An ecological sediment treatment technology based on zero emission and 4R concept

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Abstract. In order to reduce the amount of the contaminated sediment treatment and utilization, an ecological technology of sediment treatment was developed based on zero emission & 4R (Reduce, Recycle, Reuse, and Revolution) concept, centrifugal solid-liquid separation technology and high speed suspended solid settlement technology by gravity and polymeric flocculants and the biological contact oxidation technology. The polluted sediment can be accurately divided into gravel, sand, silt and clay by four-stage treatment process. The dewatered clay is made into the mixture soil of the sponge city facilities or other building materials, gravel and sand are directly used as concrete aggregate, permeable bricks and the silts are used for backfill and planting soil. The treatment efficiency of the ecological sediment treatment technology is higher than the traditional sediment treatment process used in China, and there is no secondary pollution and cost savings. It can be widely applied to quick treatment of the sediment in the polluted rivers, reservoirs and lakes, and construction wastes of subway and tunnels. The investment of the new treatment system is about CNY25 million Yuan for deposits of 2.48 million cubic meters. The innovative ecological treatment technology has been successfully used in the sediment treatment of the Qingxi River in Qingxi Town, Dongguan City, Guangdong Province in 2019.

1. Introduction
In the process of urbanization in China, a large amount of industrial wastewater, domestic sewage and agricultural wastewater have not been treated. The construction of the sewer pipelines can't keep up with the urbanization. As a result, the pollutants (heavy metals, refractory organics, etc.) and nutrients (N, P, etc.) carried in the sewage are continuously accumulated in the sediments of rivers, lakes and harbors, making river system serious pollution. Once the polluted sediment is disturbed, the accumulated pollutants in the sediment will be released into the downstream water environment and become a permanent source of pollution. If it is not treated in time, it will seriously affect the quality of the water environment and even threaten people's daily life [1-3].

Sediment dredging is a common method for controlling water pollution. The sediment that accumulates a large amount of pollutants is removed from the water body and then is needed to be treated. However, the sediment from the river is not only a large amount, but also has high water content and a large amount of pollutants. If sediment is dewatered simply and sent to landfill site...
without taking any measures, it will not only take up a lot of land, but also easily cause secondary pollution with the scouring effect of rainfall and snowfall [3]. In addition, the beneficial ingredients in the sediment cannot be fully utilized. The nature of dredged sediment is close to that of soil, and organic matter, nitrogen and phosphorus are rich in and have high utilization value. The dredged sediment can be used for environmental protection and resource conservation after being effectively reduced and harmlessly treated. This method of sediment management is a hot spot in the research of water environment rehabilitation. At present, the comprehensive utilization of dredged sediment in China is mainly based on landfill, abandonment, composting, etc. With the goal of ecological civilization construction and the improvement of relevant laws and regulations, the reduction, harmless treatment and resource utilization of dredged sediment will become the best way to deal with sediment [4,5].

In this study, taking the sediment treatment of the Qingxi River in Qingxi Town, Dongguan, Guangdong, China as an example, an ecological technology of sediment treatment was developed based on zero emission & 4R (Reduce, Recycle, Reuse, and Revolution) concept, centrifugal solid-liquid separation technology and high speed suspended solid settlement technology by gravity and polymeric flocculants.

2. Project overview

2.1. The Qingxi River
The Qingxi River flows through Qingxi Town, Dongguan, Guangdong, China, and is Class I tributary of the right bank of the Shima River. It originates from the Mount Nake of Baoan, Shenzhen, and flows through Guanlan Town of Shenzhen, Fenggang, Tangxia, Zhangmutou, Qingxi, Xiegang, Changping and Qiaotou Eight Town of Dongguan. From north to south, it flows through Yangmeikeng, merges with the Tieshiling River in Qitaiyang Village, then folds to the west, exits Jiaoling, passes through the Qingxi Town, and finally merges into the Shima River near Jufu Road in Qitaiyang Village.

![Figure 1. The location of the Qingxi River.](image-url)
Reservoir and Qingxi Reservoir, with a total length of 16.46 km, divided into three sections, of which the length of the Tieshiling River below the Maofeng Reservoir is 6.49 km, the Qingxi River below the Qingxi Reservoir has a length of 5.18 km, and the length of the mainstream of the confluence with the Tieshiling River inlet is 4.79 km. The total amount of sediment to be dredged is about 248,000 m$^3$ [6].

2.2. Problems of the Qingxi River
In order to solve the pollution problems of the Qingxi River, reduce and recycle the Qingxi River sediment, through on-the-spot investigation, it is found that there is a general shortage of river channel over-flow section, the flood control standard of dikes is low; the sewer pipelines are imperfect, and the collection rate of sewer in the Qingxi River basin is low, some sewage is directly discharged into the river; the urban non-point source pollution control measures are penurious, and the initial rainwater runoff is directly discharged to the adjacent receiving water body without treatment; the endogenous pollution is serious, long-term siltation in the river to form a polluted sediment; all kinds of pollution are released into the river, polluting the water quality of the river; the water quality of the main river is very poor, and there is a lack of cleaning water supply. These are the reasons for the black color and odor of sediment. To this end, the Qingxi River’s sediment was sampled and analyzed, and the content of each component in the river’s sediment was analyzed. A total of 12 sediment specimen from 6 sections were sampled for test analysis. The distribution position of the sediment measurement points is shown in figure 2.

![Figure 2](image)

Figure 2. Location of sediment sampling points.

According to the site investigation and the Qingxi River sediment’s test report, not only the organic matter content in the sediment of some river sections is high, but also the contents of the heavy metals are higher than the national standard. The heavy metals such as zinc, copper, cadmium, nickel and chromium in the river bottom sediment are higher than the standard, others only meet the national standard “Soil Environmental Quality Control Standards for Soil Pollution Risks (Trial)” (GB 15618-2018). The test results are shown in table 1.
Table 1. Results of sediment test indicators.

|               | ZK183-1 | ZK183-2 | ZK3-1  | ZK3-2  | ZK232-1 | ZK232-2 | Unit   |
|---------------|---------|---------|--------|--------|----------|----------|--------|
| pH            | 6.32    | 6.33    | 6.03   | 5.90   | 5.93     | 5.93     | /      |
| Cadmium       | 1.26    | 1.34    | 1.63   | 1.98   | 2.12     | 1.79     | mg/kg  |
| Mercury       | 0.65    | 1.20    | 0.74   | 0.75   | 1.11     | 0.92     | mg/kg  |
| Arsenic       | 18.1    | 15.5    | 18.7   | 17.9   | 29.5     | 29.3     | mg/kg  |
| Copper        | 1.38$\times$10$^3$ | 1.12$\times$10$^3$ | 1.28$\times$10$^3$ | 1.28$\times$10$^3$ | 3.02$\times$10$^3$ | 2.84$\times$10$^3$ | mg/kg  |
| Lead          | 101     | 88.3    | 99.0   | 85.6   | 109      | 116      | mg/kg  |
| Chromium      | 583     | 422     | 586    | 583    | 846      | 742      | mg/kg  |
| Zinc          | 3.15$\times$10$^3$ | 2.36$\times$10$^3$ | 3.80$\times$10$^3$ | 3.73$\times$10$^3$ | 5.48$\times$10$^3$ | 4.21$\times$10$^3$ | mg/kg  |
| Nickel        | 251     | 179     | 300    | 274    | 330      | 241      | mg/kg  |
| Cation exchange capacity | 41.1 | 38.3    | 43.0   | 42.6   | 60.7     | 54.2     | cmol(+)kg |
| Organic matter| 194     | 210     | 221    | 266    | 282      | 254      | g/kg   |

The results of the test index refer to the standards issued by the Ministry of Ecology and Environmental Protection of the People's Republic of China, “Soil Environmental Quality Control and Control Standards for Soil Pollution Risk of Agricultural Land (Trial)” (GB 15618-2018) Table 1 Screening Values of Soil Pollution Risk of Agricultural Land (Basic Project).

3. Technological process

3.1. Precise separation technology

In the river dredging project, the dredged sediment is in the form of mushy mixture, and the general moisture content is between 75% and 90%. The distribution of particles in the sediment is determined by various factors such as the geographical location of the river, the surrounding environment, the severity of pollution, etc., but generally can be divided into garbage, pebbles/gravel, sand, silt and clay. According to the geological survey data, the content of the sand in the sediment of this river is about 20%, and the content of the silt is about 30%. Traditional disposal methods include landfill, abandonment, settlement in grit chambers, and the like. The landfill method is bound to occupy a large amount of land and easily cause secondary pollution. Transporting to the deep sea for disposal will have an incalculable impact on the marine environment. And if the grit chamber is used to dispose the sediment, and the sand in the sludge is separated by settling, and then the other particles are extruded into a mud cake or the like by a filter press device. This process not only covers a large area, but also has low processing capacity. The treated sediment is also difficult to use for resource utilization. Reducing the quantity by precise separation technology and then recycling, it not only reduces costs but also saves space. It is a hot spot for the disposal of sediments, reflecting the economic and social needs of “ecological rivers and harmonious rivers”. It is of great significance to the healthy development of the water network, the safety of flood control and drainage, the improvement of human settlements and the improvement of comprehensive competitiveness of Dongguan City.

As shown in figure 3, an ecological sediment treatment process was developed based on zero emission and 4R (Reduce, Recycle, Reuse and Revolution) concept, centrifugal solid-liquid separation technology, high speed suspended solid settlement technology by gravity and polymeric flocculants
and the biological contact oxidation technology. The core steps of this innovative process are divided into four steps. The first step is preliminary screening and oxidation treatment. The sediment that has been dredged from the upstream, middle & downstream is temporarily stored in the pretreatment tank, and then pumped to a three-layer vibrating screen for primary screening, finally the primary sieved sediment is pumped to the biological oxidation tank, and the complex enzyme reaction is added to remove the odor, degrade the organic matter, and separate the water and the sediment. The second step is precise screening and dewatering. Using the Containerized Solids Control Equipment (ES2000C), the sediment is divided into sand, silt, and clay by different particle size, then the Containerized High Speed Suspended Solids Separation System (CH5S) and the belt filter presses were used to further dehydrate the clay with a moisture content of less than 60%, and then utilized for resource utilization. The third step is ecological treatment of residual water. Combined with the concept of the sponge city, the ecological wastewater treatment system is set up to further purify the residual water, then discharge to the Qingxi River. The fourth step is heavy metal curing. Green curing technology was used to treat caly with excessive levels of heavy metals to reach the standard for further resource utilization. The equipment required for the process is shown in table 2.

![Technological process diagram](image)

**Figure 3.** Technological process.

**Table 2.** Process equipment table.

| Equipment Name                                      | Quantity | Unit |
|-----------------------------------------------------|----------|------|
| Three-layer Vibrating Screen                        | 1        | station |
| Containerized Solids Control Equipment (ES2000C)    | 1        | station |
| Containerized High Speed Suspended Solids Separation System (CH5S) | 2        | set   |
| Belt filter press                                   | 2        | station |
| Non-burning brick equipment                         | 1        | set   |
| Automatic water quality testing equipment           | 1        | set   |
| Biological Wastewater Treatment System              | 1        | set   |

3.1.1. Preliminary screening and oxidation treatment. The sediment from the river dredging is first put into the pretreatment tank with a volume of 200 m³, and the appropriate amount of water is evenly stirred and then pumped to the three-layer vibrating screen to screen out the garbage and pebbles/gravel with a particle size larger than 5 mm to facilitate the subsequent ecological development of the sediment.
The black color and odor of dredged sediment in the river is mainly due to the high content of organic matter. The organic matter consumes oxygen in the sediment, which reduces the redox potential of the sediment and causes the anaerobic microorganisms in the sediment and water to multiply. The organic matter in sediment may decompose into methane, hydrogen sulfide, ammonia nitrogen and pyrimidine. Among them, hydrogen sulfide, ammonia nitrogen and pyrimidines are odorous substances. The hydrogen sulfide, ammonia nitrogen and pyrimidine are substances with malodorous properties, and at the same time, high-valent metal ions such as iron and manganese ions in the sediment and water body are reduced to low-valent ions such as Fe$^{2+}$, Mn$^{2+}$, etc. Under anaerobic conditions, these chemically react with the sulfur present in the water to form stable black substances such as FeS and MnS, resulting in the black color of the sediment. The best way to remove the stench of the sediment is by using the complex enzyme to break down the organic matter and remove the odor. The complex enzyme was diluted at a ratio of 1:200, added to the biological oxidation pond according to the calculated dosage, and aerated for 6 hours, and fully reacted in two ecological oxidation treatment ponds as shown in figure 4. The effect of the complex enzyme is not limited to deodorization. The sediment pretreated by the complex enzyme, the organic matter is degraded in a large amount, the water and the sediment are completely separated, the physical properties are changed, the water can be directly discharged, and the sediment is more easily separated and dewatered. The deodorization of the complex enzyme can reduce the gas emission concentration of the sediment to the first-level discharge standard of the Pollutant Discharge Standard for Urban Sewage Treatment Plants (GB18918) [8].

![Figure 4. Ecological oxidation treatment pond.](image)

3.1.2. Precise screening and dewatering. In order to reduce the amount of contaminated sediment treatment, the new precise treatment technology is used to treat the Qingxi River’s sediment. This technology can accurately screen out different particles in the sediment after primary screening into sand, silt and clay, making it easier to reuse the classified particles. The precise treatment technology refers to a set of efficient processing equipment integrated with precise hydraulic calculation based on solid-liquid separation and ingenious mechanical design. The Containerized Solids Control Equipment (ES2000C) manufactured by TriFlo Inc., Texas, USA was used to separate sand and silt in the sediment (figure 5). ES2000C uses advanced hydrocyclone (centrifugation) solid-liquid separation technology and oscillating screen dehydration to separate solids such as sand, silt and clay from the
sediment. It does not need to add any chemicals and can treat 454.25 m$^3$ of slurry containing 15% solids per hour. The entire precision screening workflow is divided into three stages. The first stage screens out sand with a particle diameter greater than 0.075 mm; the second stage screens out silt with a particle diameter greater than 0.025 mm; and in the third stage, clay less than 0.025 mm are flocculated to sediment with a moisture content of 80% by two Containerized High Speed Suspended Solids Separation System (CH5S) made in Dongguan, China, which can handle 10000 m$^3$ of slurry containing 3%-5% solids per day. CH5S was developed with 5S concept and high speed integrated gravity separation technology (figure 6). The capacity of each system is 5000 m$^3$/d, and clay with the moisture content of 80% is 150 m$^3$/d. The discharging water quality meets the national standard of Class IV. CH5S can not only rapidly separate suspended solids (clay) from the slurry, but also recycle tail water. The treatment efficiency of CH5S is four times that of traditional inclined plate sediment equipment. Two belt filter presses were used to further dehydrate the clay with the moisture content of 80% into the clay with a moisture content of less than 60%. The tail water of CH5S and the belt filter presses will be discharged to the backwater pool for recycling use. The backwater pool consists of a settlement pond and a clean pond (figure 7). The mud on the bottom of the settlement pond is pumped back to the biological oxidation pond for recycling treatment. The water in the clean pond is used to rinse the sediment of the pretreatment tank and dilute the biological oxidation pond.

Figure 5. Containerized solids control equipment (ES2000C).

Figure 6. Containerized high speed suspended solids separation system (CH5S).
3.1.3. Ecological treatment of residual water. In order to further optimize the water quality of the residual water, an ecological wastewater treatment system (BWTS) was set near the backwater pool (figure 8). The BWTS consists of a BWTF with an area of 400 m² and a wetland landscape lake with an area of 100 m². The whole system is designed as the gravity flow by using different elevations of the connection pipelines and facilities. The BWTS layout is shown in figure 9. The BWTF consists of active filtration layers and aquatic plants with specific functions, which can effectively filter pollutants, especially for phosphorus (P) and nitrogen (N). The residual water treated by BWTS can meet Class IV indicators of the National standard “Environment quality standards for surface water” (GB3838-2002) [9], which is required by the national sponge city construction. The treated water can be recycled to wash the sediment, and the excess water can be directly discharged into the Qingxi River at high water quality [10].

Figure 7. Backwater pool.

Figure 8. Biological wastewater treatment system under construction (BWTS).
3.1.4. Heavy metal curing. A large number of studies at home and abroad have shown that heavy metal ions are generally adsorbed in fine particles. For sieved clays with excessive heavy metals, it is treated with the green curing technology. By using a non-hazardous chemical bonding method, it converts the lead and other metals in the soil into minerals that do not dissolve water by chemical reaction. The heavy metals treated by green curing technology can meet the requirements for landfill and recycling of common solid waste.

3.2. Sediment resource disposal
At present, the routes commonly used for river sediment resources are mainly landscaping, engineering filling, embankment filling, road engineering, and building foundation. These treatments are more general and not fully resourced. The ecological technology of sediment treatment separates different diameter particles, and it beneficial to realizing sediment resource and harmless.

The cobblestone/gravel is used directly as a building material, backfilling roadbed or as concrete coarse aggregate. The sand is used as building materials, such as concrete fine aggregate or permeable bricks, and silt is used as backfill, planting soil or mixing soil of sponge city facility. The clay with heavy metal not exceeding the standard can be directly made into planting soil and mixing soil of the sponge city facility [11]. The clay with excessive heavy metals is treated and then fired into ceramsite, sintered brick or solidified into burnt-free bricks.

4. Conclusion
In this study, an innovative ecological sediment treatment technology was introduced, and it has been successfully used to the sediment treatment of the Qingxi River in Dongguan, Guangdong, China. The different particles in the sediment can be separated into garbage, pebbles/gravel, sand, silt and clay. Except the garbage, almost of all the treated sediment can be fully reused. Most of the wastewater was reused, and only a little of wastewater treated by BWTS discharge into the Qingxi River to replenish water source.

The centrifugal solid-liquid separation technology and high speed suspended solid settlement technology by gravity and polymeric flocculants make the sediment treatment fast separation. The complex enzyme and BWTS make water clear.

The efficiency of the newly developed ecological sediment treatment technology is higher than the
traditional sediment treatment process used in China, and there is no secondary pollution and cost savings. The investment of the new treatment system is about RMB 20 to 30 million Yuan for sediment of 2.5 million cubic meters. This technology can be widely applied to quick treatment of the deposits in the polluted rivers, reservoirs and lakes and construction wastes of subway and tunnels.

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