Factors Affecting Water Quality in the Liao River Basin

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Abstract. With the acceleration of urbanization and industrialization, the water quality of the Liao River Basin (LRB) has been seriously damaged by the influence of numerous pollution sources. This paper analyzes the main influencing factors and processes of water quality in the LRB from three aspects: natural environment changes, industrialization and urbanization, and agriculture. The study shows that the water temperature of the LRB is affected by air temperature and solar radiation. At the same time, the increase in vegetation cover reduces the river flow to a certain extent. Urbanization and industrialization are gradually affecting the water quality of the LRB, with heavy metal pollution and domestic wastewater discharge having a significant impact. Among the heavy metal pollutants, Hg is the central polluting heavy metal in the LRB. The old drainage pipe system in urban areas leads to wastewater overflow for domestic wastewater discharge, and most of the livestock and poultry wastewater in rural areas is discharged directly into the river without treatment. The large amount of water used for agricultural irrigation has reduced the flow of the LRB, and the use of chemical fertilizers has led to high levels of nitrogen and phosphorus in the river. This paper looks forward to exploring treatment options that align with the characteristics of water pollution sources in the LRB and hopes to provide a broader and deeper reference for the in-depth study and development of water quality in the LRB.

Keywords: Liao river basin, source diagnosis, water quality, heavy metal, domestic sewage.

1. Introduction

Liao River Basin (LRB) is the largest river in southern Northeast China, distributed in Liaoning, Hebei, Jilin and Inner Mongolia provinces. The Liao River has a total length of 1430km, a watershed area of 229,000 km2, and an annual runoff of 12.6 billion m3, with slow water flow, siltation, and sandy loam riverbed [1]. The area through which the Liao River flows is a heavy industrial base in northeastern China, with a dense population, developed agriculture and industry, and various pollution sources. According to the environmental quality standards for surface water in China, the water quality of the LRB is below class IV [2]. The discharge of large amounts of pollutants has directly led to the severe deterioration of the water quality of the Liao River. The polluted river water has polluted the shallow groundwater on both sides of the river so that the drinking water of the residents in the coastal areas has been seriously affected, which in turn affects the production and living conditions of the residents in the watershed as well as the economic development in the watershed.

The issue of extensive water pollution in China's surface water resources demands immediate attention. However, it is difficult for the existing mechanism of water pollution management to solve this problem effectively and symptomatically. To effectively manage water pollution in the LRB, it is essential to identify its source in the watershed and develop management strategies that address its specific characteristics. A robust mechanism for water pollution management in the watershed should also be established to ensure sustained effectiveness. The comprehensive management of the LRB is a systematic project with long-term complexity and arduousness, and there are still a lot of problems that need to be solved. Moreover, most scholars still focus on the Liao River's water environment, riparian zone and biological situation. They have yet to systematically combine the natural and anthropogenic water quality influencing factors and processes of the LRB to evaluate its water quality situation.

Therefore, based on summarizing the research results at home and abroad, this thesis intends to study the factors affecting the water quality of the LRB, analyze the sources and impacts of typical pollutants, combine the natural conditions and human construction of the LRB, and show the existing problems of the LRB by collecting data from various aspects, to lay a foundation for choosing the suitable methods of environmental assessment and proposing the specific restoration strategies for the LRB.

2. Environmental Change

2.1. Temperature

Water temperature is an important factor influencing water quality, such as atmospheric reoxygenation processes in the water column, biodegradation processes, and growth processes of algae and bacteria. Water temperature is mainly controlled by climatic and geographical factors. Climate change affects water temperature differently through changes in precipitation and air temperature. Rising air temperatures are an important driver of rising water temperatures. When the air temperature differs from the water temperature, heat is exchanged by conduction at the water-air interface. As can be seen in Fig. 1, water temperature varies significantly with air temperature and solar radiation [3]. In June, the air temperature is high and the solar radiation is strong, and in September, the air temperature and the intensity of solar radiation decrease, and the average temperature of the water flow in June is about 10℃ higher than that in September. The water temperature varies gently along the course and has a decreasing tendency, and there are more obvious changes in the water temperature where there are tributaries converging, which is caused by the temperature difference between the tributaries and the main channel.

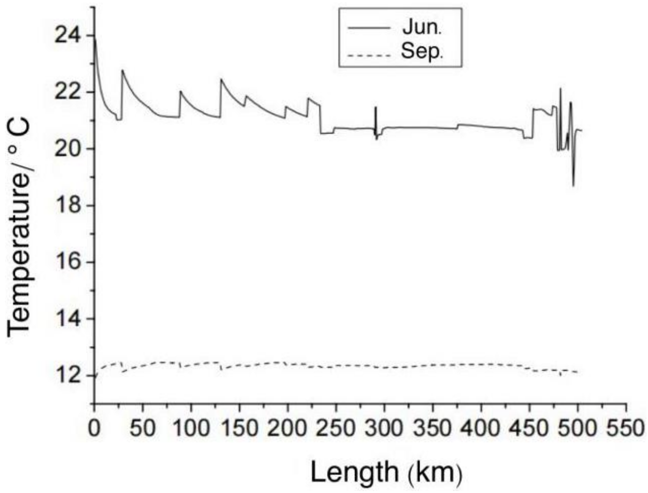

Figure 1. The temperature changes along sections. https://kns.cnki.net/kcms2/article/abstract?

Other natural drivers of water temperature in river reaches include channel characteristics, flow velocities, tributary inputs, storage capacity and groundwater discharge. Water temperature affects the composition of water by influencing mineral solubility and CO_2 partial pressure. An increase in water temperature usually leads to an increase in the solubility of salt and the salinity of water. Water temperature is also a regulator of water pH, which decreases with increasing water temperature [4]. Furthermore, dissolved oxygen (DO) is more abundant in cold water than in warm water; higher water temperatures may also promote organism respiration and metabolism, leading to increased oxygen consumption and lower DO.

2.2. Vegetation Coverage

In recent years, the LRB has implemented the Grain for Green Program (GFGP), an ecological policy aimed at restoring the region's ecological vegetation, preventing soil erosion and mitigating flooding. In addition, there are also areas in the LRB that have been reestablished through the natural process of vegetation succession, without large-scale human-prescribed or human-directed changes in land cover types. As shown in Fig. 2, from the time series, the vegetation cover in the LRB has shown a fluctuating upward trend over the past 19 years, with an annual growth rate of 0.305 $5 \cdot a^{-1}$ [5].

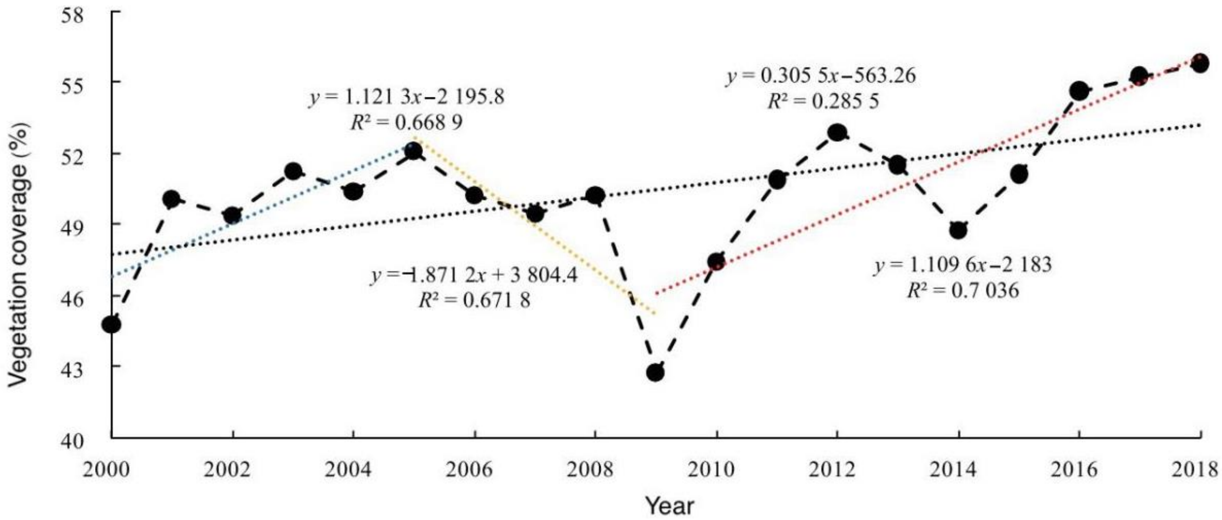

Figure 2. Time series changes of vegetation coverage in West Liao River Basin from 2000 to 2018

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Contrary to popular perception, the increase in the area of vegetation and the improvement in the quality of vegetation have had a negative impact on the hydrological balance of the Liao River to a certain extent. When the area of vegetation increases significantly over a short period of time, there is a corresponding decrease in river runoff due to enhanced evapotranspiration [6]. In addition, the significant effect of vegetation on reducing surface runoff has led to a reduction in runoff in the LRB [7].

3. Industrialization and Urbanization

3.1. Heavy Metal Pollution

Industrialization is gradually affecting the water quality of the LRB, with printing and dyeing wastewater dramatically increasing the chromaticity of the water, the coal mining industry increasing the chemical oxygen demand in the water, and heavy industrial wastewater exceeding the metal content in the water [8]. Heavy metal pollution is the most serious because Liaoning Province, where the LRB is located, is one of the heavy industrial production bases in China, in which steel, petroleum and chemical industries are more developed.

The sections with high heavy metal content in the LRB are located in the middle and lower reaches of large and medium-sized industrial cities, such as Shenyang, Anshan and Benxi, and are associated with the industrial enterprises around each section [9]. Industries in the region are dominated by metallurgical, coal, electric power, chemical and mechanical industries that require large amounts of water, consume large amounts of energy and discharge a full range of pollutants. Shenyang and Fushun are coal, energy and machinery industries; Anshan and Benxi are important metallurgical cities; Liaoyang and Panjin are important chemical and petroleum cities, and Tieling is an emerging energy base.

The primary source of heavy metal in the LRB is industrial pollution, which remains constant during both wet and dry water periods. The main heavy metal pollutants include Hg, Pb, Zn, Cu, and Cd. As shown in Fig. 3 and Fig. 4, the average concentrations of the six heavy metals are Hg>Pb>Zn>Cu>Cr>Cd. The respective concentrations are 0.046 $mg \cdot L^{-1}$, 0.034 $mg \cdot L^{-1}$, 0.056 $mg \cdot L^{-1}$, 0.135 $mg \cdot L^{-1}$, 0.029 $mg \cdot L^{-1}$, and 0.017 $mg \cdot L^{-1}$, 0.017 $mg \cdot L^{-1}$ [10].

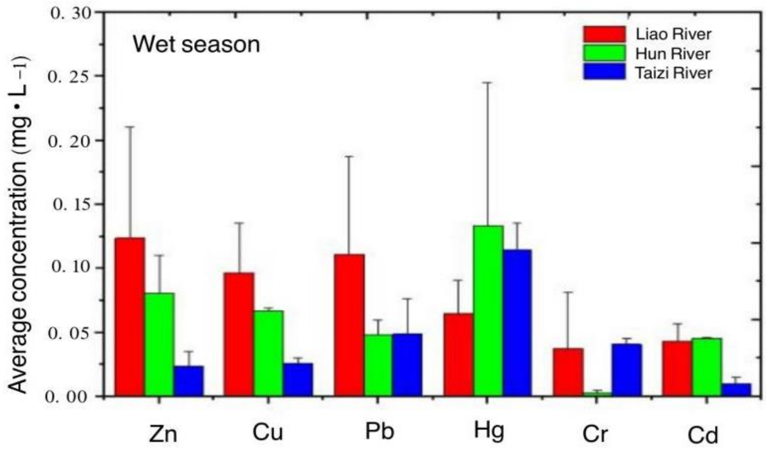

Figure 3. The distribution of body weight metals in Liaohe River, Hunhe River and Taizihe River in wet period. https://kns.cnki.net/kcms2/article/abstract?

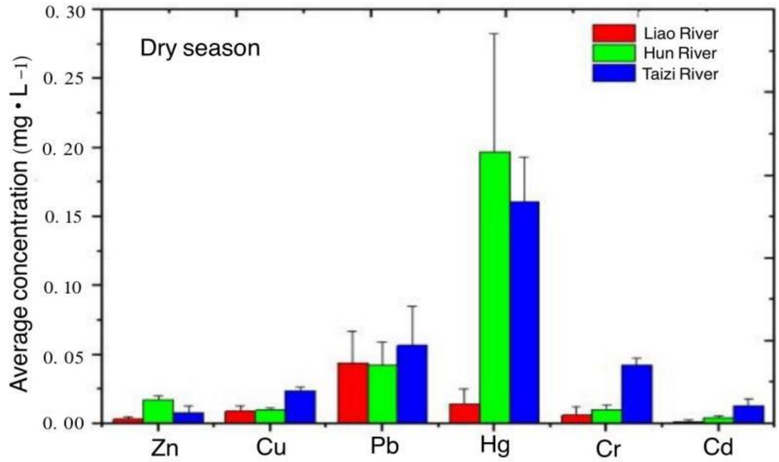

Figure 4. The distribution of body weight metals in Liaohe River, Hunhe River and Taizihe River in wet period. https://kns.cnki.net/kcms2/article/abstract?

Hg is the main polluting heavy metal in the LRB, and it is at the level of Class IV in some sections during the abundant and dry water periods [2]. The distribution characteristics of Hg in water bodies of the LRB in different water periods are shown in Fig. 5 [9].

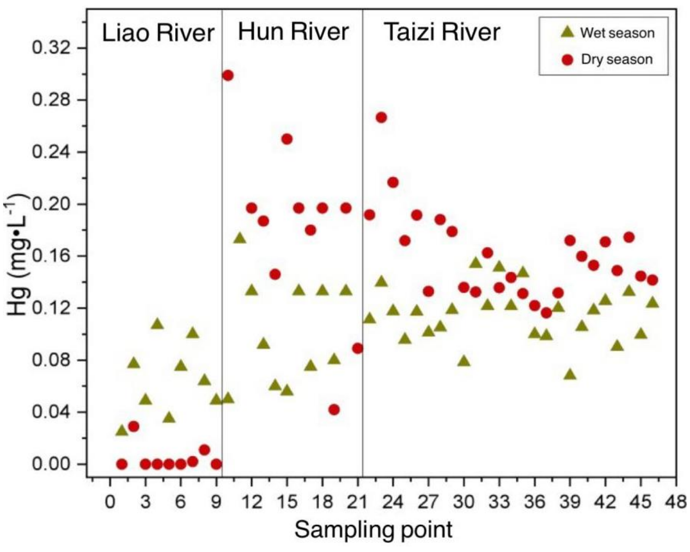

Figure 5. Hg content of Liaohe River, Hunhe River and Taizihe River https://kns.cnki.net/kcms2/article/abstract?

According to relevant studies, the main sources of Hg and Cu are mainly industrial pollution, associated with petrochemical enterprises and metal smelting enterprises [11]. Pb is mainly derived from coal combustion, industrial utilization, motor vehicle tailpipe emissions, and the combustion of crude oil and leaded petrol, etc. [12]. The main sources of Zn and Cr are the landfill of residential rubbish and the use of petrol [13]. Cd mainly derives from the exhaust gases generated by industrial processes such as smelting, coal combustion, and waste incineration [14].

Water bodies containing heavy metal pollutants enter surface water and then re-enter groundwater through natural recycling processes. Even though the concentration of heavy metals in the water body is low, it will seriously affect the service function of aquatic ecosystems after activities such as dispersion, enrichment and transformation, which in turn affects a series of production and life of human beings [15].

3.2. Domestic Sewage

The LRB is not only a source of drinking water for the residents in the basin, but also a receiving body of water for sewage discharged from cities along the river, such as Tieling, Xinchengzi and Panjin.

The capacity of sewage treatment facilities in urban areas is insufficient, and domestic sewage treatment plants are inadequate. For example, in Panjin City, the drainage pipes are old and leaky, and the drainage pipe system is imperfect. Most of the cities along the river use the combined flow drainage system, and only a few areas use rainwater and sewage diversion projects. Therefore, during the rainy season, under the influence of rainfall, some rainwater and domestic sewage overflow directly from the overflow wells without treatment, and eventually flow into the river. The incoming water from upstream is untreated or substandard, resulting in pollutant levels exceeding the environmental capacity of the water body, leading to poorer water quality and increased pollution.

Rural areas have livestock and poultry farming areas, which produce large amounts of sewage and animal faeces. Livestock and poultry effluent discharged into rivers can lead to an increase in water temperature. As can be seen in Fig. 6 [16], the water temperature at the adoption point L10 is the highest, reaching 23.00°C. The main reason for this is that it is located in the city of Kaiyuan in Tieling City, which has a large proportion of livestock and poultry farming and agriculture, so much sewage is discharged untreated into the Liao River, which leads to a temperature increase in the water body.

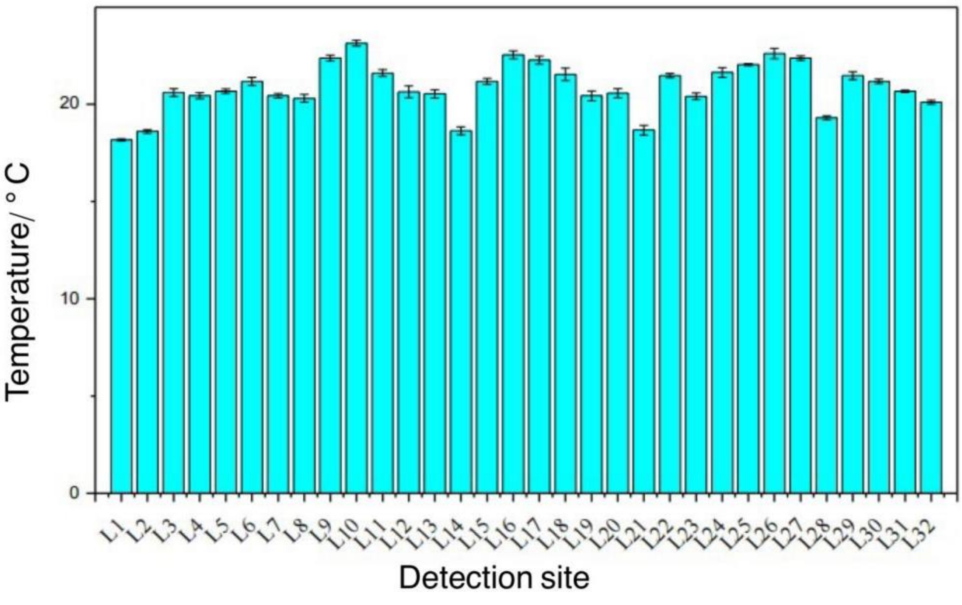

Figure 6. Variation of water temperature at 32 sampling points in the Liao River Basin
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Owing to the low population density, basically, no drainage network and sewage treatment plants have been installed, and most of the sewage is discharged directly into the nearby rivers. In addition, residents dump large quantities of domestic rubbish along rivers, causing the phenomenon of black odour in rivers and making water pollution even more serious.The main sources of pollution in rural areas are widespread, with uncertainty about the source of pollution from surface sources and a certain degree of geographical variability, making monitoring and treatment difficult.

4. Agriculture

4.1. Irrigation Supply

The lower part of the LRB has a large area of arable land, the main agricultural production area in Northeast China and Liaoning Province, where rice, wheat and maize are grown. The temperature, rainfall and other conditions in the Liao Plain are very suitable for the growth and development of rice. Therefore, rice is one of the most important crops in the agricultural production area of the LRB, occupying a large proportion of the farmland area. Rice is a typical water-consuming crop, and the irrigation method is mainly low-pressure pipeline irrigation, which uses a tremendous amount of water. At the same time, as the water used for agriculture is primarily extracted from the neighbourhood, a large amount of water used for agricultural irrigation will lead to a low water level in the LRB, which will conflict with the ecological water use in the river channel.

The LRB has a dense river network, so the construction of agricultural water conservancy was developed earlier. However, in recent years, the development of rural water conservancy projects has been slow; the last level of irrigation and drainage systems and corresponding engineering facilities in farmland fields have not been perfected, and various types of small-scale farmland water conservancy project facilities have no complementary, aged and in disrepair, resulting in a low level of irrigation efficiency and a severe waste of water resources. The use of large quantities of river water to irrigate farmland leads to a reduction in the flow of rivers, a slowing down of water velocity and a deterioration of water quality, thus affecting the river ecosystem.

4.2. Fertilizer Use

Fertilizer inputs are the most critical factor influencing the average annual content of total phosphorus (TP) and total nitrogen in the LRB. In order to meet the food supply, the main grain-producing areas in the LRB are extensively sprayed with pesticides, phosphorus and nitrogen fertilizers. Due to the backward spraying technology and improper control of pesticide concentration, only a small portion of the fertilizer is absorbed and used by the crops, while most of the rest seeps into the farmland with the irrigation water. Nitrogen fertilizers remaining in the soil and plant leaves partly enter groundwater through underground runoff, and the other part enters the LRB through surface runoff along with rainfall scouring and irrigation drainage, resulting in a large increase in the total phosphorus content, total nitrogen content, and Cd concentration of the water body, and bringing certain purification pressure to the river water body [6].

Among them, non-point source phosphorus pollution is one of the main causes of eutrophication in water body ecosystems. Dissolved phosphorus accounts for a large part of the annual river load in the LRB. The ratio of dissolved phosphorus to particulate phosphorus output increases with crop cover and fertilizer input. As shown in Fig. 7, the water quality in the middle reaches of the LRB has high TP content [16]. The main reason is that this section is the main agricultural production area in Shenyang, and the vegetation coverage on both sides of the river is low, and crops such as corn are planted seriously along the coast. Through the surface runoff and farmland drainage, the phosphorus element in the farmland enters the Liao River, which leads to the increase of TP content in the water environment. In addition, because of the proximity of this part of the grain-producing area to the river, its fertilizer use contributes more to the sediment phosphorus load.

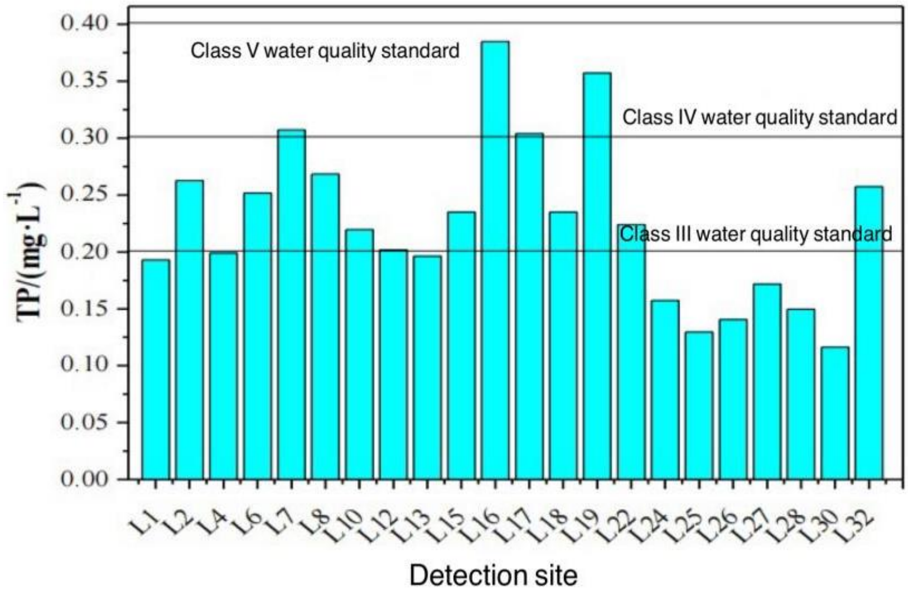

Figure 7. Variation of TP at 22 sampling points in the Liao River Basin. https://kns.cnki.net/kcms2/article/abstract?

The transportation of phosphorus towards rivers is affected by multiple factors, such as the concentration of phosphorus, soil characteristics, biological processes, climate and the path of watershed flow. The complexity of these factors makes it challenging to regulate the movement of phosphorus in watersheds. Meanwhile, the use of phosphorus fertilizers by local agriculture has been going on for decades, leading to the accumulation of phosphorus in the soil and the formation of large quantities of phosphorus-rich sediments. Due to the erosion of phosphorus-rich sediments by surface runoff and the transport of dissolved phosphorus, the LRB will be affected for a long time, and it is difficult to achieve management results in the short term.

5. Conclusion

The water quality of the LRB is closely related to the production and living conditions of the residents in the basin, the sustainable development of the urban economy and the development of Chinese society. This paper discusses the main factors affecting the water quality of the LRB, including the influence of air temperature on water temperature in the natural environment and the negative effect of the increase in the area covered by vegetation on the flow of the river; the pollution of heavy metals and domestic wastewater brought about by industrialization and urbanization, and, among the heavy metal pollutants, Hg is the main polluting heavy metal in the LRB. For domestic wastewater discharge, the old drainage pipe system in urban areas leads to overflow of wastewater, while livestock and poultry wastewater in rural areas is mostly untreated and directly discharged into the LRB; and the use of irrigation water and chemical fertilizer in agriculture. Future researchers should carry out appropriate river management measures to address the above influencing factors. This paper summarizes and analyses the factors and processes affecting water quality in the LRB.

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