Investigation and Remediation of the Contaminated Farmlands in Taiwan

1、Origin

Soil is the ultimate container, it absorbs various pollutants from air, water, and waste sources through dust, irrigation, landfill, and disposal of waste materials. Some pollutants contained toxic materials have bio-accumulative and non-biodegradable properties. When the accumulated level of pollutant in the soil exceeds the acceptable limits, then overexposure to pollutants will create health and safety hazards to human and ecology. Taiwan is a small island nation that is overpopulated and highly industrialized; therefore, it poses a severe challenge to the protection of soil pollution. The total farmland area in Taiwan is about 0.85 million hectares; the total plain areas with irrigation facilities is about 0.38 million hectares. The areas of paddy fields was about 0.26 million hectares in 1993, but in 2009 it reduced to only 0.18 million hectares. The amount of irrigation water for one season rice crop is about 0.02 million tons; however, due to the land use disorder, factories were built in farmlands. Irrigation water has been chronically polluted by industrial wastewater, which becomes the main cause of farmland pollution. Heavy metals and toxic organic matters have been continually discovered in the farmland soils, has caused serious damage to Taiwan's agricultural production.

Before the implementation of "Soil and Groundwater Pollution Remediation Act", brown rice from paddy fields in Datan, Taoyuan County (Coin Chemical Industry), was first to be found contaminated with cadmium (Cd) and lead (Pb), this was later known as the "cadmium rice" incidence in 1982, which lead to the follow-up discovery of "cadmium rice" appeared in Chungfu, Taoyuan County (Chi-Lee Chemical Industry) in 1988. These rice paddies were contaminated by wastewater with high concentrations of Cd and Pb from the nearby chemical factories producing PVC stabilizers through irrigation water. After increasing reports on the early "cadmium rice" cases in Japan and domestic farmland pollution, the Taiwanese government has started to carry out the soil pollution survey since 1982 to protect public health, and the farmland grown food crops were set as the priority target of exploration.

▲ Factories are often located close to farmlands in Taiwan

After the "Soil and Groundwater Pollution Remediation Act" was announced and implemented in 2000, soil pollutants were divided into four groups: heavy metals, organic compounds, pesticides, and other organic compounds; and the soil pollution control standards for these were also established. First, we have been verified the farmlands with high pollution potential, then improved and remediated the contaminated farmland soil that exceeds the control standards. We also have been conducting follow-up investigations of sites with high pollution potential and verifications of soil pollution petition cases. Besides, We assist Environmental Protection Bureau of every county to promote the control, improvement, and remediation works of contaminated farmlands. So far, we have accumulated 10 years of experience and achievements. On the 10th anniversary of implementing the "Soil and Groundwater Pollution Remediation Act", we will take the opportunity to take a look at the results of implementation over the past years and look into the future prospect.

2、Objectives

The main cause for heavy metal pollution in the farmlands is the irrigation ditches had been polluted by illegally discharged industrial wastewater. Some of the farmlands were irrigated by contaminated irrigation water for a long time, which ultimately caused the heavy metals accumulation in soil. This is why we not only had to subsidize the Environmental Protection Bureau of local counties to execute the improvement work of the farmland pollution, but also had to strengthen inspection and control the sources of pollution. Additionally, in order to avoid the secondary pollution of farmland, we request the agricultural organizations to removal sediment regularly. Each of the improved cases must go through rigorous verification, after the conditions of the procedure were met, the improved case will be deregulated. The goal is to restore the farmland to its original state as soon as possible, and to assure public food safety. In the future, we will continue to assist the local governments to conduct the investigation works of the soil pollution of farmland, which will ultimately control the condition of farmland. In addition, we complete the improvement works of the contaminated farmland as soon as possible and protect the safety of environment for agricultural production to ensure public health.

3、Results

1. Results of 319 Hectares of the National Farmland Pollution Survey

The systematic investigation procedure of farmland soil pollution has started since 1982, which was divided into four stages. The survey items included the following heavy metals: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel l (Ni), lead (Pb), zinc (Zn), and mercury (Hg). In the early period of the investigation project, the heavy metal contents were determined by 0.1 N HCl extraction method, and the contaminated farmlands were classed into five classes in order to evaluate the degree of soil pollution. However, after the implementation of the "Soil and Groundwater Pollution Remediation Act," the new soil pollution monitoring and control standards were announced, and the aqua regia digestion method became the standard method for measuring soil heavy metal contents. The results of "319 Hectares of the National Farmland Pollution Survey" showed that the total area of farmlands that exceeded the soil pollution control standard was 282.64 hectares, and 198 hectares of the contaminated farmlands were in Changhua County.

Therefore, in 2004, the follow-up monitoring program was to continue to investigate 87 hectares of the contaminated farmlands in Changhua County. The result indicated that 27 hectares of the farmland exceeded the soil pollution control standards for edible crops. The remediation work for these contaminated sites was completed after the monitoring program. Moreover, the extended investigation project for another 102.27 hectares of the contaminated farmlands in Changhua County was carried out in 2007. The total area of the investigated farmland that exceeded the soil pollution control standards for edible crops was 48.14 hectares. In 2009, 50.66 million NTD were used for the remediation, which is expected to be finished in 2011.

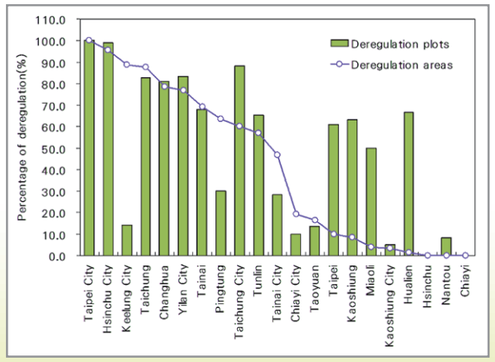
Stages	Periods	Survey area (ha)	Sampling unit (ha)	Achievements
1	1982–1986	over 1.16 million	1,600	Over 0.3 million ha exceeded the fifth class standard.
2	1987–1990	over 0.3 million	100 and 25	About 0.05 million ha exceeded the forth class standard, and about 790 ha exceeded the fifth class standard.
	1992–1999	over 0.05 million	25 and 1	Regular monitoring and pollution sources tracing were carried out by the local environmental agencies.
3	1992–2001	The regions with the high contents of heavy metals in the stage 2.	1	1,024 ha exceeded the fifth class standard, and 319 ha exceeded excluding Cu and Zn.
4	2002–2003	319	plot	About 282.64 ha exceeded the soil pollution control standard.

Notation: The farmland classified as the first or second classes of soil heavy metal contents are considered as non-polluted sites. The soil heavy metal concentrations of the third class are defined as background values. The fourth and fifth classes require intensive monitoring and remedial actions.

▲ The systematic processes investigations of farmland soil in Taiwan

2. Results of Farmland Pollution Remediation

Since the results of "319 Hectares of the National Farmland Pollution Survey" had been released, we actively implemented the follow-up improvement actions of soil pollution and invited scholars and experts to discuss the soil improvement technologies. However, the improvement works of contaminated farmlands, the polluted depth is restricted to the topsoil due to its strong adsorption property. A low-cost and high-efficiency method of "Soil Turnover and Dilution" is applied in the large area of farmland polluted by Cu, Zn, Cr, and Ni with relatively low toxicity. "Soil Acid Washing" or "Soil Dressing" methods are applied in the small area of farmland polluted by Cd and Pb with high toxicity; the "Thermal Treatment" method is applied in the Hg-polluted farmlands. In order to restore the original use of the farmland, we supervised each county to perform the improvement works of contaminated farmlands. Since 2003, we have approved grants for 12 counties to improve contaminated farmland and the related remediation expenses added up to 350 million NTD. To the end of August 2010, the total number of contaminated sites in Taiwan's farmlands are proclaimed to be 2,050 plots and the total area is 466.97 hectares. The total number of remediation of contaminated sites which has been completed and deregulated is 1,482 plots and the total area is 350.89 hectares.



▲ The percentage of deregulation plots and areas in every county until August 2010

Soil and Groundwater Pollution Remediation Fund Management Board
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3、Results

3. Results of Phytoremediation on Contaminated Sites

The phytoremediation test for a large area of heavy metal contaminated farmlands in Changhua County started from 2005. The

results showed that the removment of heavy metals and land reuse can be achieved by planting 12 species of flower plants with strong resistance to heavy metal pollution and better absorption capacity for heavy metal in contaminated plots. This method will not only improve the function of soil ecosystem and increasing the economic benefits of contaminated farmlands, but also help farmers continue farming to save the set-aside compensation payment by the government.

4. Relationship between the Heavy Metal Contents in Irrigation Systems and Contaminated Farmland

In 2002, we investigated the sediment and water in the irrigation ditches close to the fifth-class contaminated sites in Taoyuan, Changhua, and Kaohsiung counties. According to the results of the project, the consistent rate of heavy metal-polluted items reached 93% after the qualitative comparison, which indicated that the polluted irrigation water was the main reason of the soil heavy metal pollution in the farmlands in these three counties. In 2007, four highly polluted irrigation ditches in Taoyuan, Hsinchu, Taichung, and Changhua counties were selected for the further sampling and investigation. The results also showed that there is a high correlation between heavy metal pollution in sediment and in farmland.

5. Results of Rice Monitoring Programs

In 2005, we provided the Agriculture and Food Agency, the Agricultural Research Institute, and the district Agricultural Research and Extension Station with 4,600 million NTD for restoring soil fertility in the deregulated farmlands. To understand the differences in absorption capacity of soil heavy metals between different rice species, the research projects “Absorption Mechanism of Heavy Metals in Crop (Rice) and the Influence on the Safety of Agricultural Products” was conducted in 2005, 2006, and 2008. In the first two years of the project, the experiments were performed in the central regions of Changhua City, Hemei Town, Lukang Town, the northern regions of Sindian City and Bade Town. The results indicated that the soil physico-chemical properties and heavy metal concentrations directly affect the heavy metal contents in rice. In 2008, the further experiment was carried out in the southern regions. The results showed that the indica rice is easy to absorb Cd from soil. Also, the concentrations of Cu, Zn, Cd, and Ni in the indica rice in the second-crop season are higher than the first-crop season, no matter whether the soil is polluted with heavy metals or not.

6. Discovery of Arsenic Contamination in Farmlands in the Guandu Plain

During the period of 2004 to 2005, the abnormally high concentrations of As in soil were found in some areas of farmland (the survey area about 11.5 hectares) in the Guandu Plain, Beitou District, Taipei City. The concentration of As in soil was between 89 and 424 mg kg-1, and 6 hectares of the farmlands were over the soil pollution control standard (60 mg kg-1). In 2006, a grid cell size of 1 hectare was used as a sampling unit and 843 hectares of farmlands belonged to the Chihsin Irrigation Association and 72 hectares located on both sides of the Yangching Road, Shilin District and the vegetable-growing areas beside the Bamboo Lake were investigated to determine the level of As contamination. The results showed that the As concentration of the topsoil in the highly contaminated area of the Guandu Plain, Beitou, ranged between 60 and 500 mg kg-1. In addition, 128 hectares of the farmlands contained As exceeding the soil pollution control standard. The major source of pollution is the hot spring water that carries the Beudantite, which contains As from the Geothermal Valley (also called the “Hell Valley”) and has not been found in Taiwan. Since the farmers in the Guandu region have irrigated their farmlands with the water from the Geothermal Valley for the past hundreds years. Arsenic continuously accumulates in the soil in this region. Therefore, it is clear that the large-area pollution is not related to industrial activities.

There is no standard for the As concentration in crops in Taiwan, the investigation project used Germany standard that the As content in wheat should not exceed 1 ppm to, evaluate the safety of the paddy rice cultivated in the Guantou Plain. The As concentration in the paddy rice grown in the Guantou Plain was less than 0.5 ppm, which suggests that the

▲ The Beudantite found in the Beitou River

4、Prospect

The investigation work of farmland pollution went from taking samples from a large sampling area, following with investigation to determine and tracking the target area, to locking-up and remediate after enforcing the “Soil and Groundwater Pollution Remediation Act”. The investigation has produced valuable results. The cooperation between private enterprise, governmental agencies, and academic institutes have produced and accumulated valuable experience in many related investigation, analysis, technical skills, and engineering. This year the research and investigation have continued, such as the study of the afforestation benefits of farmlands with heavy metal pollution in Taoyuan, establishing the early warning system for the national farmland pollution control, the extensive investigation of the absorption difference of heavy metals between various crops and vegetables grown in different areas and assessing the hazard effects of different crops absorbing the contents of heavy metals in soil on human health, conducting field experiment on reducing the absorption of Cd on food crops, discussion on how to reduce the effects of absorption of heavy metals in soil on various food crops (including rice and vegetables), and seeking for an economical and effective solutions on reducing the risk of food crops and to build a database for the heavy metal background concentration in the soil of Taiwan’s farmlands.

We also face some challenges such as the “Soil and Groundwater Pollution Remediation Act” is only effective for soils, but the sediment is not within the scope of this Act. After the amendment to the “Soil and Groundwater Pollution Remediation Act”, sediment is included in the regulation scope. The definitions and related regulations of sediment, sediment pollution, and sediment quality criteria were also added into the regulation. And this is a great leap forward in the prevention of farmland pollution.

Starting from the year 1982, after 30 years of work, there has been a change in the Taiwan’s agricultural land use, the industrial infrastructure has changed from traditional industry to high-tech industry, which triggered the regional adjustment of land use, besides the regular eight heavy metals, new emitted pollutants such as molybdenum (Mo), indium (In), and gallium (Ga) were added, these marked the beginning of a new era and new challenge, the Soil and GroundWater Redemiation Fund Management Board will take on the great responsibility of protecting water and land resources for sustainable use.

Soil and Groundwater Pollution Remediation Fund Management Board
http://sgw.epa.gov.tw/public/