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Quantification and Evaluation of Grey Water Footprint in Yantai

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Abstract: Problems such as water scarcity and pollution frequently occur in coastal zones. This study investigated the grey water footprint and the sustainability and intensity of grey water footprint in Yantai between 2014 and 2019 by taking both surface water and groundwater into consideration. The research results indicated that the Yantai grey water footprint firstly increased and then decreased between 2014 and 2019. The lowest grey water footprint in 2019 was 744 million m^3. The agricultural grey water footprint accounted for a large proportion of the total grey water footprint. Although the sustainability of grey water footprint fluctuates in Yantai, it maintains well. The Yantai grey footprint intensity gradually decreased to <10 m^3/10,000 CNY. The economic benefit of grey water footprint and utilization efficiency of water resources have been improved yearly. The quality of the water environment in Yantai has also been improved. The research of this paper provides some useful information for water resources protection and sustainable utilization in coastal cities.

Keywords: coastal city; grey water footprint; grey water footprint sustainability; grey water footprint intensity

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1. Introduction

Various pollutants in the aquatic environment might profoundly affect water resource utilization [1–3]. The water resource is an indispensable natural resource for human society and social development [4]. The freshwater resources that can be exploited by human beings are very limited, although global water resources are plentiful. Global freshwater accounts for 2.5% of global water resources, while 86% of the freshwater resources are difficult to obtain and utilize due to complex geographical environments and limited exploitation techniques. China possesses freshwater resources of 2800 billion m^3, ranking sixth in the world [5]. However, China's per capita water resources are only 1/4 of the average world level due to the large population [6]. China has become one of the thirteen water-deficient countries in the world [7]. In addition, rapid social development has also caused problems such as water pollution, deterioration of the water environment, waste of water resources, and low utilization efficiency of water resources in China [8–10]. Rational exploitation, utilization, and protection of water resources, as well as water pollution control and improvement of water resource utilization efficiency, have become critical for sustainable development in China [11–13].

The water footprint is a comprehensive indicator that can roundly account for the real water resources occupied by human activities [14–16]. It is also a frequently used indicator that can measure the environmental pressure of regional water resources. The water footprint is the number of water resources required by a person, a region, or a country for all products and services consumed over a certain period of time. Depending on the different types of water sources used, it can be divided into green water footprint, blue water footprint, and gray water footprint [17]. Grey water footprint is the freshwater used to absorb and assimilate a certain pollutant load. The freshwater resource includes both surface water and groundwater. It is an important indicator to quantify the number of pollutant emissions generated by consuming products or services. Regional grey water footprint divided by regional water resources can indicate the regional water pollution level, which is used to represent the sustainability of regional grey water footprint and reflect water resources' environmental pressure. The sustainability analysis and evaluation of grey water footprint are beneficial to the sustainable utilization of water resources [18]. The ratio of regional grey water footprint to regional GDP represents regional grey water footprint intensity that reflects a relationship between the water resources and economic development. The intensity of grey water footprint can reflect the difference of water resource pollution discharge intensity from the spatial scale and has guiding significance for controlling water pollution discharge in different regions according to the actual development and environmental conditions [19].

Hoekstra et al. [20] first proposed "water footprint" in 2002, and relevant research has developed rapidly since then. In 2008, Hoekstra et al. [21] proposed "grey water footprint", which takes the connection between water resource consumption and water pollution into consideration. Grey water footprint reflects the impact of water pollution on the water environment and provides new ideas for evaluating the water environment. Grey water footprint is applicable to a wide range of research. In order to comprehensively introduce the concept, calculation, and evaluation of water footprint and promote the research of water footprint, Hoekstra et al. [17] compiled the Water Footprint Assessment Manual. As an effective water resource management tool [22], grey water footprint can analyze water resources from different scales of countries, regions, and watersheds [23–26]. It is widely used in agriculture, industry, service industry, and other fields. Mekonnen and Hoekstra [27] used a high spatial resolution to evaluate the grey water footprint of more than 100 crops around the world and found that grey water accounts for a relatively small proportion of crop water footprint. Ming et al. [28] applied a multi-regional input–output model to quantify the grey water footprint of global final energy demands. Fu et al. [29] quantified the Yangtze River Basin's grey water footprint and found that the average grey water footprint in the middle was high. Grey water footprint can also be researched through input-output analysis method, SWAT model, LMDI decomposition method, Life-cycle assessment method, etc. [30–32].

Compared with inland cities, coastal cities are more open, with broad markets and convenient transportation, which are conducive to the development of foreign trade and the exchange of civilizations with foreign countries. The economic development of coastal cities is rapid, and most of them have become economically developed areas. At the same time, coastal cities often require more water resources and induce more pollutants due to quick economic development [33]. The shortage of water resources and water pollution in coastal cities have become increasingly prominent [34]. In order to promote the sustainable development of coastal areas, the coordinated development of water resources and the economy is significant [35,36]. Many scholars used different methods to evaluate and analyze the water environment in coastal areas. Cong and Diao used the fuzzy variable model to evaluate water resources in northern coastal cities [37]. Li et al. used the WEAP model to analyze water resources in Binhai New Area [38]. Liu et al. used the multi-scale input-output method to comprehensively analyze the water resources of Qinhuangdao [39]. In addition, the grey relational evaluation method, the Nemerow water pollution index method, and the artificial neural network analysis are also mostly used in the evaluation of water resources and water environment [40–42]. However, most of these methods are a single evaluation of water quality or water quantity. The grey water footprint can link water quantity and water quality and evaluate water resources and water environment more intuitively and comprehensively. As an emerging novel topic, the water footprint has not been well known to the public. Most of the evaluation methods for water resources in coastal areas are traditional evaluation methods.

Yantai, as a typical coastal city, has superior geographical location, rapid economic development, and great development potential. As a city with a shortage of water resources, Yantai should strengthen the rational allocation of water resources and improve water pollution problems during economic development so as to promote the long-term development of the region. In order to achieve the rational development and protection of water resources, Yantai issued the corresponding policies. Yantai implemented the strictest assessment method for the water resources management system. It is used to achieve the rational development and protection of water resources. At the same time, Yantai strictly abides by the regulations on urban drainage and sewage treatment promulgated by China, strengthening supervision to prevent urban water pollution and waterlogging. Therefore, this study selected Yantai city as the study area to investigate the grey footprint. The grey water footprint, the sustainability of grey water footprint, and the intensity of grey water footprint were investigated. Based on this, the water environment, water resource utilization, and corresponding economic benefits of Yantai were evaluated. This can provide a certain reference for evaluating the water resources and water environment in coastal areas from the perspective of grey water footprint linked to water quality and water quantity. At the same time, for the national government and social managers, the research results can provide a basis for the rational allocation of regional water resources so as to strengthen the management of water resources. For water users, it is more conducive to the formation of water-saving consciousness and the occurrence of water-saving actions by clarifying the problems of regional water resources. Therefore, aiming at the problem of water resources in Yantai, this paper adopts the concept of grey water footprint to scientifically analyze the water environment in Yantai.

2. Materials and Methods

2.1. Overview of the Study Area

Yantai is located in the northeast of the Shandong Peninsula. It is a vital city in the Bohai-Rim region, with an advantageous geographical location, a long history and culture, and a developed social economy. Yantai is located at 119°34′−121°57′ east longitude and 36°16′−38°23′ north latitude. With Weihai on the east, Qingdao on the west, the Bohai Sea on the north, and the Yellow Sea on the south, it has convenient transportation and an open market. Yantai is located in a low mountain and hilly area. The terrain in the east and west of Yantai is high, and the terrain in the central area is low. Yantai has high terrain in the south and low terrain in the north. There are 12 counties, cities, and districts under the jurisdiction of Yantai City [43] (Figure 1).

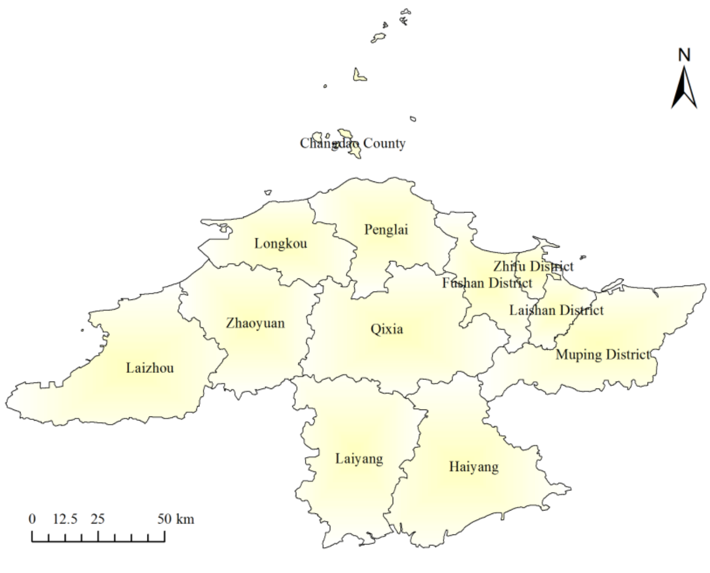

Figure 1. Administrative zoning map of Yantai.

Yantai belongs to the warm temperate monsoon zone to be livable [44]. However, due to the influence of the monsoon climate, the precipitation in Yantai is scarce, which is extremely unevenly distributed between years and within a year, resulting in alternating and uneven drought and flood each year. It is dry and rainy in the spring and autumn and prone to rainstorms and floods in the summer. Yantai's per capita share of water resources is only 487 m^3, less than 1/5 of the national average level. It is a resource-based water-deficient area. At the same time, because there is no transit River in Yantai, the river source in the area is short, the flow is rapid, the river rises and falls sharply, and most of the rivers are dry up in non-flood seasons. According to the general international evaluation standard for the division of regional water shortage based on per capita water resources, areas with annual per capita water resources less than 500 m^3 become extremely water-deficient areas. Therefore, Yantai has joined the ranks of extreme water shortage areas, and the shortage of water resources must be paid attention to [45].

In recent years, the social economy of Yantai has developed rapidly, and the demand for water resources has increased greatly. The excessive development and utilization of water resources have damaged the local water environment, resulting in water pollution, waste of water resources, and other problems. It hinders the sustainable development of Yantai City. Therefore, it is particularly important to purify water quality, save water resources, and increase water resource protection and utilization efficiency.

2.2. Data

By taking Yantai City as the research object, this paper calculated the agricultural grey water footprint, industrial grey water footprint, and domestic grey water footprint from 2014 to 2019 to obtain the total amount of Yantai grey water footprint. Simultaneously, this paper also calculated Yantai grey water footprint sustainability and intensity from 2014 to 2019. The data used in this paper included: (1) Agricultural nitrogen leaching rate, which was calculated by using the national average nitrogen leaching rate, with a value of 7%. (2) Statistical data, including nitrogen fertilizer application, water resources, regional gross domestic product, wastewater discharge of each department, chemical oxygen demand discharge of each department, and ammonia nitrogen discharge of each department. The data were collected from the 2014–2019 "Shandong Statistical Yearbook" and "Yantai Statistical Yearbook". (3) The standard concentration of water quality of pollutants referring to the first-level discharge standard in "Comprehensive Discharge Standard of Pollutants" (GB8978-1996). The standard water quality concentration of chemical oxygen demand was 60 mg/L. The standard water quality concentration of ammonia nitrogen was 15 mg/L. (4) The natural background concentration of the receiving water, usually set to 0.

2.3. Methods

2.3.1. Grey Water Footprint

Grey water footprint is the freshwater used to absorb and assimilate a certain pollutant load. The concentration difference can be obtained by subtracting the natural background concentration of receiving water from the water quality standard concentration of pollutants. Pollutant discharge was divided by the concentration difference to obtain the grey water footprint. The grey water footprint includes three sectors: agriculture, industry, and domestic grey water footprint. The formula for calculation was the following equation:

$$GWF_{tot} = GWF_{agr} + GWF_{ind} + GWF_{dom} \tag{1}$$

where GWF_{tot} is the total grey water footprint, m^3/a; GWF_{agr} is agricultural grey water footprint, m^3/a; GWF_{ind} is industrial grey water footprint, m^3/a; GWF_{dom} is domestic grey water footprint, m^3/a.

(1) Agricultural grey water footprint

Pesticides and chemical fertilizers use cause agricultural pollution. Because nitrogen ions are the easiest to enter the water body and the pure volume of nitrogen fertilizer is the highest, nitrogen fertilizer causes the largest water pollution and becomes the main pollutant [46,47]. Therefore, nitrogen fertilizer was the main pollutant. Since agricultural water pollution is mostly non-point source pollution, the formula for calculation is as follows:

$$GWF_{agr} = \frac{\alpha \times Appl}{C_{max} - C_{nat}} \tag{2}$$

where α is the leaching ratio of nitrogen fertilizer; $Appl$ is nitrogen fertilizer application, kg/a; C_{max} is the water quality standard concentration of nitrogen, kg/m^3; C_{nat} is the natural background concentration of the receiving water, kg/m^3.

(2) Industrial grey water footprint

Industrial pollution is mainly represented by point source pollution, and the pollutants produced by industrial development are mainly chemical oxygen demand and ammonia nitrogen [48,49]. Therefore, when calculating the industrial grey water footprint of Yantai, the above two pollutants are selected for calculation. Finally, the pollutant with the largest amount of dilution water required determines the footprint value of industrial grey water. The formula for calculation is as follows:

$$\begin{gathered} GWF_{ind(i)} = \frac{L_{(i)}}{C_{\max(i)} - C_{nat}} \\ GWF_{ind} = max\left(GWF_{ind(COD)}, GWF_{ind(NH_4^+ - N)}\right) \end{gathered} \tag{3}$$

where $GWF_{ind(i)}$ is the industrial grey water footprint with category i pollutants as the accounting standard, m^3/a; $L_{(i)}$ is the industrial sector emissions of category i pollutants, kg/a; $C_{\max(i)}$ is the water quality standard concentration of category i pollutants.

(3) Domestic grey water footprint

Domestic pollution is presented in the form of point source pollution. Therefore, the calculation of domestic grey water footprint is similar to that of industrial. Two pollutants, chemical oxygen demand and ammonia nitrogen, were selected for calculation [48,49]. Finally, the pollutant with the largest amount of dilution water required determines the footprint value of domestic grey water. The formula for calculation is as follows:

$$\begin{gathered} GWF_{dom(i)} = \frac{L_{(i)}}{C_{\max(i)} - C_{nat}} \\ GWF_{dom} = max\left(GWF_{dom(COD)}, GWF_{dom(NH_4^+ - N)}\right) \end{gathered} \tag{4}$$

where $GWF_{dom(i)}$ is the domestic grey water footprint with category i pollutants as the accounting standard, m^3/a; $L_{(i)}$ is the domestic sector emissions of category i pollutants, kg/a.

2.3.2. Grey Water Footprint Sustainability

Grey water footprint is an indicator to weigh the water pollution level within a region [50]. By establishing the relationship between grey water footprint and water resources, the value of the regional water pollution level can be obtained. Water pollution levels can reflect regional greywater footprint sustainability. Water resources included surface water amount and groundwater amount. The greater the water pollution level, the worse sustainability. When the level of water pollution reaches 100%, the regional assimilative capacity is fully consumed. When it exceeds 100%, the grey water footprint is unsustainable, and water resources cannot meet the requirements of diluting pollutants in the region. The formula for calculation is as follows:

$$WPL = \frac{\sum GWF}{R_{act}} \tag{5}$$

where WPL is the level of regional water pollution, that is, the proportion of consumed assimilative capacity in the total assimilative capacity; R_{act} is the amount of regional water resources, m^3.

2.3.3. Grey Water Footprint Intensity

The ratio of regional grey water footprint to regional CNY 10,000 GDP is the grey water footprint intensity, which represents the grey water footprint produced per CNY 10,000 GDP output, reflecting the relationship between economic construction and the water resources environment. The intensity of the grey water footprint reflects the utilization efficiency of regional water resources. This is helpful in maintaining the coordinated development of the economy and water resources. The formula for calculation is as follows:

$$INT_{GWF} = \frac{GWF}{GDP} \tag{6}$$

where INT_{GWF} is grey water footprint intensity, m^3/10,000 CNY; GDP is a gross domestic product, CNY 10,000.

3. Results

3.1. Grey Water Footprint

Through calculation, the total grey water footprint of agriculture, industry, and domestic in Yantai showed a trend of increasing and then decreasing as a whole (Figure 2).

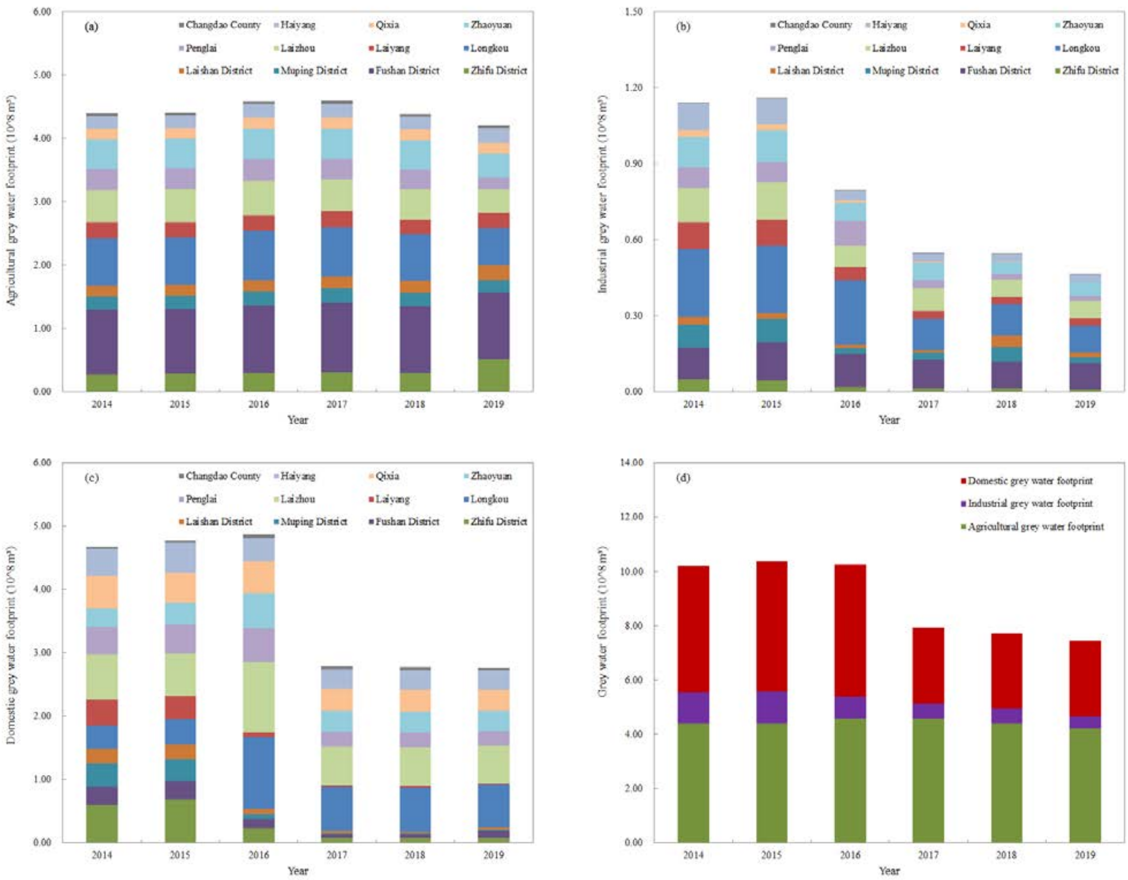

Figure 2. Variation in the agricultural grey water footprint: (**a**) industrial grey water footprint (**b**) and domestic grey water footprint (**c**) of each district and county in Yantai from 2014 to 2019, as well as the change in the total grey water footprint (**d**) in Yantai from 2014 to 2019.

The fluctuation of agricultural grey water footprint is relatively gentle, increasing from 440 million m^3 to 459 million m^3 from 2014 to 2017, accounting for an average of 47.08% of the total grey water footprint. It steadily decreased to 421 million m^3 year by year in 2018 and 2019, but the average proportion in the total grey water footprint increased to 56.74%. Among them, the agricultural grey water footprint of Fushan District, Longkou, Laizhou, and Zhaoyuan accounts for a large proportion of the total agricultural grey water footprint of Yantai, with an average proportion of 23.73%, 16.49%, 10.94%, and 10.23%, respectively (Figure 2a).

The industrial grey water footprint fluctuates greatly, increasing from 114 million m^3 to 116 million m^3 from 2014 to 2015 and decreasing year by year to 46 million m^3 from 2016 to 2019. The industrial grey water footprint mainly shows a decreasing trend, and the average proportion in the total grey water footprint is the smallest, which is 8.39%. Among them, the industrial grey water footprint of Longkou, Fushan District, Laizhou, and Zhaoyuan accounts for a large proportion of the total industrial grey water footprint of the Yantai, with an average proportion of 24.31%, 17.16%, 13.05%, and 10.36%, respectively (Figure 2b).

The domestic grey water footprint fluctuated significantly. From 2014 to 2016, it increased steadily from 468 million m^3 to 488 million m^3 year by year, accounting for 46.49% of the total grey water footprint. From 2017 to 2019, it decreased steadily to 277 million m^3 year by year, accounting for 36.12% of the total grey water footprint. Among them, the domestic grey water footprint of Laizhou, Longkou, Qixia, and Haiyang accounts for a large proportion of the total domestic grey water footprint of Yantai, with an average proportion of 19.54%, 19.03%, 11.26%, and 10.15%, respectively (Figure 2c).

From 2014 to 2015, Yantai's total grey water footprint increased from 1.021 billion m^3 to 1.035 billion m^3 and decreased to 744 million m^3 from 2016 to 2019. The fluctuating change in Yantai's total grey water footprint is significant between 2014 and 2019 (Figure 2d). The agricultural sector has steadily contributed a large number of grey water footprints, accounting for an average of 50.30%; a substantial reduction in domestic grey water footprint greatly contributed to the reduction in the total grey water footprint, accounting for an average of 41.30%. The industrial sector contributed the least amount of grey water footprint, accounting for an average of 8.39%. All districts and counties in Yantai, Longkou, Fushan District, Laizhou, and Zhaoyuan contributed to a lot of grey water footprints (Figure 3).

3.2. Grey Water Footprint Sustainability

According to the calculation, the water pollution level of Yantai showed a fluctuating trend from 2014 to 2019. The level of water pollution in Yantai increased slowly from 2014 to 2015. In 2016, it increased sharply to 1.20, and the total grey water footprint showed an unsustainable state. It dropped to 0.28 in 2017, returning to a sustainable state. In 2019, the water pollution level increased to 0.98. In 2019, the number of water resources in Yantai that can accommodate and dilute pollutants was close to the critical value.

In 2014, 2015, 2017, and 2018, Yantai's grey water footprint showed an overall sustainable state. Yantai has sufficient water resources to accommodate and dilute pollutants (Figure 4). In 2016, the grey water footprints of Fushan District, Laishan District, Muping District, and Laiyang were sustainable, while the grey water footprints of other districts and counties were unsustainable to varying levels. Among them, the unsustainable grey water footprints of Qixia were the most prominent (Figure 4c). In 2019, the grey water footprints of Zhifu District, Fushan District, Laishan District, Muping District, and Laiyang were sustainable, while the grey water footprints of other districts and counties were unsustainable to varying levels (Figure 4f).

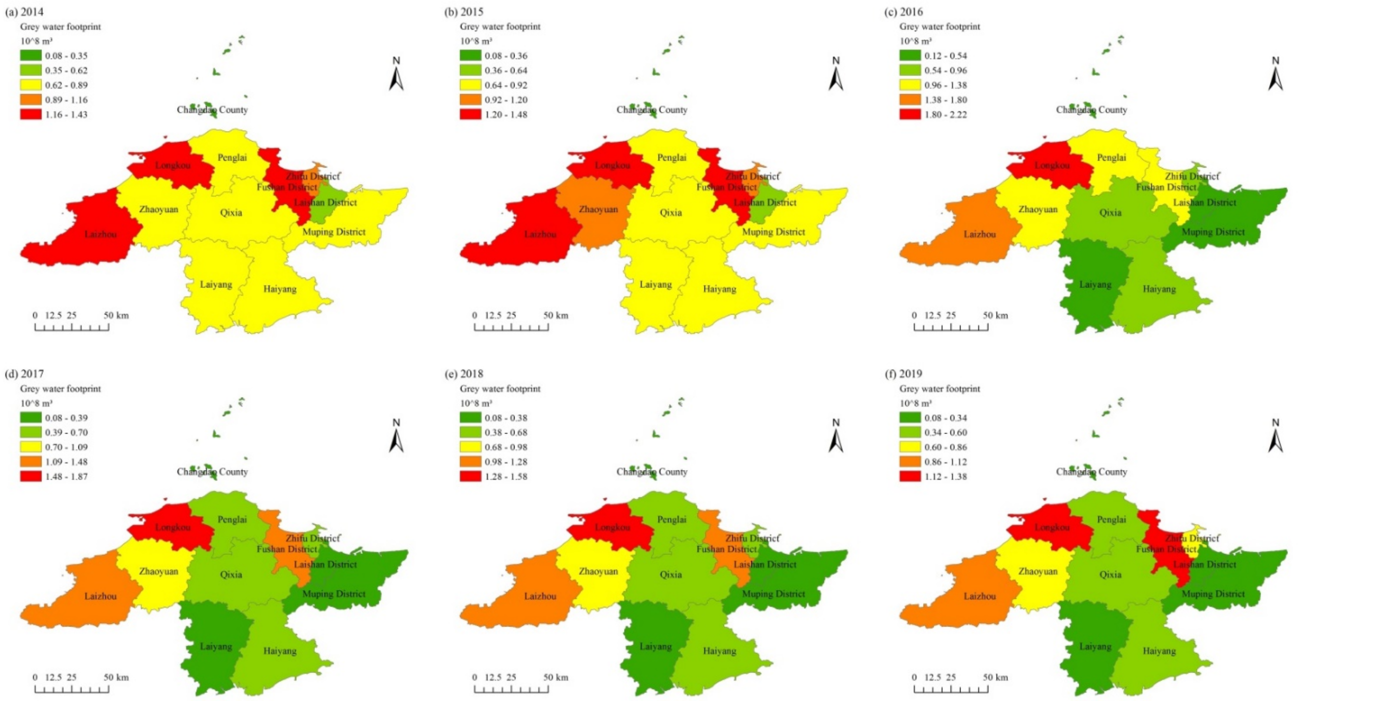

Figure 3. (**a**–**f**) The changes in grey water footprint of each district and county in Yantai from 2014 to 2019.

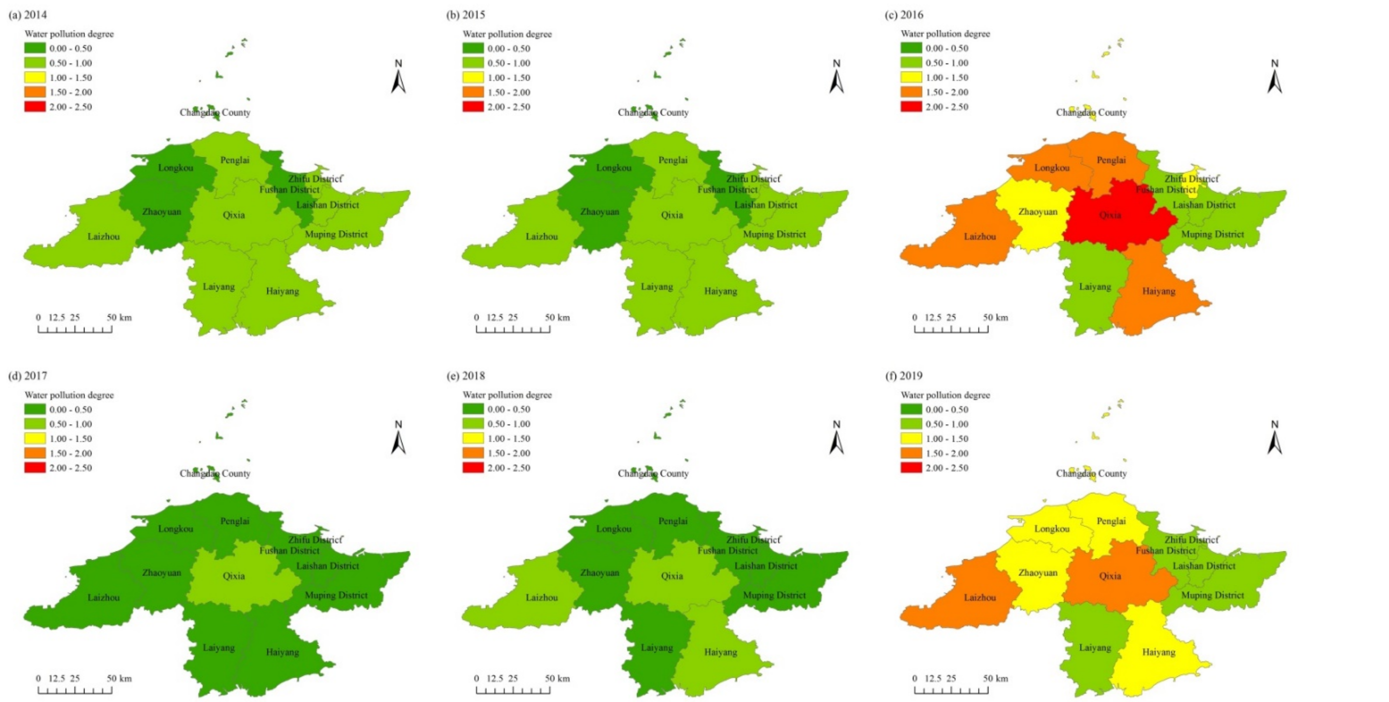

Figure 4. (**a**–**f**) The changes in water pollution levels in the districts and counties in Yantai City from 2014 to 2019, which can reflect the changes in the sustainable status of the grey water footprint.

3.3. Grey Water Footprint Intensity

Grey water footprint intensity of Yantai appeared to downtrend between 2014 and 2019. Grey water footprint required for every CNY 10,000 of GDP decreased year by year, from 17.81 m^3/10,000 CNY to 9.73 m^3/10,000 CNY. Among them, the grey water footprint intensity decreased the fastest from 15.65 m^3/10,000 CNY to 11.30 m^3/10,000 CNY from 2016 to 2017.

In 2014, the grey water footprint intensity of Fushan District, Changdao County, Longkou, Zhaoyuan, Penglai, and Laishan District was less than 20 m^3/10,000 CNY; The grey water footprint intensity of Laizhou, Muping District, Laiyang, Zhifu District and Haiyang is more than 20 m^3/10,000 CNY and less than 30 m^3/10,000 CNY; The grey water footprint intensity of Qixia is as high as 32.5 m^3/10,000 CNY, reaching the highest value of grey water footprint intensity of all districts and counties of Yantai from 2014 to 2019 (Figure 5a). In 2015, the grey water footprint intensity of Laizhou decreased to less than 20 m^3/10,000 CNY, and that of Qixia decreased to less than 30 m^3/10,000 CNY (Figure 5b). In 2016, only Laizhou and Qixia had a grey water footprint intensity of more than 20 m^3/10,000 CNY, while other districts and counties had a grey water footprint intensity of less than 20 m^3/10,000 CNY (Figure 5c). From 2017 to 2019, the grey water footprint intensity of all districts and counties in Yantai is less than 20 m^3/10,000 CNY (Figure 5d–f).

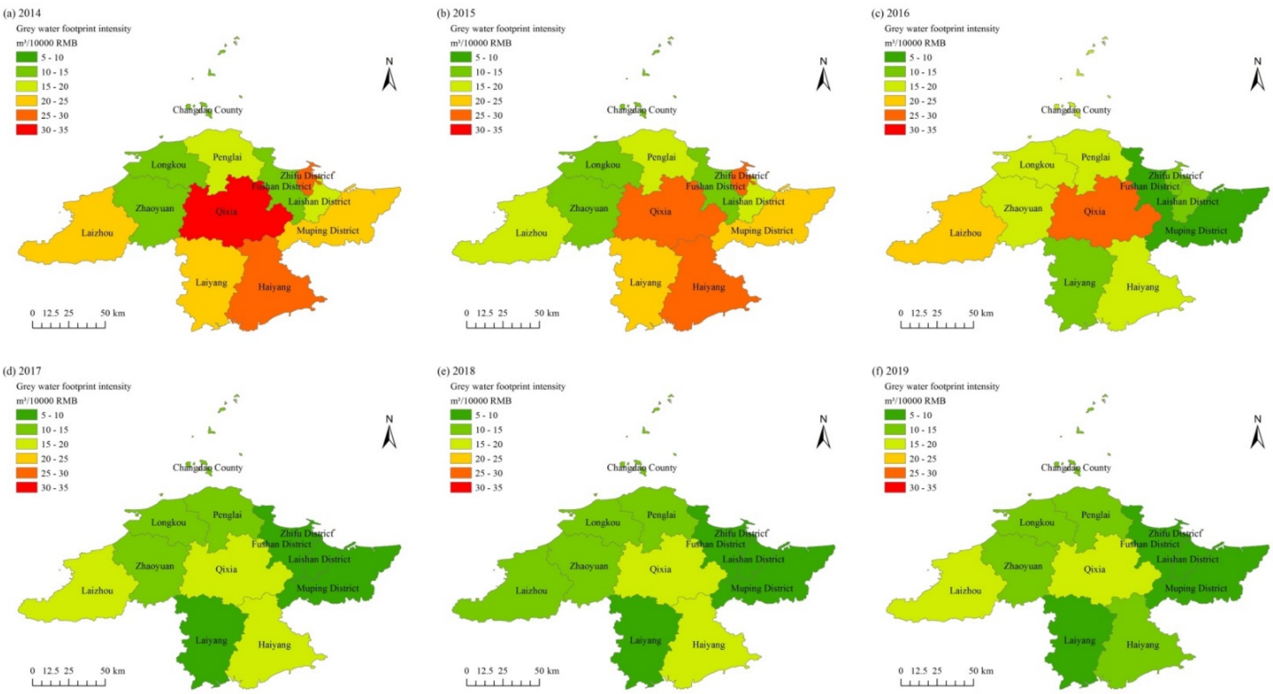

Figure 5. (**a**–**f**) The changes in grey water footprint intensity of each district and county in Yantai from 2014 to 2019, which can reflect the changes in grey water footprint economic benefits.

4. Discussion

4.1. Grey Water Footprint

From 2014 to 2019, the agricultural development, industrial development, and daily life demand of Yantai jointly affect the change in total grey water footprint. The agricultural grey water footprint is large, and the fluctuation is relatively gentle. The industrial grey water footprint is the lowest. A significantly large and varied domestic grey water footprint is vital to reducing the total grey water footprint.

The change in total grey water footprint is closely related to pollutant emission. Yantai nitrogen fertilizer application change affects the change in agricultural grey water footprint. Yantai nitrogen fertilizer application increased from 2014 to 2017 and decreased from 2018 to 2019. Yantai's agricultural grey water footprint showed a corresponding change trend. The districts and counties of Yantai are ranked in descending order according to the value of annual average nitrogen fertilizer application, which are Fushan District, Longkou, Laizhou, Zhaoyuan, Zhifu District, Penglai, Laiyang, Muping District, Haiyang, Laishan

District, Qixia, and Changdao County. This is consistent with the descending order of agricultural grey water footprint of all districts and counties of Yantai city. Similarly, the change in pollutant emission in Yantai affects the change in the total amount of industrial and domestic grey water footprint in Yantai. It makes the trend of the industrial and domestic grey water footprint in Yantai converge with the changing trend of pollutant emission. Therefore, controlling the discharge of pollutants, strengthening the management of sewage treatment plants, and improving wastewater treatment capacity is particularly important for reducing the grey water footprint [51,52].

In 2017, Shandong Province launched the "Actions to manage the river" to control the river and lake environment. Yantai actively responded to the call and implemented water environment management in the whole basin and carried out river patrols, and cleaned up the garbage in the water area. The ecological construction of the river basin and optimize the water environment were also strengthened. At the same time, the sewage treatment factories were upgraded to improve sewage treatment efficiency and purify regional water quality. Since 2017, the sewage treatment capacity of Yantai has been greatly improved compared with previous years. In 2017, 2018, and 2019, the sewage treatment capacity was 1.06 million m^3/day, 1.177 million m^3/day, and 1.145 million m^3/day, respectively. The harmless treatment capacity of domestic waste has also been greatly improved compared with previous years. The domestic waste treatment capacity in 2017, 2018, and 2019 is 5870 tons/day, 6223 tons/day, and 6520 tons/day, respectively. The pollutant emission of Yantai is significantly reduced. The total amount of grey water footprint is evidently reduced. In 2017, the total grey water footprint of Yantai was 793 million m^3, a decrease of about 23% compared with 2016. The total grey water footprint in 2018 and 2019 remained relatively stable, at 772 million m^3 and 744 million m^3, respectively, showing a slow downward trend. Among them, the industrial grey water footprint and domestic grey water footprint of Yantai decreased significantly.

4.2. Grey Water Footprint Sustainability

Grey water footprint sustainability is closely related to regional grey water footprint and regional water resources. From 2014 to 2016, the average annual precipitation in Yantai was less than that in the same period of the year, and the total amount of water resources decreased year by year. In 2016, Yantai suffered from continuous drought in summer and autumn. The continuous low precipitation and long-term high temperature caused serious drought. The total amount of water resources was only 854 million m^3, and the total amount of water used in that year was up to 842 million m^3. Water resources were in short supply. Even if the grey water footprint in that year decreased compared with previous years, it showed an unsustainable state. From 2017 to 2018, the average annual precipitation in Yantai increased compared with that in the same period of the year, and water resources were restored. In addition, the grey water footprint was greatly reduced. The grey water footprint was restored to a sustainable state. In 2019, the average annual precipitation of Yantai was 35.1% less than the average annual precipitation, only 446.6 mm, and the water resources were 74.4% less than the average annual precipitation, only 757 million m^3. The annual precipitation and water resources reached the lowest value in recent years. The grey water footprint value was lower than in previous years, the water pollution level did not reach 1, and the water resources could still meet the requirements of diluting and accommodating pollutants. However, it is close to the critical value, and the grey water footprint of Yantai is about to reach an unsustainable state. From 2014 to 2019, Yantai's water consumption showed an increasing trend. The water consumption increased from 840 million m^3 to 981 million m^3. Agricultural water consumption is much higher than industrial and domestic water consumption. However, the proportion of agricultural water consumption in total water consumption has decreased year by year, and the proportion of industrial and domestic water consumption in total water consumption has increased year by year. Attention should be paid to improving the utilization efficiency of water resources and avoiding the waste of water resources.

The precipitation in Yantai City is relatively small, and the inter-annual and seasonal distribution is uneven, which is prone to flood disasters. Surface water resources have uneven seasonal distribution, a large inter-annual variation range, and a great difference between wet and dry years. Groundwater changes periodically with precipitation and exploitation. The total amount of water resources are relatively scarce. It belongs to a resource-based water shortage area. In order to reduce water resources pressure, the government issued relevant policies to save, control, and store water. In 2018, Yantai approved the "implementation of Yantai water and soil conservation plan (2017–2030)" and issued the "opinions on strengthening water and soil conservation" to control soil erosion, conserve soil and water, and achieve the purpose of protecting water sources. In the same year, Yantai vigorously promoted the implementation of "Shandong Province Water Resources Tax Collection and Management Measures (Trial)". In order to maintain the grey water footprint sustainable status of Yantai, it is particularly important to reduce the grey water footprint, save water resources, and maintain ecological balance. The correct guidance of the government and the joint participation of the whole society is indispensable. It is necessary to stimulate the public's awareness of environmental responsibility and promote the formation of a good atmosphere of advocating ecological civilization.

4.3. Grey Water Footprint Intensity

Grey water footprint and gross domestic product jointly determine the change in Yantai's grey water footprint intensity. From 2014 to 2019, the grey water footprint of Yantai decreased, the gross domestic product increased, total grey water footprint intensity of Yantai decreased yearly. The grey water footprint produced by every CNY 10,000 of GDP produced is decreased yearly, and the water resource utilization efficiency and economic benefits are increased yearly. Comparing the gray water footprint intensity of Yantai City with the gray water footprint intensity of various districts and counties, it can be found that in recent years, the gray water footprint intensity of Qixia, Haiyang, Laizhou, Penglai, Zhaoyua, Longkou, and Changdao County are higher than The total gray water footprint intensity of Yantai, and Qixia, Haiyang, and Laizhou are far higher than Yantai total gray water footprint intensity, and water resources utilization efficiency and gray water footprint economic efficiency are low. The grey water footprint intensity of Zhifu District, Muping District, Laiyang, Laishan District, and Fushan District is lower than that of Yantai city. Among them, the grey water footprint intensity of Zhifu District, Muping District, Laiyang, and Laishan District decreases significantly, and the grey water footprint intensity of Fushan District is lower than Yantai's total grey water footprint intensity. Utilization efficiency of water resources and economic efficiency of grey water footprint is higher. The development of the economy and society, the progress of the tertiary industry, the improvement of water-saving technology and sewage treatment technology, and the enhancement of water-saving awareness greatly improved the utilization efficiency of water resources and the economic benefits of grey water footprint.

The independence of economic growth from the consumption of natural resources is called decoupling. Some Chinese scholars studied related issues about decoupling in relation to the water footprint. Existing studies found that urbanization is the main factor affecting the growth of greywater footprint [53], and technological progress driven by economic development is the main reason for the weakening of footprint intensity [54]. Moreover, from the perspective of economic efficiency, the overall economic productivity of the provincial grey water footprint across the country has improved [48,55]. Large cities have a high degree of sustainable utilization of water resources, and urban development helps to improve the efficiency of water resource utilization [56]. Yantai, as a coastal city with development potential, has a rapid economic development, while the sewage treatment capacity also increased. The intensity of the grey water footprint is reduced, the economic benefit of grey water is improved, and the utilization efficiency of water resources is improved. This is consistent with the research results of scholars. It is particularly important for Yantai to further improve the level of urbanization and technology. While promoting economic development, Yantai should also pay attention to the protection of resources and the environment.

5. Conclusions

From 2014 to 2019, Yantai's grey water footprint generally showed a downtrend. The domestic grey water footprint decreased the most, followed by the industrial grey water footprint, and the agricultural grey water footprint decreased the least. Yantai water quality was improved. Among them, the proportion of agricultural grey water footprint in Yantai is the largest, followed by domestic grey water footprint, and industrial grey water footprint proportion is the smallest. Yantai showed the unsustainable state of the overall grey water footprint only in 2016. In 2019, Yantai's overall grey water footprint sustainability was about to reach a critical value. All other years showed a sustainable state, the overall grey water footprint sustainability remained relatively good, and water resources pressure was alleviated. The grey water footprint intensity of Yantai generally shows a downtrend, the utilization efficiency of water resources is improved year by year, the economic benefit of grey water footprint is improved year by year, and the relationship between water environment and socio-economic development is coordinated.

The economy of Yantai has developed steadily, and the sewage treatment capacity and water resource utilization efficiency have been improved. The water quality environment has also been improved. The research on the grey water footprint of Yantai can fully clarify the utilization status and existing problems of water resources from the perspective of the combination of water quantity and quality. It provides the basis for rational allocation of water resources, treatment, and prevention of water pollution. This research provides a reference for the study of the water environment in coastal cities.

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