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Soil Pollution Prevention Strategies and Typical Case Studies of Agricultural Producing Areas in the Beijing-Tianjin-Hebei Region

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Abstract: The coordinated development of Beijing, Tianjin, and Hebei is the core strategy of China's political, economic, scientific, and cultural development. The environmental protection of regional agricultural producing areas is fundamental in the battle against pollution. The issue of heavy metal pollution (Cd, Hg) in the soil in agricultural producing areas is prominent in Beijing and Tianjin; hence, the pollution risk in these areas cannot be ignored. The main causes of soil pollution in these areas are: the heavy metal pollution from industrial development zones, sewage irrigation, inadequate sewage treatment capacity, imperfect regulations and policies, and the observance of outdated technical standards. Here, we propose some comprehensive strategies of soil pollution prevention and control, including a "sky-ground integrated" monitoring system for agricultural producing areas, the improvement of the clean production by industrial-mining companies, and the management of livestock-poultry pollution. We also describe a number of case studies (i.e., the prevention and control of environmental pollution in a pit pond site and in an informal refuse landfill in Tianjin). These cases can be used as references for new strategic decisions on soil pollution prevention and control in the Beijing-Tianjin-Hebei agricultural producing areas.

Keywords: Beijing-Tianjin-Hebei; agricultural producing areas; soil pollution; prevention strategy; engineering case

1 Introduction

The coordinated development of Beijing, Tianjin, and Hebei is the core strategy of China's political, economic, scientific, and cultural construction. The environmental protection of regional agricultural producing areas is key in the battle against pollution. A synergic progress in soil environmental protection is needed for the Beijing-Tianjin-Hebei agricultural production areas. Progresses in this field would promote a sustainable agricultural development, while ensuring the safety and improving the quality of agricultural products, and meeting the growing need of urban and rural residents for a better life. This is the only way in which the supply-side structural reform and the objective of a "Green Fortress" can be achieved, and the international competitiveness of agricultural products can be enhanced.

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2 Soil pollution

In recent years, the quality of the soil environment in the agricultural production areas of Beijing-Tianjin-Hebei has not been good, gaining widespread public attention. A recent investigation, termed "Study on Some Strategic Problems of Agricultural Resources and Environment in China" described over-standard points of Cr in the Qian'an county soils, with point exceeding rates of 0.9%. Over-standard points of Pb and Zn were identified only in Tianjin, with over-standard rates of 0.4% and 1.4%, respectively. The over-standard rates of Cu in the Zhao County, Changli County, and Tianjin were 5.7%, 5.2%, and 1.6%, respectively. Over-standard points of As were scattered in both Tianjin and the Yongqing County, with over-standard rates of 1.1% and 3.3%, respectively. The over-standard points of Cd were densely distributed in Tianjin, with an over-standard rate of 11.3%; they were instead scattered in Qianxi County, Beijing, Yucheng County, and Tanghai County, with exceeding rates of 33.3%, 1.8%, 9.1%, and 2.5%, respectively. The over-standard points of Hg were scattered in Tianjin, while they were densely distributed in Beijing; the over-standard rates of these points were 5.3% and 9.8%, respectively. The over-standard points of Ni were scattered in Tianjin, Jixian County, and Lulong County, with over-standard rates of 1.6%, 1.0%, and 2.4%, respectively. Over-standard points of Ni were densely distributed in Zunhua County, with an over-standard rate of 29.5%. Clean spots, which were located in Zhangzhou, Baoding, Shijiazhuang, and Shahe, still need attention [1].

In 2015, the amount of wastewater discharged from the Beijing-Tianjin-Hebei region was 5.553×10^9 t [2], accounting for 7.55% of the total wastewater discharge in China. In the wastewaters discharged from the Beijing-Tianjin-Hebei region, the total amount of chemical oxygen demand (COD), Hg, Cd, and Pb emissions were 1.579×10^6 t, 174.8 kg, 16.2 kg, and 437.1 kg, respectively. In 2014, there were ~15 300 water-related industrial companies in the Beijing-Tianjin-Hebei region: the chemical industry was the major contributor to farmland soil pollution (accounting for 51% of the pollution), followed by livestock-poultry farming (27%), metal smelting processing industry (9%), and electroplating industry (7%). Additionally, areas of Beijing, Tianjin, and Hebei were polluted in different ways. Agricultural water in Tianjin has been extremely scarce. In the past 40 years, some areas have been polluted by sewage irrigation all year round [2]. Industrial and mining companies have been the main cause of heavy metal pollution in Qianxi County [3]. There are 34 industrial development zones of relatively large scale in various districts and counties of Beijing. They involve petrochemical, pharmaceutical, metallurgical-mechanical manufacturing, electronic information, aviation logistics, food processing, fiber rubber, textile printing-dyeing, papermaking, printing, and other industries [4]. More than 80% of the sewage from Shijiazhuang gets discharged into the Dongming Canal and the Weihe River [5]. It has been calculated that the sewage production of Shijiazhuang in 2010 was ~3.9×10^8 m^3. Shijiazhuang had only two sewage treatment plants, resulting in the discharge of large amounts of sewage into the Weihe River [6−8]; this was done through a sewage pipe network and without treatment, resulting in high levels of soil chemical components in the river.

The Luancheng County is an agriculture-oriented area. Since the 1970s−1980s, it usually uses sewage to irrigate in the Weihe River Basin [9]. In the Tanghai County, major pollution sources include industries such as paper mills and fertilizer plants. In particular, the Nanbao Chemical Industry area in Tangshan, south to the Tanghai county, is affected by agricultural chemical raw materials, industry, transportation, etc. [10].

The Beijing-Tianjin-Hebei region needs an impeccable environmental safety regulation system for the agricultural products. However, the *Soil Pollution Prevention Law* has not been approved yet [11,12]. The lack of policies on market operation mechanisms and the occurrence of limited capital investments are the main causes of low soil environmental protection [13]. For a long time, the environmental protection, agriculture, land, and other departments have supervised the soil environment; however, the environmental monitoring and the early warning capabilities are insufficient. Relevant policies and technical labeling, norms, and guidelines are not well connected to each other [14]. In addition, key polluting industries (e.g., chemical, metal smelting-processing, electroplating, livestock-poultry breeding, and landfills industries) use outdated technologies and are unable to control pollution.

This study focuses on the soil pollution in the Beijing-Tianjin-Hebei region, and offers some prevention strategies for soil pollution at regional scale, in terms of the improvement of environmental supervision abilities, and the control of key pollution sources. We also describe typical case studies of agricultural producing areas in this region (focusing on environmental pollution prevention and control), which can be used as references for the prevention of pollution in Beijing-Tianjin-Hebei agricultural producing areas.

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3 Pollution prevention strategies

3.1 Overall thinking

It is proposed to adhere to the principles of “prevention first”, “protection priority”, “management and control first”, “rehabilitation as a supplement”, “demonstration guidance”, and “local conditions”. Additionally, we highlight the need for a support system, consisting of laws and regulations, standards system, management system, public participation, scientific research, publicity, and education. The proposed strategies are based on the national master plan, while considering the environmental characteristics of the Beijing-Tianjin-Hebei region. In the following sections, we will describe policy and regulatory aspects, technical standards, and demonstration projects. Our aim is to provide a base for developing special environmental pollution treatments for agricultural producing areas at regional scale.

3.2 Policy recommendations and prevention strategies

3.2.1 Improving the environmental protection legal system and building a comprehensive environmental monitoring mechanism

In Beijing, Tianjin, and Hebei, it is necessary to strengthen and improve the environmental protection legal system [15], as well as rigorously control pollution from the source. Policies should formulate new technical standards for the environmental protection of agricultural products in Beijing, Tianjin, and Hebei; these will enhance the scientific-practical level and operability of the environmental protection work. Policies should encourage the improvement of the environmental protection planning system for agricultural products in Beijing, Tianjin, and Hebei: the ecological red line should be defined based on basic farmland, and the environmental carrying capacity of agricultural products should be analyzed in a comprehensive way. Policies should propose an ecological compensation mechanism [16] and promote pollution control. The main body of compensation should be made clear, and the paid use of natural resources should be implemented. Moreover, policies should improve regional departmental cooperation, formulate emergency management plans of regional pollution, improve inter-regional and inter-departmental emergency information reporting and linkage response systems, establish emergency monitoring systems for sudden environmental pollution incidents, and improve emergency monitoring teams at all levels.

3.2.2 Constructing an integrated environmental monitoring and an early warning system for “water, soil, gas, health, and people”

Policies should aim at constructing a dynamic network to monitor the quality of the environment in the Beijing-Tianjin-Hebei region. Therefore, a coordinated monitoring of crop-soil environmental quality, in accordance with the principles of unified planning, monitoring, and evaluation, should be implemented. Moreover, the policies should identify the pollution areas within the agricultural production areas of the Beijing-Tianjin-Hebei region, together with the key polluting industries. A final objective should include a comprehensive analysis of spatial-temporal distributions and trends in pollution for regional agricultural products. Demonstrating the whole process of agricultural product quality tracking and monitoring should be another objective. Policies should also establish a regional environmental communication network system, in order to disclose and share the environmental monitoring data in a transparent way. Presently, the environmental monitoring in the Beijing-Tianjin-Hebei region exhibits an inter-connected and systematic monitoring organization and technical system [17]. This system is recommended for the coordination of environmental factors such as “water−soil−gas−sheng−human”, and for the establishment of environmental monitoring standards. Policies should also monitor the network deployment plans. In-depth investigations on the status of heavy metals and toxic organic pollutants in soils could reveal the migration and transformation of different pollutants in the soil, the interaction mechanisms between pollutants and other media (e.g., soil, water, gas, crops, the human body, etc.), and, overall, the origin of Beijing-Tianjin-Hebei agricultural products. Similar measures of environmental pollution prevention would provide objective scientific means and theoretical bases.

3.2.3 Eliminating outdated production capacities and encouraging a cleaner industrial-mining production

Policies should demand an online monitoring and an early warning of key pollution sources (e.g., chemical, metal smelting-processing, electroplating, livestock-poultry breeding, and landfill industry). Environmental protection inspections should be used as an opportunity to promote clean production in the chemical and metallurgical industries [18]. Scattered, chaotic, and dirty industrial-mining factories, characterized by old-fashioned processes should be eliminated, while the conversion toward newer technologies should be encouraged. Industrial index constraints (e.g., environmental protection, energy consumption, technology, quality, safety, etc.) should be strengthened to improve the thresholds values for acceptance. Policies should promote the application of pollutant concentration, separation, purification, and internal resource recycling technologies in the chemical production processes. Hydrometallurgical processes should gradually replace their pyrometallurgical processes, in order to reduce the source of harmful heavy metals, and increase the recovery rate of harmful metals. New guidelines should be established for the comprehensive prevention, supervision, and management of industrial-mining factories. These measures would improve the standardization of environmental emergency constructions for industrial-mining factories, through regular environmental and health risk assessments on hazardous heavy metals; additionally, they would mitigate the pollution generated by industrial production.

3.2.4 Promoting a comprehensive management of livestock-poultry pollution

Our technical model was based on the current situation of the Beijing-Tianjin-Hebei livestock-poultry breeding, on the resource-environment characteristics, and on local conditions. Focusing on source reduction, process control, and end utilization, policies should focus on promoting affordable general-purpose technological models. The Beijing-Tianjin-Hebei region is the main grain producing area in China and an advantageous location for animal breeding. Policies should try to optimize the regulation of livestock-poultry breeding, according to the land and the environmental carrying capacity; in particular, they should focus on promoting the technical model [19] in which planting and breeding, manure recycling, and biogas energy are equally important. It is necessary to scientifically delineate the Beijing-Tianjin-Hebei livestock-poultry breeding banned, restricted, and cultivated areas. National financial special support should be increased and combine the awards, in order to promote the treatment of rural livestock-poultry farming pollution. Finally, the optimization of the livestock industry structure would improve the quality and efficiency of the agricultural products supply.

4 Typical cases studies

4.1 Investigation, risk assessment report, and comprehensive environmental treatment of a pit pond in Tianjin

4.1.1 Site characteristics

The sewage pit pond area had an extension of ~1 200 m^2, the water surface area was ~800 m^2, the average water depth ~1.5 m, and the total volume of the sewage ~1 200 m^3. Observation of the water surface revealed that it had a yellowish color. According to satellite image data, in May 2017 the area to the west of the filth pit had been flattened, and a factory was being built; to the north of the pit, there was a rural road, and to the north of the road, there was an idle agricultural land. Recently, the factories located around the pit interrupted their production, and local authorities tried to reduce the acidity of the pit pond water by adding lime.

The pit pond pollution likely originated from the illegal discharge of industrial wastewater, mainly from pigment printing and electroplating factories. Wastewaters produced by pigment production processes are typically characterized by high acidity, COD, chrome, and salt content; moreover, they make the biochemical degradation of organic matter difficult. Electroplating wastewaters can be mainly categorized in chromium-containing, cyanide-containing, and other wastewaters (e.g., containing copper, nickel, zinc). The composition of these waters is difficult to define, as they usually contain Cr, Cd, Ni, Cu, Zn, Au, and heavy metal ions (e.g., silver, cyanide). According to the *Tianjin Ecological Land Protection Red Line Delineation Plan*, the land around the polluted pit pond could be considered within the Tianjin ecological red line, belonging to the agricultural protected green space. The farmland soil around the pit pond had high environmental risk hazard.

4.1.2 Environmental investigation and pollution risk

The wastewater and sediment present in the sewage pit underwent short treatment periods. In order to efficiently control the sources of pollution, the wastewater and the sediment were removed, sampled, and analyzed. The water and sediment of the pit had a high content of petroleum substances. When petroleum pollutants enter the soil, they destroy its structure and disperse its particles, reducing their permeability. The reactive group of petroleum pollutants can combine with inorganic nitrogen and phosphorus, limiting nitrification and dephosphorylation; this process reduces the content of available phosphorus and nitrogen in the soil. Polycyclic

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aromatic hydrocarbons (PAHs) are particularly harmful, due to their carcinogenic, mutative, and teratogenic activities, in combination with the facility with which they can become enriched in plants and animals through the food chain. Petroleum pollutants have been included in the list of hazardous wastes in China; hence, they should also be included in the list of pollutants of concern. In addition, semi-volatile organic compounds (i.e., phthalate esters) were identified in the pit sediment. Phthalates are commonly used as plastic plasticizers, in the production of pesticide carriers, dye additives, paints, and lubricants. These compounds comprise many types, are difficult to degrade, and are highly bioaccumulative: they are highly toxic for plants, and have carcinogenic, teratogenic, and immunosuppressive effects on humans.

The health risk assessment highlighted zinc, copper, chromium, nickel, dimethyl phthalate, dibutyl phthalate, and dioctyl phthalate as the main pollutants of concern. The maximum concentration of carcinogenic and non-carcinogenic risk values in different exposure pathways was calculated for the pit soils. For the risk assessment of contaminated sites, the acceptable value of carcinogenic risk from pollutants was fixed at 10^{-6}, while the acceptable non-carcinogenic risk value was fixed <1.

The total carcinogenic risk value of chromium in concerned pollutants was 2.89×10^{-7}, while the total non-carcinogenic risk value was >1 (1.963), implying health risks; the total cancer risk of other pollutants was $<10^{-6}$, and their non-carcinogenic risk was <1, falling in the category of acceptable cancer risk. The non-carcinogenic risk value of chromium through direct intake was 0.093, which accounted for 4.73% of the total non-carcinogenic risk; its non-carcinogenic risk value by skin contact was 1.87, accounting for 95.27% of the non-carcinogenic risk. Hence, most of chromium health risk was expressed through skin contact.

4.1.3 Comprehensive treatment project for the reduction of site pollution

Heavy metal pollutants, containing zinc and selenium, were removed from the pit pond wastewater by applying alkali precipitation first. Subsequently, ammonia-nitrogen was reduced using a sodium nitrate solution. COD and ammonia nitrogen were completely removed from the wastewater using a dimensionally stable anode (DSA) electrode, ensuring the standard quality of effluent water. The overall process involved alkali precipitation + sodium hypochlorite oxidation + DSA electrocatalysis. In order to prevent secondary pollution, while ensuring treatment of the surrounding area and economic efficiency, we used an integrated skid-mounted device to treat wastewater.

After the removal and treatment of the pit water and sediments, the original sewage pit was covered, leveled, and greened, so that it could be reused. During the covering process, it is possible to add microbial inoculant to the bottom soil. This precaution improves the ability of microorganisms to specifically adsorb, transform, dissolve, and precipitate heavy metals in the soil, reducing the activity of toxic pollutants and degrading them into non-toxic substances. Plants for the greening process should be chosen based on their adsorption capacities in respect to toxic pollutants (e.g., heavy metals): they can be used as microbial agents, to regulate soil fertility and reduce toxic pollutants. This treatment project improved the overall soil environment.

4.2 Investigation, risk assessment report, and comprehensive environmental treatment plan of an informal landfill in Tianjin

4.2.1 Characteristics of the site

The informal landfill in Tianjin corresponded originally to agricultural land. Domestic waste increased in parallel with urban development and, since 2013, this area had received the domestic garbage of nearby residents. The landfill had an extension of ~240 mu (1 mu ≈ 666.667 m^2), a depth of ~11 m, and a volume between $\sim6\times10^5$ m^3 and 7×10^5 m^3; moreover, the total leachate was between $\sim7\times10^5$ m^3 and 8×10^5 m^3, the groundwater depth was shallow, and the landfill waste had been immersed in groundwater for a long time. The hydrogeological conditions of the site were complex: the 80 m of underground section included (from top to bottom) an aquifer, one layer of weak aquifer, and one to three layers of confined water. The top and bottom of the aquifer were located respectively at −2 m and −16 m depth. The core of the aquifer, at 21 m depth, was made of a highly viscous silt layer, characterized by poor permeability and low water content. The groundwater at this site flowed in a north-south direction, and its flow rate was ~0.043 cm/d. The groundwater pH ranged between 7.07 and 8.54, being on average weakly alkaline. The background electrical conductivity at 300 m depth, in the upstream direction of the landfill, was 7.5 mS/cm; furthermore, the ammonia-nitrogen, chloride, nitrate, and TOC concentrations were 0.35 mg/L, 1.71×10^3 mg/L, 0.39 mg/L, and 5.3 mg/ L, respectively. The field waste was distributed in two main areas. The first was a landfill compaction area, located on the west side of the landfill, that covered an area of ~3.7×10^4 m^2. The second area was mainly a garbage floating area, with an extension of ~5.2×10^4 m^2; the thickness of the floating garbage was initially estimated to be 2–3 m (including the overburden layer). Since there were no environmental protection facilities (e.g., anti-seepage or leachate treatments, landfill gas drainage), the informal landfill was surrounded by permanent basic farmland, and great hidden dangers existed for the ecological environment.

4.2.2 Environmental investigation and pollution risk

We investigated the soil environment around the landfill site, following the *Technical Guidelines for Environmental Investigation of Contaminated Sites* (HJ25.1—2014) and the *Technical Guidelines for Environmental Monitoring of Contaminated Sites* (HJ25.2—2014). The results of our investigation showed the occurrence of dimethyl phthalate, diethyl phthalate, dibutyl phthalate, dibutyl benzyl phthalate, phthalic acid (2-ethylhexyl) ester, and di-n-octyl phthalate at variable concentrations in the soil organic matter. The concentrations of lead, cadmium, chromium, arsenic, and mercury (all heavy metals) were 12.1−38.5 mg/kg, 0.10−0.32 mg/kg, 32.1−243.6 mg/kg, 5.4−16.0 mg/kg, and 0−0.50 mg/kg, respectively. The concentrations of ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen were 0.24−27.3 mg/kg, 0−1400 mg/kg, and 13.5−128 mg/kg, respectively. We conducted a risk assessment of the landfill referring to the *Technical Guidelines for Risk Assessment of Contaminated Sites* (HJ25.3—2014). The results of the pollution survey indicated a high risk of soil contamination in the farmlands surrounding the site, and the need for additional prevention measures.

The groundwater was also investigated: its pH ranged between 7.07 and 8.54, while its main over-characteristic pollutant (in the proximity of the landfill) was the ammonia-nitrogen. Our analysis of organic components detected variable concentrations of naphthalene, decene, phenanthrene, anthracene, fluoranthene, benzo [*b*], fluoranthene, anthracene [1,2,3-*cd*]-indole, diphenyl [*a*,*h*] hydrazine, benzo [*g*,*h*,*i*] perylene, δ-HCH, heptachlor, dimethyl phthalate, diethyl phthalate, dibutyl phthalate, phthalate dibutyl benzyl formate, (2-ethylhexyl) phthalate, di-n-octyl phthalate, phenol, 2-cresol, 4-cresol, and 4-chloro-3-methylphenol. In addition, the permanganate index repetitively exceeded the standard values. The biodegradability of groundwater around the landfill was generally poor; its biochemical oxygen demand (BOD)/COD ratio varied between 0.04 and 0.54.

4.2.3 Comprehensive treatment project for the reduction of site pollution

An in-situ sealing technical solution was selected for this site. This solution included the following main engineering measures:

(1) The setting up of 10 oxygen aeration wells and aeration systems for the in-situ stabilization of waste, in order to improve the safety of landfills and prevent fires/explosions.

(2) The setting up of 20 leachate drainage wells, and the construction of a landfill leachate treatment facility with a capacity of 500 m^3/d. The core process included advanced oxidation and biochemical technologies, namely: an ozone catalytic oxidation system, a biological activated carbon (BAC) reaction system, a hematite bioreactor system, a membrane bioreactor system, an advanced Fenton oxidation technology, and an electrocatalytic oxidation technology. In addition: quantification of the leachate (with no concentrate production) up to the standard efflux and reduction of the pollutants from the source.

(3) The construction of a water-proof curtain with a total length of 1 700 m and an average construction depth of 14.7 m. A cement grouting was positioned 2 m below the top of the first weakly permeable layer in the landfill area, to block the downward migration of pollutants into the soil.

(4) The use of a high-density polyethylene (HDPE) film (1.5 mm-thick, floating bed type, and flexible), in order to cover the entire water surface of the landfill site (240 mu); additionally, 2×10^4 m^2 of turf were laid to improve the site of the landfill. We also adopted additional restoration measures, such as ecological greening, flood control, and surface runoff.

(5) The construction of equipment for groundwater, landfill gas, and garbage pile settlement detection/early warning. The aim was to realize a groundwater monitoring/early-warning system, for the landfill site. Additionally, a funnel-type permeable reactive barrier (PRB) was constructed to limit groundwater pollution in the southern part of the site, removing both C and N from the groundwater.

5 Conclusion

The problem of heavy metal pollution (Cd, Hg) in the soil of the Beijing-Tianjin-Hebei agricultural production area is prominent, and the related pollution risk cannot be ignored. High-risk areas of Cd pollution are distributed

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around Tianjin, while high-risk areas of Hg pollution are distributed around both Tianjin and Beijing. The chemical, livestock-poultry breeding, and metal smelting-processing industries are the main potential sources of heavy metal pollution for the agricultural production areas of Beijing, Tianjin, and Hebei. We proposed a comprehensive prevention/control strategy for the environmental pollution of agricultural products, and described key projects of farmland pollution control in Beijing, Tianjin, and Hebei: a pit-pollution site in Tianjin and an informal landfill. These two case studies can be used as references for the elaboration of strategic decisions, aiming at the prevention and control of soil pollution in the Beijing-Tianjin-Hebei agricultural production area.

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