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Proceeding Paper

Application of Ion Exchange Resin Capsules in Water Pollution Source Investigating in Taichung Area, Central Taiwan †

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Abstract: In central Taiwan, due to the complex urban regions and the distribution of industrial and agricultural areas, there are high potential risks of irrigation water pollution caused by urban drainage or industrial wastewater. Heavy metal pollution from industrial wastewater significantly impacts water and soil. In this study, time-lapse ion exchange resin capsules were used to investigate heavy metal water pollution in the Taichung irrigation area of central Taiwan. The resin capsules were put in pollution canals for a few days and retaken. X-ray fluorescence analysis was conducted to detect the amount of heavy metal absorption and investigate the degree of heavy metal pollution in the irrigation water. The investigation was performed from 2018 to 2021, and during which, 48, 140, 620, and 217 resin capsules were placed to investigate the pollution of the irrigation area. The results show that the Babao irrigation area in the Dajia River basin and the Dali irrigation area in the Wu River basin were significantly polluted with Ni and Cr. Ion exchange resin capsules were recommended as being a valuable tool for a quick test to investigate heavy metal pollution.

Keywords: resin capsule; water pollution; heavy metal

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1. Introduction

In the early days of Taiwanese history, agriculture was the primary economic source. In the 1960s, product exports increased, and economic emphasis was placed on industry and trade [1], with many factories established. Due to a lack of land planning in Taiwan, the arable area was mixed with industrial and urban areas. If industrial and urban drained water is treated properly, the irrigation system is polluted. The direct or indirect inflow of domestic sewage and industrial wastewater containing heavy metals causes various degrees of deterioration of irrigation water quality and soil pollution, crop pollution, and food safety concerns [2]. In contaminated land sites, data represent diverse soil pollution, depending on types of land use (including factories, gas stations, illegal disposal, storage tanks, military sites, and other types of sites).

In Taiwan, agricultural land accounts for 79.39%, factories account for 18.63%, others account for 0.89%, gas stations account for 0.69%, and military sites account for 0.40% of the total land use [3]. There were 7287 heavy-metal-contaminated agricultural land sites (about 1149 ha) in Taiwan by the end of 2021. The remediation of agricultural land pollution is expensive, and the total expenditure for 2020 was NTD 1.313 billion. A total of 95.85% of the pollution remediation has been completed. With the efforts of environmental protection agencies, 7174 farmland sites of about 1127 ha have been remedied and released from control. On the other hand, 113 farmland sites of about 22 ha are still under control [3]. By analyzing the contaminated land site distribution [4], it was found that most of the sites are distributed in Changhua (3293 sites), Taoyuan (2825 sites), and Taichung (738 sites). Among them, the irrigation area of Taichung was about 25,691 ha and about 84.8 ha in the Dali area was remedied by the end of 2021, where the most polluted areas were found (Figure 1 and Table 1).

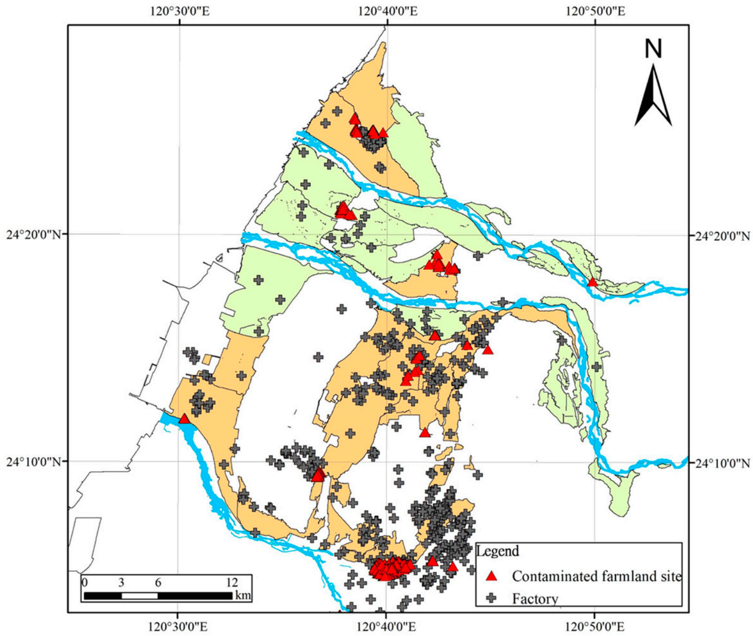

Figure 1. Contaminated land sites.

Table 1. Controlled contaminated land sites in the Taichung irrigation area.

Irrigation Area	Sites	Area (ha)
Zhuolan	1	0.2
Yuanli	19	1.5
Rinan	33	5.2
Tunzijiao	16	3.2
Ciyao	2	1.0
Dajia	16	4.7
Babao	4	0.3
Fengyuan	14	0.2
Tanzi	2	0.4
Xitun	23	7.1
Nantun	23	58.6
Dalio	578	0.3
Dadu	7	2.3
Summary	738	84.8

As the characteristics of pollution sources are irregular, short-lasting, highly concentrated, and wide-ranging [5], traditional water sampling may not be an effective way to determine long-term water pollution. Thus, the ion exchange resin capsule invented by Chang [6] is used for water pollution source investigation. The capsule absorbs and exchanges heavy metal elements in the water, and the analysis result is used to record the water pollution degree [5]. The resin capsule was applied to the pollution potential investigation in the Dayuan and Dazhu areas (Nankan River and Puxin River) in Taoyuan City in 2016, in which Cu and Zn pollution was reported [7]. The resin capsule was used to determine and monitor potential heavy metal water pollution by the electroplating industry in the Dongxier canal in the Changhua irrigation area. After 2 months of continuous monitoring, the specific factories were located and charged for discharging wastewater illegally in 2015. In addition, the resin capsule was also used to investigate the potential pollution in Taoyuan, Hsinchu, and Tainan in 2016 [8].

2. Study Area and Method

2.1. Study Area

The Taichung Irrigation Area is located in central Taiwan. The area stretches across 3 river basins of the Daan River, Dajia River, and Wu River, from north to south. The irrigation area of the Daan River, Dajia River, and Wu River is 10,575 ha, 12,222 ha, and 2894 ha, respectively [9,10]. According to the data from the soil and groundwater pollution remediation fund management board [4], there are 738 contaminated land sites (84.8 ha) under control, whereby most of which are in the Dali area (578 sites) and regarded as seriously contaminated areas (Figure 1 and Table 1). Through the efforts of the related bureau, none of the 738 contaminated land sites in Taichung have been under control yet. In this research, 2 potential pollution irrigation areas (Yuanli and Rinan) in the Daan River basin, 5 areas (Babao, Xitun, Nantun, Shalu, and Tunzijiao) in the Dajia River basin, and 3 areas (Dali, Wangtian, and Dadu) in the Wu River basin were chosen for investigation (Figure 2).

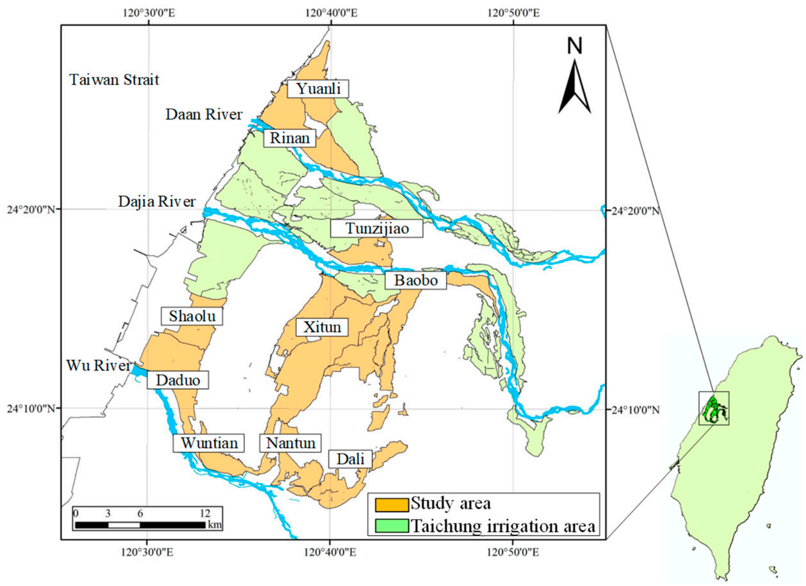

Figure 2. Study area.

2.2. Properties of Ion Exchange Resin Capsules

Chang tested the adsorption capacity of the ion exchange resin capsules using the bottle-cup test (JAR-TEST) [6]. The results showed that it took 20 min to reach the resin's adsorption rate of above 35% for Pb, Ni, Ca, Mn, and Zn, and 30 min to reach the resin's adsorption rate of above 40% for Cu, Ni, and Ti. In an open environment, the ion exchange resin adsorbs heavy metals. The resin capsule is a yellow-brown granule (Figure 3) similar to an agent for hard water softening or the demineralization of water. It is made of gel polystyrene with a polymer structure, a functional group characterized by sulfonic acid, and sodium-form (Na^+) ion exchange. The cation exchange capacity is 2.0 eq/L at a water content of about 44−48%. A single particle size is about 300−1200 μm, with a particle density of about 1.29 g/cm^3 and an enduring temperature of up to 120 °C [7].

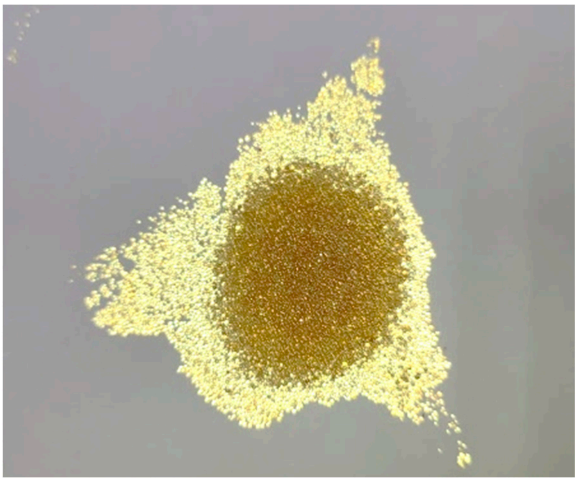

Figure 3. The resin capsules.

Before the resin capsule was placed, a site survey was needed to confirm the exact location of a suspicious pollution source. To avoid loss by flushing or human destroying, it needed to be placed in a hidden place such as under waterweed shade or on the canal side and be fixed with steel nails or iron wires. It is suggested that it be placed for 3–7 days for insufficient absorption to occur. Biofilm may be formed on its surface and decrease the absorption if placed for longer than 7 days [6]. After heavy metal absorption, the resin capsule was retaken and cleaned to remove the surface biofilm and other material on the surface. Then, X-ray fluorescence (XRF) was used to detect the content of different heavy metals adsorbed by the ion exchange resin [7,11].

First, the Ca concentration of the resin capsule was determined. If the Ca concentration was between 40,000 and 50,000 mg/kg, the absorption time needed to be shortened. If the Ca concentration was less than 3000 mg/kg, data were considered to be invalid as this represents a low water flow rate. Equation (1) was used to calculate the ratio of different metals' concentrations and Sr concentration (Sr is the environmental background element and was used to represent the flux of the background element). Then, whether the concentrations exceeded the standard was determined using Equation (2) [7].

$$X = \frac{C_x}{C_{Sr}} \tag{1}$$

$$X \geq \overline{X} + 2\sigma \tag{2}$$

where X is the ratio of a heavy metal concentration to Sr concentration, C_x is the concentration of a heavy metal detected via XRF, C_{Sr} is the concentration of Sr detected via XRF, $\overline{X}$ is the average of the ratio of a heavy metal concentration to Sr concentration, and σ is the standard deviation. When the ratio of a metal concentration to that of Sr was more than the average ratio plus 2 standard deviations, the sample was regarded as being polluted with the metal. The resin capsule was suitable for finding pollution sources. However, the resin capsules had inconveniences, such as easy loss and recovery failure. The placement, arrangement, and concealment of the capsule need to be improved. The resin capsules need to use the relative Sr ratio of the upstream and downstream to judge whether there is pollution. When the result was not obvious, it was difficult to decide on water quality monitoring, and traditional water quality sampling and laboratory testing are required.

3. Results

In 2018, the resin capsule was used to be implemented to determine the high or possible pollution potential of canals. The recovery ratio was about 85.4%. The investigation was continued in 2019. A total of 140 resin capsules were planted, of which 8 were lost, and

132 were successfully recovered with a recovery ratio of 94.3%. In 2020, 620 capsules were planted with 19 capsules lost and 601 capsules recovered, and the recovery ratio was 96.9%. In 2021, 217 capsules were planted. Briefly, 24 were lost and 193 were recovered with a recovery ratio of 88.9%. In total, 1025 resin capsules were planted with a recovery ratio of 94.3%. The calculation result of the ratios of heavy metals to the concentration of Sr is shown in Table 2. The concentration of Ca and Sr in the resin capsules is displayed in Figure 4. The correlation between Sr and Ca was 0.835. The Sr/Ca ratio in Taoyuan was 0.017, which was slightly lower than in the Taichung area.

Table 2. The criteria of the resin capsule in different heavy metals.

Ratio of Metal to Sr	Average	σ	Criteria
Cu/Sr	0.007	0.053	0.114
Pb/Sr	0.013	0.189	0.392
Zn/Sr	0.095	0.295	0.684
Cr/Sr	0.026	0.452	0.929
Ni/Sr	0.011	0.069	0.149

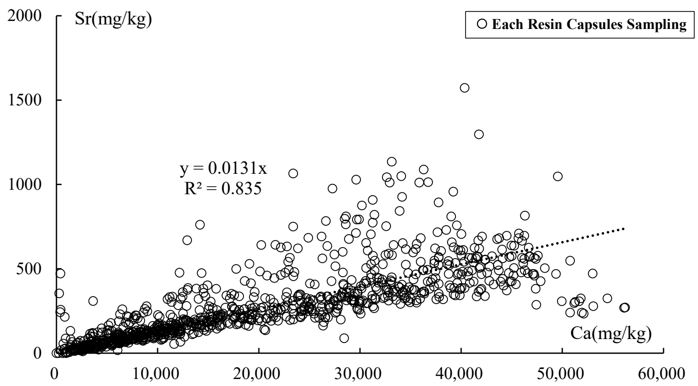

Figure 4. The relationship between Ca and Sr in resin capsules.

In 2018, a survey was conducted in the polluted potential irrigation area in Taichung. The results showed that Pb and Zn were high near the rainwater outlet in the drainage system of the industrial park in the Yuanli irrigation area. The Dali area was slightly polluted by heavy metals such as Zn. The results in 2019 showed that the Dali irrigation area was slightly polluted by Zn and Cr. In the Niuchou branch canal of the Babao irrigation area and the Shenpi branch canal of the Xitun irrigation area, Cu and Ni polluted the downstream of the specific suspected factory. In 2020, it was found that the industrial drainage system of the Rinan and Yuanli irrigation areas was polluted by wastewater containing a high concentration of Cu and Zn. The Tunzijiao irrigation area was investigated too, and the result showed Cu and Zn pollution in the downstream area of the steel plant neighboring a rice paddy. An investigation in the Niuchou branch canal in the Babao irrigation area and the Shenpi branch canal in the Xitun irrigation area showed high concentrations of Cu and Zn in the wastewater from factories near the irrigation areas. The Amili canal in the Dali area showed Zn pollution. The survey results in 2021 showed Cu pollution in the Niuchou branch canal of the Babao irrigation area and Zn pollution in the Dali area. Other irrigation areas such as Nantun, Shalu, Wangtian, and Dadu did not show any pollution.

In terms of pollution source, when the industrial zone is located nearby, discharged wastewater may contain heavy metals of high concentrations. If the downstream agricultural area is irrigated, heavy metal pollution may be observed. The pollution in the Tunzijiao area originated from nearby steel factories, but the degree of pollution was relatively low. The Xitun and Babao areas were affected by metal surface treatment factories. The Dali area was heavily polluted since the upstream water contained the regional drainage and the wastewater of factories. In the Dali irrigation area, the wastewater from factories seems to contaminate water and soil.

4. Conclusions

The resin capsule was used to investigate water pollution in the Taichung area. The research was conducted for 4 years from 2018 to 2021. The results showed that the Babao, Xitun, and Dali areas were seriously polluted by heavy metals. The pollutants in the Babao area were Cu and Ni, while Zn and Cr pollution was found in the Dali area. Other areas such as the Yuanli and Rinan areas were also affected by water pollution. The Shalu, Nantun, Wangtian, and Dadu areas showed a lower degree of pollution. The resin capsule is convenient for the investigation of pollution sources and can be a useful tool to replace time- and resource-consuming operations of traditional water quality monitoring and conduct long-term water quality monitoring.

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