RESEARCH ARTICLE

Effects of land use and slope on water quality at multi-spatial scales: a case study of the Weihe River Basin

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Abstract

Exploring the impact of land use and slope on basin water quality can effectively contribute to the protection of the latter at the landscape level. This research concentrates on the Weihe River Basin (WRB). Water samples were collected from 40 sites within the WRB in April and October 2021. A quantitative analysis of the relationship between integrated landscape pattern (land use type, landscape configuration, slope) and basin water quality at the sub-basin, riparian zone, and river scales was conducted based on multiple linear regression analysis (MLR) and redundancy analysis (RDA). The correlation between water quality variables and land use was higher in the dry season than in the wet season. The riparian scale was the best spatial scale model to explain the relationship between land use and water quality. Agricultural and urban lands had a strong correlation with water quality, which was most affected by land use area and morphological indicators. In addition, the greater the area and aggregation of forest land and grassland, the better the water quality, while urban land presented larger areas with poorer water quality. The influence of steeper slopes on water quality was more remarkable than that of plains at the sub-basin scale, while the impact of flatter areas was greater at the riparian zone scale. The results indicated the importance of multiple time–space scales to reveal the complex relationship between land use and water quality. We suggest that watershed water quality management should focus on multi-scale landscape planning measures.

Keywords Land use · Water quality · Multi-scale · Slope · Landscape indicators · Multiple linear regression

Introduction

Surface water flow processes is a complex system, with various forms of water converging into rivers through the physical action of precipitation, runoff, and infiltration (Vannote et al. 1980). These rivers transport nutrients and sediments in the flow processes from the upland to the downstream systems (Gomi et al. 2002). The whole process affects the ecosystem variation and has to be one of the crucial elements in the ecological environment system circulation (Pak et al. 2021). River water quality degradation is affected by both natural and anthropogenic factors (Rutledge and Chow-Fraser 2019; Mainali and Chang 2021). Rivers react with the outside environment through physical, chemical, and biological processes that affect the health and good ecological functioning of the watershed (Vrebos et al. 2017; Varol et al. 2022). Water-soil parent rock interactions and other natural processes, such as precipitation and erosion. These natural drivers could introduce pollutants into the water and affect water safety (Khatri and Tyagi 2015). However, anthropogenic factors such as urban construction, industrial, and agricultural activities have become the biggest forces affecting surface water resources and water quality (Pak et al. 2021; Ali and Muhammad 2022) These external sources of pollution can affect the health of the water environment and limit water use for domestic use, agricultural irrigation and industrial production (Gurjar and Tare 2019; Kumar et al. 2022). As a result, water pollution has become one of the most pressing global issues for surface water (Amin et al. 2021; Wang et al. 2022b). It is of great significance to clarify the

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driving factors of water quality change for water protection and ecological cycle.

As one of the key elements of hydrological alteration, land use patterns impact almost all hydrological processes (Wu and Lu 2019; Wang et al. 2021). Since the 1970s, scholars have gradually explored the positive and negative effects of different land use patterns on water quality change (Rimer et al. 1978; Mwaijengo et al. 2020). Transformation of natural lands to different land uses increased the production of pollutants and aggravated the deterioration of water quality (Chang et al. 2021; Liu et al. 2021b; Zeng et al. 2022). The large-scale expansion of agricultural land and the rapid development of urbanization have caused water pollution (Tu 2011; Shi et al. 2017; Xiao et al. 2019; Santos et al. 2019), while forestland and grassland play an inhibitory role in the process of nutrient cycling (Wilson and Weng 2010; Pacheco et al. 2015; Xu et al. 2019a). The relationship between land use and water quality is particularly complex, as different river areas and variations in the surrounding environment can make the relationship heterogeneous (Kibena et al. 2014; Dalu et al. 2017; Ramesh et al. 2019; Wang et al. 2022a). To illustrate this complex relationship, a number of scholars have started with the response of land use and water quality at different spatial scales, including watersheds, buffer zones, and riparian zones (Zhang et al. 2019; Tang and Lu 2022). However, the results of studies on the relationship between spatial scale and water quality response are inconsistent. Many researches have shown that land at the watershed scale more strongly interferes with water quality changes (Kuemmerlen et al. 2014; Ding et al. 2016), but some scholars have pointed out that land near rivers better explains the variation in water quality. Tran et al. (2010) have shown that land use at the riparian scale had the most significant impact on river water quality than the basin scale, and Shi et al. (2017) reached the same conclusion. The reasons for such inconsistent results may be the geographical differences of the study areas and the different river types. Some studies have shown that topographic factors such as elevation and slope in the watershed also affect water quality. Wan et al. (2014) stated water quality was significantly influenced by topography, with steeper topography in the upper reaches of rivers where water quality was less correlated with land use, and flatter areas downstream where water quality was more disturbed by land use. Buck et al. (2004) reported that land use had a more significant impact on water quality in smaller rivers and that different classes of rivers were affected by land use to different degrees. Cheng et al. (2018) indicated that topography, climate, and discharge all have different impacts on water quality and that delineating ecological functional zones allows for a more accurate analysis of the interrelationship between land use patterns and water quality. Therefore, separate spatial scale analyses for different catchments are required to draw accurate conclusions.

To comprehensively analyze the impact of land use on water quality, it is necessary to consider the relationship between landscape configuration and water quality under different land uses (Xu et al. 2019b; Wu and Lu 2021). Landscape configuration is a spatial structural feature of land use, which also has scale effects on water quality (Umwali et al. 2021). Therefore, combining land use and landscape configuration can better identify the drivers of water quality change in the watershed. Nevertheless, the relationship between water quality parameters and landscape indicators (Landscape Shape Index, Percentage of Like Adjacencies…) can be non-linear, and there is no consensus on which spatial scale is best for the landscape configuration (Dou et al. 2022). Zhang et al. (2019) reported that landscape indicators were more strongly correlated with water quality parameters at the watershed scale, but Shi et al. (2017) stated that riparian-scale landscape indicators better reflected changes in water quality. Although the interrelationship between landscape configuration and water quality at the spatial scale varies considerably, the use of landscape indicators to analyze the characteristics of water quality changes can be more specific for managers to filter out the appropriate landscape configuration. Lee et al. (2009) found that high values of patch and edge density in landscape indicators were significantly associated with water quality degradation. Bu et al. (2014) studied the relationship between the aggregation and Shannon's diversity indices and river water quality and revealed that landscape indicators can effectively predict water quality changes. Ding et al. (2016) found that different landscape configurations had a greater impact on downstream water quality through quantitative analysis of the correlation between landscape indicators and water quality. In general, assessing the multi-scale relationship between land use and water quality with landscape indicators is helpful for us to better understand the complex factors controlling water quality change.

The Weihe River is the first tributary of the Yellow River, and the WRB is an important ecological reserve in northwest China, which plays an important role in the high-quality development of the Yellow River basin. The WRB has undergone rapid urbanization and dramatic land use changes in the last 20 years and is currently characterized by a large proportion of agricultural land and dense urban clusters, which have exacerbated water pollution. It is of strategic importance to clarify the key elements affecting water quality changes in the WRB. It is of strategic importance to clarify the key elements affecting water quality changes in the WRB. Therefore, we focused the WRB on the research object and used MLR to investigate the response relationship between land use, landscape configuration, slope, and water

quality at different spatial scales. The objectives of the study were (1) to clarity the characteristics of river water quality and the spatial difference of dry–wet seasons; (2) to explore the effects of different land use types, landscape configuration and slope size on water physic-chemical parameters; and (3) to quantify the multiple scale effects of the variation relationships between landscape configurations and river water quality.

Materials and methods

Study area

The WRB is located in northwestern China, originates in Gansu Province, and flows into the Yellow River in Tongguan County, Shaanxi Province (Fig. 1a), with a total length of 818 km and a drainage area of 13.5×10^4 km^2 (Chen et al. 2021). The study area is comprised of three watersheds: the Weihe river (WHR, 47% of the total drainage area), the Jinghe river (JHR, 34% of the total drainage area), and the Beiluohe river (BLR, 19% of the total watershed area). The basin elevation ranges from 286~3935 m and decreases from northwest to southeast. The major landform types are platforms and hills. The main soil types are semi-eluvial soil and primary soil (Fig. S1). The whole area

has a temperate continental monsoon climate. The annual average temperature is 9.7 ℃. The annual rainfall is about 515.5 mm (Zhang et al. 2021). The major land use types are agricultural land, forestland, and grassland in this basin. The region provides numerous ecosystem services that are essential in the Guanzhong Plain for residential life, industrial development, and agricultural production, and have an important effect in the economic and social development of western China. In recent years, due to the rapid urbanization of the region, the population density has increased in this area (Zhang et al. 2022). The land use pattern has changed and the river water quality has been significantly affected by anthropogenic activities. The industrial and agricultural development has increased the ecological risk in the basin to some extent (Zhao et al. 2016; Zhang et al. 2021).

Sample collection and analysis

Water samples were collected from the mainstream and main tributaries of the WRB during the dry (April 2021) and wet (October 2021) seasons, including 25 sampling sites in the WHR, 9 sampling sites in the JHR, and 6 sampling sites in the BLR (Fig. 1a, labeled as wh1 to wh25, JH1 to JH9 and BL1 to BL6). The sample sites were chosen far away from the river sewage outlet. All samples were collected at a depth of 50 cm below the water surface through the water
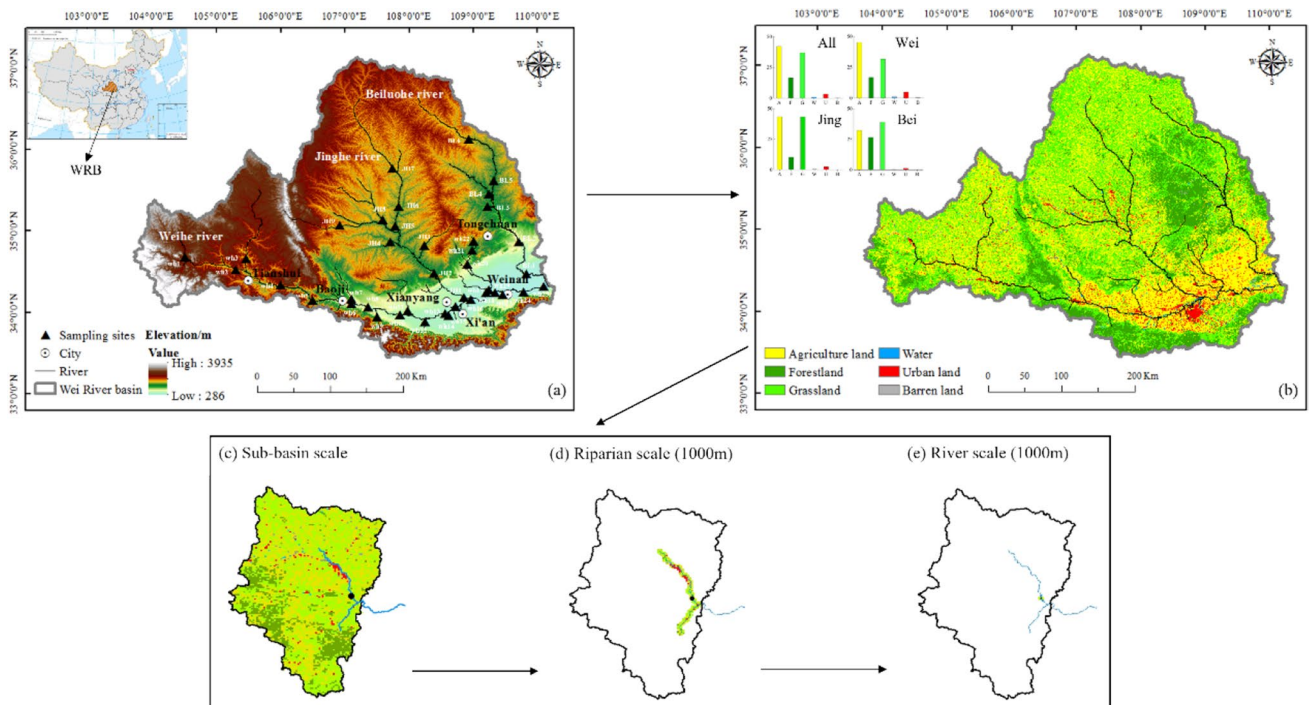

Fig. 1 Basic information of the study area. **a** The geographical location of the WRB and the distribution of 40 sampling sites. **b** The land use distribution in the WRB, where the abscissa axis of the histogram is marked by A (agriculture land), F (forestland), G (grassland), W (water), U (urban land), B (barren land). **c–e** The division of the spatial scale

sample collector. In situ pH, EC (electric conductivity), DO (dissolved oxygen), and TDS (total dissolved solids) measurements using the HANNA multi-parameter water quality tester (HI98194). The collected samples were sealed in 100-mL polyethylene plastic bottles and were stored at 4 °C as they were transported to the laboratory. The remaining indicators including $KMnO_4$ (permanganate index) NH_3-N (ammonia nitrogen), TN (total nitrogen), TP (total phosphorus), COD (chemical oxygen demand), and NO_2-N (nitrite nitrogen) were determined in the laboratory, as shown in in the Supplementary Material (Table S1). The experimental error between the samples and the control group was less than 5%.

Data sources

The Digital Elevation Model (DEM) data was obtained from Geospatial Data Cloud, with a spatial resolution of 30 m × 30 m. The DEM data was used to divide the river network and hydrological response units, along with slope calculations and grading. The slope is divided into 4 categories, I (0–5°), II (5–15°), III (15–30°), IV (> 30°), respectively. The land use, soil type, and landform type were obtained from the Resources, Environment and Data Center, Chinese Academy of Sciences. We classified the land use types in the study area into six categories, namely agricultural land (A), forest land (F), grassland (G), water (W), urban land (U), and barren land (B) (Fig. 1b). Soil type data were divided into 13 types (1:100,000). Landform type data were divided into 6 types (1:10 000,000). The above data processing was carried out in ArcGIS 10.6.

Landscape pattern analysis and multi-spatial scales

In this study, we used the 30-m resolution land use data in 2020 for analysis of landscape pattern indicators. The five landscape pattern indicators were chosen: Percentage of land use types (PLAND), Landscape Shape Index (LSI), Percentage of Like Adjacencies (PLADJ), Aggregation Index (AI), and Shannon's Diversity Index (SHDI), respectively, as shown in the Supplementary Material (Table S2). The landscape pattern indicators were calculated using FRAGSTATS V4.0. The spatial scale is divided into three types: sub-basin scale, 1000-m riparian zone scale, and 1000-m reach scale (Fig. 1c–e). Sub-basins were created by the Soil and Water Assessment Tool (SWAT). The process is as follows: first, generate the sub-basin grid according to DEM, then set the outlet point, and finally generate the hydrological response unit. The riparian scale and river scale were defined as the sampling sites enclosed by the buffer zone around the river and the sub-basin, respectively.

Data analysis

MLR and redundancy analysis (RDA) methods were used to analyze the internal relationship between land use and basin water quality from a statistical point of view, and to clarify the main factors affecting the variation of basin water quality. Before the calculation of the MLR model, the data is processed by logarithmic transformation. The stepwise regression method is used to calculate the prediction variables, and the R^2 value is used to judge the prediction performance of the model. The variance inflation factor *VIF* evaluates whether the prediction factors have collinearity. If the *VIF* value is greater than 10, it indicates that the prediction factors have collinearity. Finally, the contribution of different prediction factors is compared with the standard partial regression coefficient *B*. This study considers the results of samplings conducted in the dry and wet seasons as the analysis object. The specific research process is presented in Fig. 2.
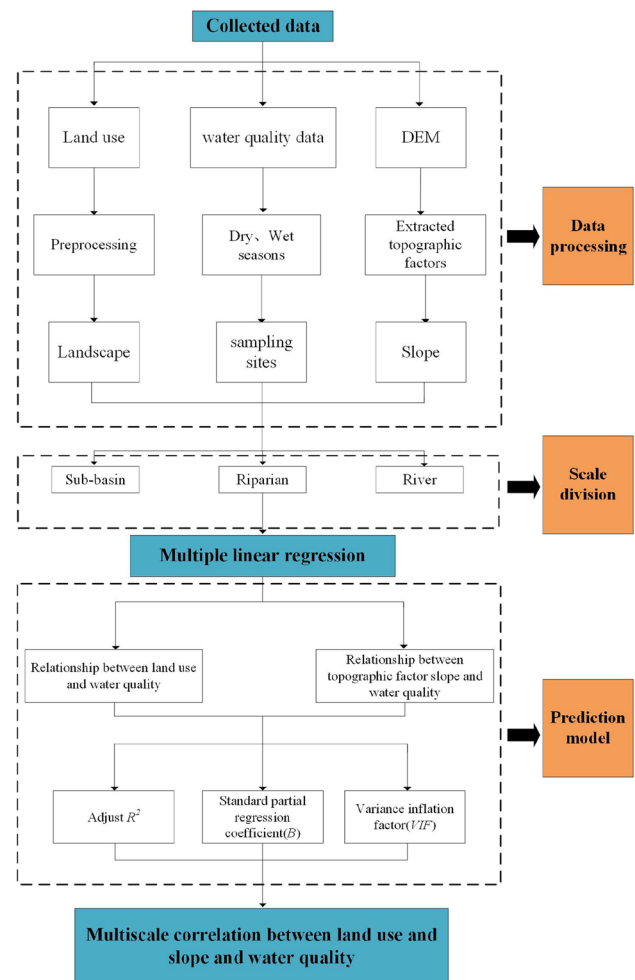

Fig. 2 Framework of the study

Results

Land use patterns at different scales

Figure 3 a showed the proportion of various types of areas in the WRB at different spatial scales. It can be seen from the figure that agricultural land (42.2%) and grassland (37.1%) account for the largest proportion in the WRB, while the other four types account for relatively small proportions. The urban land area of wh14, wh15, wh16, and wh17 was relatively large in the sub-basin and riparian zone scales. It is indicated that these points are located in the Weihe Plain, including cities such as Xi'an and Xianyang. This area has faster urbanization and the urban land area is large. The urban expansion compresses the area of grassland. However, the change in the proportion of agricultural land was not significant. The process of urbanization has reduced the amount of grassland. The higher population density has maintained the proportion of agricultural land at a higher level.

At the sub-basin scale, the proportion of agricultural land is the largest, accounting for 8.5 to 70% (average 42%). Grassland area is second only to agricultural land, accounting for 7.5 ~ 73% (average 33%). The JHR has the least area of forestland, while the BLR has the least area of agricultural land.
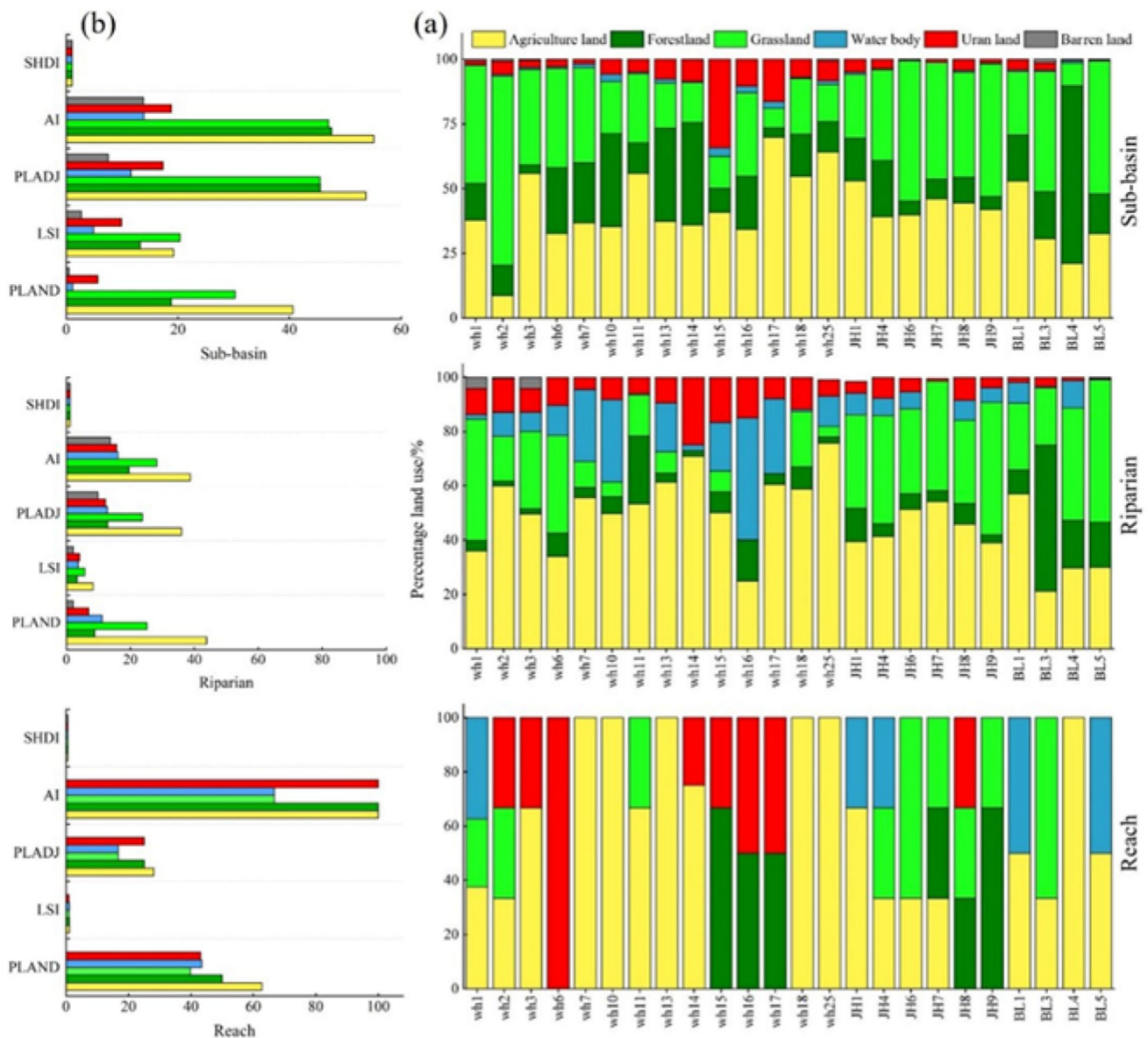

Fig. 3 Land use and landscape indicators at sub-basin, riparian and reach scales. (**a**) Percentage of land use for each site. (**b**) Mean PLAND, LSI, PLADJ, AI and SHDI across sites

Land use indicators showed similar trends at different spatial scales (Fig. 3b). SHDI was the lowest at the river scale because of the small size of this scale, and the highest AI and PLADJ values were detected for the arable land use, indicating a greater aggregation of agricultural land, followed by grassland and forest land uses.

Analysis of spatial and temporal variation of water quality

Time trend

Figure 4 shows the variation characteristics of water quality parameters in the WRB in different seasons. pH value in the dry season was lower than that in the wet season, while other indicators showed that the concentration in the dry season was higher than that in the wet season, and the seasonal variation of some water quality parameters was conspicuous. There was little difference between DO and $KMnO_4$ in the two seasons; TP varies greatly, and the area with the largest distribution of nuclear density in the dry season was significantly higher than that in the wet season. The average concentration of NO_2-N in the dry season was 2.4 mg/L and that in the wet season was 0.69 mg/L; The variation of COD was the largest, and the average concentration in the dry season (14.75 mg/L) was 2.03 mg/L higher than that in

the wet season (12.72 mg/L). The difference in TN variation was second only to COD, and the concentration of TN in the dry season (7.51 mg/L) was 1.96 mg/L higher than that in the wet season (5.55 mg/L). Most values of NH_3-N were in the lower part of the nuclear density map in the wet season, while the dry season has a larger area in the area of high values than in the wet season. The shape of TDS and EC nuclear density maps were similar, which also showed that the area of high-value areas in the dry season was larger. In general, except for pH, the water quality parameters of WRB indicated that the concentration in the dry season was higher than that in the wet season. The variation of NO_2-N, NH_3-N, and TP in the two seasons was quite different.

Spatial variation

Different water quality parameters showed different spatial patterns at the spatial scale (Fig. 5). In the WR, the average concentrations of TN, TP, $KMnO_4$, NH_3-N, COD, and NO_2-N were 7.06 mg/L, 0.24 mg/L, 3.23 mg/L, 1.64 mg/L, 13.36 mg/L, and 1.90 mg/L, respectively. They were significantly higher than the values measured in the JHR and the BLR. The results showed a strong negative correlation between domestic sewage, industrial wastewater and agricultural surface pollutants, and river water quality. The reasons for this are twofold: first, the proportion of agricultural
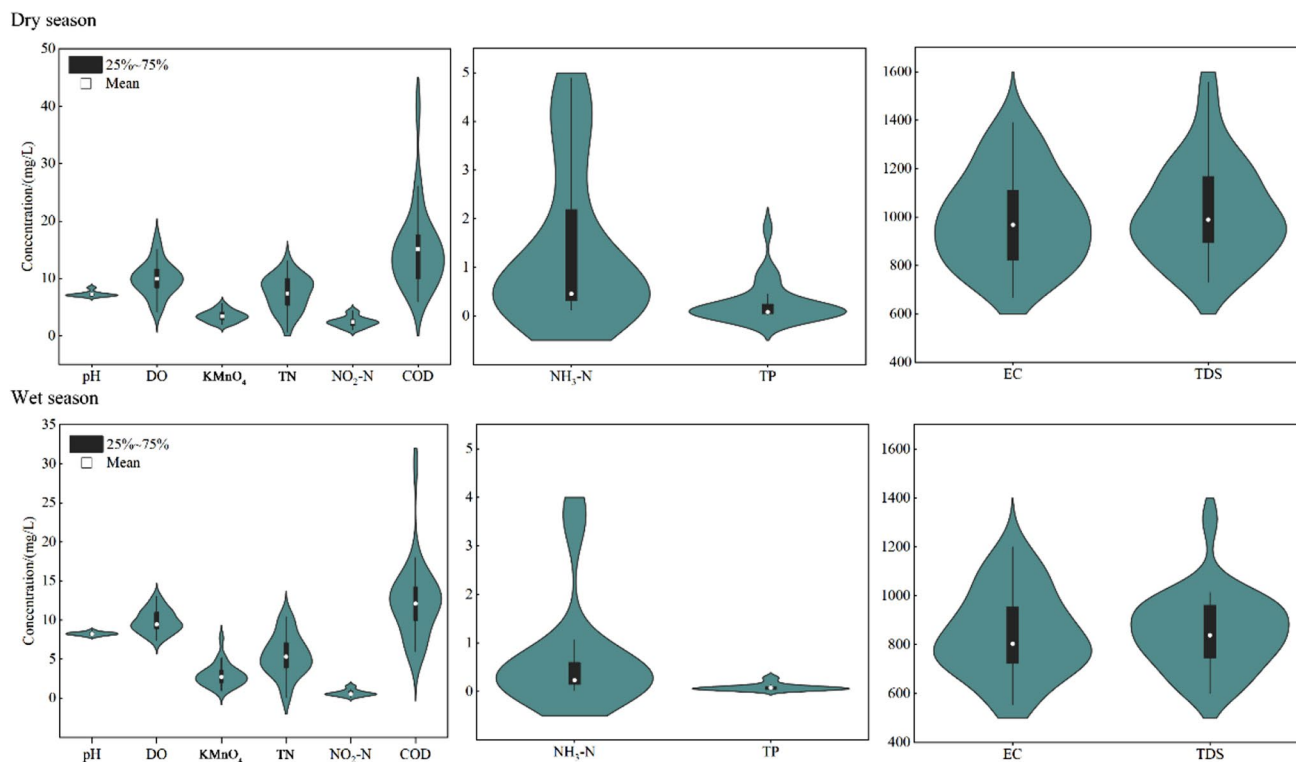

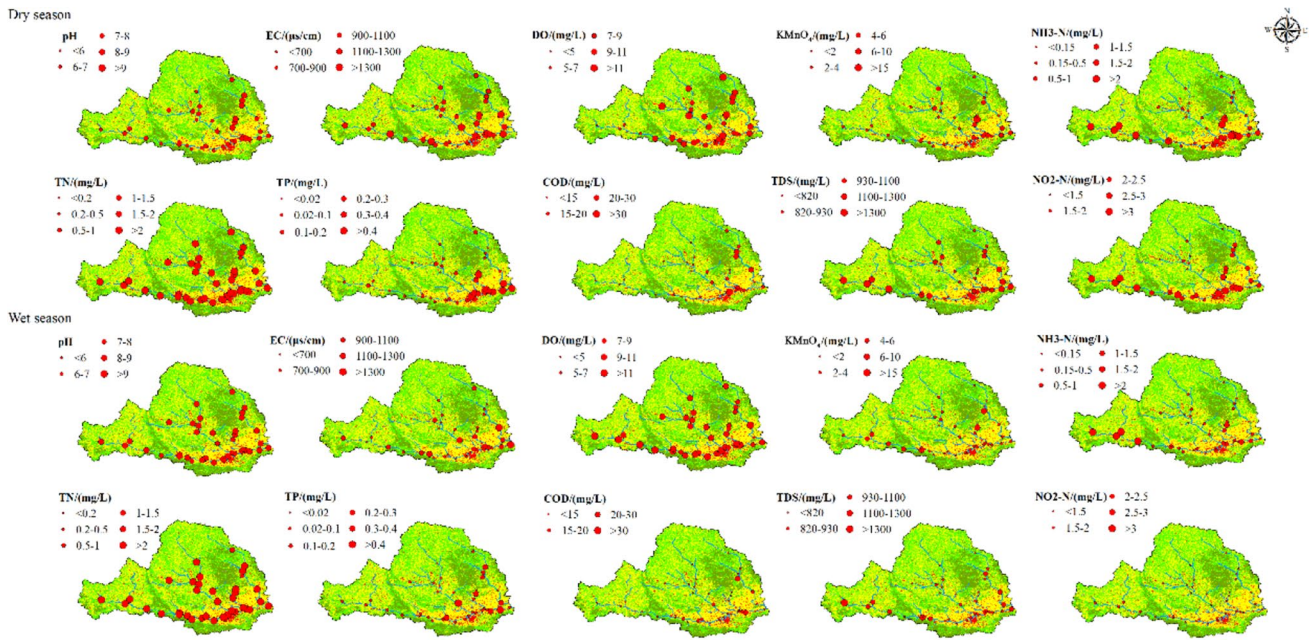**Fig. 4** Time variation trend of water quality parameters in WRB

Fig. 5 Spatial variation trend of water quality parameters in WRB

land is higher in the WR than in the other two rivers, and agricultural activities significantly affect nutrient content; second, urban agglomerations are distributed along the WRB. These circumstances have led to a higher degree of river development and to the discharge of residential sewage and urban industrialized wastewater in the river, resulting in higher concentrations of the abovementioned indicators. In contrast, the EC and TDS contents in the WR (824 μs/cm, 869.34 mg/L) were lower than those in the BLR (986.98 μs/cm, 971.25 mg/L) and JHR (861.86 μs/cm, 944.94 mg/L), and the high percentage of grassland in both these rivers, where livestock rearing is more common than in the WR, can cause serious soil erosion problems in the riparian zone. The higher pH value detected in the WR is due to the higher area of agricultural land present here compared to that in the other two rivers and to the higher salinity of the land caused by the use of chemical fertilizers.

Correlation analysis of land use and water quality in different seasons

A normal distribution test was performed on the water quality parameters, and those that did not conform to the normal distribution in the dry and wet seasons were logarithmically transformed to ensure that the results of the subsequent statistical analysis were accurate. In the dry season, several water quality variables were significantly correlated with agricultural land, forestland, grassland, and urban land areas at $p < 0.005$. Among them, NH_3-N, TN, TP, and COD were more significantly correlated with agricultural and urban

land, while agricultural activities and urban residents' life had a significant positive impact on water pollution (Table 1). As April falls within the season of agricultural activities, this month of low rainfall requires crops to be artificially irrigated and most of the irrigation water flows back into the river, resulting in generally high nutrient levels in the watershed, due to the fertilization of agricultural lands. Urban land has a lower impact on water quality than agricultural activities, indicating that agricultural land has a significant impact on water quality in the dry season. Grassland and forest areas showed significant negative correlations with TN, TP, and NH_3-N; and vegetation had a trapping effect on nutrient salts.

In the wet season, most water quality variables were associated with land use types (except pH and DO), and most variables were significantly related to forest, grassland, and urban land area. During the wet season, when urban point source pollution can have a greater impact on river water quality, and DO values tended to be lower in urban areas due to impeded denitrification, indicating that these areas are a source of pollution (Bu et al. 2014; Huang et al. 2013; Guo et al. 2010). Moreover, grassland is conducive to reducing surface runoff and erosion to retain nutrients (Allan 2004); thus, the relationship between grassland and water quality was negative. EC was negatively correlated with grass, while TDS showed a positive correlation with it, and grass was shown to reduce the erosion phenomenon to some extent.

The results of statistical analyses for water quality parameters and their relationship with land use in the two seasons showed that water quality variables are significantly affected by different

Table 1 Correlation analysis between water quality parameters and land use in different seasons

	Agriculture land	Forestland	Grass land	Water	Urban land	Barren land
Dry season						
pH	−0.397	0.447*				
EC	0.390				0.325	
DO				0.384	−0.479*	
KMnO$_4$			−0.233			
NH$_3$-N	0.470*	−0.361			0.475*	
TN	0.461*	−0.554**			0.408**	
TP	0.588**		−0.612**	0.528**	0.657**	
COD	−0.247	0.259				
TDS						0.642**
NO$_2$-N						0.502*
Wet season						
pH						0.411*
EC	0.344		−0.316			
DO	−0.385				−0.365	
KMnO$_4$		0.358			0.534**	
NH$_3$-N		−0.266			0.651**	
TN					0.356	
TP					0.230	
COD		0.436*	−0.420*		0.499*	
TDS				0.531**		
NO$_2$-N					0.499*	

Unlisted indexes fail to pass the $p < 0.05$ test

*means $p = 0.05$ is significantly correlated

**means $p = 0.01$ is significantly correlated

land use types and that the correlation was stronger in the dry season. In addition, the seasonal changes affected the mutual relationship between the land use type and river water quality to a certain extent; the strongest influence of agricultural land on river water quality in the dry season, and the significant influence of urban land in the wet season.

Variation in the influence of land use on water quality among different scales

The MLR model was used to select the predictors with the most significant impact on water quality, and the overall explanatory extent of significant predictors was revealed by RDA. RDA analysis indicated that significant predictors account for more than 50% of the overall spatial variation of water quality, which can well clarify the main factors affecting water quality at different spatial and seasonal scales (Table 2). The results showed that the riparian scale is the best one to explain the process of water quality change among the three scales, and the overall explanatory extent in the wet season (74.6%) is higher than that in the dry season (68.8%). Under the two seasons, the overall explanatory extent of the river scale is the smallest. In summary, there are spatial differences in the variation process of water

Table 2 Results of redundancy analysis (RDA) in different seasons

Season	Scale	Explained variation (%)			Explanatory variables selected by the final MLR models
		Axis 1	Axis 2	All axes	
Dry season	Sub-basin	51.9	9.8	61.7	PLAND1, PLAND2, PLAND3, PLAND5, PLAND6, LSI6, PLADJ1
	Riparian	**58.6**	10.2	**68.8**	PLAND2, PLAND3, PLAND5, PLAND6, LSI3, AI2, AI6
	River	49.4	12.1	61.5	PLAND2, PLAND5, LSI1, LSI6, PLADJ4
Wet season	Sub-basin	53.7	8.4	62.1	PLAND2, PLAND4, PLAND6, LSI1, LSI6, PLADJ6, SHDI
	Riparian	**57.4**	17.2	**74.6**	PLAND2, PLAND5, PLAND6, LSI2, LSI5, PLADJ3, PLADJ5, AI2, AI6
	River	47.9	9.5	57.4	PLAND1, PLAND5, LSI1, LSI3, LSI5, PLADJ1

Bolded: explanation with the highest value

quality, which are affected by seasons, and there are also differences in the explanatory extent of water quality at the same spatial scale.

RDA analysis results are shown in Fig. 6. In the dry season, at the basin scale, the forestland indicator (PLAND2) was negatively correlated with NH_3-N, NO_2-N, and TDS, and the grassland indicator (PLAND3) was negatively correlated with TP and EC, suggesting that the area covered by forestland and grassland at the basin scale affected river water quality. The urban indicator (PLAND5) and pH and the arable area (PLAND1) and DO were vertically distributed in the bilinear plots, thus exhibiting a divergent relationship. The riparian zone indicator (PLAND3) was vertically distributed in the bilinear plots, indicating a phase dissimilarity relationship. At the riparian zone scale, the grassland indicator (PLAND3) was positively correlated with DO and negatively correlated with pollution indicators, and the forestland indicator (PLAND2) was negatively correlated with TN. At the river scale, pollution indicators were vertically correlated with the urban indicator (PLAND5) showing a phase dissimilarity relationship, and forestland and water body indicators (PLADJ2, PLADJ4) with TP were positively correlated.

The correlation of the same spatial scale in the dry season and the wet season were different. At the basin scale, TP, TDS, NO_2-N, NH_3-N, and TN were positively correlated with agriculture land indicators (PLAND1, PLADJ1) and urban land indicators (PLAND5) in the dry season. The pollution indicators were positively correlated with barren land indicators (PLAND6, PLADJ6, LSI6) in the wet season. At the riparian scale, TN was negatively correlated with forestland indicators (PLAND2, AI2) in the dry season. The other pollution indicators were not significantly correlated with forestland indicators. TN was not significantly correlated with forestland indicators in the wet season. The other pollution indicators were negatively correlated with forestland indicators (LSI2). At the river scale, TP and COD were positively correlated with the forestland indicator (PLADJ2) and the water indicator (PLADJ4) in the dry reason. The other pollution indicators were negatively correlated with the barren land indicator (LSI6). In the wet season, TP, EC, and COD were positively correlated with agriculture land indicators (PLAND1) and (PLADJ1), DO, TN, and pH were positively correlated with grassland indicators (LSI3), while $KMnO_4$, NO_2-N, NH_3-N, and TDS were positively correlated with urban indicators (PLAND5) and (LSI5).
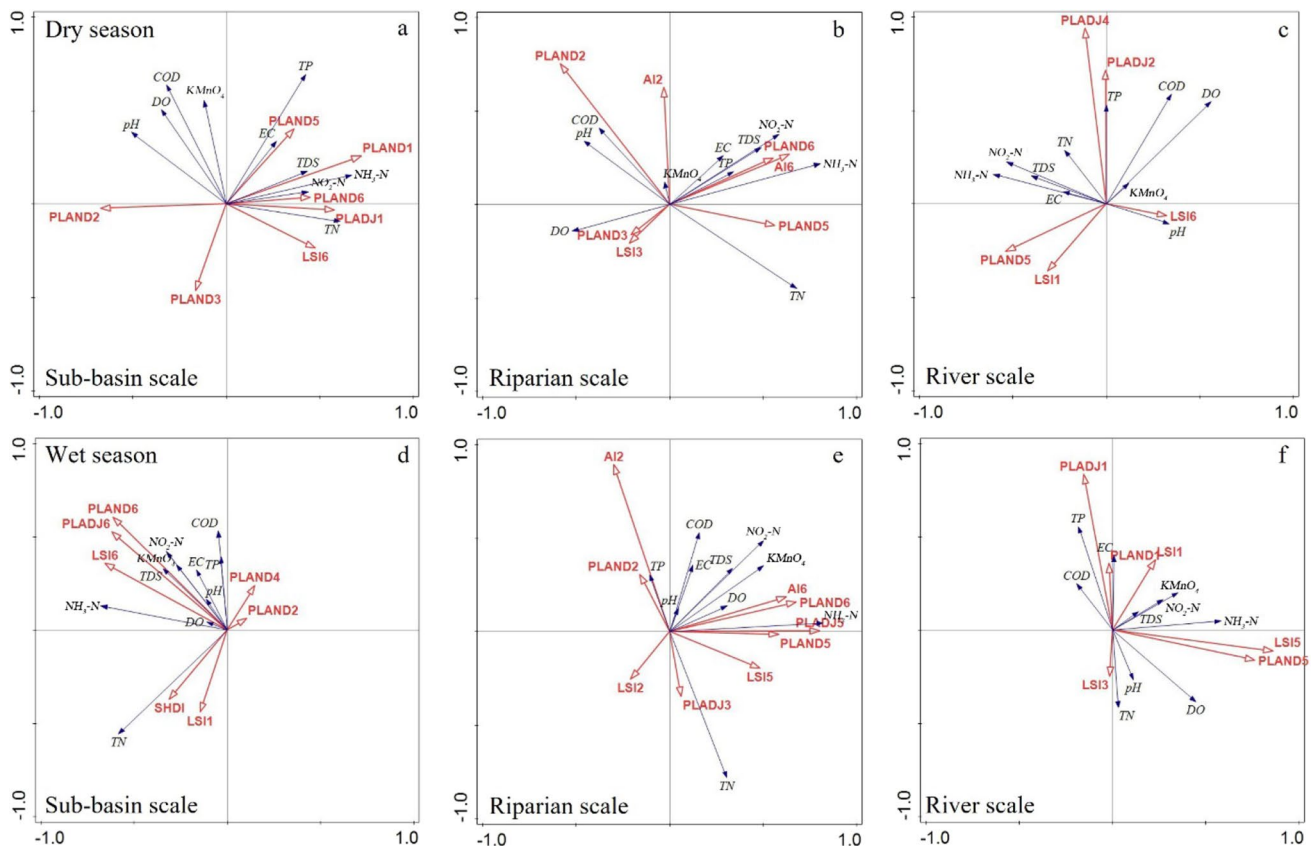

Fig. 6 RDA analysis of water quality indexes and land use types in different scales. The RDA analysis was carried out at three scales: watershed (**a**, **d**), riparian zone (**b**, **e**), and river (**c**, **f**)

Different water quality variables showed different characteristics at each scale (Table 3). In the dry season, the basin scale was the best scale model for EC, NH_3-N, NO_2-N, and TDS; the riparian zone scale was the best scale model for DO, $KMnO_4$, and TP, and the river scale was the best scale model for pH and TN. In the wet season, the best scale model for NO_2-N changed to the basin scale. The best scale model for both TDS and NH_3-N changed to the riparian zone scale.

Analysis of the impact of topographic factors on water quality

The slope directly or indirectly affects the change process of water quality (Tran et al. 2010; Xiong and Wang 2022). We choose the sub-basin scale and the riparian scale to quantify the relationship between slope and water quality in order to better explain the factors affecting watershed water quality (Table 4). At the sub-basin scale, TN, TP, NH_3-N, $KMnO_4$, and NO_2-N have a strong correlation with the steep slope areas of agricultural land, forestland, grassland, and barren land in the dry season. The slope directly affects the rate of water flow through the surface. As the slope increases, the increased rate of water flow can lead to soil erosion, resulting in the degradation of river water quality. At the same time, the steep slope areas have less vegetation cover and the roots have a reduced ability to adsorb pollutants, indirectly accelerating the rate of pollutants entering the river. The content of EC and TDS in rivers is affected by soil particle size. Generally speaking, larger soil particles carry more organic and inorganic matter, thus increasing TDS and EC in rivers. We found that EC and TDS showed a strong correlation with land use at different slopes, such as agricultural land, forestland, grassland, and urban land, suggesting that these land uses result in more soil particles entering the river (Allan 2004; Liu et al. 2021a). The correlation between slope and water quality variables is weaker in the wet season

than in the dry season, particularly for land uses with higher slopes. EC and NH_3-N were highly correlated with slope classes II and III for agricultural land, forestland, and grassland. TDS and NH_3-N were strongly correlated with classes II and IV for barren land, respectively. There was no correlation between other water quality variables and slope class. The above results indicate that the degree of influence of slope magnitude on water quality variables is diminished due to increased rainfall.

At the riparian zone scale, the correlation coefficients of water quality variables with slope were significantly weaker than the sub-basin scale (Table 5). In the dry season, NH_3-N, TN, and TP had a strong correlation with class I and class II slopes of agricultural land, forestland, and grassland. In the wet season, pH, EC, and DO were strongly correlated with the class I slope of agricultural land, grassland, and barren land, while TN, COD, and NO_2-N were negatively correlated with the class IV slope of agricultural land. It can be seen that the influence of land use on water quality variables at the riparian zone scale was predominantly exerted in flatter areas.

Discussion

Key landscape indicators affecting water quality variation

The landscape indicators that affected water quality parameters at different spatial scales were heterogeneous (Table 6). In the dry season, agricultural land (PLADJ) (B = − 0.615) had the most significant negative effect on pH. Agricultural activities produce large amounts of amines that make the soil alkaline, thereby affecting the pH of the river. Forest land (PLAND) (B = − 0.802) had a stronger effect on EC at the watershed scale. The forestland intercepts and retains dissolved substances in the hills and gullies, preventing

Table 3 Prediction results of the optimal scale of water quality parameters by MLR model in different seasons

Parameter In(x+1)	Dry season			Wet season		
	River scale	Riparian scale	Sub-basin scale	River scale	Riparian scale	Sub-basin scale
pH	**0.997**	–	–	0.741	**0.937**	0.389
EC	0.385	0.276	**0.616**	0.236	0.286	**0.589**
DO	0.368	**0.96**	0.502	**0.977**	0.824	0.839
$KMnO_4$	0.655	**0.984**	0.607	0.721	**0.759**	0.478
NH_3-N	–	0.86	**0.871**	0.194	**0.477**	0.22
TN	**0.411**	0.238	–	0.475	0.512	**0.715**
TP	**0.562**	0.322	–	0.301	0.28	**0.762**
COD	0.305	**0.587**	–	**0.972**	0.765	0.162
TDS	0.429	0.844	**0.936**	0.175	**0.922**	0.875
NO_2-N	0.569	0.437	**0.778**	0.298	0.413	**0.99**

Bolded: model with the highest adjusted R^2

Table 4 Correlation analysis between sub-basin scale slope and water quality parameters

Sub-basin	Agriculture land				Forestland				Grassland			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Dry season												
pH		0.315								0.341		
EC	0.614**	0.589				-0.302	-0.440	-0.419			-0.449	
DO	0.207	-0.290			0.322				0.467			
KMnO$_4$				-0.617*		-0.323	-0.643*				0.245	
NH$_3$-N			-0.298			-0.372	-0.667*			-0.375		
TN		0.362				-0.453	-0.544*			-0.427	-0.358	
TP			-0.408	-0.382	0.001	-0.259				-0.395	-0.418	-0.453*
COD			-0.347	-0.247	0.320					-0.213	-0.252	
TDS	0.610	0.687					-0.421	-0.526			-0.501	-0.566
NO$_2$-N		-0.311*	-0.314*		-0.447	-0.471*						
Wet season												
pH			-0.293					-0.254				
EC	0.642**					-0.343	-0.463		0.579	0.266		
DO	-0.333				-0.332							
KMnO$_4$				0.345		0.307						
NH$_3$-N		0.312	.517*			-0.337	-0.411			-0.313		
TN				-0.323								
TP		0.207								-0.207		
COD												
TDS												
NO$_2$-N						-0.394						

Sub-basin	Water				Urban land				Barren land			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Dry season												
pH										0.262		
EC			0.239			0.393		-0.609				
DO										-0.597		-0.658*
KMnO$_4$						0.485					0.632*	
NH$_3$-N		0.310					0.515*	0.523*			0.615**	0.572**
TN	0.373				0.487*						0.661	
TP	0.377				0.790**						0.550*	
COD		0.295										
TDS	0.258							0.575**		0.445*	0.659**	0.579**
NO$_2$-N	0.288	0.358					0.537*	0.448*		0.721**		0.665**
Wet season												
pH	-0.513					-0.234						
EC												
DO					-0.320							
KMnO$_4$								0.379				
NH$_3$-N												0.879**
TN												
TP												
COD												
TDS										0.552*		
NO$_2$-N												

Unlisted indexes fail to pass the $p < 0.05$ test

*means $p = 0.05$ is significantly correlated

**means $p = 0.01$ is significantly correlated

Table 5 Correlation analysis between riparian scale slope and water quality parameters

Riparian	Agriculture land				Forestland				Grassland			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Dry season												
pH									-0.207			
EC	0.529**				0.342							
DO		-0.336			0.377				0.305			
KMnO$_4$	0.426*				-0.306							
NH$_3$-N	0.280				-0.304	-0.232				-0.363		
TN	0.380					-0.423*						
TP	-0.282	-0.439*				-0.291			-0.442*	-0.348	-0.328	-0.346
COD		-0.293			0.464*	0.046						
TDS	0.354				0.050	-0.279						
NO$_2$-N	-0.338	-0.281			-0.328				-0.341			
Wet season												
pH	0.293*								0.255		0.315	
EC	0.517*											
DO	0.278*					0.336			0.267			
KMnO$_4$												
NH$_3$-N					-0.344					-0.297		
TN		-0.316				-0.251			-0.224			
TP						-0.290			-0.258			
COD		-0.434*							-0.407	-0.384		
TDS												
NO$_2$-N		-0.235				-0.289			-0.217	-0.370		

Riparian	Water				Urban land				Barren land			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Dry season												
pH												
EC	0.318								-0.342			
DO	0.250				-0.425*				-0.419*			
KMnO$_4$					0.293							
NH$_3$-N		-0.378			0.679**				0.435*	0.503*		
TN					0.456*				0.204	0.212		
TP												
COD												
TDS					0.307				0.621**			
NO$_2$-N					0.436*				0.448*			
Wet season												
pH												
EC		-0.425*										
DO					-0.505*							
KMnO$_4$												
NH$_3$-N												
TN												
TP												
COD					0.244							
TDS		-0.534*										
NO$_2$-N					0.460*				0.446*	0.582**		

Unlisted indexes fail to pass the $p < 0.05$ test

*means $p = 0.05$ is significantly correlated

**means $p = 0.01$ is significantly correlated

their transport along hydrological channels. This attenuates the effects of land use, reduces solutes in rivers, and ultimately results in lower conductivity levels (Walsh and Kunapo 2009). During the wet season, agricultural land (PLAND) significantly affected EC values; urban land (PLAND) (B = −0.668) had the most significant effect on

Table 6 The relative importance of the significant predictors in the best models

Parameter In($x+1$)	River scale			Riparian scale			Sub-basin scale		
	Significant predictors(B)	Adj. R^2	VIF	Significant predictors(B)	Adj. R^2	VIF	Significant predictors(B)	Adj. R^2	VIF
Dry season									
pH	**LSI6(0.539)**	0.657	1	PLAND2(0.533)	0.251	1	PLADJ1(−0.615)	0.35	1
EC	LSI2(0.207)	0.225	1.112	AI1(0.356)	0.301	1.011	**PLAND2(−0.802)**	0.67	1.201
DO	PLAND5(−0.567), LSI1(−0.775) PLADJ2(−0.415), PLADJ4(0.441)	0.618	1.266	**PLAND5(−0.668), AI6(−0.643)**	0.787	1	LSI6(−0.59)	0.319	1
KMnO$_4$	PLAND5(−0.511)	0.456	1	**PLAND2(−0.823), AI3(−0.612)**	0.602	1.311	AI2(−0.461)	0.415	1.029
NH$_3$-N	PLAND2(−0.455)	0.489	1.2	PLAND5(0.498), PLAND6(0.529)	0.535	1.048	**PLAND1(0.487), PLAND6(0.515)**	0.792	1.013
TN	**PLAND1(0.603)**	0.819	1.367	PLAND2(−0.616)	0.351	1.647	PLAND1(0.677)	0.434	1
TP	**PLADJ5(0.547)**	0.566	1	PLAND3(−0.535)	0.254	1.731	PLAND2(−0.467), PLAND3(−0.817)	0.741	1.026
COD	PLAND5(−0.373), PLADJ4(0.455)	0.341	1.027	**PLAND2(0.514), LSI5(−0.366)**	0.455	0.905	PLAND5(0.673), PLADJ1(−0.863)	0.358	1.835
TDS	LSI1(0.337)	0.287	1.085	PLAND6(0.755), AI2(0.421)	0.444	1.779	**PLAND6(0.588)**	0.316	1
NO$_2$-N	AI2(−0.455)	0.401	1.099	LSI3(−0.41), AI6(0.588)	0.378	1.651	**PLAND4(0.398), PLADJ6(0.559)**	0.307	1.057
Wet season									
pH	LSI3(0.437)	0.153	1	**PLADJ3(0.432)**	0.649	1	–	0.167	1
EC	PLAND2(−0.512)	0.398	1.211	AI2(−0.354), AI3(−0.298)	0.366	1.304	**PLAND1(0.785)**	0.809	1.001
DO	**PLAND5(0.451), AI2(−0.631)**	0.766	1	LSI5(0.557)	0.279	1	PLAND2(−0.410)	0.13	1
KMnO4	**PLAND5(0.59)**	0.467	1.011	PLAND2(−0.83), AI3(0.31)	0.689	1.128	PLADJ6(0.648)	0.394	1
NH3-N	**PLAND1(−1.180), LSI1(1.147) LSI5(0.562)**	0.494	1.069	PLAND5(0.347), PLAND6(0.74)	0.687	1.008	PLAND6(0.637)	0.379	1
TN	**PLAND2(−0.501)**	0.445	1.088	PLADJ5(0.413)	0.133	1	LSI1(0.449), SHDI(0.785)	0.696	1.185
TP	**AI2(0.412)**	0.347	1	PLAND2(−0.411), PLAND3(−0.502)	0.289	1.011	PLADJ1(0.614)	0.651	1.344
COD	**PLAND5(0.667)**	0.585	1.223	PLAND2(0.434)	0.151	1	PLAND6(1.038), LSI6(−0.772)	0.331	2.797
TDS	**PLAND2(−0.412)**	0.387	1.092	PLAND6(0.678), AI2(0.426)	0.353	1.192	PLAND6(0.472)	0.187	1
NO2-N	**PLADJ1(0.331)**	0.401	1.055	PLAND5(0.2), LSI2(−0.34) AI2(0.449), AI6(0.64)	0.611	1.127	PLAND4(0.475), PLAND6(0.604)	0.351	1.113

Unlisted indexes fail to pass the $p < 0.05$ test

*means $p = 0.05$ is significantly correlated

**means $p = 0.01$ is significantly correlated

Bolded: variable with the greatest absolute standard partial regression coefficient (B)

DO, as the waste produced by urban residents increases, as well as the organic waste load, and large amounts of oxygen are consumed through oxidation, resulting in lower DO values. In contrast, during the wet season, forestland (AI) ($B = −0.631$) had a more prominent effect than urban land, as rainfall events over large areas of forestland wash soil or

fallen leaves into the river, increasing the organic matter in it, and again reducing the DO values (Ding et al. 2016; Bo et al. 2017). In the dry season, the change of COD affected by agricultural land (PLAND) (B = 0.541) is positive. During this period, the application of fertilizers causes organic matter to flow into the river, increasing the consumption of oxygen in the water. In the wet season, COD was positively correlated with urban land (PLAND) (B = 0.667), as the discharge of urban sewage and wastewater increases the load on this parameter (Lee et al. 2009; Bu et al. 2014; Yu et al. 2016; Cheng et al. 2018). NH_3-N was positively correlated with water (LSI) (B = 0.446) in the dry season and with cities (PLAND) (B = 0.347) in the wet season. In general, the flow characteristics and self-purification capacity of the water bodies will degrade the pollutants in this process; thus, the rivers are negatively correlated with NH_3-N (Liu et al. 2018), but it has also been suggested that wetlands close to water bodies absorb pollutants such as NH_3-N, and the relationship between this compound and water bodies is complex (Shen et al. 2015). At the same time, wastewater treatment plants discharge a certain amount of pollutants into water bodies, causing NH_3-N to be positively correlated with town and city lands; TN was positively influenced by arable land (PLAND) (B = 0.603) and (LSI) (B = 0.449), due to the high use of urea in agricultural fertilizers, which has a high nitrogen content; and agricultural land use affected the TN input into the river. TP was significantly influenced by cities (PLADJ) (B = 0.547) in the dry season, and its concentration in rivers was affected by urban sewage and other reasons; in essence, TP concentration in rivers increases with the urbanization level. In contrast, TP was positively influenced by arable land (PLADJ) (B = 0.614) in the wet season, and the application of chemical fertilizer was the key factor in the variation of nitrogen and phosphorus contents.

Analysis on the influence mechanism of spatial scale change of land use on basin water quality

The riparian zone scale is better than the sub-basin scale in both dry and wet seasons (Table 2). Because it better explains the overall variation of river water quality, indicating that water quality pollution prevention and control depend to some extent on regional management. The research conclusion is consistent with the results of other scholars (Gove et al. 2001; Buck et al. 2004; King et al. 2005). The MLR model revealed that different water quality parameters did not respond to the same extent to large and local scale factors, while some parameters varied consistently at different scales in different seasons such as EC and $KMnO_4$. The sub-basin scale could better explain the changes in EC, while the riparian zone scale could explain the changes in $KMnO_4$. In the wet season, the sub-basin scale better reflected the transformation processes of

pollutants such as TN, TP, and NO_2-N, indicating that, at large scales, the main sources of these compounds are nonpoint sources and that surface runoff and erosion play a key role in the loss of organic matter and hydrological transformation processes in the basin (Allan 2004; Dodds and Oakes 2008). At the riparian zone scale, the variation of NH_3-N can be better explained in the wet season, during which the riparian zone can effectively immobilize N and exert an inverse effect on it in the river water. In contrast, the dry season can reflect the variability of DO and TDS. In summary, as different biogeochemical processes occur under different conditions (Strayer et al. 2003), the optimal scales for each water quality indicator are therefore different. These complex scale effects also highlight the fact that selecting an optimal scale to control water quality changes is highly challenging, and water environment control and protection with land use planning should be carried out using a multiscale perspective.

Effect analysis of slope change on basin water quality

Topographic features, which determine the flow of pollutants from nonpoint sources to rivers, have been identified in previous studies as important factors affecting how land use influences basin water quality (Wang et al. 2015). The studies have shown that the change in slope size on the water quality of the basin was also affected by seasonal variation. In the WRB, the correlation with water quality was stronger during the dry season, with forestland, grassland, and urban land being the dominant land uses. In the dry season, the pathways of pollutant discharge represent a key factor in the significant correlation observed between urbanization and water quality, and urban land is generally considered to be the main source of pollution. Precipitation possibly diluted the discharged wastewater to some extent, leading to the weaker correlation between urban land and water quality observed in the wet season.

The greater the slope at the basin scale, the stronger the correlation and water quality variables. Slope can be used as a parameter for the rate of water flow over the surface, and usually, water quality is positively correlated with the slope coefficient. In addition, as the slope increases, the rate of water flow increases as well, leading to soil erosion exceeding the rate of pollutants and further increasing the risk of water quality degradation. However, the forestland slope coefficient is negatively correlated with water quality variables, and at lower slopes, forestland can act as a sink and intercept pollutants. In contrast, at the riparian zone scale, water quality variables are significantly correlated with lower slope coefficients, because the land type in flat areas is generally urban or agricultural land. The steeper forestland is more likely to accumulate and discharged pollutants,

leading to water quality degradation. The deviations in slope coefficients at the two scales have different effects on water quality variables, mainly because the water flow at the watershed scale is in contact with vegetation for a longer period of time, thus increasing the effectiveness of filtered nutrients in the runoff. Therefore, attention needs to be paid to the degree of influence of slope on basin water quality.

Prevention and control of regional pollution in river basins

The study area covers a wide range. The topographic features of different regions are different. The urban development and population density levels are inconsistent. For water quality protection and control, the scale effect of space and season should be considered comprehensively. The WRB, with its dense urban agglomerations, has a high degree of river development and a large area of agricultural land. In the wet season, chemical fertilizer application in agricultural activities is the main source of pollution, while in the dry season, the pollution source is the discharge of industrial wastewater and domestic sewage from urban agglomerations, with the most significant impact visible at the riparian zone scale. Therefore, it is suggested that the basin water quality management in the WRB should pay attention to spatial scale planning. The water quality protection measures in the riparian zone should be taken as the focus, such as increasing vegetation cover near agricultural activities and river channels and planting riparian vegetation, to ensure that the discharge of sewage and wastewater meets the appropriate discharge standards.

The BLR and JHR are located in the Loess Plateau erosion area, and the vegetation cover in their basins mitigates the impact of land use on water quality to some extent. The size, aggregation, and landscape shape of forestlands and grasslands will reduce the surface runoff carrying nutrient salts into the river caused by rainfall flushing. At the same time, slope is also an important factor affecting the influence of land use on basin water quality. The terrain of the BLR and JHR basins is complex, and it comprises both plains and mountains. In the mountainous regions of the basins, it is possible to reduce nutrient and organic concentration and alleviate the impact of soil erosion on rivers by maintaining a certain extent of grassland and forest area, whereas in the plain areas, the development of cluster agriculture, rational fertilization, and the use of vegetation buffers along riverbanks can contribute to the improvement of basin water quality to a certain extent.

In summary, to preserve water quality in the WRB, which is subjected to rapid urbanization, it is necessary to focus on the sewage and wastewater discharge. In regions with high agricultural aggregation, the adoption of modern agricultural methods and rational fertilization represents management measures that can reduce non-point source pollution, whereas in mountainous areas affected by serious soil erosion, increasing vegetation coverage can effectively reduce the negative impact on water quality. In essence, the water quality management of the WRB should focus on the landscape planning of riparian zones, which can better develop the river and build a healthy watershed ecosystem.

Conclusions

For the WRB, which is affected by both natural factors and human disturbances, exploring the relationship between river water quality and spatial-seasonal variations in land use and slope can provide support for water ecology conservation. The results of the present study show that there is a significant correlation between land use types and river water quality in the WRB. Water quality changes depend on seasonal, multi-spatial scale, and landscape indicators. The impact of land use type on water quality variables is stronger in the dry season than in the wet season. The riparian zone scale can better explain the variation characteristics of water quality parameters in wet and dry seasons. The study found that slope and land use have significant effects on river water quality, and there are seasonal variations. We suggest that water quality management in the WRB should focus on riparian zone scale landscape planning. At the same time, exploring the spatial effects and seasonal variations of different landscape features on river water quality can identify the main factors affecting river water quality under different spatial and temporal conditions. Sub-regional management of water pollution prevention and control can be achieved.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval Not applicable.

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