Using a water quality index to assess the water quality of the upper and middle streams of the Luanhe River, northern China

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HIGHLIGHTS

• Organic pollutants and nutrients were the main challenge in the Luanhe River.
• Water quality affected by forest and grass land (%) and fertilizers in tributaries.
• WQI was significant negatively correlated with cultivated land (%) in summer.
• WQI was significant negatively correlated with built-up land (%).

GRAPHICAL ABSTRACT

ABSTRACT

The water diversion project from the Luanhe River to Tianjin city has been a “lifeline” for the economic and social development of Tianjin city since the 1980s. The water quality of this project has received considerable attention due to the degradation of the river environment during the last decade. A comprehensive water quality index (WQI) was applied to provide a clear understanding of the water quality in the upper and middle streams of the Luanhe River. We utilized 12 water quality parameters from 85 sampling sites along the major tributaries in July 2017 (summer), October 2017 (autumn) and April 2018 (spring) respectively. The results showed that the WQI values ranged from 37.6 to 90.0, indicating “bad” to “excellent” water quality in the upper and middle streams of the Luanhe River. The seasonal variations in the WQI were significant and the relationship between land use and WQI also have certain seasonal characteristics, such as WQI of 85 sampling sites were significant negatively correlated with the proportion of cultivated land in summer, and with the proportion of built-up land in three sampling periods. The water quality pollutants, such as organic pollutants (permanganate index), nutrients (total phosphorus), total suspended solid, and chlorophyll-a were significantly influenced by the proportion of forest and grass land and the consumption of phosphate fertilizers in tributaries. The evident variation in the WQI was also found in the tributaries with higher proportions of cultivated land and built-up land. Overall, we think that agricultural and urban related activities are important factors affecting the water quality in this region. Water quality improvements should control the sewage in the urban area and the consumption of fertilizers, especially on the cultivated land along the riverside in the upper and middle streams of the Luanhe River.

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1. Introduction

Rivers, as reliable surface water sources, are essential for providing a precondition for public health and aquatic life (Ouyang, 2005; Astel et al., 2006; John et al., 2014). In recent years, anthropogenic activities (urban, industrial, and agricultural) accompanied by natural processes (precipitation inputs, erosion, and seasonal effects) have caused aquatic ecosystems to suffer from high levels of land-based pollutant loads (Subramani et al., 2005; Kazi et al., 2009). As a result, the quality of water resources has deteriorated, the biodiversity and functionality associated with streams has diminished, and river ecosystem health has been under threat. Therefore, it is essential to protect fresh water resources and to identify the factors influencing water quality in streams (Pesce and Wunderlin, 2000; Simeonov et al., 2002; Behmel et al., 2016).

On this account, there is great need to assess river water quality. The evaluation of water quality is commonly based on a comparison of physical, chemical, and biological parameters with established water quality guidelines (Simeonov et al., 2003). Many studies have established various methods for assessing water quality, including 1) univariate water indicators, which use the most impaired water quality parameter and neglect other water quality parameters (Horton, 1965; Debels et al., 2005); 2) the trophic state, such as nitrogen and phosphorus concentrations, which are the water quality parameters of highest concern (Wu et al., 2018); 3) a comprehensive assessment, such as the water quality index (WQI), which is a mathematical instrument used to integrate numerous physical, chemical and biological parameters into a single number and can represent a comprehensive picture of the water quality level (Bordalo et al., 2006; Sánchez et al., 2007). Compared with the former two methods, which provide substantial professional information about water quality parameters, the WQI not only makes results easy to understand (Abbasi and Abbasi, 2012) but can also eliminate the variations between different water quality parameters that are used individually or unilaterally, although these methods are simple (Noori et al., 2019). In order to provide an accurate depiction of water quality status, the WQI method preferably encompass a wide-range of water quality parameters, which requires more cost and time to measure (Akoteyon et al., 2011). However, as an effective comprehensive assessment method, the WQI has been used as one criterion for surface water assessment based on the standard parameters for water quality characterization (Debels et al., 2005).

According to the WQI method, water quality ranges have been defined as five grades: excellent, good, moderate, poor and bad (Chaturvedi and Bassin, 2009). In recent years, the WQI method, thought to be one of the most effective ways to communicate information on water quality trends to the general public and policy makers in water quality assessment, has been widely used in aquatic ecosystems (Abbasi and Abbasi, 2012; Hou et al., 2016; Sutadian et al., 2016). Based on the WQI, water pollutants (inorganic and organic pollutants) could be highlighted for a comprehensive treatment of water quality (Debels et al., 2005; Sener et al., 2017). Wu et al. (2018) assessed the water quality in the Lake Taihu Basin as “moderate” using the WQI, screened out five crucial parameters (ammonia nitrogen, permanganate index, nitrate nitrogen, dissolved oxygen, and turbidity) affecting water quality and speculated that anthropogenic influences and land use were most likely responsible for the variations in the water quality of this basin. Krishan et al. (2016) classified the water quality in the Muzaffarnagar and Shamli districts (India) as “good” for domestic use by the WQI, and determined that industrial and agricultural areas might influence water quality. These above studies assessed water quality using the WQI method and supposed the impact of anthropogenic influences on water quality, but few studies have analyzed the quantitative relationship between comprehensive water quality and the socioeconomic and land use factors related to anthropogenic activities.

The water diversion project from Luanhe River to Tianjin city is the “lifeline” for the economic and social development of Tianjin city. The water source is located in the Daheiting and Panjiakou reservoirs in the Luanhe River Basin. The Daheiting reservoir cut the Luanhe River Basin into two regions. One of the regions contains the upper and middle streams of the Luanhe River, and determining the quality of the water resources in this water diversion project has received considerable attention due to the degradation of the river water environment (Li, 2014). From the north to the south of this region, the intensity of built-up and cultivated land has a certain increasing gradient, and the water quality has been affected by these factors. Consequently, multiple water quality assessment studies have been performed in the Luanhe River, including the analysis of the distribution and variation in the water quality parameters and the potential pollution sources (Lv et al., 2014; Guo et al., 2015; Wang et al., 2017). However, these studies were mainly based on univariate water indicator assessments and primarily focused on reservoirs and main streams. There was no comprehensive assessment of water quality and no mention of the causes affecting water quality in the Luanhe River. Therefore, the aims of this study were 1) to assess and compare the comprehensive water quality status in different tributaries of the upper and middle streams in the Luanhe River and 2) to establish the response of water quality variables to land use, fertilizers and socioeconomic factors.

2. Methods and materials

2.1. Study area

Our study area, belonged to the upper and middle streams of the Luanhe River Basin, lies in North China between 115°32′–118°53′ E and 40°11′–42°45′ N (Fig. 1). This region covers an area of 3.6 × 10^4 km² and has a population of approximately 3.5 × 10^8 inhabitants. This area has a typical temperate monsoon climate and had an average annual atmospheric temperature of 6.1 °C and precipitation of 444.1 mm from 1986 to 2015 (http://data.cma.cn). According to the hydrological and meteorological records, the mean annual average runoff of the study area was 39.3 × 10^8 m³, approximately 66% of which is from precipitation from June to September (http://data.cma.cn). In our study area, several major tributaries of the Luanhe River (i.e., the Xiaoluan River (XL), the Yixun River (YX), the Wulie River (WL), the Laoniu River (LN), the Bao River (BR), the Liu River (LR), the Sa River (SR), the Xing Zhou River (XZ), and the Shandian River (SD)) flow into the main stream (MS), eventually draining into the Daheiting and Panjiakou reservoirs.

2.2. Water sampling

Water samples were collected from the middle of the stream 0.5 m below the water surface (if the depth of a stream is no >0.5 m, the depth of our sampling is half the depth of the stream; if a stream is too long in width, sampling is processed on the bridge) at 85 sampling sites in July 2017 (summer), October 2017 (autumn), and April 2018 (spring), which covered the main stream and the associated tributaries within the study area. The lack of sampling in winter is due to the fact that most of the rivers in the study area are frozen during this season. The sampling sites were located at the places where the conditions were most representative and homogeneous and away from sewage drains. The sampling timing was planned in advance without capturing significant rain events (<10 mm over 48 h). The water samples at each site had three replicates collected in prewashed polyethylene bottles. The raw water samples were filtered through pre-combusted Whatman GF/F filters (0.45 μm mesh size). The samples of chlorophyll a, total suspended solid and 5-day biochemical oxygen demand of each sampling sites were not acidified, chlorophyll a and total suspended solid were filtered to the filters above and cryopreserved and 5-day biochemical oxygen demand was stored at normal temperature. All the other filtrates and the unfiltered water samples were acidified to about pH = 2.
and stored in an incubator with dry ice and ice packs in fields. Then transported to the laboratory and kept in –20 °C until further analysis.

2.3. Water quality parameter measurements

Water temperature (Tem, °C), pH, electrical conductivity (EC, μs/cm), and dissolved oxygen (DO, mg/L) were measured in situ with portable meters: a YSI DO200 (YSI Incorporated Company, USA) and a METTLER SG Duo (Mettler Toledo international LTD, USA). In laboratory, permanganate index (CODMn, mg/L) was analyzed by the permanganate titration (detection limit: 10 mg/L), 5-day biochemical oxygen demand (BOD5, mg/L) was measured by YSI DO200 and calculated the reduction of dissolved oxygen in the raw water samples after 5 days of sampling (detection limit: 0.1 mg/L), total phosphorus (TP, mg/L) was measured by potassium persulfate molybdenum antimony spectrophotometry (detection limit: 0.01–0.6 mg/L), total nitrogen (TN, mg/L) was determined by potassium persulfate oxidation spectrophotometry (detection limit: 0.05–4 mg/L), chlorophyll a (Chl.a, μg/L) was measured by the acetone extraction spectrophotometry and total suspended solid (SS, mg/L) was measured by weighting method (detection limit: 0.0001 g). Ammonia nitrogen (NH₄⁺-N, mg/L) was determined by the Nessler’s reagent spectrophotometry (detection limit: 0.025–2.0 mg/L) and nitrate nitrogen (NO₃⁻-N, mg/L) was determined by ultraviolet spectrophotometry (detection limit: 0.08–4.0 mg/L). These two water quality parameters were measured in the filtered water. A detailed description of the water chemical analysis followed the national standard methods for the examining water and wastewater in China (State Environmental Protection Administration, 2002a, 2002b).

2.4. Water quality index calculations

As different National and International Agencies involved in water quality assessment and pollution control, and defines water quality criteria for different uses of water considering different parameters. Consequently, it emerged various water quality indices calculation from different water quality parameters for assessing surface water quality (Katyal, 2011). Essentially, these various WQI methods were based on the National Sanitation Foundation Water Quality Index (NSFWQI) (Brown et al., 1970; Noori et al., 2019) with non-original rather than originally defined parameters of the model.

The WQI was calculated in this paper based on the 12 water quality variables above at each sampling site. The WQI Eq. (1) was referred to Brown et al. (1970) as follows:

\[
WQI = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} 
\]

where \( n \) is the total number of the selected parameters included in the study, \( C_i \) is the normalized value of parameter \( i \), and \( P_i \) is the weight of parameter \( i \). The minimum value of \( P_i \) was 1, and the maximum weight...
assigned to the parameters that affect water quality was 4, which has been verified in previous publications (Debels et al., 2005; Kocar and Svegili, 2014). In this study, twelve conventional water quality variables were transformed to a common scale of 0–100 through corresponding mathematical equations and assigned a weight based on the perceived effect on primary health (Table 1) (Conesa Fdez-Vitora, 1995; Pesce and Wunderlin, 2000; Ramesh et al., 2010). The WQI ranges from 0 to 100, with higher values representing better water quality conditions. Based on the WQI, the water quality was classified into five grades: excellent (100–90), good (90–70), medium (70–50), bad (50–25), and very bad (25–0) (Horton, 1965; Noori et al., 2019).

The proportion of forestland, grassland, cultivated land and built-up land of the study area is 56.9%, 17.9%, 18.3% and 3.9% respectively. The forestland and grassland are mainly located in the upstream and have some tourism activities. The cultivated land is predominantly located along the river channels. The built-up land is primarily located in the downstream of the tributaries. Among these sub-catchments, the Bao River, the Liu River, the Wu River and the Xingzhou River had a proportion of built-up land above 5%; the Shandian River, the Yixun River, the Xingzhou River and the Bao River had a proportion of cultivated land above 10% (Table 2).

2.6. Socioeconomic datasets

All of the socioeconomic data mainly included two aspects: 1) economically relevant data (unit: China Yuan per capita), including gross domestic product (GDP), the annual added value of agriculture (AVA), industry (AVI), the information and service industry (AVS) and the manufacturing industry (AVM); 2) the relevant fertilizer data (unit: ton per km²), including the total consumption of chemical fertilizers (TF), compound fertilizers (CF), nitrogen fertilizers (NF), phosphate fertilizers (PF), potassium fertilizers (KF) and pesticides (Pes.). These datasets originated from the Hebei Statistical Yearbook (Hebei Province Bureau of Statistics, 2018) and the Inner Mongolia Statistical Yearbook (Inner Mongolia autonomous region Bureau of Statistics, 2018).

The economy of our study area is not sufficiently developed. The GDP in 2017 was 1311 × 10^8 China Yuan (CNY), including the agriculture of 227 × 10^6 CNY, the industry of 623 × 10^6 CNY, the information and service industry of 460 × 10^6 CNY.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weight</th>
<th>Normalized Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>T° (°C)</td>
<td>1</td>
<td>16–21</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>4</td>
<td>&gt;7.5</td>
</tr>
<tr>
<td>EC (μS/cm)</td>
<td>2</td>
<td>&lt;75</td>
</tr>
<tr>
<td>BOD₅ (mg/L)</td>
<td>3</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>COD₅ (mg/L)</td>
<td>3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>3</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>NHL-N² (mg/L)</td>
<td>3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>NO₃-N² (mg/L)</td>
<td>2</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>SSa (mg/L)</td>
<td>3</td>
<td>3–10</td>
</tr>
<tr>
<td>Chla (μg/L)</td>
<td>3</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Notes: YX-Yixun River; XL-Xiaoluan River; SD-Shandian River; LN-Laoniu River; SR-Sa River; ZZ-Zhao River; WS-Xingzhou River; WR-Wulie River; LR-Liu River; BR-Bao River.

2.5. Classification and statistics of the land-use metrics

Landsat Thematic Mapper (TM) images with 30-m resolution for 2016 were used to map land use in our study area. Land use data origin from the Chinese Academy of Sciences-Computer Network Information Center-International Scientific Data Service Platform (http://www.cnics.ca/Ncfw/gsjf/gkxssjx/c). In this study, land use data and water quality data were not in the same period. Field surveys have found that there have been little land use changes in the study area for the past two years, and the impact of land use on river ecosystems is often expressed in accordance with the relationship between Chla and phytoplankton biomass and water eutrophication.
2.7. Data analysis

The data analysis was performed using SPSS 22.0 and Canoco 5.0. It is verified by Kolmogorov-Smirnov test (Feio et al., 2009) that the water quality variables were normally distributed. One-way ANOVA was used to explore the differences between the tributaries. We selected LSD (Least Significant Difference) to make multiple comparisons among the tributaries. A paired t-test based on the normally distributed data was used to explore the seasonal variations in the WQI. Redundancy analysis (RDA) was used to determine the relationship between land use proportion, fertilizers and socioeconomic factors and the water quality parameters. Before the RDA, a forward selection of the explanatory variables was used to select the significant factors among the socioeconomic and land use factors above that contributed and possibility affected the water quality parameters.

3. Results

3.1. Water quality assessment based on the WQI

Based on the 12 measured water quality parameters above, we calculated the WQI in the upper and middle streams of the Luanhe River during three sampling periods. The mean WQI value was 66.4, 63.6 and 63.3 in summer, autumn and spring, respectively. The paired t-test showed that the WQI value in summer was significantly higher (p < 0.05) than that in autumn and spring (Fig. 2a). Based on the WQI classification, the water quality was rated at a “medium” level during all three sampling periods.

The “medium” sampling sites were dominant in the three sampling periods, and the proportion was 75.3% (192/255). The “excellent” sampling site was only occurred once, the proportion was 0.4% (1/255). The sampling site was only occurred once, the proportion was 0.4% (1/255). The proportion of “good” sites was 4.7% (12/255). And no “very bad” sampling site was found in these three sampling periods.

The average WQI value of each tributary in the three sampling periods in the upper and middle streams of the Luanhe River are shown in Fig. 2b. The highest WQI was found in the Shandian River (72.9), accompanied Sa River (70.3) reaching the “good” level (WQI > 70.0). The WQI in the Xiaoluan River (69.4) was close to the WQI in Shandian River and Sa River (p < 0.05). The lowest WQI value was found in the Bao River (57.2), which was also classified as “medium” level, closely to the WQI in the Liu River (61.0) and the Yixun River (62.2) (p > 0.05), and significantly lower than the others (p < 0.05). In terms of sampling sites, the highest (90.0) and lowest (37.6) WQI values occurred in the Shandian River and the Yixun River, which reached the “excellent” level and “bad” level, respectively. In addition, the sampling sites at the “bad” level were mainly located downstream or in the urban areas of the Yixun River and the Bao River. The sampling sites at the “good” level were mainly located in the Shandian River and upstream of the Xiaoluan River and the Yixun River (Fig. 3).

3.2. Correlation between the available water quality parameters and land use, fertilizers and socioeconomic factors

We analyzed the relationship between the 12 water quality parameters in summer, autumn and spring and land use, fertilizers and socioeconomic factors in the tributaries of our study area by RDA. Before RDA, we used a forward selection of the explanatory variables to determine the land use, fertilizers and socioeconomic factors used for this analysis. Table 4 indicates that phosphate fertilizers (PF) and the proportion of grassland (GL) and forestland (FL) significantly influenced the water quality parameters in three sampling periods (p < 0.05).

Fig. 4 indicates that the selected socioeconomic factors significantly affected (p < 0.05) the water quality parameters, and they explained 83.2%, 71.6% and 67.8% of the variation in summer, autumn and spring, respectively. Chl-a, SS and TP were positively correlated with the consumption of phosphate fertilizers in three sampling periods. However, NH4-N and BOD5 showed a positively correlation only in summer. NO3-N, TN and EC were positively correlated with the proportion of forest land in three sampling periods. However, BOD5 showed a positively correlation only in autumn. The water quality parameter positively correlated with the proportion of grassland have their own

![Fig. 2a](image1.png)  ![Fig. 2b](image2.png)

Fig. 2. WQI values in different sampling periods and tributaries (A, B, C, D and E represent the seasonal or tributary variation in the WQI). Notes: YX-Yixun River; XL-Xiaoluan River; SD-Shandian River; LN-Laoniu River; SR-Sa River; XZ-Xingzhou River; WL-Wulie River; LR-Liu River; BR-Bao River.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proportions of different water quality grades in the upper and middle streams of the Luanhe River.</td>
</tr>
<tr>
<td>Sampling period</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Summer</td>
</tr>
<tr>
<td>Autumn</td>
</tr>
<tr>
<td>Spring</td>
</tr>
<tr>
<td>All</td>
</tr>
</tbody>
</table>
characteristics in three sampling periods, such as COD$_{Mn}$ in summer, pH in autumn, Tem and SS in spring.

3.3. Linear regression of land use and WQI

We analyzed the relationship between the proportion of land use and WQI of 85 sampling sites in summer, autumn and spring in our study area by linear regression. The results of Fig. 5 indicated that the proportion of forest land was significantly negatively correlated with WQI in autumn and spring ($p < 0.05$). However, the proportion of grass land was significantly positively correlated with WQI in these two sampling periods ($p < 0.05$). The proportion of cultivated land was significantly negatively correlated with WQI only in summer ($p < 0.05$). The proportion of built-up land was significantly negatively correlated with WQI in three sampling periods ($p < 0.05$).

4. Discussion

4.1. Seasonal characteristics of water quality in the upper and middle streams of Luanhe River

According to the WQI assessment, the water quality was “medium” in the upper and middle streams in the Luanhe River in summer, autumn and spring. And we found that the WQI value in summer was significantly higher ($p < 0.05$) than that in the other two seasons, and the differences in the WQI value in spring and autumn were not significant ($p > 0.05$) (Fig. 2a). In addition, there existed certain seasonal characteristics in the relationship between socioeconomic and land use factors and water quality. Such as, NH$_4^+$-N and BOD$_5$ showed a positively correlation with fertilizers only in summer (Fig. 4A), WQI in summer was significantly negative correlated with the proportion of cultivated land (Fig. 5). We suppose that seasonal variation in the hydrological conditions influenced the input or concentrations of the pollutants (Tamtam et al., 2008; Sun et al., 2016). Compared the seasonal variation in the water quality in previous studies, we found that there was no uniform conclusion on whether the water quality in summer is better or worse. Some scholars believe that more runoff in summer would increase the quantity of eroded material and cause more serious water pollution (Alberto et al., 2001; Wang et al., 2004; Boyacioglu, 2006; Bu et al., 2014). Others believe that more runoff in summer would dilute the existing pollutants and result in better water quality (Shrestha and Kazama, 2007). However, there is a general rule that sampling within 24 h after a rainfall event would result in poor water quality due to the short-term increase in the pollutant concentration caused by surface runoff. When sampling was performed 48 h after a rainfall event (base flow sampling), the concentration of the pollutant

![Fig. 3. The WQI value and the grade of each sampling site in the upper and middle streams of the Luanhe River in summer, autumn and spring.](image-url)
would dilute due to the high flow rate, so that the water quality would be better (Boyer et al., 1999; Carroll et al., 2013).

In our study, the sampling in summer (rainy season) was performed 48 h after the rainfall event (base flow conditions) and avoided the short-term increase in pollutant concentration caused by surface runoff. Therefore, we speculate that in the Luanhe River, N%66% of the annual runoff in summer may have a dilution effect on the existing pollutants in the rivers, making the water quality better than that in spring and autumn, the normal-flow season (Boyer et al., 1999; Carroll et al., 2013). In addition, considering the intense microbial activity in summer with higher temperatures, the degradation of pollutants and material circulation are accelerated, resulting in a reduction in nutrients in the rivers (Bao et al., 2015; Li and Li, 2015).

4.2. Variation in WQI values in the tributaries of up and middle streams of the Luanhe River

According to the WQI assessment, the overall water quality was “medium” in the upper and middle streams of the Luanhe River. From the results of one-way ANOVA, we found significant variation in the tributaries (Fig. 2b). The water quality in the Bao River, the Liu River and the Yixun River were poorest among all the tributaries. The Bao River and Liu River had the highest proportion of built-up land (7.7% and 5.7%, respectively). This result suggests that industrial and domestic sewage in the built-up land deteriorated the water quality more seriously than the other land uses, though the proportion of built-up land in these rivers was not substantial. In the Yixun River, having the lowest proportion of built-up land (2.6%), the cultivated land proportion reached 19%, the second highest of all the tributaries. Agricultural sewage might be the primary source in this river, which is also supported by the highest consumption of chemical fertilizers in all the tributaries (Chengde Municipal Statistics Bureau, 2018).

On the other hand, the highest WQI value was in the Shandian River, the Sa River and the Xiaoluan River. Notably, the WQI grade in the Xiaoluan River was “medium”, though it was the third highest in our study area. In this river, many protected areas for grassland and woodland have been established (Zhu et al., 2004), and the proportions of built-up land and cultivated land were very low. Generally, the water quality in this case should be “good” or even “excellent” (Qiao et al., 2018; Wang et al., 2018). Fig. 4 showed that TN, NO3−N and CODMn were positively correlated with the proportion of forest and grassland. We speculate that visitors attracted by the tourism industry and recreational activities might play an important role in the deteriorated water quality, which was also reported by Regmi et al. (2017). In the Sa River, the WQI value was the second highest of all the tributaries due to the minimal proportion of built-up land and cultivated land.

Table 4
The contribution %, pseudo-F and p-value of the economic, fertilizers and land use factors relevant to 12 water quality parameters in summer (A), autumn (B) and spring (C).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Economical relevant</th>
<th>Relevant fertilizer</th>
<th>Land use composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVA</td>
<td>AVI</td>
<td>AVS</td>
</tr>
<tr>
<td>A Con. %</td>
<td>11.4</td>
<td>22.6</td>
<td>7.7</td>
</tr>
<tr>
<td>F p</td>
<td>0.8</td>
<td>1.8</td>
<td>0.5</td>
</tr>
<tr>
<td>B Con. %</td>
<td>9.5</td>
<td>20.2</td>
<td>5.9</td>
</tr>
<tr>
<td>F p</td>
<td>0.6</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>C Con. %</td>
<td>22.4</td>
<td>34.8</td>
<td>23.5</td>
</tr>
<tr>
<td>F p</td>
<td>1.7</td>
<td>3.2</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Notes: Con.-contribution; AVA-the annual added value of agriculture; AVI-the annual added value of industry; AVS-the annual added value of the information and service industry; Pes.-pesticides; PF-phosphate fertilizers; NF-nitrogen fertilizers; TF-total consumption of chemical fertilizers; CF-compound fertilizers; BL-built-up land; CL-cultivated land; FL-forestland; GL-grassland.

Bold represents the factors significantly affect water quality parameters.

Fig. 4. The relationship between 12 water quality parameters and the selected land use and socioeconomic factors in summer (A), autumn (B) and spring (C). Positive correlations are represented by red and blue arrows in the same direction, and the projected length between two arrows is the degree of their correlation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
The Shandian River had the highest proportion of cultivated land (>40%), which would significantly constantly deteriorate the water quality (White and Greer, 2006; Rodríguez-Romero et al., 2017). However, the water quality was highest in this river. We also found that the Shandian River has >41 km² of wetlands, which has been shown to play an important role in the entrapment of organic matter and nutrients (Lu et al., 2009; Yu et al., 2015).

In a whole, the water quality ranged from “excellent” to “bad” in the upper and middle streams of the Luanhe River through WQI method. However, the results of previous studies presented that the water quality of the sampling sites were either almost have exceeded the water quality standards or reached the healthy level in Luanhe River based on the assessment of certain water quality parameters, such as TN, NO₃-N, CODₘₐₙ, DO (Lv et al., 2014; Guo et al., 2015; Wang et al., 2017). Based on these above, we think WQI can be employed for comparing and assessing the comprehensive water quality of different water bodies, and can make the result easy to understand. In terms of water quality management, the method based on water quality standards of individual water quality indicators is a preference choice for designated uses of a waterbody.

4.3. Factors affect water quality in the upper and middle streams of the Luanhe River

According to Table 4 and Fig. 4, the proportion of forest land, the proportion of grass land and phosphate fertilizers significantly influenced the water quality parameters. We found that the proportion of cultivated land and built-up land had a nonsignificant impact on the water quality.
quality parameters, while the proportion of forest land were the important factors influencing TN and NO$_3$-N in tributaries. The proportion of grassland was negatively correlated with TN and NO$_3$-N, which may suggest that grassland could have a capture effect on pollutants and result in positive water quality. In general, cultivated and built-up land can produce a large amount of domestic sewage and factory sewage, which have the most significant effect on river water quality (Seeboonruang, 2012). In this study area, cultivated land was mainly covered along the riverbank, and built-up land was located in tail water in a small proportion (Fig. 1). Linear regression results of 85 sampling sites of land use at catchment scale and WQI showed a significant negative correlation between the proportion of cultivated land and WQI in summer; the proportion of built-up land was significant negative correlated with WQI in three sampling periods. At the catchment scale, forestland is the prominent land use type rather than the cultivated land and built-up land. If the number of samples is not enough at this catchment scale, such as the number of the tributaries in this paper was limited, the pollution properties of the cultivated land and built-up land could not significant displayed. In addition, based on the characteristics of the study area, the pollution properties of the cultivated land and built-up land may demonstrate a significant influence to water quality at the riparian scale. We also found that the fertilizers were correlated with the water quality parameters, especially the organic pollution parameters (COD$_{MLSS}$), the biological parameters (Chl-a), the TP and SS. This also suggests that agricultural wastewater might be one of the most important pollutant sources in the Luanhe River. Chen (2016) demonstrated that the relevant fertilizers were the main reasons for the impact of agricultural nonpoint source pollution on water quality. The economically relevant factors did not significantly influence the water quality in three sampling periods. However, many studies have found that GDP and industrial-related activities significantly affect water quality in developed regions, such as East and South China (Wang et al., 2008; Zhou et al., 2012). Compared with these studies, the economy of our study area is not sufficiently developed (GDP2017: 1311 × 10$^6$ CNY. In the same year, the GDP of eastern cities such as Shanghai was 30,133 × 10$^8$ CNY, Hangzhou was 12,556 × 10$^8$ CNY. And that of southern cities such as Shenzhen was 22,286 × 10$^8$ CNY, Guangzhou was 21,500 × 10$^8$ CNY), as agriculture and tourism are the pillar industries, and therefore the effect of the economically relevant factors was not evident or was replaced by other more direct factors.

4.4. Limitation

In this study, the water quality characteristics were mainly expressed by a comprehensive index, the WQI, which was calculated from ten available water quality parameters. This comprehensive index provided the overall evaluation results of the upper and middle streams of the Luanhe River. However, the factors that deteriorated the water quality need to be quantified through the study of the relationship between water quality parameters and human activities. In addition, the land use data were derived from the catchment area of each tributary, and the impact of cultivated land and built-up land along the riverside on water quality was not reflected. Based on these findings, we will consider using the riparian buffers of the sampling sites to analyze their impact on the water quality parameters in our future work.

5. Conclusions

In this study, the WQI method was applied to assess the water quality in the upper and middle streams of the Luanhe River. In this region, the water quality was mainly influenced by “inorganic and organic pollutants”, and the agriculture-related variables were the dominant factors influencing the water quality. Variances existed in the tributaries due to the different proportions of land use and the consumption of fertilizers. The WQI value in summer (wet season) was significantly higher than that in autumn and spring (normal season), and we think more runoff in summer would dilute the existing pollutants and result in better water quality. Based on the results above, water quality improvement should control or ration the consumption of the relevant fertilizer, especially on the cultivated land along the riverside in the Luanhe River. And we think these results would provide a scientific basis for the restoration and management of the water pollution. In our future work, we will explore the impact of land use on water quality, such as the scale effect of land use. In addition, we will also focus on the application of landscape index in optimizing land use allocation and improving river water quality.

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Appendix A. Supplementary data

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References
