Applying Constructed Wetland to Treat Wastewater of Baoding City

LWS 548 Major Project

By

Shaochen Yuan

Master of Land and Water Systems

Faculty of Land and Food Systems

University of British Columbia

Vancouver, British Columbia

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EXECUTIVE SUMMARY

The project is about applying constructed wetlands to remove pollutants from wastewater in Baoding, China. Baoding is at a critical traffic crossroad between Beijing and Tianjin and the Baiyangdian river is the most important water resource for the Huabei plain area. It is, therefore, necessary to improve and maintain high water quality in the river.

Constructed wetlands are in an advanced stage and offer numerous services that reduce flooding impacts and improve the water quality. However, constructed wetlands are still relatively new and many cities in China have little experience in deciding what the best design options are to deal with the different climatic conditions, the local environmental settings, and the different contaminants in the rivers.

This study aims to evaluate the options and challenges of using constructed wetlands in Baoding to improve the water quality in the river. The research focus is to identify the best design of core elements and find the best solutions to operate and manage such systems. The target location of the project is the Fuhe river watershed and the main pollutants are heavy metals especially Zn and Cd which originate from industrial activities. Wetlands techniques are no doubt the most efficient and cost-effective option. Once the plan is developed, the issues associated with the water flow path, plant and substrate selections, and monitoring program will be identified. The results will show what the major type and pollution sources are, which will help the government decide how best to improve the water quality. The design plans of the wetland will provide the Baoding government with the opportunity to find a higher efficient way to improve the water quality in the river. Finally, the project will provide a blueprint on how to achieve the goals set in the environmental plan in the next five years.

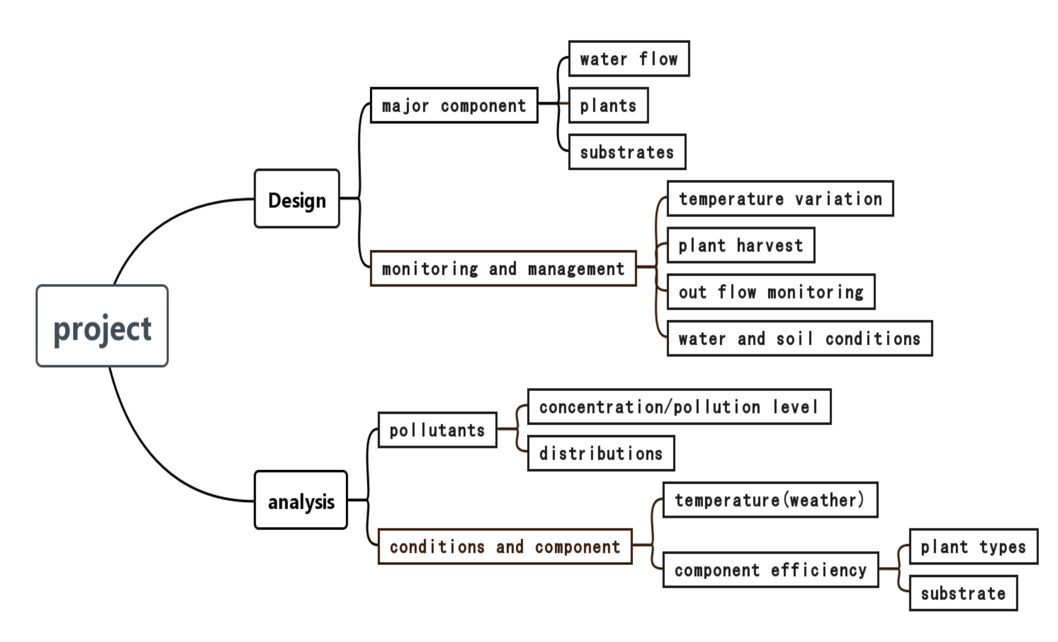


Figure.1. structure of the project

INTRODUCTION

Project Background

In 2020, Baoding has a population of 12.67 million people and ranks as the third-largest city in Hebei Province (Baoding Gov, 2020). The city is in the process of constructing major urban sewage treatment facilities as part of the 14th five-year plan (Baoding Gov, 2020). The focus is on providing domestic sewage treatment for the entire city and increasing the regional sewage treatment capacity. Building and operating constructed wetland may offer a new way to reach a higher treatment efficiency than what water plant releases. It cannot only remove pollutants efficiently but also has fewer maintenance expenses and less construction cost.

Water pollution overview

Many investigations have focused primarily on the following water pollutants: BOD, COD, nutrients, and inorganic pollutants such as heavy metals.

Recently the heavy metal pollution in the water body has become more serious because of the rapid rate of industrialization and increases in traffic. In China, heavy metal contamination levels exceeded regulatory standards in all ten major river basins in 2003 (Gao, 2019), including the Yellow River, Huaihe River, Songhua River, and Liaohe River. Total copper, total lead, and total cadmium levels in Lake Taihu sediments (Liu, 2018) were relatively low In most cases, the Zn, Pb, Cd, Cu, Hg, and Cr concentrations in sediment are of greatest concern since they frequently exceed regulatory standards set by the national government.

In our study, the sources of these pollutants are likely from heavy industries such as electroplating, metal production, grinding, edging, and polishing of metal surface treatment, (Shammas, 2009). Also, printed circuit board manufacturing is a source of Pb and Arsenic originating from the wood processing industry (Leist, 2000), Cr and Cd pigment manufacturing industry (Zalyhina, 2021) as well as Pb, Zn, and Cu from transport are the main contributors the metal problem in the wastewater.

Objectives

The objectives of this paper are: (1) Provide an overview of the opportunities and challenges associated with building constructed wetlands in Baoding; (2) Determine the operating and management issues for constructed wetlands. The focus is on how to adjust design plans for the site-specific conditions in Baoding regarding water flow, substrate, and plant design; (3) Identify the processes that need to be monitored to assure that high water quality can be maintained.

METHODS

This project is divided into two parts: project design and data analysis. The design of the constructed wetland is based on a literature review and by providing a case study. Cases were reviewed that closely relate to constructed wetlands designs and operations that are similar to the situation in Baoding. To be more specific, the design of water flow, plants, and substrates is based on summarizing the literature for a wide range of different situations. The sources for the detailed operation plan were handbooks of wetland techniques. Advantages and difficulties on wetland operations were reviewed to arrive at a guideline for the city.

Single-factor Pollution Index Method

The single-factor pollution index method is a method to compare the measured concentration of a certain pollutant with the evaluation standard of the pollutant to determine the water quality category. That is to compare each water quality monitoring parameter with its evaluation standard to determine the water quality category, and finally select the category of the worst water quality single indicator to determine the comprehensive water quality category of the water body in the measured area, while weakening the role of other factors. Through single-factor pollution index evaluation, the main pollution factors in groundwater bodies can be determined (Effendi, 2016).

The calculation method of the comprehensive pollution index is shown in formulas:

$$Pi = Ci/Si$$

In the formula, Pi is the single pollution index of the evaluation factor; Ci is the actual measured value of the evaluation factor; Si is the standard limit of the evaluation factor; P is the comprehensive pollution index of the monitoring point. The water quality level corresponding to the comprehensive pollution index is $P \leqslant 0.25$, clean; $0.25 < P \leqslant 0.40$, relatively clean; $0.40 < P \leqslant 0.50$, light pollution; $0.50 < P \leqslant 1$, medium pollution; $P > 1$, heavy pollution.

Nemeiro Pollution Index Method

The Nemeiro index method is developed from the single factor index method and is currently one of the most commonly used methods for comprehensive pollution index calculations. This method is a weighted multi-factor environmental quality index that takes into account the extreme value or the prominent maximum value. It can more comprehensively reflect the synergy of various pollutants to more accurately evaluate the pollution degree of various environmental elements (Hossain, 2020).

The calculation method of the Nemeiro pollution index method is shown in the formula:

$$F = \sqrt{\frac{\overline{P_i}^2 + P_{imax}}{2}}$$

In the formula, F is the Nemeiro pollution index at the monitoring point; Pi^2 is the average value of the individual pollution index of each evaluation factor; Pi_{max} is the maximum value of the individual pollution index of each evaluation factor.

The water quality level corresponding to the Nemeiro pollution index is $F < 0.8$, excellent; $0.8 \leq F \leq 2.5$ good; $2.5 < F \leq 4.25$, medium; $4.25 < F \leq 7.2$, poor; $F > 7.2$, extremely polluted.

SYNTHESIS

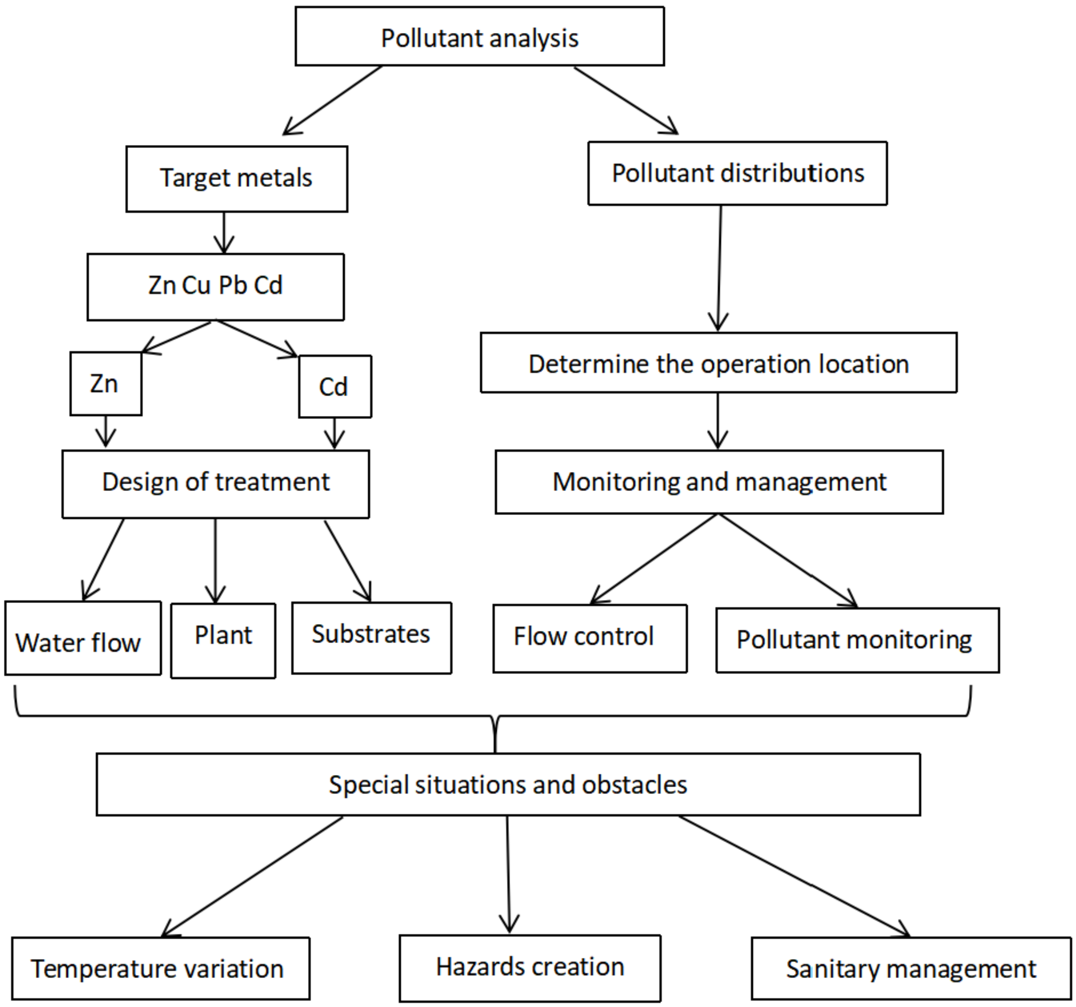


Figure. 2 . structure of the synthesis of literature review and data analysis

PART 1 POLLUTION ANALYSIS OF TARGET AREA

1. Major pollutants and pollution sources study

The sewage discharged by the Baoding metropolitan area exceeds 100 million tonnes/year. According to Wang (1999), industrial chemicals accounted for more than 52% of total industrial wastewater, with papermaking and the metal industry accounting for 41% of the waste. The Fuhe River, which drains or flows to the Baiyangdian Lake, is the pivotal water resource of Baoding. In addition to the industrial waste, municipal wastewater also enters the river in the upstream portion of the watershed.

Chen (2019) investigated the levels of mercury and arsenic in Baiyangdian Lake in fish and found that the levels of mercury (Hg) and As in fish bodies exceeded the US Environmental Protection Agency's guidelines (Zerizghi, 2020). Yang (2005) also found high levels of Cd and Pb in Baiyangdian Lake sediments, indicating that the ecological and the aquatic organisms are at risk (Yang, 2005). Samples from the Fuhe River showed toxic conditions are widespread within the watershed with high levels of COD, NH3-N, Zn, Cu, and CO (Chen, 2019). Sediments samples in the Fuhe River have average levels of 1147 mg of Zn/kg, 190 mg of Cu/kg, 110 mg of Pb/kg, and 3.3 mg/kg of Cd (Hu, 2011).

According to historical surveys, there are about 200 enterprises in Baoding City that discharge sewage into the Fuhe River, mainly from papermaking, chemical industry, electric power, printing and dyeing, petroleum, and other industries. The daily discharge of wastewater is about 300,000 tons. Combining with pollution distribution analysis, the main sewage discharge from companies in the Fu River Basin are mainly in four areas (Chen, 2019):

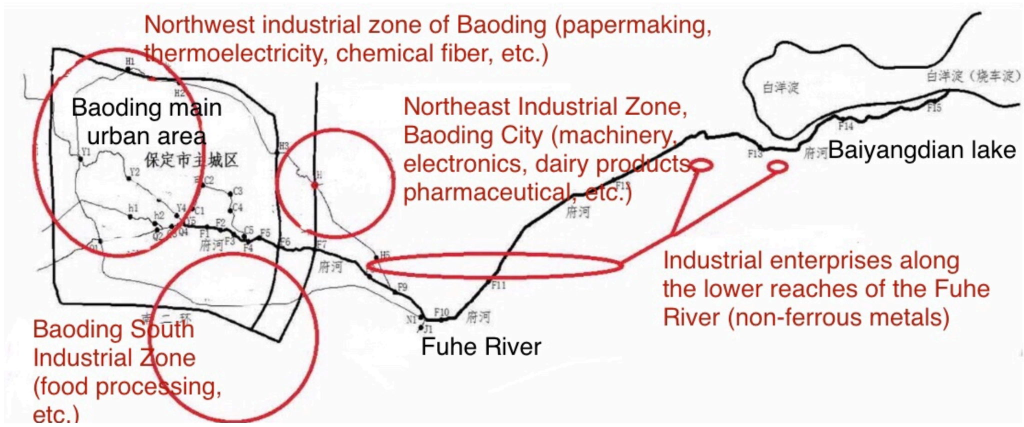


Figure 3. The location of the industrial zone in the Fuhe watershed in Baoding city

(modified from Hu Guocheng 2011)

(1) Northwest Industrial Zone of Baoding City, where papermaking, chemical fibre, thermal power and other enterprises are mainly distributed in this area;

(2) The industrial zone in the northeast of Baoding City, which is mainly divided into mechanical and electronic, dairy processing, pharmaceutical and other enterprises;

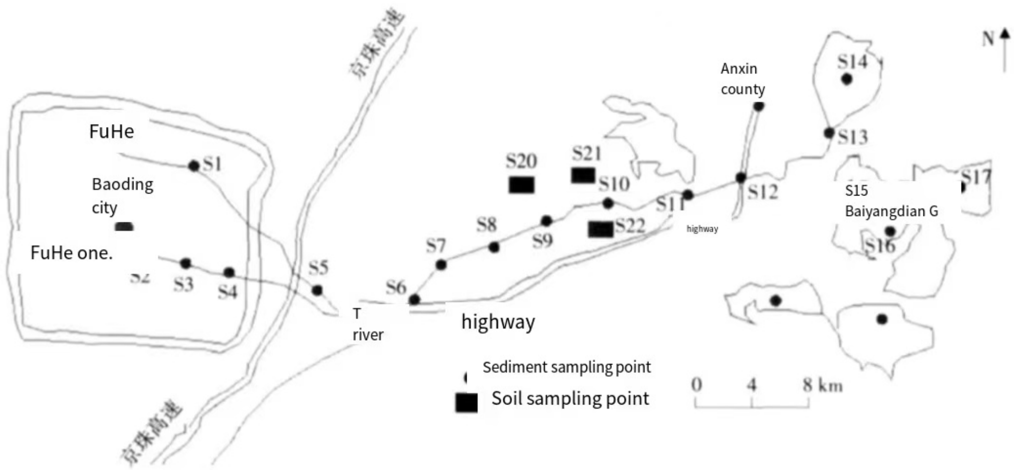
(3) Baoding Southern Industrial zone, which is mainly distributed in automobile manufacturing, mechanical processing, food processing and other enterprises;

(4) The industrial zone along the middle and lower reaches of the mainstream of the Fuhe River, where waste recycling and non-ferrous metal recycling and processing enterprises are mainly distributed.

DATA PART 1: POLLUTANTS DISTRIBUTIONS AND POLLUTANT LEVEL ANALYSIS OF THE PROJECT AREA

Single pollution index

The metal pollution level in the Fuhe River was determined by Hu Guocheng (2011), which shows the location of the sampling sites, the pollution index and the metal concentrations.



(S1-S12 meters from the Fuhe River,513-S19 from Baiyangdian Lake, and S20-S22 from the soil along the Fuhe River)

Figure. 4 . sampling sites distribution of the research Hu, 2011

Table. 1. Results of Single Pollution Index analysis of samples

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
P(Cu)	0.15	1.39	7.92	5.93	0.32	2.43	0.90	1.15	1.20	0.60	0.33	0.52	0.21
P(Cd)	0.22	0.22	4.00	2.67	0.22	11.11	6.67	4.00	17.7	7.33	0.22	4.67	0.67
P(Zn)	3.89	4.82	8.29	2.76	19.0	1.85	1.73	3.59	3.08	1.26	1.98	2.79	1.10
P(Pb)	0.18	1.30	5.73	2.32	0.23	1.90	0.90	1.49	1.36	0.37	0.37	0.31	0.24

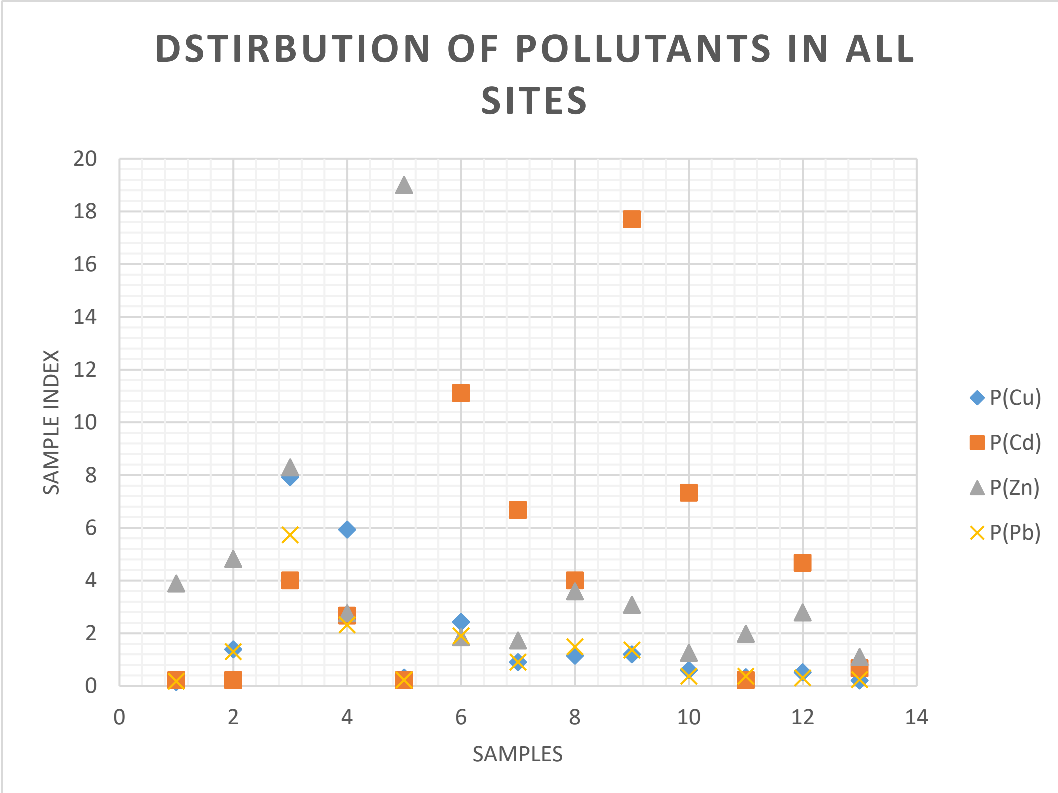


Figure. 5 . Results of the distribution of metals in all sampling sites

The water quality levels corresponding to the comprehensive pollution index are P≤0.25, clean; 0.25<P≤0.40, relatively clean; 0.40<P≤0.50, light pollution; 0.50<P≤1, medium pollution; P>1, heavy pollution.

The average concentrations of Zn, Cu, Pb, and Cd in the surface sediments of Fuhe River were 147.1, 190.5, 109.7 mg/kg-1, and 3.3 mg/kg-1, respectively. The metal pollution in Baiyang Lake, for Zn, Cu, Pb and Cd in sediments were 269.4, 31.3, 16.3 mg/kg-1, and 0.3 mg/kg-1, respectively. The Fuhe River has significantly higher metal levels than Baiyangdian Lake. The average contents of Cd, Zn, Cu, and Pb are 47, 17, 10, and 5 times higher than the national topsoil background value, respectively.

Nemeiro pollution index analysis

Results of Nemeiro Pollution Index analysis

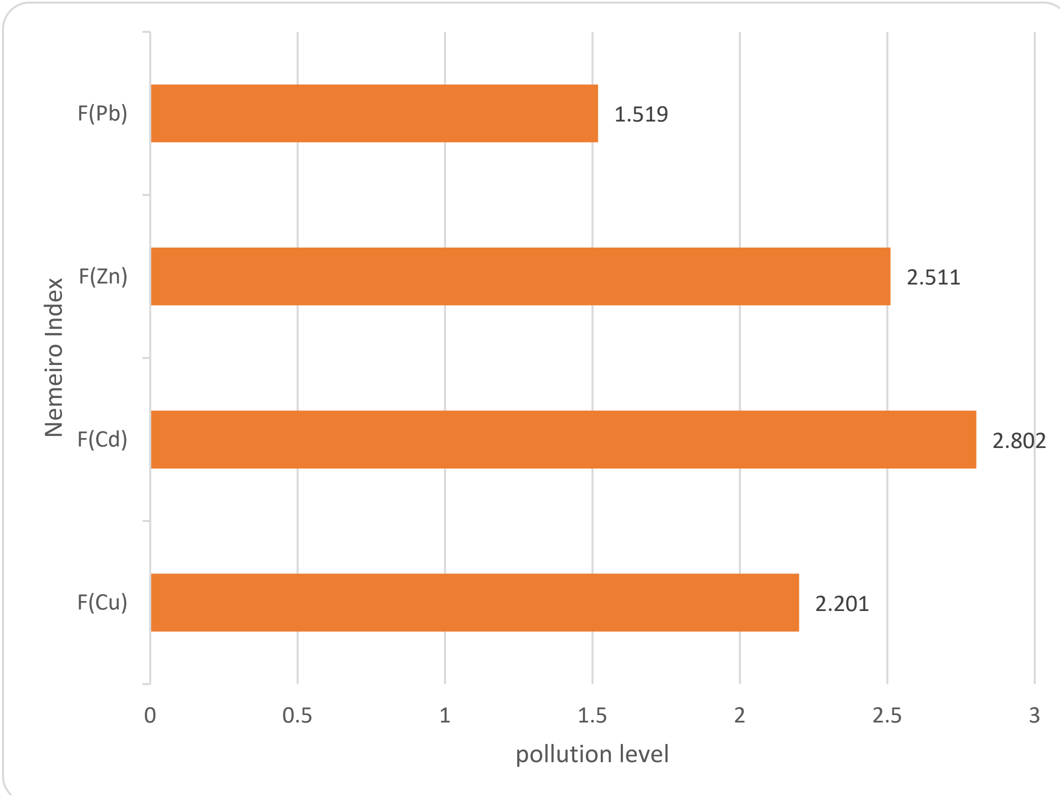


Table. 2 . Results of Nemeiro Pollution Index analysis on metals for the river

The water quality level that corresponds to the Nemeiro pollution index is $F<0.8$, excellent; $0.8 \le F \le 2.5$ good; $2.5<F \le 4.25$, medium; $4.25<F \le 7.2$, poor; $F>7.2$, extremely polluted.

Based on these results for single pollutants we can conclude that the Zn levels in the Fuhe river are serious, and the pollution degree ranges from moderate to extreme. In particular, the S5 (Suncun) sampling site has the highest Zn value based on the Nemerio index. The source might be a large amount of industrial wastewater and domestic sewage that was discharged in Baoding City (Jiaozhuang and Xiazha). Using the 13 sampling points in the Fuhe River the Zn metal problems are more pronounced than the others (Zn>Cd>Cu>Pb). The above research results show that the high metal levels in the soils near the Fuhe River are likely from the dismantling activities of nearby wires, cables, and electronic waste. The small workshops near Anzhou town obtain valuable metals from recycling waste products through simple treatment methods such as incineration and pickling. While disassembling these waste products, they have contributed to the pollution in the surrounding soils of the city. We can determine that the most polluted metals are Zn and Cd (Hu, 2011). From distribution analysis, we can conclude that the main source of metals is likely from industrial air pollution and wastewater discharge in Baoding, downstream of metal smelting enterprises, and incineration of waste materials. The project will now focus on two industrial discharge areas of Fuhe river and the target pollutant are Zn, Cu, Pb, and Cd.

2. Feasibility of wetlands on treating heavy metal pollution

Constructed wetland is the latest wastewater treatment technique that is efficient and has the potential to reduce water pollution because it requires less manpower and energy input than general treatments to remove organic pollutants, nutrients, suspended solids, and heavy metals. It provides a long-term and relatively stable purification system for domestic sewage. It can deal with non-point source pollution runoff from farmland wastewater, secondary sewage treatment plant effluent and runoff from transportation surfaces. Research and application of constructed wetlands are mostly focused on three essential components: water systems, substrates, and plants.

Bragato (2006) shows that plants play a very important role in constructed wetlands. Aquatic plants can directly absorb nutrients in the water for their growth and development as well as absorb some toxic and harmful substances, such as heavy metals such as lead, cadmium, mercury, arsenic, chromium, etc.

The research shows how metal concentrations in sewage can be reduced by using aquatic vegetation. Cd, Cr, Ni, Pb, and Zn in water can be taken up by plant roots but are difficult to move into the plant body. In the matrix, the cumulative uptake proportion (AP) of Ni and Cu is 86.99%, while the AP of plants is 114% (Ge, 2014).

To conclude, constructed wetlands can remove significant amounts of heavy metals. Research results show that constructed wetlands can play a role in reducing metal pollution in the river. In addition, the treatment of wetland technique is mainly carried out by metal uptake in substrates and plants. We need to set up different cells and plant communities to remove different target metals.

Project monitoring and managing highlights

As the knowledge system of constructed wetland is developing, there are still some potential practical factors that need to be addressed in the project. (1) More information is needed in construction design and combinations of essential components for wetland systems. (2) The current design is based on general models, and adaptations are needed to address local conditions, pollution loading variability, and operation details in the projects.

Practical considerations are: (1) A monitoring plan is needed for the constructed wetland that will trace the target pollutants, environmental conditions, and plant development to ensure the system functions efficiently. (2) Plant growth and pollution uptake rates are influenced by seasonal temperatures and precipitation variations and are usually lower during cold winters. (Liu, 2008). (3) For constructed wetlands to work well requires that they have a large and diverse bacterial community, that can also deal with pathogens (Liu, 2008).

LITERATURE REVIEW

WETLANDS' COMPONENTS STUDY

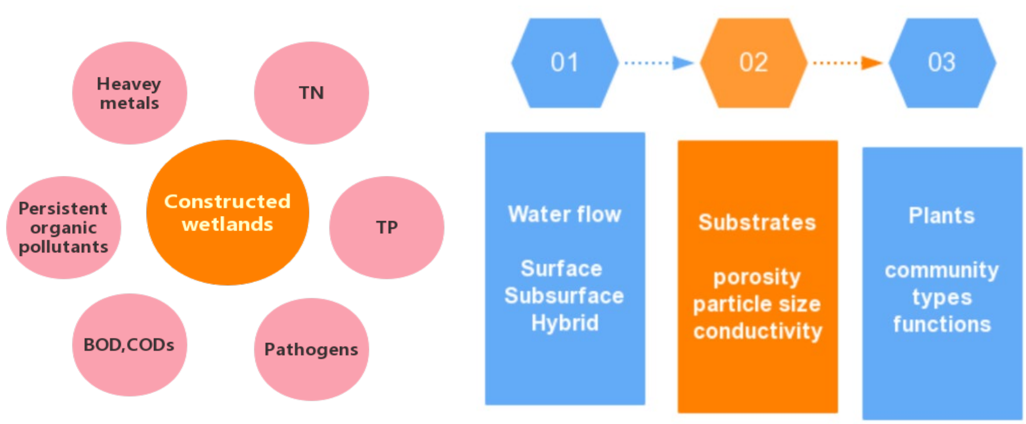


Figure. 6. Function and characteristics of wetlands

Water flow

The basic flow pattern in a constructed wetland consists of three main types: surface flow, subsurface flow, and hybrid flow (Brix, 1994). Surface flow is difficult to be used because it requires a large operation area and has a low treatment capacity. Subsurface flow systems perform at higher efficiency in smaller areas than surface flow wetlands (Trang, 2010). Zou (2010) designed a new type of composite constructed wetland, which is composed of vertical flow and horizontal subsurface flow to increase the flow distance of water in the system. In this case, the wetland is no longer limited to a single flow design.

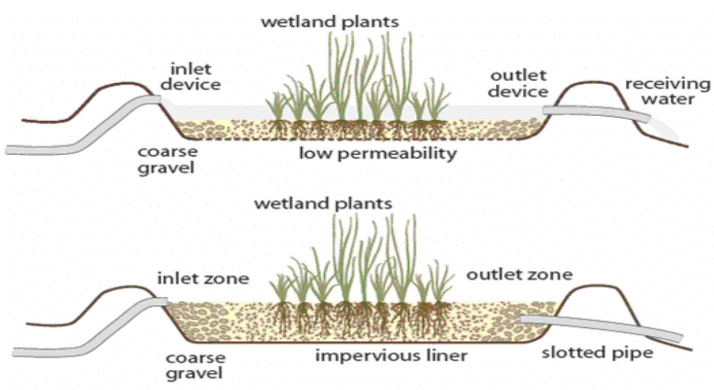


Figure. 7 . structure of surface wetland & subsurface wetland. (modified from Brix, H 1994)

However, there are several obstacles in operating such systems. First, the flow design has to be different depending on what the target pollutants are. The question of how to operate the water flow most efficiently is challenging. Second, the way to maintain stable and sufficient water levels to optimize treatment is not well described.

Substrate

Another crucial component of the technique is the substrate. The substrate is the key factor affecting the hydraulic performance, the plant growth in the constructed wetland system blockages (Melián, 2010). Factors affecting substrate selection include substrate particle size, porosity, hydraulic conductivity, and chemical properties. In Europe, gravel service as the main filler, the gravel particle size is generally 8 - 16 mm (Zhu, 2009). Zhang (2009) found that gravel with a particle size of 60-100 mm is generally used in the inlet water distribution area and the outlet water collection area. The most commonly used particle size range in the treatment area is 4-16 mm.

However, there are some gaps when designing the substrate phase. Firstly, the pH and permeability of substrate vary from site to site and more research is needed to decide what the proper range is. Secondly, the structure of the substrate is important in providing optimum environments for aquatic organisms and soil. The best type and combination of material need more specifications.

Plants

Wetland plants are one of the most essential factors for water purification and pollutant removal. The plants in a constructed wetland can be divided into floating plants, emergent plants, and submerged plants (Liang, 2003). According to Münch (2005) plants need to have a broad root environment to facilitate the uptake of nitrogen. According to Paul (2005), different plants have very different N-uptake rates in the winter and the number of stems and leaves affect the oxygen transport capacity of the roots during their growth and dormancy period.

Figure. 8. Wetland plants: a Reeds; (b) Cattails; (c)Scirpus; (d) Cyperus papyrus (modified from Ahuja, 2014)

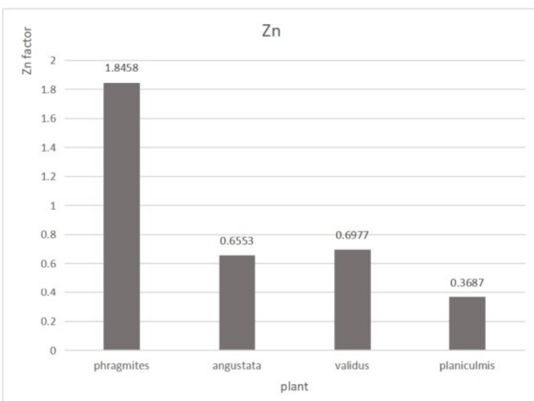
In practical operation, it is important to establish a diverse plant community and the plants need to be managed regularly. In addition, the selection of plants also needs to be determined based on the water pollutants and their concentrations.

To summarize, these pivotal components of wetlands have different functions and need to be adjusted based on the local conditions. There is no doubt that wetland systems will have high efficiency for pollution removal of wastewater due to multiple operation zones (plants, microbes, and substrates) and provide a positive impact on ecological system protection. However, wetlands have complex structures that need careful selection (see in data part 2) to cope with the local environmental conditions. In addition, wetlands may have risks of species invasion and hygiene issues, which means we need to create a monitoring and management plan(see in design part).

DATA PART 2: COMPONENTS EFFICIENCY ANALYSIS

1. Plant analysis

Li (2016) provided some data on the rate of Cd and Zn uptake by stems, leaves, and roots of the following wetland plants: Australis, Validus, Planiculmis, and Cattails (Angustata). The concentration of Cd in the roots of the plant was highest for Validus 1.4 mg·kg- of biomass followed by Australis > Angustata > Planiculmis, with had the lowest values (0.297 mg·kg-1 of plant biomass). The root Zn concentration of the plant reached 388.1 mg·kg-1 for Validus followed by Angustata and Planiculmis (80.2mg·kg-1). The root enrichment factor for cadmium is the largest (4.17) for Australis roots and the smallest (0.69) for reed roots. Zinc uptake was larger than for Cd.



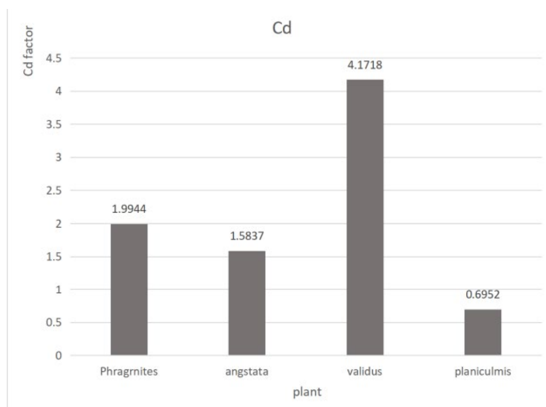


Table. 3 . Results of the concentration factor of Zn and Cd in analysis data from (Li, 2016)

From this analysis, we can conclude that reeds and Validus are the best options for removing Zn and Cd. Different parts of the plants had different rates of uptake as shown in table 5 below.

Table. 4 . Rate of metal uptake by plants data from (Li, 2016)

items	Cd (mg)		Zn (mg)	
plants	weeds	cattails	weeds	cattails
roots	1.64	1.27	116.94	43.93
stems	0.60	0.21	43.62	9.14
leaves	0.11	0.07	16.27	8.75
Total	2.35	1.55	176.83	61.82
Metals removal	3.90		238.65	

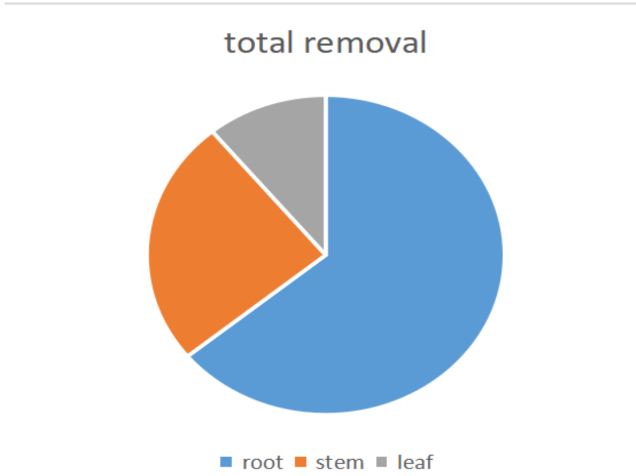


Table. 5 . analysis of removal efficiency of different parts of plants' body

2. Substrate

The two common types of substrates: sand + loam and sand+aluminum. sand + aluminum type contains aluminum sulphate that has good retention of organic matters and industrial pollutants in wastewater. Sand + loam is beneficial to plant growth. It's obvious that the Sand+Aluminum type is more effective and the sand + loamy type has limitations. In addition, they have different porosity and water retention capacity. The total water retention of sand + loam is larger than sand+ aluminum (Chen, 2019).

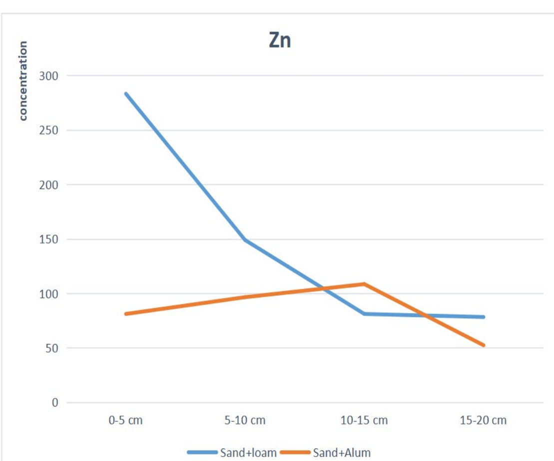
Table. 6. Retention of metals in different substrates of wetland (Chen, 2019)

Metals (mg/kg)	Zn	Pb	Cu	Cd
Sand+loam	283.2	57.2	75.0	1.8
Sand+alum	138.9	47.3	53.6	0.7

Analyzing the vertical concentration of Cd and Zn in those two substrates, we can observe the distribution and movement of metals within the different layers (Table 8).

Table. 7 . Concentration of target metals in the vertical distribution of substrates (Chen, 2019)

substrates	Metals (mg/kg)	Zn	Cd
Sand+loam	0-5 cm	283.2	1.8
	5-10 cm	148.9	4.6
	10-15 cm	81.1	0.5
	15-20cm	78.3	0.1
Sand+alum	0-5 cm	81.1	0.5
	5-10 cm	96.5	0.2
	10-15 cm	108.5	0.3
	15-20cm	52.4	0.4



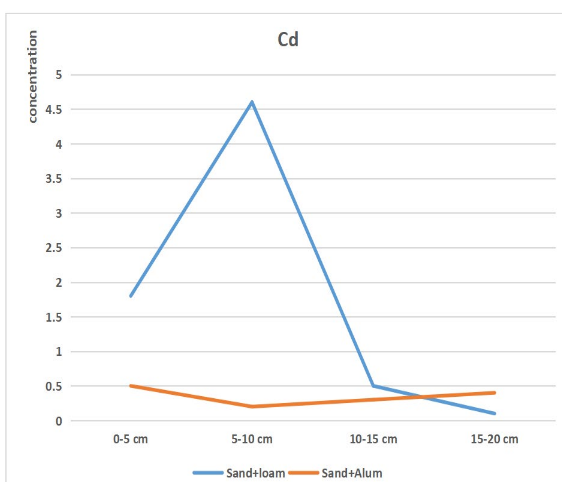


Figure. 9 . Distribution of target metals in two substrates

As would be expected the surface layers tend to absorb the largest amount of metals because the loam has a much larger surface area than sand. The loam components have good physical structures that are soft and friable, allowing for easy rhizome and root penetration.

PROJECT DESIGN

1. Plants

The plants that are most often used in constructed wetlands are persistent emergent plants such as bulrushes (Scirpus), spikerush (Efeocharis), other sedges (Cyperus). rushes (Juncus), common reed (Phragmites), and cattails (Typha) (Zhang, 2010).

Duckweed can effectively accumulate zinc, iron, and manganese, the reed can effectively accumulate lead, manganese, and chromium, and cattail and black triangle are more suitable for absorbing and enriching lead and zinc in the Fuhe River (Dou, 2006). Dong Zhicheng (2008) found that the reeds in the study area have better resistance to high levels of metals. The absorption and accumulation of heavy metals such as Zn, Cu, Cd are particularly efficient.

For plant selection, bulrushes are commonly selected in wetlands designed to treat household sewage, agricultural wastewater, and other wastewater which is high in organic matter. They are effective in taking up high levels of nutrients, are not invasive, and grow rapidly (Davis, 1995). Because of the excellent tolerance for a wide range of effluent, cattails and common reeds have been widely employed in constructed wetlands (García, 2008). Many SSF wetlands in the United States have employed bulrush, common reed, cattail, or a mixture of the three (Tchobanoglous 1997, Whetstone 2009).

From my case study, common reeds and cattails are likely the best options to treat some of the municipal wastewater. Establishing a dense stand of vegetation is the most important first step

(García, 2008). The best option is to select plants that are common in wetlands of the area and a diversified selection of species is more effective and resilient to cope with highly variable water flow conditions and concentrations of pollutants. It's obvious that selecting cattails and bulrushes are high efficiency, but combining with local (emergent) plants is more pivotal. Common native reeds (Zhang, 2019) in the Baiyangdian watershed are the best option.

2. Substrate

Substrates are another pivotal part of treatment and many factors will affect the wetland efficiency. The availability and retention of heavy metals and nutrients are influenced by the pH of the soil. The texture of the soil influences root growth and the retention of pollutants. Sandy, coarse-textured soils have a low pollutant retention potential but little restriction on root growth. These soils are positive for growing plants but have low nutrient holding capacity (García, 2008). Many domestic sewage SSF wetlands in the United States have used a media ranging from medium gravel to coarse rock but may need to be irrigated to maintain water levels while the vegetation is becoming established (Sundaravadivel, 2001). Organic matter additions to coarse-textured soils have been shown to improve plant survival and growth during the first several years. Dense soils, such as clay, should be avoided because they may restrict root penetration, and have low hydraulic conductivity (García, 2008).

Substrates should be designed to avoid underground contamination of groundwater aquifers. A combination of soil and synthetic materials can also be used (Wu, 2015). Soils with more than 15% clay content are normally appropriate to prevent subsurface leaching (García, 2008). Bentonite and clay, provide adsorption and reaction sites as well as alkalinity. Asphalt, synthetic rubber, and plastic membranes are examples of synthetic liners that should be topped with 3 to 4 inches of soil to prevent vegetation roots from entering the liner.

In our case, medium-grained or loamy soils are an excellent choice since they retain metal pollutants and allow excellent plant development. Loamy soils are particularly beneficial since they are soft and friable, allowing for easy rhizome and root penetration. Because of the huge amount of industrial wastewater needed to be treated, we need to design a substrate that mainly consists of medium gravel and has a pH of about 7-8. Synthetic materials can be used as a liner. Our ideal structure of the substrate is in three parts: topsoil for the surface area that provides good conditions for root growth, a good coarse substrate below the soil, and a synthetic liner at the bottom to prevent leaching.

3. Water flow

Surface flow wetlands, subsurface flow wetlands, and hybrid systems are the three types of constructed wetlands. A surface flow (SF) wetland is made up of a shallow basin, soil, or another medium to support the roots of vegetation, and a water control structure that keeps the water at a shallow depth. In SF wetlands, the near-surface layer is aerobic while the deeper waters and substrate are usually anaerobic. A subsurface flow (SSF) wetland is made up of a sealed basin with a porous rock or gravel substrate. The water level is set to stay below the top of the substrate (Crites, 1994).

Comparing the characteristics between these two types of systems shows that SSF wetlands have higher cold tolerance, less pest and odour problems, and have a higher assimilation potential per unit of land area than SF systems. SSF wetlands may be more difficult to regulate than SF wetlands, and their maintenance and repair costs are generally higher (García, 2008). SF wetlands are efficient in treating organic pollution as well as adjusting inflow conditions because of the longer water residence time in the wetland. SSF wetlands will be employed to remove different heavy metals in specific locations.

In the design of our case, we are facing multiple pollutants in the wastewater that are attributed to different areas. A hybrid system might be the best option for the conditions of the different situations in our areas. SF cells are applied to adjust water flow velocity and other conditions (eg: pH: 6.5-7.5) as well as lower or screen SSF inflow.

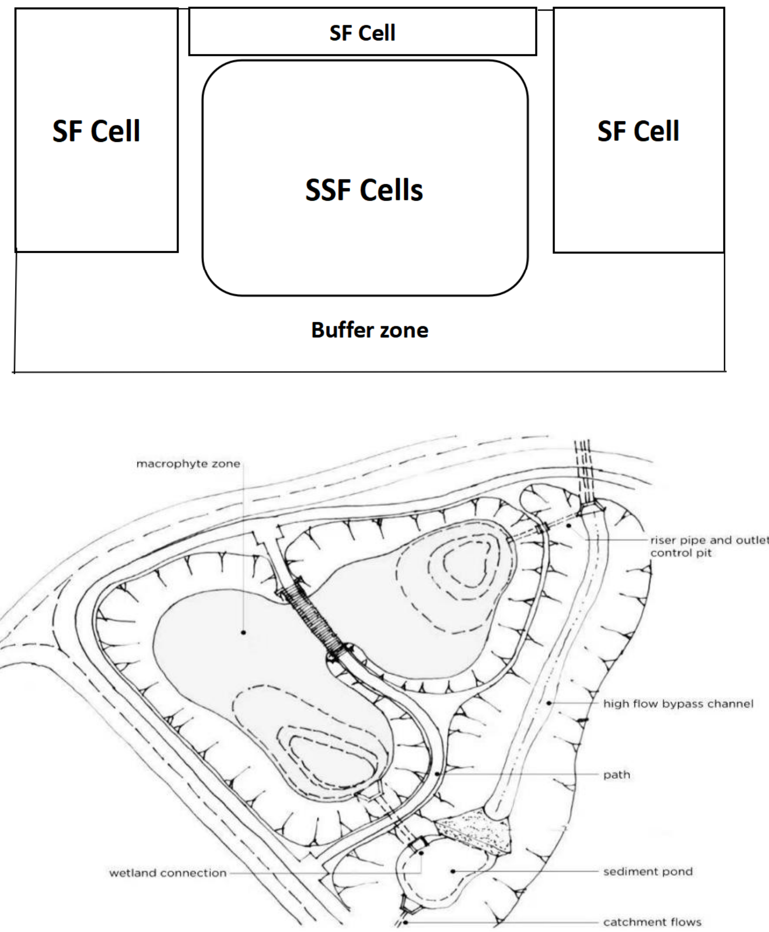


Figure. 10. Ideal structure of wetlands (referred from García, 2008)

To develop an equal flow distribution, we need to set the length to width ratio as small as possible and the water level in the outlet part of the SF wetlands needs to be regulated by the outflow structure, which might be weirs and spillways that must be designed to pass the maximum probable flow (Crites, 1994). The SSF cells require a surface manifold that can adjust the outlets' flow. This offers the most flexible approach for future flow changes and maintenance. It also avoids back-pressure issues. Subsurface manifolds and weir boxes or similar gated structures are used as outputs in SSF wetlands. To maintain an acceptable hydraulic gradient in the bed, an adjustable outlet is suggested.

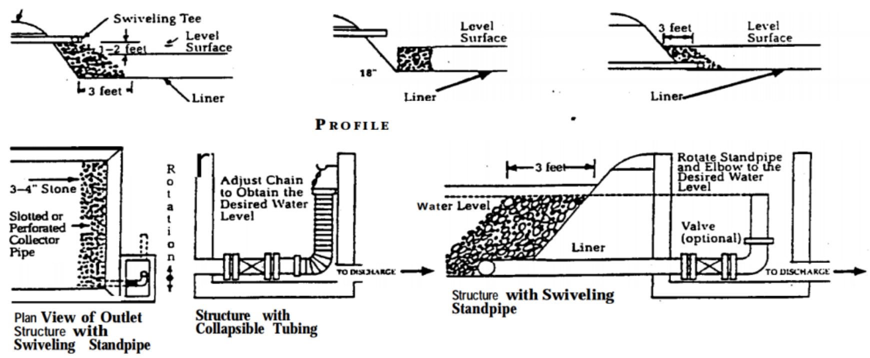


Figure. 11. Image of inlet and outlet structure (modified from Crites, 1994)

To promote the desired plant development and prevent weeds, SSF beds should be designed to provide regulated flooding to a depth of 6 inches (15 cm). SF beds are designed to maintain 1-2 inches(5cm) flooding depth and to get stable efficiency in all seasons. Water residence time needs to be greater than 3 days (Davis, 1995).

Table. 8 . Major parameter of the constructed wetland in project

Waste/day (t)	**263,000**	**Residence time (days)**	**3**	**Total treatment Volume (t)**	**789,000**
Flooding depth of SF (cm)	**5**	**Flooding depth of SSF (cm)**	**15**	**Flooding depth in average (cm)**	**10**
Operation area (Km²)	**8**	**Ideal removal efficiency**	**>80%**		

4. Location

Another aspect is the site selection. Based on multiple cases study, surface and groundwater issues include probable pollution and drainage concerns, thus a constructed wetland should not be sited on a floodplain unless specific steps can be taken to restrict its influence (Davis, 1995).

Monitoring and management in specific situations

1. Temperature variation

First of all, the temperature variation must be considered, because that affects the type of plants to be used. Water levels can be raised in advance of a freezing event and can be decreased once a layer of ice has developed to allow for under-ice flow. As temperatures drop, the pace of microbial decomposition becomes slower, so the wetland may need to be expanded to meet the slower response rates. Another issue is high flows, which are typical in the late winter and spring due to snowmelt, spring showers, and high groundwater tables. During high water flow through a wetland, there isn't enough time for proper treatment (Stein, 2007). During the colder months, the water depth can be raised to maximize retention duration and protect against freezing (Davis, 1995). During the summer, wetlands lose a lot of water due to evapotranspiration. Summer flow must be adequate so that the water levels in the wetland can be maintained.

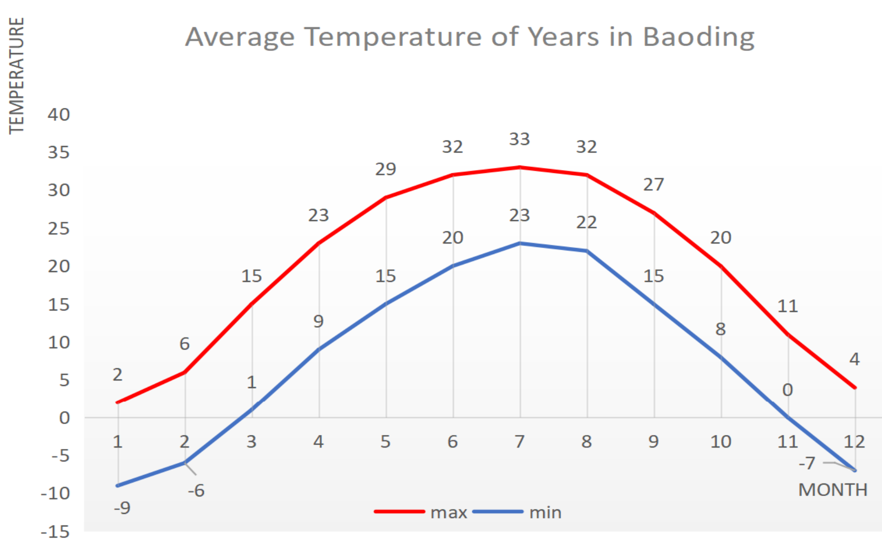


Table. 9. Average temperature of Baoding city in a year (data from Yue, 2015)

In the operation of the wetlands, there must be specific water flow control plans, that offer stable water levels for different cells to operate. From May to August, the temperature of Baoding is around 33-38°C, and from October to December, the temperature is -10-5°C (Yue, 2015). Different stages of water flow adjustment will be required based on temperature differences. The water supply from early November to late Feb is subject to freezing and that will have a negative impact on plants and organisms. The water stress stage is from late April to June, and during high water flow conditions. Another action must be taken to protect plant roots by using a temperature control system.

Table. 10. Schedule of water flow adjustment

	January	February	March	April	May	June
Water strain				√	√	√
Water supply	√	√				
	July	**August**	**September**	**October**	**November**	**December**
Water strain						
Water supply	√	√	√		√	√

2. Hazards recreation

One of the risks is that the wetland sinks may become saturated with contaminants such as metals and will need frequent maintenance. This means proper planning, management, and monitoring are required regularly. To ensure that sediments do not clog up the wetland a forebay is required where the sediment can settle and this will require the removal of the accumulated sediments from time to time. Groundwater should also be monitored once or twice a year to make sure the wetland is not contributing contaminants to the groundwater (Davis, 1995). Sampling that includes BOD, COD, pH, TN, and TP should be conducted at the in and outflow of the wetland. Plants harvesting and replacement are necessary to assure optimum phytoremediation.

3. Hygiene management (Mosquitoes)

The health and quantity of vegetation should be assessed regularly. Vegetation monitoring does not need to be quantitative in wetlands that have low contaminant input. If the source pollution is high, more frequent monitoring is required (Thunhorst, 1993). During the first five years after construction, a more regular monitoring system can be put in place. A rise in the number of aggressive invasive species, a reduction in the density of the vegetative cover, or symptoms of the disease are all causes that need to be addressed (Davis, 1995). Herbicides should only be used in extreme situations to address the problem of invasive species.

Mosquitoes are widespread in all wetlands. The best way to minimize mosquito issues in constructed wetlands is to: 1. Avoid stagnant water pools within the wetland. 2. Use a variety of plants and assure that small spaces of open water are maintained for UV light penetration. 3. Managed blue-green algae that might emerge when nutrient-rich effluent enters the wetland. 4. Introduce fish (Gambusia) that consume mosquitoes and larvae but can tolerate the poor water quality conditions that enter the wetland. 5. Once larvae are developed they also can be physically be removed by using screening systems (Russell, 1999).

Birds and dragonflies provide some control by preying on mosquito larvae. Mosquito control using pesticides is also an option. Pesticides are not very effective in building wetlands with high volumes of organic matter because the insecticides adsorb onto the organic matter and are quickly diluted or destroyed by moving water (Russell, 1999). However, regular monitoring with regular maintenance can minimize odour problems and hygiene issues.

Summary of operation and monitoring

Table. 11. Summary of operation and monitoring

Monitoring items	Timeline/frequency
Sampling of water inlet &outlet (BOD, COD,TN,TP, Metals)	In first year: twice After first year: once
Sampling of sediments (Metals: Zn, Cd,Pb,Cu)	In first year: twice After first year: once
vegetation	After first two years
pH (for water)	Daily collecting
Temperature(for water)	Daily collecting
pH (for soil)	First year: weekly collecting After first year: monthly collecting
Temperature(for soil)	December-February /year

CONCLUSIONS

This project evaluated that the advantages and challenges are that need to be considered when planning to introduce constructed wetlands to treat contaminant effluent from domestic and industrial discharge. The feasibility of using a constructed wetland technique in Baoding city is particularly challenging because of the high level of metals that are discharged from heavy industrial activities. the constructed wetland is a hybrid system that consists of SF and SSF units.

The project provided an overview of the opportunities and challenges associated with building constructed wetlands in Baoding. Based on available data from soil and sediment analysis and examining the type of industrial activities that discharge effluent into the river, the key contaminants that require treatment were Zn, Cd, Cu, Pb. The Nemeiro index showed that Zn and Cd are the main problems in the discharge of domestic sewage and industrial wastewater in Baoding. The most efficient solution is to use a constructed wetland in the Fuhe river (Baoding watershed) to help reduce heavy metal pollution that enters the river. It is concluded that the challenges of such a project are mainly about temperature variation, finding the best type of plant communities to be used in the wetland, and hygiene issues associated with mosquito and odour.

The practical issues of choosing the best design, how to manage the system, monitoring and maintaining the construction managing were identified as follows:

Table. 12. Design and information of the constructed wetland in project

<table>
<tr><th colspan="8">Operation</th></tr>
<tr><td>Area (Km²)</td><td>8</td><td>Residence time (day)</td><td>3</td><td>Flooding depth in SF(cm)</td><td>5</td><td>Flooding depth in SF(cm)</td><td>15</td></tr>
<tr><th colspan="8">design</th></tr>
<tr><td>Water flow</td><td>Hybrid system(SF+SSF)</td><td>Plants</td><td colspan="2">Common reeds(native) Cattails & bulrushes(invited)</td><td>Substrates</td><td colspan="2">Medium grained size(loamy if possible)</td></tr>
<tr><th colspan="8">Monitoring</th></tr>
<tr><td>BOD, COD, TN, TP,metals</td><td>First year: twice/year
After a year: once/year</td><td>pH(water)

pH(soil)</td><td colspan="2">Daily(water)
First year:weekly
After a year: monthly(soil)
PS: pH in soils: 7-8
In water: 6.5-7.5</td><td>Temperature (soil)

Temperature(water)</td><td>Dec-Feb/year

Daily</td><td>Plant community check should be twice in first 2 years</td></tr>
</table>

The design plan for the wetlands in Baoding City needs to be adjusted to meet the local situation and consider knowledge gaps in water flow, substrate, and plant design parts. It is suggested that a hybrid water flow system that consists of SF cells for adjustment of inflow conditions would be the best choice. Selecting common local reeds to combine with functional plants like cattails and bulrushes will be suitable for the project. We determined the substrate structure should consist of three parts: a) top area is topsoil that is stable in conditions that are suitable for root zone development and similar to local conditions; b) a middle area with a designed substrate that consists of medium gravel as well as coarse rock and c) the pH should be about 7-8. A synthetic liner can also be used in the lower part of the system.

Finally, we stated the detailed processes and guidelines of constructed wetland that focused on the monitoring plan is an important component and solution to assure efficient operation of the wetland. To ensure each design part and operation is high efficiency, we set up a series of monitoring plans that considers the concentration of organic pollutants and target metals. Monitoring plants community is also required to avoid species invasion. Regular checks on the performance of pH and temperature of soil and substrates as well as pH are needed, and water flow condition also needs to be controlled. Based on these plans, we developed a solution for the specific situations in our case study. For temperature variation, we set up a water flow adjustment plan in different seasons. In addition, the installation of a temperature control system is also required. A plant harvest schedule needs to be maintained to assure efficient pollutant uptake. Site selection is also important to avoid further underground pollution. For hygiene management, monitoring of vegetation and organic pollution of the water is essential. Unblocking flows to minimize stagnant backwaters and darkening the water surface and introducing species to hunt mosquitoes is the main operation on solving mosquito issue.

RECOMMENDATIONS

- The project provided a fundamental design and operation plan of a constructed wetland technique in Baoding, that will help to reduce the pollution problem by removing heavy metals in the effluent water. For specific situations, it offers constructive and efficient guidelines for solving issues such as temperature variation, recreational hazards, and hygiene management.
- Due to a lack of local data collection, detailed construction plans are not provided. The wetland structural model needs to be further adjusted or revised by analyzing local conditions. Construction must be approved by the Baoding government and monitoring must be conducted based on China's analytical standards.
- The project design part referred to the Davis, L. (1995). *A handbook of constructed wetlands: A guide to creating wetlands for agricultural wastewater, domestic wastewater, coal mine drainage, stormwater*. The data part of Fuhe river is mainly from Hu Guocheng, Xu Muqi, Xu Zhencheng, Dai Jiayin, Cao Hong, Peng Xiaowu, & Qi Jianying (2011). Pollution characteristics and potential risk assessment of heavy metals in Fuhe-Baiyangdian sediments (Doctoral dissertation).

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APPENDIX

Appendix. 1. Concentrations of heavy metals in surface sediments from Fuhe River and Baiyangdian Lake, North China (mg•kg-1)

Sample	Cu	Pb	Cd	Zn
SI	15.4	14.7	<0.1	972.2
S2	139.4	103.9	<0.1	1206.0
S3	792.1	458.6	1.8	2072.5
S4	593.0	185.6	1.2	691.0
S5	31.7	18.0	<0.1	4752.7
S6	243.4	152.0	5.0	463.3
S7	89.9	71.9	3.0	433.3
S8	115.4	119.3	1.8	898.6
S9	120.3	109.0	8.0	769.7
S10	59.9	29.4	3.3	314.9
S11	33.2	29.3	<0.1	494.7
S12	52.4	24.4	2.1	696.7
S13	21.4	19.5	0.3	275.8

Appendix. 2. temperature in Baoding in a year

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Highest T ℃ (°F)	14. 9 (58. 8)	23. 1 (73. 6)	27. 0 (80. 6)	33. 8 (92. 8)	38. 4 (101. 1)	41. 6 (106. 9)	43. 3 (109. 9)	37. 7 (99. 9)	36. 2 (97. 2)	31. 1 (88)	23. 5 (74. 3)	17. 1 (62. 8)	43. 3 (109. 9)
Average High T ℃ (°F)	2. 5 (36. 5)	5. 8 (42. 4)	12. 6 (54. 7)	21. 3 (70. 3)	27. 0 (80. 6)	31. 7 (89. 1)	31. 7 (89. 1)	30. 1 (86. 2)	26. 5 (79. 7)	20. 0 (68)	10. 8 (51. 4)	4. 1 (39. 4)	18. 68 (65. 62)
Daily Average T ℃ (°F)	−3. 2 (26. 2)	−0. 1 (31. 8)	6. 6 (43. 9)	14. 9 (58. 8)	20. 6 (69. 1)	25. 4 (77. 7)	26. 8 (80. 2)	25. 3 (77. 5)	20. 6 (69. 1)	13. 6 (56. 5)	5. 1 (4). 2)	−1. 2 (29. 8)	12. 87 (55. 15)
Average low T ℃ (°F))	−7. 7 (18. 1)	−4. 7 (23. 5)	1. 3 (34. 3)	8. 8 (47. 8)	14. 5 (58. 1)	19. 6 (67. 3)	22. 6 (72. 7)	21. 4 (70. 5)	15. 7 (60. 3)	8. 7 (47. 7)	0. 8 (33. 4)	−5. 2 (22. 6)	7. 98 (46. 36)
Lowest T ℃ (°F)	−22. 0 (−7. 6)	−20. 9 (−5. 6)	−14. 8 (5. 4)	−4. 3 (24. 3)	4. 2 (39. 6)	9. 7 (49. 5)	13. 4 (56. 1)	12. 6 (54. 7)	4. 2 (39. 6)	−2. 3 (27. 9)	−13. 1 (8. 4)	−17. 9 (−0. 2)	−22. 0 (−7. 6)
Average Precipitation mm	2. 0 (0. 079)	4. 8 (0. 189)	8. 0 (0. 315)	17. 1 (0. 673)	32. 6 (1. 283)	64. 0 (2. 52)	172. 2 (6. 78)	133. 7 (5. 264)	43. 1 (1. 697)	21. 4 (0. 843)	10. 5 (0. 413)	3. 1 (0. 122)	512. 5 (20. 178)