Sludge pollution, social impacts and its treatment—Case study of Yongding Town and Chaoyang City

Zicheng Shan

Stevenson School, 3152 Forest Lake Road, Pebble Beach, California, 93953, USA

jshan23@stevensonschool.org

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Abstract: This paper investigates the social impacts of sludge pollution, measured in health, environmental and economic aspects. The paper applies the method of case study, in which two vivid stories about Yongding Town and Chaoyang City in China are examined. Included in the case study method is the idea of event study and counterfactual analysis commonly used in econometrics to enhance reliability. The main finding of this paper is that sludge pollution has significant negative social impacts. Sludge pollutes the environment through the soil and water system, increases the morbidity of certain diseases such as pulmonary tuberculosis, and decreases the natural growth rate while suppressing innovations of the economy in polluted areas. Worse, the negative social impacts on the environment, health, and economy interact, forming a vicious cycle and leading to cumulative disadvantage in polluted areas. The paper concluded by providing a case-based solution matrix for both prevention and treatment in technological, economic and community dimensions.

1. Introduction

In June 2018, the disclosure of China's Ministry of Ecological Environment brought the problem of sludge pollution in Taixing City under the spotlight. A company named Taixing City Binjiang Wastewater Treatment Co., Ltd. discarded and illegally stored 40,000 tons of sludge in Taixing City, which caused serious pollution by contaminating the water and soil in the Yangtze River Delta [1]. However, few actions were taken after the disclosure, which aroused people's attention to the treatment of sludge pollution [1]. The sludge pollution in Taixing City is not alone. Back in 2016, the United Nations have been appealing to the public about the importance of dealing with sludge. In chapter 6.3 of its Sustainable Development Goals, the UN advocated that "safely treated wastewater, including sewage and fecal sludge, (should be) in proportion to total wastewater generated by households" [2].

Sludge pollution caught international attention like above because it is toxic and prevailing. Sludge is a semi-solid slurry produced from industrial processes, including wastewater treatment and sanitation systems. [3] The US Environmental Protection Agency estimated that sludge contained 116 types of chemicals harmful to humans and 134 types of chemicals devastating to the environment [4]. However, the production of sludge is ubiquitous, as it is a byproduct of the wastewater that is produced by cities in large amounts every day. While the wastewater treatment market continues expanding, the total sludge produced worldwide may well grow proportionally in the near future [5].

Unfortunately, the harmless disposal rate of sludge remains relatively low. For instance, only about fifty percent of sludge in China is disposed of harmlessly [6]. In fact, the sludge market is a significant missed opportunity. Its total market size amounted to USD$6.4 billion in 2019 and is expected to grow to USD$9.5 billion in 2026 [7]. Therefore, sludge and its pollution are meaningful topics to be further investigated.

Based on existing studies, this paper investigates the social impacts of sludge and sludge pollution. I apply the framework of the case study to include two cases. The first case uses the event study method in Yongding Town, China. The second case applies the idea of comparison and

controlled experiment to Chaoyang City, China. Both cases gain inspiration from ideas in econometrics, which helps to enhance the reliability of the findings in this paper.

This paper proposed that sludge pollution is a prevailing and severe problem that occurs but is not limited to China and its social impacts cannot be neglected. Those social impacts significantly affect people's health, such as increasing the morbidity of certain diseases and drag on economic growth. What's worse, these two negative effects always mix together. Based on these findings in the case study, the conclusion part provides a matrix of feasible solutions. The solutions are divided into ex-ante and ex-post, considering the perspective of technology, economy, and society.

2. Literature Review

Existing studies about sludge can be divided into four categories as follows.

2.1. Type One — Studies on Sludge from a Technical Perspective

Most studies investigate sludge from a technical perspective. The first sub-branch focuses on the ex-post treatment of sludge that has already been produced. For instance, Feodorov [8] proposed a new composting technology to increase the harmless disposal rate of sludge. Seleiman et al. [9] further developed a recycling process to turn sludge into fertilizers. Meanwhile, Zhang et al. [10] discussed generating electricity by sludge. The second sub-branch focuses on the pre-treatment process of sludge, which is ex-ante. For instance, thermal and thermo-chemical methods are widely supported by Qian and Jiang [11]. Ultrasonic pre-treatment of sludge is also advocated [12].

While the effect of implementing technical methods cannot be leveraged without considering the social contexts where they are carried out, investigating the social impacts of sludge, which this paper focuses on, is necessary to help implement these methods appropriately and effectively.

2.2. Type Two — Assessing and Measuring the Impact of Sludge in a Quantitative Way

The second type quantitatively assesses and measures the impacts of sludge.

One of the sub-branches focuses on assessing sludge disposal options. For instance, Lundin et al. [13] assessed different types of sludge disposal options economically and environmentally. Kacprzak et al. [14] systematically investigated several sewage sludge disposal strategies for sustainable development to dig out the comparative advantages of each.

Another sub-branch focuses on assessing the impact of sludge pollution by conducting chemical experiments and supporting their ideas with statistics. For instance, Huang et al. [15] quantitatively evaluated heavy metals' pollution of sludge. Tytła [16] assessed heavy metal pollution of sludge and further summarized its potential ecological risk.

Nevertheless, few quantitative assessments focus on the social impacts of sludge pollution. On the one hand, it proves the difficulty in assessing its social impacts. On the other hand, this paper gains inspiration to make up for the blanking by using concrete examples. It helps dive into the social impacts of sludge pollution, which constitutes the case study part of this paper.

2.3. Type Three — Investigating the Mechanism of Sludge Pollution and Its Social Impacts

Some studies investigate the mechanism of sludge pollution and its social impacts theoretically. For instance, Bibby and Peccia [17] identified viral pathogen diversity in sewage sludge. Lowman et al. [18] discovered the impacts of sludge's land occupation on community health and the environment. Those theoretical mechanisms need to be put into practice to illustrate what specific social impacts sludge pollution may well bring about. Therefore, this paper gain enlightenment to further analyze the social impacts of sludge pollution by giving concrete examples, aiming to test and complement existing theoretical mechanism.

2.4. Type Four — Pure Case Studies on Sludge Pollution

Some case studies on the topic of sludge exist. These case studies narrow down to specific regions or countries by giving concrete examples. Economically and environmentally, Islam et al. [19] investigated the impacts of industrial sludge in Dhaka City, Bangladesh. Shamuyarira and

Gumbo [20] studied similar topics in Limpopo Province, South Africa. Inspired by these studies, this paper makes a comprehensive analysis covering all aspects of technology, economy, and environment in the case study.

2.5. Innovative Points of This Paper

Based on existing studies, this paper tries to thoroughly investigate the social impacts of sludge directly through case study. The case study may well facilitate its readers to engage themselves in the social context and scenario where sludge pollution happens, helping them understand the social impacts of sludge pollution more intuitively. It also helps readers understand the proposed solutions in this paper more easily since most solutions are come up with based on the case studies.

Meanwhile, the paper innovatively applies the idea of event study and counterfactual analysis in econometrics under the framework of the case study method to enhance the reliability of these two cases. The paper also expands the sludge problem in China to a worldwide problem by giving concrete examples in Europe and the US, two regions apart from China, and proposes practical and implementable solutions for sludge pollution in ex-ante and ex-post ways. Unlike the invention of a single sludge treatment technology that can theoretically improve the efficiency of sludge treatment, solutions in this paper are comprehensively structured in all three aspects of technology, policy, and community. They are expected to inspire more ideas about sludge pollution treatment.

3. Methodology and Case Study Design

The case study method has become prominent in investigating community-based problems. Therefore, the case study method perfectly fits to explore the social impacts of sludge pollution, such as its impacts on health and society. The paper applies the multi-case design with two cases. The first case of Yongding Town in Mentougou District, Beijing, China, uses the framework of event study, and the second case of Chaoyang City, Liaoning Province, China, focuses on the concept of comparison and controlled experiment.

The event study method of Yongding Town is commonly used to dig out the impacts of an unanticipated shock. Originally, the method aimed to assess the impact of changes in corporate policy in finance [21]. The idea of an event study is process tracing. We trace the research subject's performance and compare it before and after the event to get a conclusion.

Chaoyang City's case applied the comparison and controlled experiment approach. We try to find two cities with anything similar to each other at a given point, except that one is polluted by sludge and the other is not. Then what contributes to the differences beyond the given point of these two is owing to sludge pollution, corresponding to the idea of counterfactual analysis.

3.1. Case Description

Yongding Town's case focuses on the illegal disposal of sludge in 2006-2007, which was disclosed by a trial in 2009 by the Court of Mentougou District. Yongding Town is a relatively undeveloped town in Beijing, China. It is called "The first and the most serious sludge pollution in Beijing" [22]. Therefore, Yongding Town may well be a typical representative to measure the social impact of sudden sludge pollution caused by illegal disposal.

Chaoyang City's case is based on the Central Ecological and Environmental Protection Inspection Team disclosure in 2021. The city is reprimanded for neglecting the harmless disposal of sludge for more than ten years, which causes severe pollution. Chaoyang City lies in northeast China and represents the average development status of Liaoning Province. It may well reflect the long-term social impacts of sludge pollution since the city's neglect of sludge disposal for more than ten years. The brief introduction and geographic locations of Yongding Town and Chaoyang City are shown in Figure 1.

Figure 1 Brief introduction of Yongding Town and Chaoyang City.

The concept of cumulative disadvantage can be used in the case study. Cumulative disadvantage says that people who start from a disadvantage may face more challenges and growing inequality over their lifespan [23]. In the sludge pollution case in Yongding Town and Chaoyang City, citizens who live in these two areas face poorer environmental conditions, which becomes their disadvantage from the start. Worse, the economic and medical conditions are less developed than in other regions of China. Therefore, sludge pollution can significantly cause cumulative disadvantages, hindering the development of both. Cases like the two cities should be paid enough attention to save their people from the trap of cumulative disadvantages.

3.2. Strengths and Weaknesses of the Methodology

Regarding the case of Yongding Town, the event study method demonstrates its specificity and vividness. It helps explain the complexity of real-life situations that may not be captured through experimental research. Also, the event study method does not require a controlled group to serve as a benchmark. However, the method may well face confounding effects. Yongding Town's sludge pollution may mix with other factors that also affect the town's development.

Regarding the case of Chaoyang City, we select Tieling City as the controlled group, which is similar to Chaoyang as the treatment group in fourteen aspects except for the sludge pollution. It helps better explores the causality, making the results more convincing. However, the two cities cannot be entirely identical.

The paper also applies expert calls to validate the feasibility of proposed solutions. It increases the reliability of the findings in the paper, but the experts can only represent their perspectives.

4. Case Study

4.1. Yongding Town, Mentougou District, Beijing

It was September 22nd, 2009. Several angry people crowded the court of Mentougou District, Beijing, holding their ID cards to attend a court trial. Among them are deputies to the National People's Congress, officials from the Environmental Protection Bureau of Mentougou District, and of course, residents of Yongding Town. Angrily, one of the residents shouted, "I want to see how many years will the criminal who polluted our homestay in prison!" The trial was about the sludge pollution in Yongding Town, Mentougou District, from 2006-2007 [22].

The resident who shouted served as the witness for the pollution event in the court trial. He claimed that he had lived in Yongding Town for about forty years since he was born, and now he was the father of his twelve-year-old son. In his childhood, he always swam in the nearby Yongding River with his parents. After growing up, he became a farmer, planting wheat in the town as his parents did. The water used for irrigation was from Yongding River for years. However, about five years ago, as he claimed, the Yongding River turned muddy, resulting in about twenty percent of wheat planted dying yearly. Accompanied by the poor harvest of wheat was the disgusting smell. He complained that his parents, who were over seventy years old, could not take a walk on the street for years because of the odor.

“The most inconvenience caused by the odor was that my son had to transfer to another school far away from home. It was because his original school was near the giant sandpit with swamps. My son complained that he always felt disgusting after studying the whole day. I have to find another school far away from home for my son!” That was how the witness ended his speech.

His claims corresponded with the media’s disclosure [22]. The National People’s Congress deputies had submitted proposals for three consecutive years concerning the odor smell in Yongding Town. All required the government to investigate the odor’s source thoroughly.

The Court of Mentougou District confirmed that the disgusting smell was due to sludge pollution. The giant sandpit near the town was forty-meter deep and filled with 200,000 to 400,000 steres sludge. Ironically, the sandpit was only five hundred meters from Yongding River of Yongding Town, which was claimed to be one of the most preserved rivers in the Mentougou District. Meanwhile, biochemical oxygen demand, heavy metal elements, and fecal coliform had seriously exceeded the environmental standards in the sandpit nearby Yongding Town. The odor in the air reached stench levels between three and five, which is the level of offensively disgusting. Ironically, the criminal’s revenue from illegally discarding sludge was only RMB￥26 per ton, which can hardly cover its prohibitive treatment cost. A harmless treatment plan like drying sludge costs about RMB￥400 per ton while burning costs RMB￥100 per ton, somewhat incentivizing the criminal to discard it illegally to pursue profits.

As the sludge could easily penetrate the ground and pollute underground water, the Yongding River could hardly survive the pollution, let alone the occupation of sludge for arable lands. After all, Mentougou District relies heavily on its primary sector, like agriculture, for economic growth. According to the Statistical Bureau of Beijing, from 2009-2020, its primary sector accounts for about 0.8 percent of GDP (higher than 0.2 percent for Beijing), and the tertiary sector only accounts for about 53.6 percent of GDP (the ratio for Beijing is 78.9 percent). It implied that residents in Yongding Town still need enough arable lands not polluted by sludge to make their living. It somewhat explains the anger of residents in Yongding Town at the beginning of the trial.

Sludge disposal in Yongding Town has severe health concerns. It was disclosed by the Center for Disease Control of Mentougou District that from 2011-2014 after the sludge pollution happened, the probability of catching diarrhea in Yongding Town, mainly caused by polluted water and food, ranked second among all towns in Mentougou District. Also, the morbidity of tuberculosis kept ranking top three among all towns in Beijing. These diseases, especially tuberculosis, can pose severe and long-term social impacts if not appropriately treated. After all, Mentougou District was one of the most undeveloped districts in Beijing. The average unemployment rate in Mentougou District from 2009-2020 is 4.0 percent, higher than that of Beijing (1.5 percent). The medical care development is also behind the city's average. From 2009-2020, the medical care industry's contribution to GDP falls behind four percent of Beijing’s, according to the National Bureau of Statistics. Many villagers in Yongding town cannot afford or have access to medical treatments.

Worse, higher morbidity of tuberculosis causes long-term mental health problems. It is a disease with a long treatment time, easily recurring, causing patients to worry about their health conditions regularly. Also, because of its infectiousness, most patients must stay at home for treatment, reducing their social interactions and increasing the probability of mental illness. About thirty percent of tuberculosis patients suffer from mental problems [24]. Furthermore, mental health conditions were worse for those who suffered from poor economic conditions and low satisfaction in life [24]. The probability of having a mental illness was 196 percent higher for those with poor economic conditions than those with satisfying economic conditions.

With bad economic and medical conditions caused by sludge in Yongding Town, it is much easier for its villagers to suffer mental illness if they catch tuberculosis resulting from sludge pollution. Further, villagers’ mental problems reduce their passion for work, exerting pressure on employment conditions, suppressing economic growth, and improving medicare.

After the sentence of the trial at the beginning of the case, the defendant’s mother frustratedly jumped up, arguing that her son should not be put in prison. She ridiculously claimed that her family made a living by discarding waste for generations, and the behavior of discarding sludge

secretly had nothing wrong. Her statements illustrated that education on environmental protection was still lacking in Yongding Town and Mentougou District, which may further increase the probability of environmental pollution like the illegal discarding of sludge in this case.

4.2. Chaoyang City, Liaoning Province

"My land where I planted crops was gradually surrounded by a swamp with disgusting smells these years, and it was not once that my cattle were trapped in the swamp!". That was what one resident who lived all his life in Longcheng District, Chaoyang City, told the Central Ecological and Environmental Protection Inspection Team (CEEPIT). The Ministry of Ecology and Environment of China established the team, which represents the central government. It was April 2021 when the team criticized the government of Chaoyang City for having long neglected the harmless disposal of sludge for more than ten years. The disposal rate of sludge in Chaoyang City was lower than sixty percent, far less than the national standard of ninety percent.

Also disclosed by the inspection team was that Chaoyang City stored a large amount of sludge illegally. It corresponds to what the resident of Chaoyang City said to the team. The swamp mentioned in the beginning was just the illegally stored sludge. The inspection team found a five-meter-high land larger than ten soccer fields, filled with about 400,000 tons of sludge (see Figure 2) [1], which could easily flow away when it rained and pollute the nearby river.

Unfortunately, a river named Daling was only five hundred meters from the stored sludge, serving as the primary source of daily-used water in Chaoyang City. The inspection team found that the land where sludge was stored had not received the permission of the Ministry of Ecology and Environment and had operated illegally for at least thirteen years. Since 2008, the regulatory authorities of Chaoyang City have changed several times. However, there was hardly one record of fines or punishments regarding the vast amount of illegally stored sludge [1].

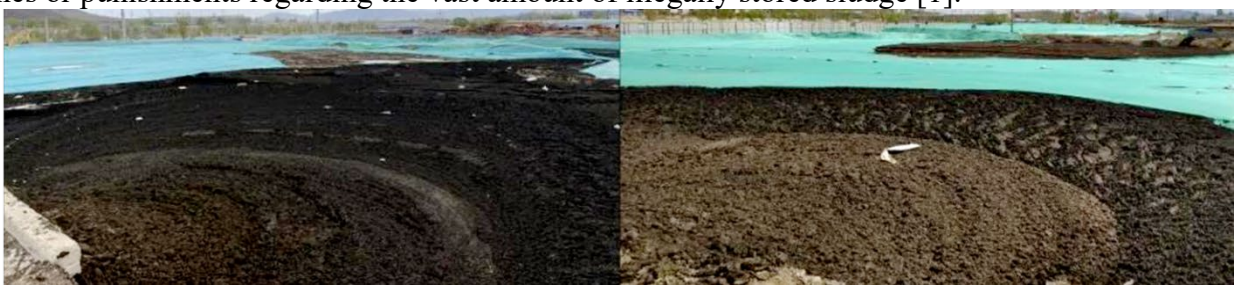

Figure 2 Sludge illegally stored in Chaoyang City.

"We do not know what happens here. The responsibility for the illegally stored sludge should belong to the transportation companies who dumped sludge here." These were ridiculous words from one official of the regulatory authority when they were asked about their responsibilities in an on-site inspection carried out by the CEEPIT.

Table 1 Chaoyang City and Tieling City are similar in fourteen indicators.

		Demographic Indicators			Economic Indicators						Healthcare and Environmental Indicators			
City	Period	Geographic Location	Population	Population Density (Person/km^2)	GDP	GDP per capita	% of primary sector	% of secondary sector	% of tertiary sector	# of total workers' salary	# of hospitals	# of doctors	Disposal rate of sewage	# of green areas (km^2)
Chaoyang	2005-2007	Liaoning Province	3.4M	172	¥ 26B	¥ 7,858	25	42	33	¥ 3.4B	191	3.8K	42	41
Tieling	2005-2007	Liaoning Province	3.0M	234	¥ 33B	¥ 10,895	25	43	32	¥ 3.8B	106	4.1K	63	34

Source: National Bureau of Statistics of China

Because of the neglect of Chaoyang's government on sludge pollution, no wonder Chaoyang City has not developed as well as its "twin" city both in economic and social aspects. Tieling, another city near Chaoyang in Liaoning Province, had everything like Chaoyang regarding economic, educational, and healthcare aspects from 2005-2007, as the Table 1 showed, except that Tieling did not suffer from sludge pollution. From 2008, as the inspection team disclosed, Chaoyang began suffering from sludge pollution. Therefore, considering the development of the two cities from 2008-2019, Chaoyang lagged behind Tieling, from which we could conclude that

sludge pollution negatively correlated with social factors, including economic, education, and medicare.

Residents in Chaoyang City have suffered from higher morbidity of infectious diseases since 2008, when the sludge pollution happened, primarily caused by polluted water and food resulting from sludge pollution. In 2009, the morbidity of catching HAV, a disease commonly caused by contaminated water and food, was 3.3/100,000 in China, while in Kazuo County and Lingyuan County, two counties in Chaoyang City, the morbidity was 6.8/100,000 and 5.1/100,000, according to Chinese Center for Disease Control and Prevention. For pulmonary tuberculosis, during 2017-2018, the morbidity in Chaoyang was 59.2/100,000, higher than the average in Liaoning Province, which is 54.1/100,000. For brucellosis, its morbidity rate is 5.8/100,000 from 2009-2018, higher than that of Liaoning Province, which is 4.0/100,000, according to Phsciencedata.

Moreover, sludge pollution in Chaoyang poses a threat to its economic growth in seven aspects. When values in the following table are negative, it implies that an increased amount of sludge, a proxy for sludge pollution given a constant disposal rate, would negatively impact variable 2. The smaller the value, the more severe it is. If Chaoyang's value is smaller than Tieling's, it implies that sludge pollution worsens Chaoyang's economic growth compared to Tieling. As shown in Table 2, sludge pollution profoundly suppresses Chaoyang's innovation ability and harms tourism, the housing market, and the natural growth rate of the economy.

Table 2 Impacts of sludge pollution on the economy, society and innovation.

Variable 1: ***Amount of Sludge Produced through 2008-2019***
Data in table: Pearson Correlation Coefficient of ***Amount of Sludge Produced through 2008-2019*** **and** ***Variable 2***

Variable 2	Amount of PE/VC Investment Deals	Innovation Index①	Domestic Tourism Revenue	Average land price	GDP	GDP per capita	Natural Growth Rate of Economy
Chaoyang	-0.57	-0.32	-0.54	-0.72	-0.28	-0.20	-0.21
Tieling	-0.31	-0.03	0.63	-0.37	-0.57	-0.59	0.24

Source: National Bureau of Statistics of China, Macrodatas, Wind
① Innovation Index in the table is calculated by Macrodatas. It is the index calculated by 9 characteristics to measure the innovation ability of a city, including # of deals, # of startups, # of patents, $ of land, etc.

To make things worse, Chaoyang's education lagged behind Liaoning Province's. In 2010 and 2020, the average year of education for people over fifteen years old was 8.69 and 9.37 in Chaoyang, while 9.67 and 10.34 in Liaoning Province. The lower level of education brings about low awareness of sludge pollution, which could unavoidably cause more illegally stored sludge to pollute the environment, forming a vicious cycle. Worryingly, poor education conditions may well be a prerequisite for cumulative disadvantages and further accelerate the vicious cycle.

5. Solution

While the case study of this paper mainly focuses on sludge pollution in China, the treatment for harmful sludge is a problem that keeps raising public concerns worldwide.

The implementation of sludge treatment is on-the-way both in Europe and the US. For instance, Suez Group provides a one-stop solution to treat sludge produced in Alsace from sauerkraut wastewater [25]. The US government began its recovery plan for the Gowanus Canal [26].

Similar to the two examples carried out worldwide, this paper comes up with the following solution matrix (see Table 3). Prevention solutions have limited short-term but significant long-term impacts. Treatment solution has limited long-term but significant short-term impacts, which are more likely to be ex-post. Experts have validated the feasibility of these solutions through expert calls.

Table 3 Solution Matrix of sludge pollution.

	Prevention	Treatment
Technology	(1) Increase profits for sludge treatment methods such as composting to incentive firms not to discard it illegally. (2) Increase the harmless disposal rate of treating sludge through technology such as fermentation to make fertilizers. (3) Improve preceding processes to remove harmful materials before sludge production.	(1) Reprocess the sludge that has been discarded through technology such as high-efficiency burning or fermentation to turn it into fertilizers or electricity. (2) Use chemicals such as hypochlorous acid to kill the bacteria and eliminate the sludge odor.
Policy	(1) Increase subsidies, cut taxes, and offer more financing for sludge disposal firms. (2) Enhance the punishment for sludge illegally discarded for alertness. (3) Strengthen the regulation of the regulatory authorities.	(1) Take emergency actions to deal with the sludge already produced. (2) Heavily punishing those responsible for the illegal disposal of sludge. (3) Compensate for people affected by sludge pollution.
Community	(1) Enhance people's education about sludge's harmfulness to raise awareness. (2) Infrastructure-based methods include building more sludge treatment plants.	(1) Increase the media coverage and exposure to sludge pollution events. (2) Diversify the financing channels to dispose of sludge already produced to guarantee financial support, such as “public-private partnership” finance patterns.

Sludge pollution is a global problem that keeps raising people’s concerns. This paper finds that sludge pollution has significant social impacts on the environment, health, and the economy, which is justified by making an in-depth analysis of its social impacts through two case studies of Yongding Town and Chaoyang City in China under the framework of counterfactual analysis.

Sludge pollution increases the morbidity of diseases such as HAV, tuberculosis, and brucellosis. Meanwhile, the increasing amount of sludge drags economic growth and lowers the natural growth rate of the economy. More importantly, worsening health conditions slows economic growth, and poorer economic conditions are not likely to breed well-developed health systems. Therefore, the worsening of one will cause the worsening of the other, which forms a vicious cycle and leads to cumulative disadvantages. The problem is not only limited to China, but also exists in Europe and the US. Based on the findings, the paper proposes case-based solutions for sludge pollution, which have received validation from experts.

This paper still lays out potential fields for conducting next-stop research, which is beyond the scope of this paper but still requires deeper investigation. As for policymakers, as they are likely to have access to more diversified statistics sources, they can benefit from sufficient supporting data to conduct in-depth comprehensive research. As for scholars, they may further dig out the causality of sludge pollution and its social impacts. For instance, they may start tracing the performance of a specific area that has just been contaminated by sludge pollution. They can also conduct on-site visits to the polluted area on a regular basis. In this way, first-hand information can be gathered, which is more reliable and convincing. They can also carry out case studies in more areas to check the robustness of the findings in this paper.

While the problem of sludge pollution is still prevailing, it is not impossible to overcome. As long as we commit ourselves to consciously controlling sludge pollution, learning lessons from previous sludge pollution cases, and adopting feasible solutions as suggested by the paper, the harmless disposal of sludge is around the corner.

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