

## Research Article

# Human Activities Increase the Nitrogen in Surface Water on the Eastern Loess Plateau

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Human activities have greatly accelerated the input of nitrogen into waters, resulting in water quality degradation. Facing the water crisis of nitrogen pollution, the state of surface water in arid areas needs close attention. Although numerous studies have indicated that waters' nitrogen is often impacted by land use covers, the correlation between the two remains obscure. This paper explored the spatial relationship between anthropogenic activity and waters' nitrogen on the eastern Loess Plateau, based on the Geographic Information System (GIS) spatial analysis using land use covers. There were 3 human land use types and 2 nitrogen indices used to assess the rivers' state at the watershed scale. The results showed that rivers' nitrogen was closely associated with human land use covers. Nitrogen pollution was most serious in urban areas. This study provided new evidence for the relationship between anthropogenic activities and river ecology. The findings may be helpful for policymakers to make strategic decisions of water resource management and land use planning in arid areas.

## 1. Introduction

Nitrogen (N) is one of the most important nutrients for ecosystem function and also a limiting factor for the productivity of many ecosystems in the world [1]. Nitrogen pollution can cause adverse ecological effects on the environment, including soil acidification, hypoxia, and subsequent fish death [2]. High concentration of nitrogen is the main factor leading to eutrophication of the water environment, resulting in the reduction of biodiversity and deterioration of water quality [3]. To make matters worse, some high levels of nitrogen forms in drinking water increase the risk of human disease [4]. How to make rational use of nitrogen and reduce the negative effects of nitrogen while meeting human needs has become a scientific challenge that human beings must solve in the 21st century [5].

About 99% of the global nitrogen is stable atmospheric nitrogen, which is not available to ecosystems unless it is converted into active nitrogen species, such as nitrate ( $\text{NO}_3^-$ ), nitrite ( $\text{NO}_2^-$ ), ammonia ( $\text{NH}_3$ ), and ammonium ( $\text{NH}_4^+$ ), and organic nitrogen [6]. Through nitrogen fixation, plants

make inorganic nitrogen exist in soil in the form of  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ , and ammonia nitrogen ( $\text{NH}_3\text{-N}$ ). Through rainfall erosion and surface runoff, inorganic nitrogen in soil migrates to water [7]. Biological nitrogen fixation can input  $120 \text{ Tg N yr}^{-1}$  nitrogen to the ecosystem [8]. Due to the non-uniformity of the spatial distribution of nitrogen flux, there are great differences in the nitrogen cycle in different regions of the world. Human beings enlarge the differences and make the process more complicated. Human activities have greatly accelerated the input of nitrogen into water, resulting in water quality degradation, including eutrophication, acidification, and nitrate pollution [9–15].

Anthropogenic nitrogen entering waters comes from industrial, municipal, residential, and agricultural sources [16]. Nitrogen deposition from fossil fuel combustion in the atmosphere is another important anthropogenic nitrogen source, which is discharged into surface water. Chemical inputs to water bodies are also classified by point sources (such as municipal wastewater treatment plants) and non-point sources (such as agricultural activities and atmospheric deposition). Annual nitrogen fixation from human sources

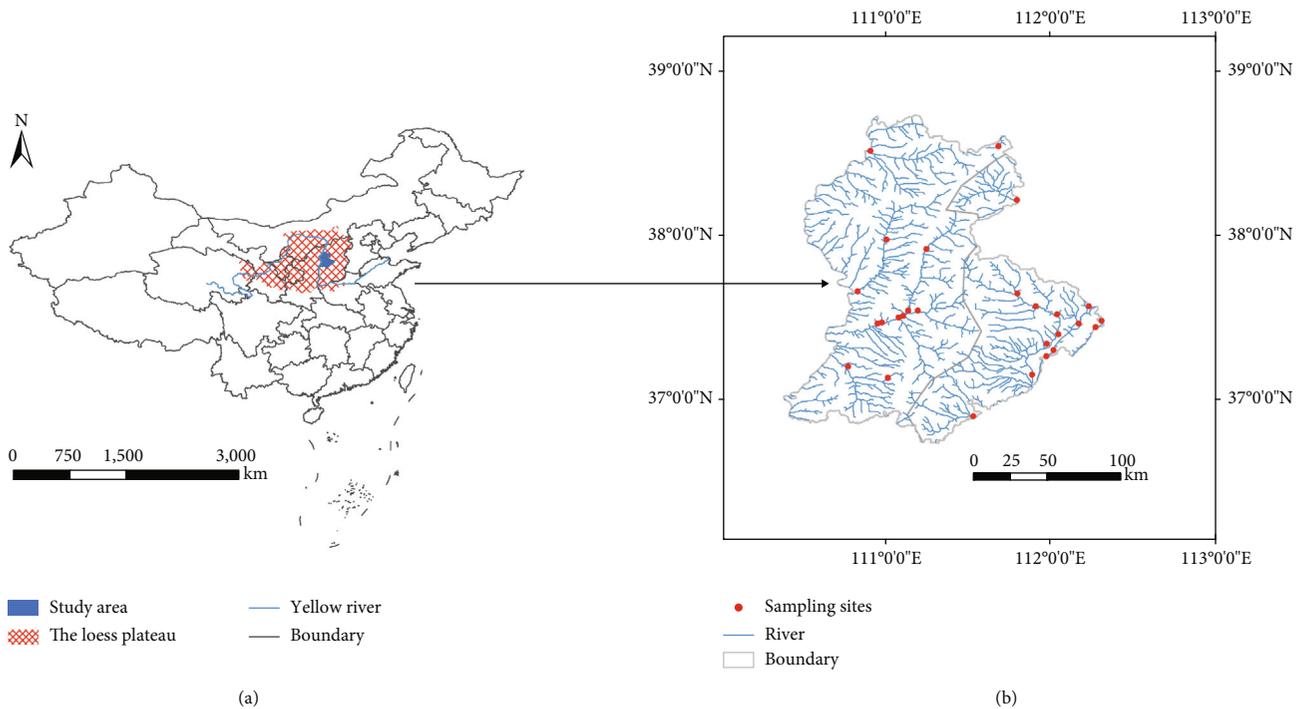


FIGURE 1: Location of the Loess Plateau, study area, and sampling sites.

has exceeded that from natural sources [17]. As time goes on, human activities increase the input of nitrogen into water. The nitrogen load of major rivers in the United States has increased [18]. It is expected that the nitrogen input into the water body will continue to increase all over the world. Kroeze and Seitzinger [19] predicted that by 2050, 90% of the dissolved inorganic nitrogen load in the world's rivers will be anthropogenic.

The water quality of several major rivers in northern China, Huaihe River, Yellow River, Haihe River, Liaohe River, and Heilongjiang River, cannot meet the Class III standard of China's surface water, plus China has large nitrogen fertilizer applications but lower nitrogen utilization efficiency, which greatly increases the nitrogen accumulation in waters [20]. Soil nitrogen may also increase because of the interference of human activities, such as the large amount of nitrogen fertilizer application in farmland and urban soil covered by impervious layers. Schlesinger [21] traced the final fate of 150 Tg nitrogen per year from human emissions. It was found that there was about  $9 \text{ TgN yr}^{-1}$  nitrogen accumulating in the biosphere. Human activities have profoundly influenced the long-term dynamics of nitrogen concentrations in rivers, lakes, and aquifers worldwide. Under the disturbance of human activities, the reserves of terrestrial ecosystems may be increasing [22].

Land use/cover change (such as farmland expansion, afforestation, deforestation, urbanization, and industrialization) increases the vulnerability of the water ecosystem, which is an important way and response of human activities to the surface environment [23]. Nitrogen in industry, city, and people's life mainly comes from sewage. Agricultural nitrogen fertilizers include fertilizers, nitrogen-fixing crops, human and animal excreta, and soil erosion caused by land

use changes such as deforestation and grassland reclamation. Construction sites also contribute to nitrogen input into the water body [24]. Nitrogen concentration in surface water is strongly affected by land use in settlement areas, especially by agriculture [25]. Zhao and Huang [26] found that nitrate concentration decreased with the increase of woodland proportion. Changing a paddy field to dry land or construction land will increase water yield while changing a water area to a paddy field or dry land will reduce water yield. The transfer of land use to the surface with a high evaporation rate will reduce runoff [27]. Agricultural coverage explained the 69% variability of mean nitrate concentrations in the Mediterranean river basin during the 25 years (1981–2005) [28]. In fact, land use is always associated with fertilization (cropland) and soil erosion (conversion of natural vegetation to arable land), which increases the concentration of nitrogen in the rivers discharging disturbed catchments.

Land use change plays an extremely important role in the fields of ecological environment, climate change, and food production. It plays a very important role in maintaining biodiversity and water environment systems. Land use/cover has become the main cause of global change [29]. However, few studies focused on the spatial relationship between land use and waters' nitrogen. In particular, the water ecosystem-based management in the arid areas lacked strong technical support. Here, we seek to develop a strategy to study the impact of human activities on surface water through a case study of a typical arid area in the Loess Plateau of northern China. Specifically, we analyzed the characteristics of different land use covers and waters' nitrogen by adopting remote sensing and field investigation. Our results contribute to a better understanding of the ecological effects that anthropogenic activities have on different landscape configurations

TABLE 1: Descriptive statistics of the nitrogen concentrations in Yellow River and Fen River Basins.

Basin	Nitrogen (mg/L)							
	Minimum	NH <sub>3</sub> -N Maximum	Mean	SD	Minimum	TN Maximum	Mean	SD
Yellow River	0.11	13.20	1.82	2.55	2.09	22.30	10.42	4.83
Fen River	0.10	34.10	4.28	5.91	1.47	70.50	17.48	14.75

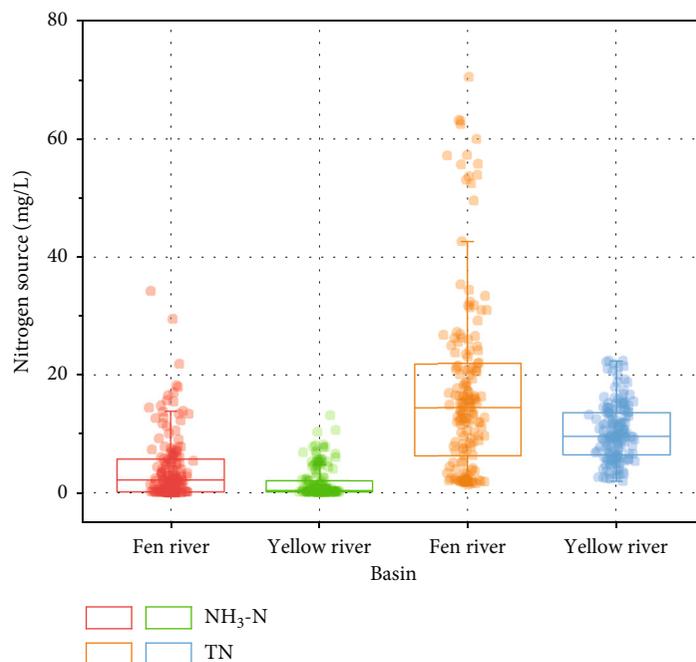


FIGURE 2: Box plots of NH<sub>3</sub>-N and TN concentrations in Fen River and Yellow River Basins.

TABLE 2: Seasonal variations of the nitrogen concentrations in Yellow River and Fen River Basins.

Basin	Nitrogen (mg/L)							
	Minimum	NH <sub>3</sub> -N (dry season)			Minimum	TN (dry season)		
Yellow River	0.11	Maximum	Mean	SD	2.09	Maximum	Mean	SD
Fen River	0.12	34.10	7.35	8.11	1.47	63.10	21.25	18.20
Basin	Minimum	NH <sub>3</sub> -N (wet season)			Minimum	TN (wet season)		
Yellow River	0.22	Maximum	Mean	SD	2.75	Maximum	Mean	SD
Fen River	0.10	9.09	2.19	2.73	1.99	7.05	14.71	13.50

in the study area. This research will provide scientific guidance for water ecosystem management and regional sustainable development for maintaining ecological balance and regulating anthropogenic activities in arid areas.

## 2. Materials and Methods

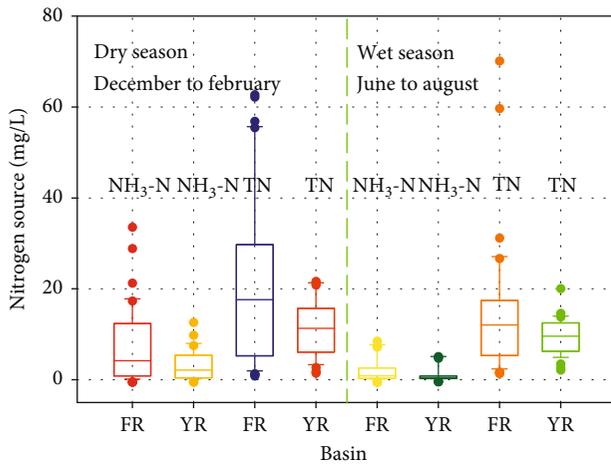
2.1. Study Area. Loess covers about 10% of the earth’s land surface and lies in semiarid zones [30]. The Loess Plateau of China is located in the middle reach of the Yellow River in northwestern China [31]. The Loess Plateau (Figure 1(a))

is the most concentrated and largest loess area on the earth. The Loess Plateau is more than 1000 kilometers long from east to west and 750 kilometers wide, with a total area of  $6.4 \times 10^5$  km<sup>2</sup>. It is located on the second step of China, with an altitude of 800–3000 meters.

Lvliang City (Figure 1(b)) is located in the west of Loess Plateau and the west of Shanxi Province. It is located between a latitude of 36°43’N and 38°43’N and a longitude of 110°22’E and 112°19’E. The city basically belongs to the temperate continental monsoon climate zone, cold in winter and hot in summer, with four distinct seasons. The total area of the

TABLE 3: The variations of the nitrogen concentrations in Yellow River and Fen River Basins during January to December in 2019.

Nitrogen (mg/L)	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	
NH <sub>3</sub> -N													
Yellow River	4.26	3.66	2.64	1.75	2.11	1.50	1.58	0.53	0.54	0.72	0.92	2.05	
Fen River	10.41	8.99	5.56	4.78	5.85	3.51	0.95	2.10	1.78	1.45	3.34	2.42	
Eastern Loess Plateau	8.76	7.67	4.74	3.79	4.62	2.92	1.40	1.55	1.31	1.26	2.45	2.62	
TN													
Yellow River	12.30	12.54	9.07	12.68	10.67	10.56	10.66	7.35	9.72	9.82	10.09	10.01	
Fen River	21.96	23.67	15.23	20.51	14.40	14.91	15.62	13.58	15.85	16.63	19.44	18.07	
Eastern Loess Plateau	20.03	21.49	13.85	18.89	14.05	14.42	14.70	11.84	14.37	15.04	16.71	16.14	

FIGURE 3: Temporal variations of NH<sub>3</sub>-N and TN concentrations in dry and wet seasons.

city is  $2.1 \times 10^5$  km<sup>2</sup>, and the average annual precipitation is only 472 mm. Lvliang has wide loess coverage, broken terrain, steep slope, less flat land, rare vegetation, and serious soil erosion.

## 2.2. Sampling Strategy

**2.2.1. Sample Collection.** The surface water samples were collected from 28 rivers in the Loess Plateau. The sampling time was from January to December 2019 (the dry and wet seasons), and the sampling frequency was tested once a month, which was from Yellow River and Fen River Basins. The details of the sampling sites are shown in Figure 1(b). The water samples were stored in 5.0 L polypropylene (PP) bottles, which were prewashed with the water samples 3 times before collection. All the samples were stored at 4°C for no more than 7 days before the analysis.

**2.2.2. Sample Determination.** We determined TN and NH<sub>3</sub>-N using the methods of potassium persulfate ultraviolet spectrophotometry and Nessler's reagent colorimetry with reference to GB3838-2002. The standard of TN and NH<sub>3</sub>-N in this paper referred to the Class III standard value of surface water (1 mg L<sup>-1</sup>).

**2.3. Data Statistics and Analyses.** We conducted box plots to compare the spatiotemporal variations of nitrogen concen-

trations based on SigmaPlot 14.0 (Systat Inc., US). Data on human land use was collected from the Resource Environment Data Cloud Platform (<http://www.resdc.cn/>) and was accurate to 1 km. Considering the heterogeneous distribution of sampling scatters, inverse distance weighting (IDW) interpolation was used to evaluate the spatiotemporal distribution and density of nitrogen [32]. We predicted the spatial distributions of eutrophication and water quality state using Kriging interpolation based on ArcGIS 10.2 (ESRI Inc., US).

## 3. Results and Discussions

**3.1. Spatial Variations of Nitrogen Concentrations.** The spatial variations of nitrogen concentrations are shown in Table 1. The range of NH<sub>3</sub>-N is in 0.11–13.20 mg L<sup>-1</sup> (mean  $1.82 \pm 2.55$  mg L<sup>-1</sup>) and 0.10–34.10 mg L<sup>-1</sup> (mean  $4.28 \pm 5.91$  mg L<sup>-1</sup>) in Yellow River (YR) and Fen River (FR) Basins, respectively. The range of TN was in 2.09–22.30 mg L<sup>-1</sup> (mean  $10.42 \pm 4.83$  mg L<sup>-1</sup>) and 1.47–70.50 mg L<sup>-1</sup> (mean  $17.48 \pm 14.75$  mg L<sup>-1</sup>) in YR and FR, respectively. All the mean concentrations of NH<sub>3</sub>-N and TN (>1.0 mg L<sup>-1</sup>) exceeded the Class III standard of surface water (shorter form Class III). As shown in Figure 2, both NH<sub>3</sub>-N and TN in FR were higher than those in YR. The nitrogen in FR had more volatility than that in YR to the spatial distribution.

Lvliang is a hilly and ravine area with a shortage of water resources and inconvenient transportation and is relatively closed to external communication. The population is mostly concentrated in the small river basin near the two sides of Lvliang Mountain. Lots of studies have proved that agriculture (fertilizer), population, and industry increased nitrogen input in the river basin [33]. In the Yellow River Basin, most areas are rural land, and the industries in the basin are not well developed. Therefore, industrial wastewater does not have a major impact on nitrogen transportation. The nitrogen load is sufficiently impacted by fertilizer use and population growth. In addition, the wastewater and soil erosion in the Loess Plateau intensified the input and transportation of nutrients (phosphorus) [34]. The Lvliang area is the most serious area of soil erosion in the Yellow River Basin. Considering the western part of the FR basin is high and the eastern part is low, the pollutants in the west basin are easily spread in FR. Excess nitrogen is enriched in surface water, which can negatively affect water quality and cause eutrophication.

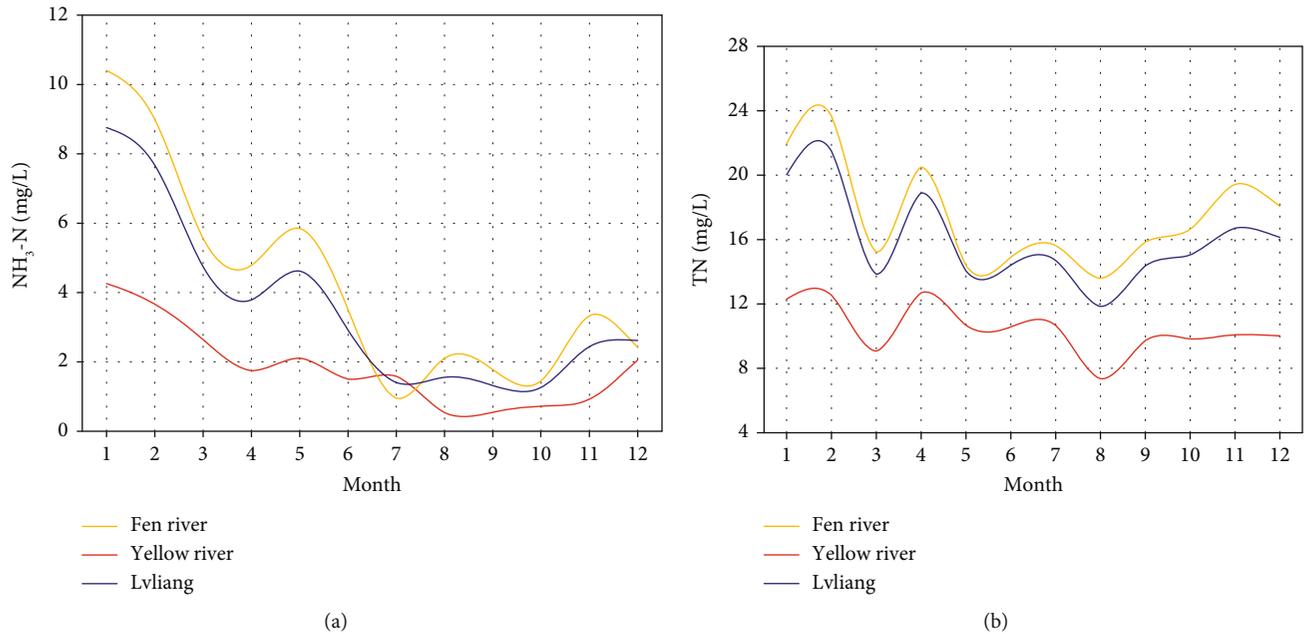


FIGURE 4: Comparison of  $\text{NH}_3\text{-N}$  and TN concentrations during January to December in 2019.

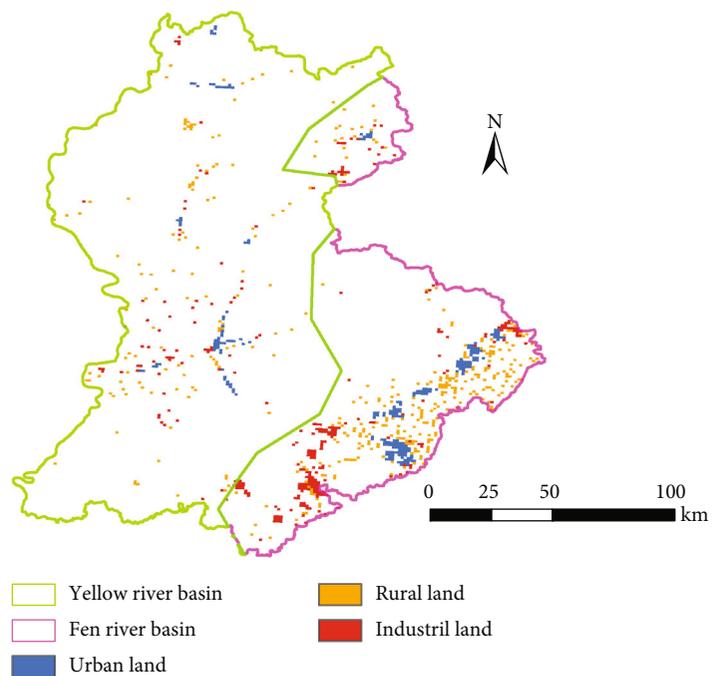
**3.2. Temporal Variations of Nitrogen Concentrations.** The Loess Plateau is a typical semiarid area with a wide range, which is short of water due to its low precipitation and high evaporation. The annual precipitation is 538.6 mm, and the annual evaporation is 1120 mm [35, 36]. The unreasonable and excessive development of water resources leads to the serious consequences of the reduction of groundwater storage. Some rivers even dried up in the dry season.

We calculated and compared the nitrogen concentrations in the wet/dry season and every month (Tables 2 and 3; Figures 3 and 4). The results showed that the  $\text{NH}_3\text{-N}$  in the dry season (YR: 3.32, FR: 7.35  $\text{mg L}^{-1}$ ) was higher than that in the wet season (July to September: YR: 1.21, FR: 2.19  $\text{mg L}^{-1}$ ). The  $\text{NH}_3\text{-N}$  in FR in dry and wet seasons had more volatility. The  $\text{NH}_3\text{-N}$  was highest in YR (4.26  $\text{mg L}^{-1}$ ) and FR (10.41  $\text{mg L}^{-1}$ ) in January. Rainfall is the major source of surface water supply in FR and YR. Precipitation has a certain dilution effect on the  $\text{NH}_3\text{-N}$  concentration in the rainy season. The dry season is the main period of farmers applying nitrogen and nitrogen-containing substances, and nutrients easily enter the surface water with rainfall and runoff [37]. These are the important reasons for the high nitrogen content in the dry season.

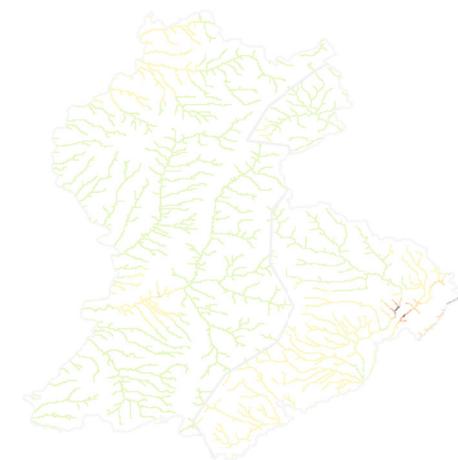
The above research results also showed TN (dry season: YR: 11.59, FR: 21.25  $\text{mg L}^{-1}$ ; wet season: YR: 9.52, FR: 14.71  $\text{mg L}^{-1}$ ). The TN was highest in YR (12.68  $\text{mg L}^{-1}$ ) and in FR in February (23.67  $\text{mg L}^{-1}$ ). TN is defined as the total amount of dissolved inorganic nitrogen and dissolved organic nitrogen in water. Figure 4 shows that the change of TN is mainly due to the change of  $\text{NH}_3\text{-N}$ , which means  $\text{NO}_3\text{-N}$  is basically unchanged. The  $\text{NO}_3\text{-N}$  is the main existing form of dissolved inorganic nitrogen in the Fen River [35].  $\text{NO}_3\text{-N}$  is the final product of oxidative decomposition of nitrogenous organic compounds, which indicates that the FR is polluted not only by agricultural pollution but also by

industrial pollution. In the dry season, TN is 23.67  $\text{mg L}^{-1}$  which means that the river in the FR region is extremely polluted.

**3.3. Relationship between Nitrogen and Human Land Use.** We predicted the spatial distribution of nitrogen in YR and FR, based on GIS interpolation (Figure 5). The results showed that the concentrations of  $\text{NH}_3\text{-N}$  were mostly <3.0  $\text{mg L}^{-1}$  and 3.0–6.0  $\text{mg L}^{-1}$  in YR and FR, respectively. The concentrations of TN were mostly 5.0–10.0  $\text{mg L}^{-1}$  and 15.0–30.0  $\text{mg L}^{-1}$  in YR and FR, respectively. The  $\text{NH}_3\text{-N}$  (12.0–13.4  $\text{mg L}^{-1}$ ) and TN (45.0–63.0  $\text{mg L}^{-1}$ ) were highest in the east of the study area. It should be noted that the  $\text{NH}_3\text{-N}$  and TN were much higher in FR than in YR. As shown in Table 4, the human land use in the Yellow River Basin (1.4%) was smaller than that in the Fen River Basin (8.12%). The land use types have an obvious impact on the nitrogen concentration distributions in FR. The sampling sites of the FR were mostly located near the Fen River Reservoir Two. There are some industrial facilities and human activities around this area. The sewage is discharged around the sampling sites. The results showed that high nitrogen contents should be related to anthropogenic sources, such as domestic sewage, animal manure and nitrogenous fertilizer, and industrial sewage. Xing and Liu [38] pointed that the TN in the Yellow River is mainly formed by soil organic nitrogen. Figure 5 shows that the highest TN region is at the southeast of Lvliang, the land use type of which is rural land. Another possible reason is that Lvliang's Fen River comes from the Taiyuan Basin, so the Taiyuan Basin might also be a source of nitrogen pollution in FR. Human beings affect surface water quality by interfering with land use and cover types [39]. The dynamic characteristics of water quality, nutrient density, and landscape will be affected [40]. The loss of nitrogen and sulfur in the landscape has a great



(a)



(b)

FIGURE 5: Continued.

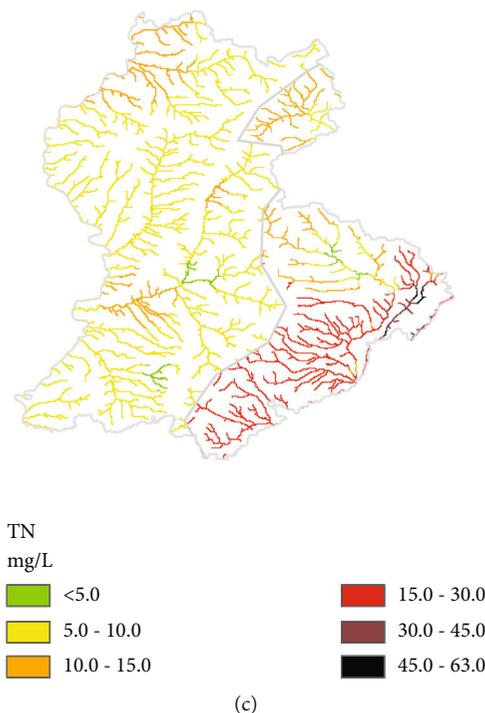


FIGURE 5: Spatial distribution of human land use (a), NH<sub>3</sub>-N (b), and TN (c) in surface water on the eastern Loess Plateau.

TABLE 4: Comparison of the human land use in Yellow River and Fen River Basins.

Basin	Human land	Land use type (%)		
		Urban land	Rural land	Industrial land
Yellow River	1.40	0.39	0.65	0.36
Fen River	8.12	2.33	3.02	2.77

impact on the water quality of rivers, estuaries, and coastal waters.

Lvliang is located in the central of Shanxi Province, which has high GDP, population density, and concentrated industry. The large numbers of artificial land use in this area might be the cause of nitrogen pollution. In order to reduce the risk of water quality degradation, policymakers should carry out management and care assessment mechanisms at the source of rivers and pollution in accordance with the principle of Beneficiary Pays Principle and User Pays Principle. They should focus on the proportion of complete interference land use types by increasing the area of green land and natural water.

#### 4. Conclusions

A GIS spatial analysis based on land use covers was used to understand the correlation between anthropogenic activity and rivers' nitrogen. The results showed that rivers' nitrogen was closely associated with human land use covers. Nitrogen pollution was most serious in urban areas. The method used in this study was effective and feasible for assessing the rivers'

nitrogen under the background of different anthropogenic activities.

Our results suggest caution in developing cities and industries and stress the importance of sustainable intensification of land use. Overall, people have to a fair extent managed to protect water resource security and ecological sustainability. This research provided useful results concerning the relevant management decisions to reduce anthropogenic disturbance to the water resource management and land use planning in arid areas.

#### Data Availability

The data used to support the findings of this study are included within the article.

#### Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Authors' Contributions

The contributions of the authors involved in this study are as follows: conceptualization: Yuxian Hu and Gaiqiang Yang; data curation: Yuxian Hu, Yanan Sun, and Hongyan Li; funding acquisition: Yuxian Hu, Gaiqiang Yang, and Hongyan Li; investigation: Yuxian Hu and Ke Zhang; supervision: Yuxian Hu and Ke Zhang; writing—original draft: Yuxian Hu; and writing—review and editing: Yuxian Hu and Yuan Li.

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