, including Brazil, India and so on, are also facing similar problems. As the largest developing country in the world, China's experiences, lessons and approaches to solve soil problems could benefit other developing countries in process of industrialization and urbanization, so it's a very meaningful job to deep analyze and study the current situation and countermeasures of China's soil pollution. In this paper, the overall situation of China's soil pollution is introduced, the concrete causes and hazards of China's soil contamination are analyzed, and the suggestions and advice related to soil remediation are recommended in order to improve the status of soil contamination and enhance social sustainable capacity.**

***Index Terms*—Soil pollution, soil protection, soil legislation, soil decontamination.**

I. Introduction

Soil pollution primarily originating from industrial activities, mining, mechanized agriculture, improper disposal of waste etc., has already constituted new risks to public health and the environment. Compared with advanced economies and developed countries affected by soil problems, developing countries are facing more serious challenges of soil contamination. As the biggest developing country in the world, China's "Economic Miracle" succeeded to absorb much attention coming from all over the world in past 30 years. In the meanwhile, increasingly serious environmental pollution in China is attracting more and more attention, from toxic soil to water contamination, from smog to offshore pollution, severe polluting situation not only greatly damaged national ecological environment, but also harmed to public's health.

In contrast with water pollution and air pollution, soil pollution is a hidden pollution, which attracted less attention for a long time in China. However, constantly exploding scandals involving the soil contamination in recent years, for examples, toxic cadmium rice happened in China's Hunan province in 2013 [1], the case of China's "toxic school" happened [2] in 2016, have aroused a growing concern about soil pollution in China, especially in the academic circle. More and more research has been devoted to seeking innovative and sustainable solutions for the remediation of soil contamination. Among of these, some scholars focused on the research of soil heavy metal pollution and agricultural soil contamination, others paid more attention on the study of soil remediation policies and laws. For instance, the research of Xiuying Zhang *et al*. showed that Cd had the highest pollution rate of 7.75%, followed by Hg, Cu, Ni, Zn, Pb and Cr, and about 13.86% of grain production was influenced because of heavy metal pollution farmland soil [3]; Ruishan Chen *et al.* thought that farmers should be encourage to decrease heavy input of chemicals in order to guarantee the cultivated land [4]; Hong Yang insisted that China's soil plan need strong support coming from laws and technology [5]; Changsheng Qu *et al*. argued that soil clean-up not only needs funding but also streamlines the administration and supervision [6]; Yang Zhou *et al*. proposed that China should strengthen its soil pollution prevention and control through consistent legislation [7].

There are various complex factors responsible for soil contamination, including overall industrial level, environmental policy and related soil legislation, environmental technical capacity, social culture and so on. Thus, confronting with sophisticated condition of soil, it's essential to take comprehensive and coordinative measures to govern soil pollution, any single or some means is powerless to solve these issues. In this paper, beginning with the overall introduction of China's soil pollution status, then the concrete causes and hazards of China's soil contamination are analyzed, after that the suggestions and advice related to soil decontamination are recommended in order to improve the status of soil contamination and enhance social sustainable capacity.

II. The Current Situation of China's Soil Pollution

In a long term, as the lack of precise and larger scale's soil investigation, the exact data of soil contamination in China is inexplicit, even if sometimes there is some limited data related to the soil contamination, official institutions have always, intentionally or unintentionally, avoided this

Manuscript received October 4, 2019; revised March 31, 2020.

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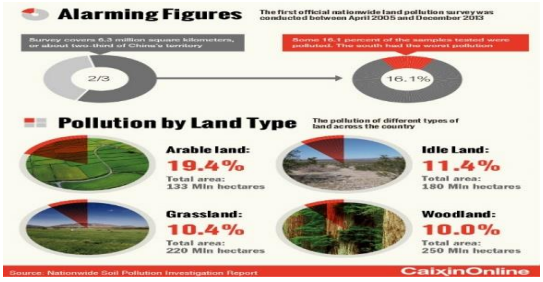
sensitive issue. From April 2005, China's Ministry of Environment Protect and the Ministry of Land and Resources had carried out an extensive survey, which ended in December 2013, spent about one billion yuan, covered around 630 square kilometers of land across the country (about two-thirds of China's land area) and took around 100,000 samples [8].

In Aril 2014, the government released the investigation bulletin of national soil pollution about this soil survey. According the official bulletin, the overall situation of China's soil environment is not good, about 16.1% of China's soil, 19.4% of its arable land, 10.4% of grassland and 10% of forest land were polluted (Table I). The distribution of national soil contamination is unbalanced, soil pollution in China's south is serious than the north. Most of the affected farmland lies along the eastern coast which is the most developed region and home to much of the country's heavy and chemical industry, such as in the Yangzi River Delta, Pearl River Delta and so forth. Heavy metal pollution is prevalent in South Central and southwest regions. About 82.8% of the polluted land was contaminated by inorganic materials. The main pollutants include Cadmium, Nickel, Coper, Zinc, Mercury, Arsenic etc., among of these, Cadmium, Nickel and Arsenic are the top three pollutants found [9].

TABLE I: THE DATA OF CHINA'S SOIL CONTAMINATION



Compared with a previous small-scale survey conducted in the 1980s, available data indicated a significant increase in inorganic pollutants in surface soil. The increase in Cadmium content has been nationwide, with a 50% increase in the southwest and coastal areas and a 10%-40% increase in eastern, north-eastern and western regions [10] (Table II). Obviously, it is difficult to make any judgement on these limited and no detailed information. Moreover, because the size of each sample represented is too big to provide an accurate estimate of the polluted area in China, but published results still reflected the serious situation of current nationwide soil pollution.

TABLE II: THE SITUATION OF CHINA'S SOIL CONTAMINAITON

III. THE MAIN CAUSES OF CHINA'S SOIL CONTAMINATION

As an open and complex system, the quality of soil environment at a large extent is superimposed by external multiple factors. In the last three decade years, the explosive and extensive economic growth, the implement glitch and lack of soil protection and management policy, rapid industrialization with high pollution emission, large-scale urbanization, inappropriate use of fertilizers and chemical pesticide, and the use of polluted water for irrigation have jointly lead to the increasingly serious soil contamination in China.

A. The Polluting Emission of Industrial and Mining Enterprises Is the Most Important and Direct Cause of Soil Contamination

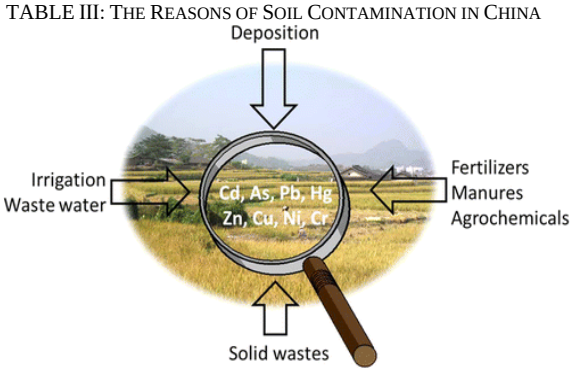
The pollution of industrial enterprises. Since the reform and opening in 1978, because of backward industrial productive level, the model of China's economic growth remained extensive, characterized by more input and less output, high pollution and poor profit, and the inefficient use and waste of resources [11]. The development of China's industry mainly concentrated on the blossom of the heavy-chemical industrial enterprises, most of which are built around cities, lakes and upper reaches of rivers. During the production process of these high-polluting enterprises, due to the outdated technological capacity, the aging of equipment, the poor awareness of environmental protection, the implement laxity of environmental protection policy and law, uncontrolled pollutant emission not only caused the surrounding soil pollution of these enterprises, but also polluted the neighbor lakes and rivers because of the discharge of industrial effluent, which maybe contained heavy metals and toxic chemical substance, then a large area of soil was polluted when farmers used the polluted water of these lakes and rivers for irrigation of crops (Table III). In addition, the leak of chemical substance and industrial product also migrated directly into the soil and resulted in the soil pollution. According to the related research, every year in China about 600 thousand of ton oil permeated the soil. From the 1990s, accompanying the adjustment of China's industrial structure and the land planning and utilization, a large amount of the most polluting industries were relocated and shut down, as much legacies of soil pollution left by these industries aren't be resolved timely and scientifically due to various reasons, then became new pollutant sources and posed a new threat to surrounding soil [12].

The pollution of mining enterprises. Except for the polluting industries, the activities of mining companies also gave rise to extensive soil pollution. Non-ferrous and black metal metallurgy is the leading cause of soil pollution in mining region and mining resourced-typed city. A great deal of dust, which contained heavy metal and harmful substance, was produced in the process of open cut mining and metal smelting, and then caused the heavy metal pollution of neighboring soil. Meanwhile, the effluent of mining companies directly discharged into soil without any treatment intensified the periphery soil contamination. Besides, in the exploitation process of mineral resources, large amount of barren rock, mill tailings, waste residue and coal ash open stacked on the earth's surface, finally entered into the soil in

various forms through the weathering, activation eluviation and so on [12] (Table III), which further deteriorated soil environment.

The pollution of energy burning, especially coal combustion. In the structure of China's energy, coal accounted for about 66% [13], is still the dominant fuel of China's energy consumption. Burning coal produced much sulfur dioxide (SO2), nitrogen oxides (NOx), mercury, particulate matter, and other toxic substance, most of which eventually entered into the soil by means of atmosphere sedimentation, gradually accumulated in the soil, furtherly caused regional soil pollution or large scale soil pollution (Table III).

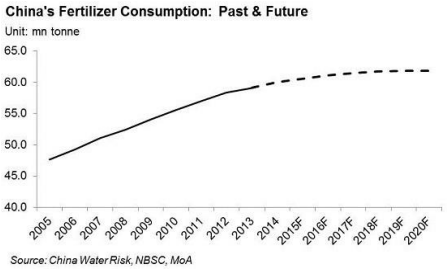
TABLE III: THE REASONS OF SOIL CONTAMINATION IN CHINA



B. The Overuse of Fertilizers and Pesticide Is an Important Reason of China's Soil Contamination

China is the biggest consumer of fertilizer and pesticide in the world. China consumes around a third of global fertilizers, with rapid growth in use in recent years driven largely by higher fruit and vegetable production. Over the past three decades, China's use of chemical fertilizer grew by an average 5.2 percent a year, reaching 59 million ton in 2013 (Table IV). China's vice agriculture minister Zhang Taolin said, growers apply 550 kgs of fertilizer to a hectare of fruit trees and 365 kgs of fertilizer to a hectare of vegetables, World Bank data showed China used 647.6 kgs of fertilizer per hectare of arable land in 2012, compared with 131 kgs in the United States and 124.3 kgs in Spain [14].

TABLE IV: CHINA'S FERTILIZER CONSUMPTION: PAST AND FUTURE



Alongside overuse there is misuse, which lowers uptakes rates – only 30% of the fertilizer China applied virtually do any good, much lower than the 40% rates in developed countries. A survey by agricultural authorities in Henan Province found that only one-third of the three million tons of fertilizer used was really absorbed by crops. Besides, China consumes 310 thousand of ton pesticide each year, the utilization rate accounts for about 35% [15]. The misuse of pesticides is reaching a tipping point. What's more, now Chinese agriculture has become reliant on these chemicals. As year-round planting requires the large-scale use of pesticides and fertilize, which inevitably create soil and water pollution. That in turn implies more fertilizer and pesticides are needed, causing a vicious cycle.

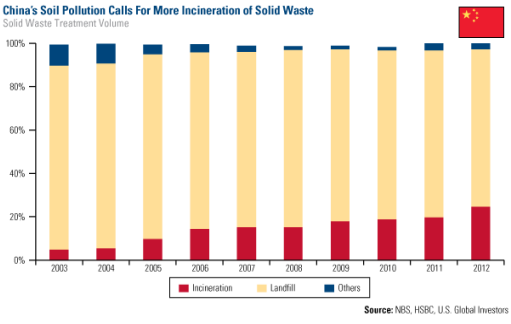
The unused fertilizer and pesticide lead to soil pollution with heavy metal and groundwater contamination (Table III). High pesticide residues on food, threatening both public health and agricultural productivity. A Chinese Academy of Agricultural Sciences' (CAAS) survey of intensive vegetable farms in 20 counties in five Northern provinces found that half of 800 points surveyed had excessive levels of nitrates in ground water attributable to fertilizer [15]. At present, agricultural non-point source pollution is worsening, exacerbating the risk of soil and water pollution.

Moreover, when these chemical fertilizer and pesticide sept into the ground after they mixed with water and slowly reduced the fertility of the soil, they would damage soil's composition and make it easier to erode by water and air. Plants absorbed many of these chemicals and when they decomposed, they also caused soil pollution because they became a part of the land.

C. The Improper Disposal of Household Solid Waste in China's Urban and Suburb Area Is Intensifying the Soil Pollution

Except that industrial and mining enterprise's solid waste brought about soil pollution, China's urban and suburb's household solid waste has been resulting to more and more serious soil pollution. In China, there was no classification and recycle system for solid waste by the end of 2018, the rate of waste incineration in China is very low compared with Japan (Table V), most household waste in cities were piled up and abandoned in housing estate's or roadside's garbage cans, then these rubbish were transferred to the waste landfill sites or the open dumping sites around the urban area. With the rapid growth of urban household waste, many cities were surrounded by increasingly enormous garbage cans, as these landfills occupied a great number of lands, and thus sharpened soil contamination. In China's rural area, most villages have no garbage cans and sewerage system, people usually threw away rubbish and dumped sewage randomly, which intensified the farmland's pollution. When solid waste is piled up in the open area, the pollutants may dissolve, seep, drain and permeate into the ground surface with rainwater after being washed by rain for long, then polluting groundwater plus rivers and lakes, and further endangering farmland, aquatic products and human health (Table III).

TABLE V: CHINA'S SOIL POLLUTION CALLS FOR MORE INCINERATION OF SOLID WASTE



D. The Lack and Lax Implementation of Soil Protection Policy and the Poor National Environmental Right Are Also Accounting for the Soil Contamination

In China, the arable land protection is always regarded as the fundamental national policy status. However, in the process of China's industrialization and urbanization since 1980s, in order to pursue immediate economic self-interest, this policy has been weakened, even be ignored, which is the underlying reasons of soil deterioration.

Compared with the western developed countries, China's soil pollution management started late. Although a major milestone in Chinese soil pollution management began in 2005, China had no specialized designed national-level law to address the soil pollution crisis before the law on the Prevention and Control of Soil Pollution came into effect on 1 January in 2019. There were only some national laws that scattered the soil of contaminated sites, such as Law of Environment Protection, Land Administration Law, Law on the Prevention and Control of Environment Pollution Caused by Solid Wastes and so on. Even if in these laws' limited provisions that involved soil protect, as the enforcement glitch and lax, they hadn't played the role to protect soils. For example, under China's Environmental Protection Law, a polluting enterprise "that has caused an environmental pollution hazard shall have the obligation to eliminate it and make compensation to the unit or individual that suffered direct losses" [16], and the Solid Waste Law states that units where industrial waste is generated shall take measures to prevent and control pollution. However, as it is still a dominant thought the economic growth took precedence over safeguarding the ecological environment in central and local governments, thus local governments often reduced to the protective umbrella of polluted firms in order to taxes and employment's growth, which made the laws become a mere scrap of paper. In addition, for a long time, because China's citizens have no the environment public interest litigation in accordance with China's civil law's regulation, and have less chance to know environmental information, most environmental information is classified as "state secrets", so few people could realize that he is a victim of soil pollution and achieve the soil damage compensation through the environmental lawsuit. Without the effective supervision and management originated from governments and the people, it is not curious that why China's soil pollution remained continuously deteriorating.

IV. The Main Hazard Analysis of China's Soil Contamination

Soil contamination is often invisible and decade of years can exist between when the contamination occurs and the damage becomes apparent, so soil contamination gets the least attention, but as soil has a close relationship with human, so soil contamination brings a great danger to public health and nation's food security. For example, crops and plants grown on polluted soil absorb much of the pollution and then pass these on to people. This could explain the sudden surge in small and terminal illnesses. According to China's official estimated, heavy metals contaminate at least 12 million tons of Chinese grain each year. In 2013, Hunan rice which was found Cadmium content greatly exceeded national criterion, caused a major scandal. Meanwhile, in Guangzhou, a city of 12 million population near Hunan, almost half the rice for sale tested was also found to be tainted with cadmium (Hunan province is the country's top producer of rice. It's also China's top producer of heavy metals and the home of major mining operations) [1]. As is well-known, cadmium and other heavy metal can cause kidney failure and other cancers. Besides, the contaminated soil in cities and industrial sites poses a serious threat to human health and ecological environment in China. For another, the petroleum hydrocarbons pollutants in the soil of industrial sites of the petrochemical industry have a big impact on yield and quality of crops; the soil polluted by petroleum may cause changes in other environmental elements; the petroleum hydrocarbons can go into human or animal bodies in such forms as breathing, skin contact or food intake, resulting in cancers, mutagenesis and teratogenicity. Since the 1970s, studies on cancer causes have found benzo (a) pyrene and other carcinogenic substances in soil from many industrial urban and outskirts regions. Most "cancer villages" recognized by Chinese government, are located around the heavy polluting enterprises [17]. Also, long term exposure to such polluted soil can affect the genetic make-up of the body, causing congenital illnesses and chronic health problems that cannot be cured easily.

In addition, many contaminated sites remaining after relocation, shutdown or closedown of industrial enterprises located in the city's downtown, and attractive for development of commercial or civil real estate. Although the enterprises have been relocated or shut down, their impact on the environment of the original sites has not been addressed. The pollutants accumulated in the soil and underground water of the original sites will not degrade naturally. If those sites can't be harnessed and restored, the pollutants will go into the human body via underground water or air. For example, the scandal of "Changzhou Toxic School" in 2016, almost 500 students at the Changzhou Foreign Languages School , which was built close to a former chemical factory, suffered symptoms such as skin inflammation, eczema and bronchitis after taking lessons at a school that had only been open for six months. For another, during construction of the Songjiazhuang subway station in Beijing in 2004 three workers fainted while doing excavation work. It was later discovered that the site had belonged to a fertilizer factory, and the polluted soil was later removed and incinerated. A similar incident in Wuhan, central China's most populous city, involved a fertilizer factory site that was sold to a developer. The buyer was not made aware that the site was polluted. When construction started in 2007 workers mysteriously fell ill. The vendor later had to refund the developer's purchase price and pay 120 million yuan (US$18.5 million) in compensation [2].

Finally, soil contamination has seriously threatened China's food safety. In order to guarantee the supply security of national food, Chinese government has set 300 million acres of arable land as the minimum amount of land. As of 2012, China had 334 million acres of arable land. If the 65 million acres of polluted land were to be declared unfit for

food production, which meant the total amount of arable land would fall 31 million acres below Chinese government's self-defined "red line", and the food security of the whole country would be affected [18].

V. The Analysis of Specific Countermeasures

Confronting with more and more severe situation of soil pollution, at present, China's government has already realized the severity of soil problems and has been taking some measures to control and curb the continual deterioration of soil pollution. But because China's soil environmental protection and pollution control began in the late 1960s, whether the technical level of soil decontamination or the measures related to the prevention and control of soil pollution, compared with the developed countries, there are many obstacle factors existing in China's soil environmental protection and pollution control.

A. Conferring on Soil Protection Fundamental National Policy Status and Enhancing the Awareness of Soil Protection

Soil contamination is a related and important issue, it matters national food security, human health and ecological protection. In current China, facing the serious soil pollution crisis, it is essential to attach importance to soil protection from the perspective of national strategy. China is a powerful-government leading country, the settlement of soil pollution couldn't be done without enough importance and support from central government. If soil problems received enough attention, then it could be solved as soon as possible.

From a long time, soil is constantly regarded as an unlimited resource to be developed and utilized in China, whether all levels of government or common people, less realized that soil is an irreplaceable limited natural resource and the resource of life on the earth. At a large extent, it is closely related to the lack of the environmental education in China, especially soil environmental education. In order to conquer this challenge and cultivate the consciousness of environmental protection from childhood, China's Ministry of Education had already made environmental education incorporate into the coursework of primary and middle school, which will provide the basic guarantee of organization and system for green education and change the dilemma of environmental education in the past 40 years.

B. Improving China's Systems for Laws and Regulations on Soil Environment Protection and Ensuring the Enforcement Efficiency

There's no systematic and special law governing soil pollution in China, but a series of exposed cases brought by soil contamination over the past decades has stimulated the central government to act. The Law on Prevention and Control of Soil Pollution came into effect, which solved the problems that China's laws and regulations on soil environment protection and pollution control were ever fragmented, unsystematic, unfocused, unworkable and not enforced allowing soil to be adversely affected for a long time. This new law clarifies responsibility for the prevention, control and management of soil contamination, establishes 13 types of responsible party and stipulates that a risk assessment of soil pollution must be achieved before a site is put into use.

In the meanwhile, it is noteworthy that the effective enforcement of laws and regulations related to soil protection is more important than the laws by themselves. Just like Thomas Jefferson said, "the execution of the laws is more important than the making of them". The glitch of environmental laws in China remained a serious problem, which is closely related to the deficiency of legal consciousness and environmental awareness, but more importantly, which rooted in the traditional thinking of the rule of man. In recent years, China has set to 370 new local environmental courts as part of institutional reforms that aim to curb pollution [19], which showed that central government wished to apply environmental laws to reverse the continuous deterioration of environmental pollution. Taking it as a trigger, we believed the enforcement of environmental laws would be increasingly strengthened.

C. Establishing China's Soil Bank of Polluted Sites and Ensuring the Citizen Right to Know Environmental Information

In China, much environmental information is regarded as "state secrets", especially the detail information about polluted soil out of consideration for certain interest, so ordinary people have less chance to understand the soil environment where they live is safe or not, the existence of cancer villages also proved it. Every citizen has the right to know environmental information, which is directly related to citizen's health. Covering up the information is adverse for solving polluted soil.

In stark contrast to China, most developed countries have established polluted soil information databases for the public to inquire. For example, the Superfund Information System in the USA contains more than 10 000 sites and the public can get basic information on a site online in many retrieval forms, like the site's name, number, street, city, county, state, region or postal region. The federal contaminated site directory, set up by the Real Property and Material Policy Division of the Treasury Board Secretariat, has been open to the public since July 2002. There are 6700 active contaminated sites identified in the directory, and the public can get information on a site, including its location, pollution level, polluting media, pollutant nature, current progress on identifying and clarifying pollution problems, and the quantity of treated liquid and solid media. There are many key word retrieval forms including: typing in the site's name, province or region, population census metropolis, federation electorate, pollutants of the site, the schedule of federal action plans for contaminated sites, and site management plans. This approach has been taken in order to allow all stakeholders to access the available information [10]. US' experiences are worth learning for China.

In order to build the soil bank and realize the risk-based management and supervision of polluted soil, it is essential to carry out investigation, classification and assessment of legacy contaminated sites in detail under the strong support of all levels of government. Then all the data and relevant information of polluted soil, including located points, polluted causes, type of pollutant, hazard extent, harm consequence and so on, should be put in the database and

allow ordinary people to scrutinize related information.

D. Establishing the Soil Protection Fund and Strengthening the Technical Support of China's Soil Remediation and Supervision

According to decontaminating practice of polluted soil sites in China's different regions, fund shortage for restoration is the biggest bottleneck problem, most developed countries encountered the same problem in the process of polluted soil remediation. It's necessary to establish the special soil protection fund and find a reasonable and scientific mechanism for raising fund for decontamination projects. Referring to the western countries' experiences, just like US's Super Fund, the capital should mainly come from central and local government, pollution taxes levied from polluting enterprises, developers of polluted plots, government grants, responsible parties, penalties from companies and individuals evading their relevant environment responsibilities, local communities and residents, public donations, interests of funds and so on. In addition, considering the actual conditions, China could implement the policies of "who invests in remediation takes the benefit" and "who remediates the land takes the privilege of redevelopment" for relieving the huge pressure of fund shortage.

The technical lag of soil decontamination is another obstacle factor of polluted soil restoration. In recent years, although China's research institutions have already achieved some progress in remediating technologies, as the causes and characteristics of soil pollution in different regions are more complex and various, thus it is very difficult to find an effective method to solve the large scale polluted soil in a short time. In view of the good market prospects, it is a good choice for China to encourage participation of social funds in developing related technology of soil decontamination according to the local characteristics of soil pollution and different purpose of soil usage.

For example, for agricultural soil (including sewage irrigation areas), efforts should be made in developing biological remediation and stabilization technologies to safeguard safety of agricultural products.

VI. Conclusion

Soil is closely related with food safety and the sustainable future of a country, so it should become one of the most important issues for any country in the world to prevent the soil pollution. The soil decontamination isn't just a technical problem, which concerned with policies, regulations and supervision of soil protection, soil legislation and enforcement level, technical capacity of soil restoration, national environmental awareness and so forth. Nowadays, China has already taken many related measures to solve the soil pollution issues step by step and got a head start over many developing countries. As developing countries are in about the same developmental stage and face the similar challenges, so China's countermeasures aiming at soil pollution are beneficial for other developing countries. In the foreseeable future, soil remediation and protection will remain pressing problems for the global, so there still has a great amount of work need to be done.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Lihui Zhou conducted the whole process of research and analysis, wrote the paper and approved the final version.

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