CURRENT STATUS AND INTEGRATED POLLUTION CONTROL OF BLACK AND ODOROUS WATER BODIES IN DONGXINKAI RIVER BASIN OF CHINA

ZHAO, S. Y.[1] – WANG, D. D.[1] – WANG, Y. L.[2] – CHEN, L.[1*]

[1]*College of Municipal and Environmental Engineering, Jilin Jianzhu University*
Changchun 130000, China

[2]*Urban and Rural Planning and Design Institute of Jilin Province*
Changchun 130000, China

**Corresponding author*
e-mail: coffeezsy@163.com

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Abstract. This paper monitors and analyzes the surface water and sediments in the Dongxinkai (DXK) River basin. The analysis shows that the water bodies mainly suffer from aerobic pollution, with chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) being the primary causes of pollution. Considering the main causes of the pollution, the author put forward an integrated pollution control plan for the basin focusing on pollutant interception, source control, and ecological construction. After the treatment, the dissolved oxygen (DO) values at all sampling points were greater than 2 mg/L, the NH_3-N values were all smaller than 8 mg/L and the water transparency values were all above 25 cm, indicating that the river is no longer black or odorous. The implementation of the entire plan costs RMB 26.2×10^8 yuan. The research findings shed important new lights on pollution control in other rivers across China.
Keywords: *black and odorous waterbody, chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), wetland, sponge city*

Introduction

As urbanization has been picking up speed in China, a lot of sewage have been discharged into rivers without any treatment. As a result, water quality indices like chemical oxygen demand (COD), ammonia nitrogen (NH_3-N) and total phosphorus (TP) have greatly surpassed limits in many rivers, making the water bodies black and odorous (Wang et al., 2014, 2016a; Corsino et al., 2016). In 2015, the State Council, China's cabinet, unveiled its *Action Plan for Water Pollution Prevention and Control*, setting out the goal to control the proportion of black and odorous water bodies in urban built-up regions at prefecture-level and push it below 10% by 2020 (Chi et al., 2019; Li et al., 2018).

In light of the above, this paper attempts to prepare an integrated plan to solve the water pollution in the basin of Dongxinkai (DXK) River, northeastern China's Jilin Province, aiming to control the water quality indices within the limits. The prepared plan would promote the construction of sponge cities and provide reference to river pollution control across China.

With a basin of 98.12 km^2, the DXK River is a 16.5-km-long primary tributary of Yitong River, which crisscrosses Jilin Province. The mean slope of the river is about 1.5‰. The main tributaries include Xibaizi (XBZ) Ditch, Dabaizi (DBZ) Ditch, Baizi (BZ) Ditch, Weizi (WZ) Ditch, Jinqian (JQ) Ditch, etc. Currently, the water bodies are of poor quality in the river basin. The COD and nutrient salts (nitrogen and phosphorus)

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far exceed their respective limits. As a typical black and odorous water bodies, the river and its tributaries cannot even reach Class V specified in China's environmental quality standard for surface water, which seriously affects the life quality of nearby residents. This calls for immediate pollution control and regulation.

Materials and methods

Sampling and analysis method

During 11:00-15:00 on March 22- 25, 2016, the project team collected water samples from 50 cm of obvious flow on both Banks and river center in each monitoring section at the same time. After fully mixing, 500 ml of mixed water samples were taken, sealed with polyethylene bottles, and brought back to the laboratory for physical and chemical determination within 24 h. Each indicator of each water sample was measured three times and averaged. The surface water and sediment samples were collected from 29 points (*Fig. 1*) in the DXK River and its main tributaries. During the collection, a YSI (Yellow Springs Instrument Co) water quality meter and other portable water quality analyzers were adopted to measure the following indices of the surface water samples: temperature, pH, oxidation reduction potential (ORP), conductivity and dissolved oxygen (DO) (Moungar et al., 2018; Uddin et al., 2017; Zhao et al., 2016, 2019). Meanwhile, the surface sediments were collected with a gravity column sampler (Behaddya and Hadjel, 2014; Bhuiyan et al., 2010; Wang et al., 2016).

The sediments were analyzed to determine their water content, organic content, particle size and heavy metal content. Specifically, the distribution of particle size was determined by a laser particle size analyzer, while the heavy metal content was measured by inductively coupled plasma optical emission spectrometry (ICP-OES). Before the ICP-OES, the sediment samples were freeze-dried by a freeze dryer, and then digested by microwave (Zhou et al., 2011).

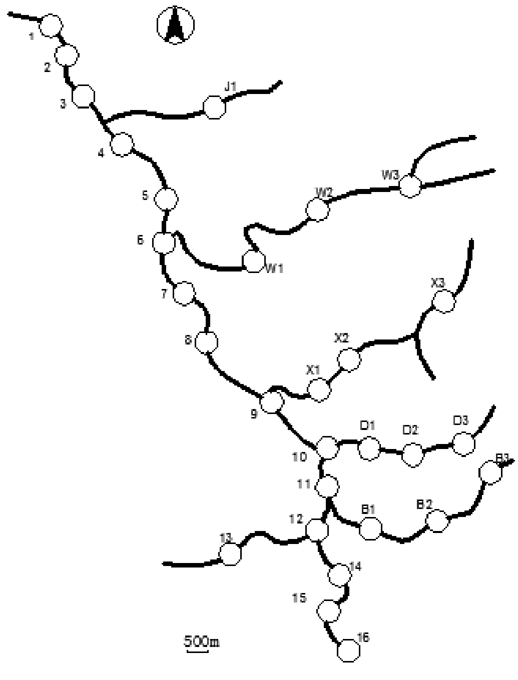

Figure 1. *Distribution of sampling points*

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Water quality analysis

The results of water quality and sediment analysis are listed in *Table 1*. In general, the surface water COD in the river basin fell in 13~222 mg/L, averaging at 106.9 mg/L. The WZ Ditch and DBZ Ditch had relatively high mean CODs, respectively, 166 mg/L and 148 mg/L. The values were 4 and 5 times that for Class V in China's environmental quality standard for surface water. In the main stream, the COD at about 82% of sampling points was greater than the Class V level.

Table 1. *Results of surface water quality and sediment analysis*

	Results of surface water quality analysis						**Results of sediment analysis**				
Sampling point	**COD mg/L**	**NO_3-N mg/L**	**NH_3-N mg/L**	**TN mg/L**	**TP mg/L**	**SRP mg/L**	**TN mg/kg**	**TP mg/kg**	**TC %**	**TS %**	**LOI %**
1	100	0.05	14.2	28.13	1.87	1.98	3218.4	1456.8	5.2	0.21	0.083
2	98	0.28	14.1	28.10	5.16	5.46	898.5	500.3	0.2	0.03	0.064
3	122	0.97	15.1	28.11	2.13	2.13	1998.6	478.6	1.8	0.07	0.072
4	120	0.55	16.2	39.24	1.71	1.88	3048.5	1639.6	3.7	0.22	0.058
5	126	0.68	17.2	23.52	3.69	3.78	3128.7	1586.9	3.6	0.18	0.046
6	118	0.57	15.2	30.26	1.54	1.63	2082.3	456.9	2.9	0.16	0.135
7	130	0.60	16.3	21.68	1.62	1.67	2278.6	698.3	2.8	0.07	0.033
8	126	0.62	15.4	20.96	1.60	1.65	789.9	121.6	3.9	0.31	0.065
9	25	1.08	5.9	4.61	0.17	0.26	2001.9	689.7	3.5	0.25	0.054
10	96	0.28	11.8	18.15	3.06	3.52	1978.6	498.6	3.8	0.26	0.057
11	119	0.34	20.4	28.74	4.79	5.03	438.6	396.5	0.9	0.04	0.051
12	32	3.45	1.04	13.11	0.43	0.63	1847.7	452.3	2.1	0.06	0.047
13	220	4.57	51.3	77.61	6.05	5.92	5875.1	426.9	2.3	0.05	0.049
14	220	4.01	46.7	60.41	5.82	5.63	431.6	415.6	0.3	0.03	0.028
15	30	4.98	1.97	15.84	0.36	0.42	3568.7	894.6	5.1	0.14	0.084
16	121	0.04	6.87	17.26	1.12	1.44	1894.5	487.7	2.9	0.08	0.048
J1	78	0.28	9.87	13.27	0.71	0.65	3248.6	600.1	3.1	0.16	0.063
W1	220	2.88	81.2	107.7	10.12	8.82	214.9	587.6	1.6	0.02	0.028
W2	222	2.65	70.6	44.91	6.73	6.12	1846.5	189.6	1.5	0.03	0.025
W3	196	0.78	0.91	18.79	2.61	2.63	5876.4	689.1	6.6	0.12	0.011
X1	26	0.58	3.12	11.54	0.52	0.29	687.6	220.3	4.3	0.06	0.016
X2	20	0.50	1.25	12.83	0.13	0.13	690.5	497.6	2.4	0.09	0.009
X3	71	2.98	5.37	13.69	0.68	0.33	246.8	498.9	1.6	0.11	0.008
D1	39	0.58	0.08	12.16	0.50	0.24	278.6	396.5	1.4	0.07	0.010
D2	197	5.83	10.16	70.61	11.24	10.21	428.7	788.6	3.9	0.05	0.011
D3	188	0.57	24.5	36.83	0.48	0.21	528.6	758.3	4.1	0.06	0.013
B1	39	2.87	2.01	14.21	0.51	0.23	2000.2	425.3	5.1	0.31	0.014
B2	40	2.45	6.37	16.53	0.54	0.35	398.3	345.6	1.7	0.05	0.135
B3	13	3.31	0.09	15.64	0.41	0.01	401.2	754.6	3.0	0.21	0.012

*NO_3-N: nitrate nitrogen. TC: total carbon. SRP: soluble reactive phosphorus. TS: total sulfur. LOI: loss on ignition. COD: chemical oxygen demand. TN: total nitrogen. TP: total phosphorus. NH_3-N: ammonia nitrogen

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The NH_3-N in the water bodies ranged between 0.04 mg/L and 5.83 mg/L. In the main stream and each tributary, the NH_3-N gradually decreased streamwise. The mean NH_3-N was the highest in the BZ Ditch, while that of the WZ Ditch and the DBZ Ditch were 36 mg/L and 13.1 mg/L respectively. In the main stream, the NH_3-N exhibited an obvious spatial difference. In the downstream, the NH_3-N obeyed a relatively uniform distribution and all exceeded the Class V level. This is attributable to the industrial wastewater and domestic sewage discharged from cities, towns and villages.

The total nitrogen (TN) fluctuated between 4.61 mg/L and 107.7 mg/L across the river basin, and always stayed above the Class V level. The peak TN was observed at the sampling point W1, about 54 times the Class V level. This means all water bodies in the basin have been seriously polluted by nitrogen.

The mean TP in the basin stood at 2.4 mg/L, more than 7 times the Class V level (0.4 mg/L).

The soluble reactive phosphorus (SRP) of the basin averaged at 2.26 mg/L, indicating that an average of 84% phosphorus in the water bodies mainly exist in the dissolved state. The SRP proportion of the main stream even surpassed 90%.

Sediment analysis

The analysis results in *Table 1* show that the TP of surface sediments in the basin averaged at 613.03 mg/kg, far above the internationally accepted TP threshold (500 mg/kg) for sediments. The TN of surface sediments in the basin averaged at 1,951.3 mg/kg. This level greatly surpassed the internationally accepted TN threshold (1,000 mg/kg) for sediments, posing the risk of pollutant release.

The sediment samples differed greatly in total carbon (TC), which ranged between 0.27% and 6.6%. The peak TC belonged to the sampling point W3. The distribution of TC changed significantly from place to place in the tributaries.

The total sulfur (TS) of sediment samples, an indicator of pollutant content, averaged at 0.113%, and peaked at sampling points 8 and B1. The spatial distribution of TS was relatively stable.

The loss on ignition (LOI) characterizes how much organic matter exists in the sediments, and how much gaseous products come from the thermal decomposition of sediments. The analysis results demonstrate an obvious difference in organic content between sediment samples. The highest organic content was discovered at sampling points 6 and B2. Therefore, TC and LOI must have similar pollution sources.

The author monitored 29 sampling points with 4 indicators including TN, TP, COD and NH_3-N for a total of 4 times in March 2016, and extracted 3 samples from each sampling point for a total of 1392 (29 × 4 × 12) monitoring samples for laboratory analysis. The specific statistical description of the results is shown in *Table 2*. According to the statistical data, the flowing water of this river is seriously polluted. TN, NH_3-N and TP all seriously exceed the category V of surface water environmental quality standards. Normal test was carried out on the average data set of sampling points, and the results showed that all monitoring indexes except TN followed normal distribution with 95% or higher reliability.

Diagnosis of water environment problems

The water bodies in the river basin mainly suffers from aerobic pollution, with COD and NH_3-N being the primary pollutants. According to the analysis on surface water

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quality indices, the surface water is severely polluted by nutrient salts. On average, the surface water samples exceeded the standard level by 7.3 times, 13.6 times, 5.8 times and 2.6 times in terms of NH_3-N, TN, TP and COD. Considering the current states of pollution and sewage pipe network, the blackness and odor of the water bodies can be attributed to the following reasons:

(1) Our survey shows that agricultural land (63.02 km^2) takes up 64.2% of the river basin (98.12 km^2); For the pollution load of the basin, 70% comes from agricultural non-point source pollution and 5% from scattered discharge of rural sewage. Thus, the rural area is the main contributor to non-point source pollution of the basin. The non-point source pollution load in the river basin is specified in *Table 3*.

(2) There is no sewage treatment plant in the river basin. Neither has any sewage treatment plant been planned for this region. The sewage is mainly collected by the pipe network, and transported to the Beijiao Sewage Treatment Plant in the downstream. As a result, the water flow in the middle and lower reaches of the DXK River is not stable. The river often dries up in the dry season.

(3) The runoff is seriously polluted in rainy days. In the basin, the rainwater and sewage are still discharged in the same pipe network. During rainstorms, the sewage often flows over and carry garbage into the river.

(4) The rivers have weak self-purification ability due to ecological degradation. The river basin does not have enough ecological space (Podani, 1994; Xu, 2005). Many river channels are illegally occupied by buildings and lots of beaches are turned into farmland, leaving a narrow watercourse for flood discharge (Lazaro, 1979). These behaviors severely undermine the regional flood control and discharge, water regulation and storage, river self-purification and river landscape. This is the main threat to the ecological space of the river basin.

Table 2. *Statistical description of water quality variables and the environmental guideline of national quality standards for surface waters*

Parameter	TN mg/L	NH_3-N mg/L	TP mg/L	COD mg/L
Mean value	29.154	17.442	2.658	7.352
Standard deviation	2.48	2.16	0.34	0.98
Standard error	0.13	0.11	0.02	0.09
Least value	4.61	0.09	0.13	13
Maximum value	107.7	81.2	11.24	222
I*	0.2	0.15	0.02	2
II	0.5	0.5	0.1	4
III	1.0	1.0	0.2	6
IV	1.5	1.5	0.3	10
V	2.0	2.0	0.4	15

*State Environmental Protection Administration (2002)

Results

The cause analysis of the black and odorous river bodies indicates that the river basin is mainly affected by agricultural non-point source pollution. Considering the segmented features of the pollution status, the author put forward a pollution control

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plan focusing on pollutant interception, source control, and ecological construction. The plan mainly covers five areas, namely, sewage treatment plant, sponge city, garbage treatment and sediment cleaning, rural water pollution control and wetland construction.

Table 3. *Non-point pollution load in the river basin*

Land use	Area km^2	Percentage %	TSS*	COD	TN t/a	TP	NH_3-N
Farmland	53.47	54.5	2491.7	498.3	74.8	7.5	24.9
Rural construction land	13.39	13.6	1559.9	468.0	31.2	3.1	12.5
Urban factory land	7.6	7.7	929.7	796.9	18.6	1.9	5.3
Urban residential land	11.36	11.6	1032.3	894.6	24.1	2.4	6.9
Forest land	3.72	3.8	26	13.0	1.3	0.1	0.3
Grass land	5.83	5.9	54.3	27.2	2.7	0.3	0.5
Water body	2.75	2.8					
Total	98.12	100	6093.9	2698	152.6	15.3	50.4

*TSS: total suspended solids. COD: chemical oxygen demand. TN: total nitrogen. TP: total phosphorus. NH3-N: ammonia nitrogen

(1) The sediment and garbage were removed from 46.4-km-long river channels. In total, 8.4×10^4 m^3 of sludge was cleaned away, which effectively reduces the sediment release and boosts the flood discharge ability. The sediments being removed were separated from water through a five-stage coagulative precipitation tank, dried in open air, and finally backfilled (Bohn, 2002). After dredging, COD and NH_3 - N index of the river cut nearly 50%, after dredging, adding the volcanic debris (size 6 ~ 10 mm) and pebbles on the bottom of the riverbed sediment improvement, on the microorganism immobilized bacterium agent, the bacteria agent by photosynthetic bacteria, spores, bacteria, to produce alkali bacteria, yeast and other 10 genera and more than 120 kinds of microorganism distribution and slow release cycle for 3 ~ 6 months.

(2) The sponge city project was implemented in view of the following facts: the surface runoff coefficient (0.7) and surface runoff is obviously higher in the built-up area than other areas in the basin, the water quality is greatly affected by surface runoff, and the ecosystem is serious undermined. Specifically, a 0.8 km^2 wetland park was built in the upstream of the DXK River and another 5.4 km^2 one was constructed in the downstream of the JQ Ditch. The two parks were constructed to restore the natural water system and wetlands, which can retain, regulate and purify the surface runoff pollution, reduce the load of non-point pollution from the upstream, and ensure the ecological flow in the river basin. In addition, a pilot program of sponge city was implemented in the middle reaches of the WZ Ditch. The 4.7 km^2 sponge city could cut down the surface runoff load by 50~75%.

(3) The 82 ponds in the basin were expanded into a pond-wetland system. To maintain the water volume and purify the water in the basin, the following key wetlands were constructed: two reservoir wetlands, three pond wetlands, one estuary wetland and one artificially enhanced wetland (using the tail water from sewage treatment plant) (Ascelin et al., 2002; Zhu et al., 2019; Barinova, 2017). The area, pondage, and pollution reduction amount of each wetland are listed in *Table 4*. The locations of the wetlands are shown in *Figure 2*.

(4) The urban sewage was carried by lift pump stations to the sewage treatment plant for centralized treatment. The plant was newly constructed, with a capacity of

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1×10^4 t·d^{-1}. Using the Anaerobic/Anoxic/Oxic (A/A/O) process, the sewage treated by the plant can reach the IA level in the *Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant* (GB18918-2002). The pollutant interception pipe network was constructed as an auxiliary project of the plant. The quality of the treated sewage is illustrated in *Figure 3*.

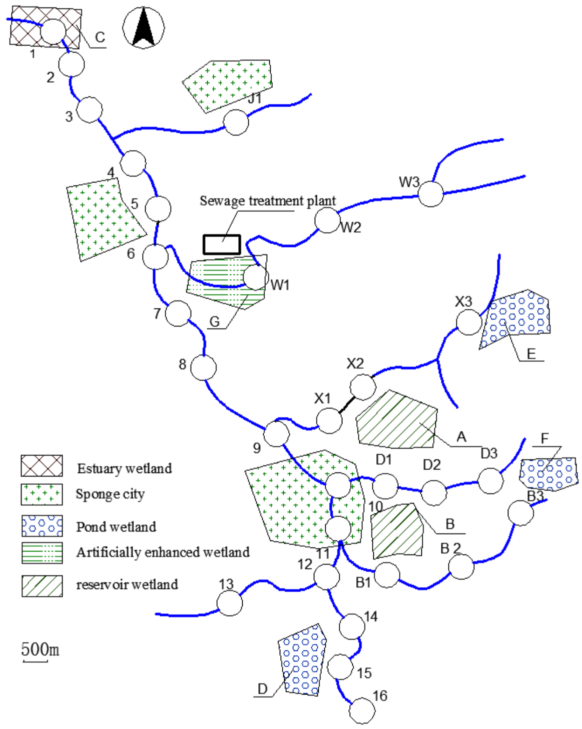

Figure 2. *Distribution of different types of wetlands and sponge cities. (J: JQ Ditch, W: WZ Ditch, X: XBZ Ditch, D: DBZ Ditch, B: BZ Ditch)*

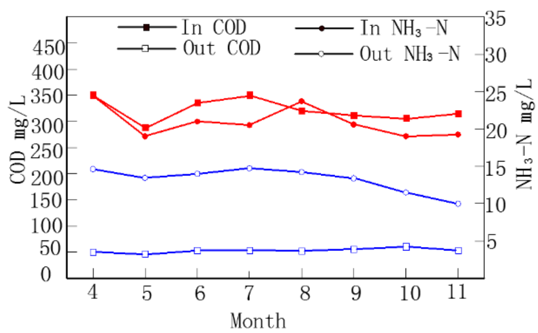

Figure 3. *Comparison between inlet and outlet water of the A/A/O sewage treatment plant*

(5) In light of the scattered discharge of rural sewage in the basin, the author developed a system to utilize and purify domestic sewage and rainwater. The system, encompassing rainwater and sewage collectors, sewage purifier, and ecological pools, can collect and purify domestic sewage and rainwater separately, and discharge them after they reached the relevant standard. In this way, the proposed system makes full use

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of water resources, and opens up a new way to replenish the groundwater. As shown in *Figure 4,* the sewage purifier consists of such four parts as sewage collector, primary purification tank, secondary purification tank and tertiary purification tank. The primary purification tank has three layers, which respectively filters coal cinder, medium-coarse sand and fine sand. The secondary purification tank mainly relies on a fiber filter layer consists of bio-fiber straws extracted from corn and wheat. This layer provides the function of biological purification. The tertiary purification tank works with an activated carbon filter layer. After entering the sewage purifier, the sewage passes through the three purification tanks in turn, and undergoes thorough purification.

Table 4. *Statistics of multi-level pond-wetland system in the basin*

No.	Type of project	Longitude	Latitude	River	Area (10^4 m^2)	Pondage (10^4 m^3)	COD reduction (t/a)	NH_3-N reduction (t/a)	Function
1	Reservoir wetland A	125.443561	43.892365	XBZ Ditch	4	6	9.8	2.4	Water storage and purification
2	Reservoir wetland B	125.444718	43.873799	DBZ Ditch	4.9	8.1	11.2	3.1	Water storage and purification
3	Estuary wetland C	125.366975	43.957737	DXK River - Yitong River	16.1	6.1	64	12	Water purification
4	Pond wetland D	125.426149	43.861221	DXK River	6.5	9.8	43.1	6.9	Water storage and purification
5	Pond wetland E	125.460136	43.885143	XBZ Ditch	5.5	8.3	38.4	5.9	Water storage and purification
6	Pond wetland F	125.4700	43.871532	DBZ Ditch	8.7	13.1	57.6	9.2	Water storage and purification
7	Artificially enhanced wetland G	125.410269	43.912186	WZ Ditch	7.8	5	18.2	2.3	Purification of tail water from sewage treatment plant

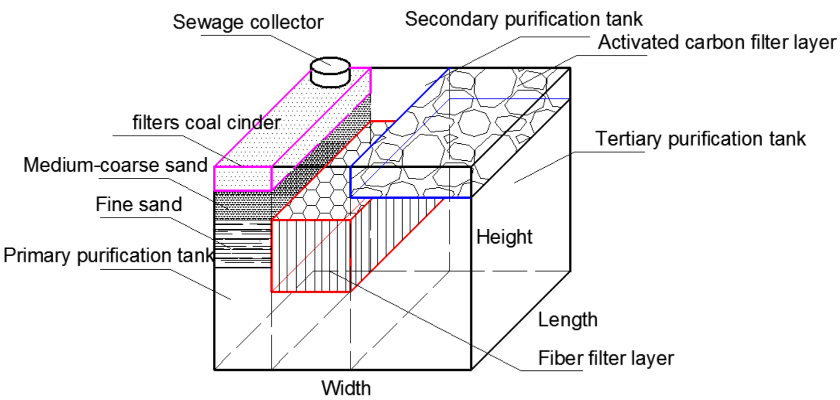

Figure 4. *Sewage purifier*

Discussion

The treatment of black and odorous waterbody should be adapted to local conditions and different treatment schemes should be adopted in different areas. The lower reaches of Fuchuangxi River in HaiNan province of China are tidal river sections with high salinity. Therefore, sewage interception, wastewater treatment, aeration and mangroves ecosystem were used to remediate the black and odorous waterbody of Fuchuangxi River (Chi et al., 2019). Yitng river of JiLin province, black and odorous waterbody is

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caused by farming and agriculture, so the construction of biogas greenhouse ecological system, heat storage and utilization of the manure, straw compost renewal, on the one hand, can make use of biogas technology in biochemical treatment, on the other hand can purify livestock farming aquaculture wastewater, reduce its pollution material such as COD, nitrogen, phosphorus content, reach discharge standards to reduce the surface water pollution (Zhao et al., 2019). Considering the segmented features of the pollution status, the author put forward a pollution control plan focusing on pollutant interception, source control, and ecological construction. The pollution control plan mainly covers five areas, namely, sewage treatment plant, sponge city, garbage treatment and sediment cleaning, rural water pollution control and wetland construction.

The pollution control plan was fully implemented by October 2017. From May to November, 2018, the author collected water samples from the DXK River at sampling points 5, 11 and 14, and analyzed the DO, ORP, NH_3-N and transparency of the samples. The results in *Figure 5* show that, through the seven months, the DO values at all three points were greater than 2 mg/L, the NH_3-N values were all smaller than 8 mg/L and the water transparencies were all above 25 cm, indicating that the river is no longer black or odorous. The implementation of the entire plan costs USD 3.47×10^8. The investment is break down in *Table 5*.

Table 5. *Main workloads and investment breakdown of the pollution control plan*

No.	Name of project	Project contents	Workload	Investment (USD thousand)
1	Drainage system and sewage treatment plant	Main sewage pipes ng the rivers	Pollutant interception pipes (49 km)	45714
		Rainwater and sewage interception wells	Interception wells (39)	55714
		Sewage treatment plant	10^4 m^3/d	29997
2	Sponge city	Green rainwater foundation	0.8 km^2	14286
		Green road construction	5.9 km × 45 m	8286
		Green communities and squares	4 km^2	28571
3	Sediment cleaning	Mechanical dredging	30 places	214
		Dehydration and capacity reduction	84514 m^3	1207
		Transport and disposal	94514 m^3	714
4	Rural water pollution control	Village demolition	3500 J^3	5000
		Domestic sewage treatment	20000 J^3	2857
		Fecal composting	1 station	2143
		Others	/	571
5	Wetland construction	Estuary wetland	100,000 m^2	571
		Artificially enhanced wetland	78,000 m^2	1114
		Reservoir wetlands	106,000 m^2	1514
		Pond wetlands	65,000 m^2	650
6	Water ecological project	Rubber dams	4	929
		Ecological revetment	Soil and earthworks 52,600 m^3	511
		River landscape	990,000 m^2	28285
		Parks	1160,000 m^2	82857
		Wetland spaces	170,000 m^2	7286
		Riverfront landscape belt	810,000 m^2	40500
		Leisure nodes	210,000 m^2	13500
Total				3.74×10^8

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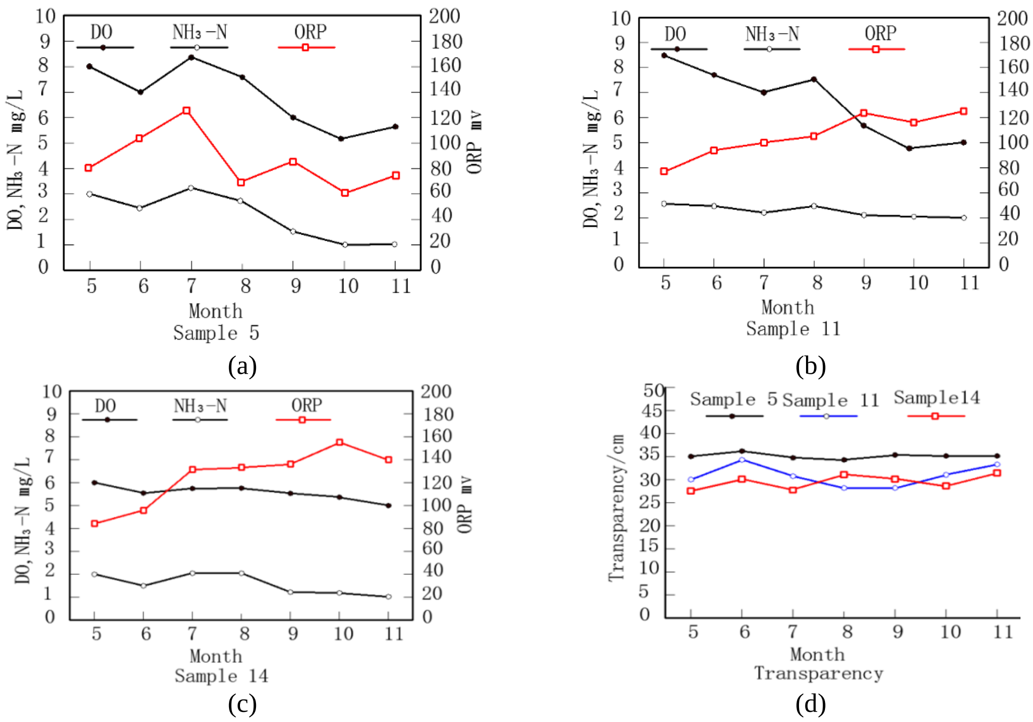

Figure 5. *Analysis results on water sample quality*

Conclusions

This paper monitors and analyzes the surface water and sediments in the DXK River basin, and discovers that the water bodies mainly suffer from aerobic pollution, with COD and NH3-N being the primary pollutants. Agricultural non-point source pollution accounts for 70% of the pollution load, and scattered discharge of rural sewage accounts for 5% of the pollution load, which is the main source of water pollution.

Considering the main causes of the pollution, the author put forward an integrated pollution control plan for the basin focusing on pollutant interception, source control, and ecological construction.

Removing the sediment and garbage from the river can reduce COD, NH3-N and other indicators in the river by nearly 50%. The immobilized microbial agent was used to remove NH_3-N and COD in black and odorous waterbody. The construction of wetland park, the ponds in the basin were expanded into a pond-wetland system, can significantly reduce NH_3-N and COD.

After the treatment, the DO values at all sampling points were greater than 2 mg/L, the NH_3-N values were all smaller than 8 mg/L and the water transparencies were all above 25 cm, indicating that the river is no longer black or odorous. The implementation of the entire plan costs USD 3.47×10^8. The research findings shed important new lights on pollution control in other rivers across China.

Also suggested that the basin water pollution comprehensive treatment to pollution load distribution in the process, on the one hand, it can realize basin within the scope of reasonable layout and the load sharing ratio of the control area, on the other hand, within the scope of the basin can be unequal distribution of technical and economic investment, implement the specific implementation of total amount control load index, the governance effect is better.

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