Spatial evaluation of land use variability on water quality of the Densu Basin, Ghana

Rita Akosua Anima Gyimah, Anthony Yaw Karikari, Charles Gyamfi, Patricia Asantewaa-Tannor and Geophrey Kwame Anornu

ABSTRACT

The effect of different land use types on the physicochemical water quality of a semi-arid coastal basin is examined. From nine sites, a comprehensive sampling campaign was executed during October 2018 to January 2019. One-way analysis of variance (ANOVA), Pearson correlation and multiple regression analyses were used to determine the relationship between water quality characteristics and land use types at the sub-basin and buffer-zone scales. The one-way ANOVA test indicated that most of the parameters are significantly different ($p < 0.05$) among the sampling sites with the exception of pH, total hardness (TH), nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), dissolved oxygen (DO), chemical oxygen demand (COD) and iron (Fe). Agriculture and built-up/bare land had a positive relationship with turbidity, TSS, conductivity and Fe within 50 m and 150 m buffer zones. Built-up/bare land showed a positive relationship with turbidity, TSS and Cl at the sub-basin scale. Forest cover correlated negatively with water quality although not significantly. Grassland correlated significantly with temperature, Cl and total hardness. Results of the multiple regression analysis indicate that land use types within the riparian buffer zones had greater impact on water quality than at the sub-basin scale. This work provides essential information for land use planners and water managers towards sustainable water resources management.

Key words | Densu Basin, multiple regression analysis, physicochemical parameters, riparian buffer

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HIGHLIGHTS

- The effects of land use variability on water quality of a coastal basin have been examined.
- High TSS and nitrate concentrations found in the Densu River.
- Built-up and agricultural fields strongly identified as pollution sources.
- Land uses at riparian buffer zone have greater influence on water quality.
- Dynamics of water quality variation is influenced by multi-spatial scales.

INTRODUCTION

On the global scale many rivers are experiencing deteriorating water quality as a result of activities within their catchments. The nature of rivers on a land surface is mostly reflected by the effect of several activities along their pathways. Among other factors, the relationship between landscape characteristics and surface water quality is influenced by urbanisation, population increase and agricultural activities with tendencies of altering the ecological health of water systems (Lintern *et al.* 2017). Contemporary

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studies allude to the impacts of land use on water quality (Yu *et al.* 2016; de Mello *et al.* 2018; Xu *et al.* 2019). Generally, built-up/ bare-land and agricultural land uses are mostly associated with organic pollution, heavy metals and nutrients (Lee *et al.* 2009; Bu *et al.* 2014; Yadav *et al.* 2019). On the other hand, forest cover is observed to have an inverse relationship with degraded water quality and is thus deemed to be a good predictor for reducing the deteriorating nature of water quality (Sliva & Williams 2001; Tu 2011; Wang *et al.* 2014; Gyamfi *et al.* 2016a). In exploring the link between land uses and water quality, researchers have adopted diverse statistical techniques inclusive of multivariate methods, linear models and redundancy approaches. For example, de Mello *et al.* (2018) studied the effects of land use and land cover on the quality of low-order streams in southern Brazil using multivariate and linear mixed models. From their work, it was concluded that agricultural and urban areas contribute to water quality degradation while forest cover plays an important role in keeping the water clean. Namugize *et al.* (2018) used Pearson correlation to determine the effects of land-use and land-cover changes on water quality in the uMngeni river in South Africa. From the results, built-up/urban areas within the sub-catchments positively correlated with NH_4, NO_3, TSS, and TP, an indication of high pollution levels. Characteristically, the relationship between land use and water quality varies significantly over space and geographic locations mainly due to the different catchment physiognomies and pollution sources (Tu 2011). Moreover, some studies are of the view that land use on riparian-buffer scale influences water quality better than on a catchment scale (Tran *et al.* 2010; Shi *et al.* 2017), while others are also of the view that catchment scale better influences the water quality (Ding *et al.* 2016; Zhang *et al.* 2019).

The Densu River is one of the most important river systems in Ghana and provides several benefits to humans and the ecosystem. Diverse anthropogenic activities within the basin have caused land use cover changes and have predisposed the basin to a number of pollution challenges (Gyimah *et al.* 2020). Several studies carried out in the basin have used mathematical models and theories to evaluate the pollutant loadings from point and non-point sources (Karikari & Ansa-Asare 2006; Asante *et al.* 2008; Fianko *et al.* 2010; Osei *et al.* 2010) with none too little focus on the relationship between spatial distributions of land use types and water quality. In the era of Integrated Water Resources Management, it is imperative to consider land use planning in water quality monitoring and compliance frameworks (Mantey *et al.* 2011; Antwi-Agyakwa 2014). It is imperative therefore to integrate Geographic Information Systems (GIS) and statistical techniques in unravelling the impacts of land use spatial variability on water quality with the view of enhancing water resources management (Mainali & Chang 2018; Kimengich *et al.* 2019).

To this end, the study seeks to investigate the spatial variation of physicochemical parameters and land use types of the Densu River and subsequently evaluate the complex relationship between land use and water quality parameters at the sub-basin and buffer-zone scales. This study will help explore the impact of land use and landscape pattern on water quality and also inform water resources managers to target appropriate scales for the improvement of water quality.

MATERIALS AND METHODS

Study area

The Densu River Basin (DRB), one of the coastal basins in Ghana, is under focus in this study (Figure 1). The DRB with an estimated drainage area of 2,490 km^2 and length of 160 km takes its source from the Atewa forest range and meanders downwards into the Weija Reservoir, and flows finally into the sea. The water resources contribute to the economic livelihood of the people living within the basin. Agriculture is one of the main economic activities within the basin especially in the rural areas. Most people practice both commercial and subsistence farming. The majority of the farmers practice slash and burn as traditional bush fallow, which amounts to deforestation in the basin (WRC 2007). Koforidua and Nsawam are the two most populated urban settings within the DRB with estimated populations of 146,473 and 44,738 respectively, projected from 2010 data (Ghana Statistical Service 2010). The average temperature is about 27 °C with mean annual precipitation of about 1,600 mm–1,700 mm at the upstream and 800 mm–900 mm downstream (WRC 2007). The mean annual runoff of the total basin is about 280 million m^3

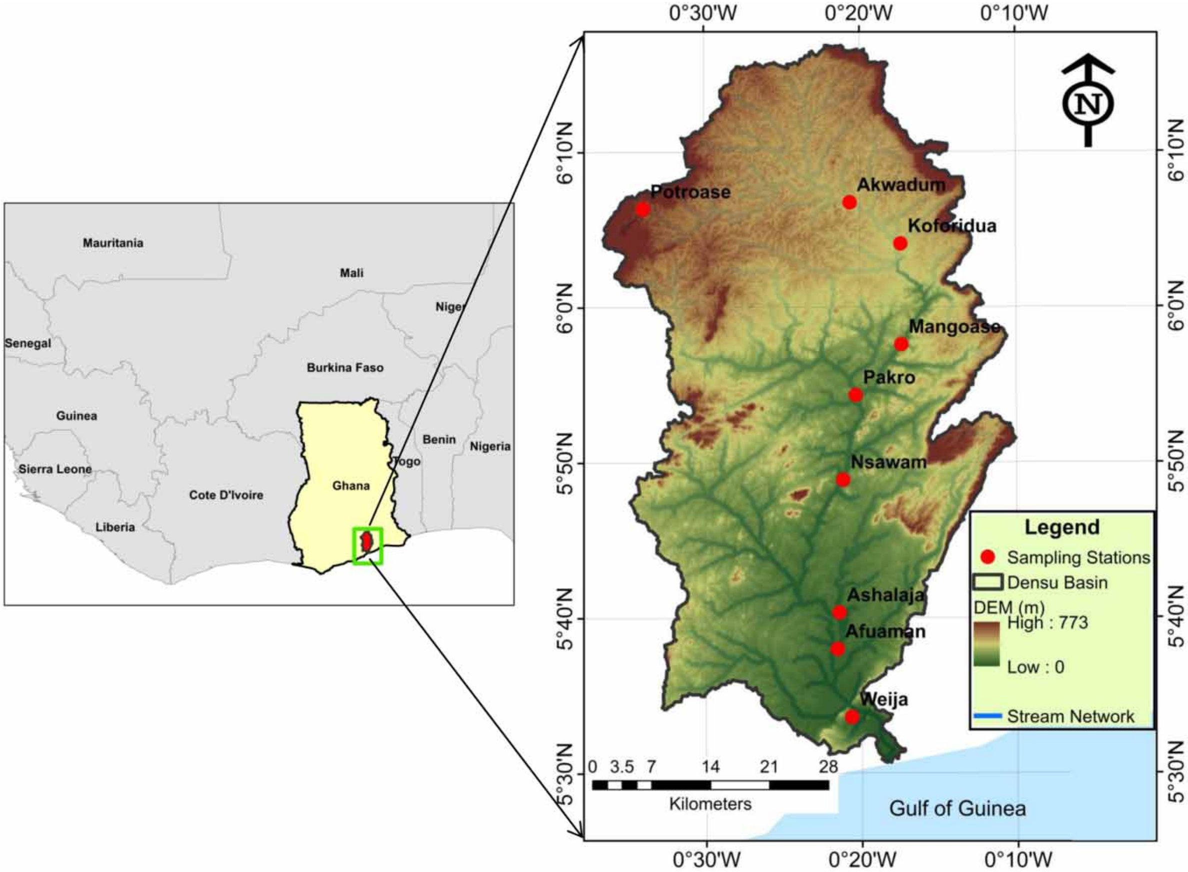

Figure 1 | Map of Densu River Basin showing drainage network and sampling sites.

(WRC 2007). The geological formation of the basin is comprised mainly of upper and middle Birimian rocks and the Togo series. Three major soil groups, namely Togo soils, Granite soils and Birimian soils, are found in the basin (Alfa *et al.* 2011).

Sampling framework and water quality analysis

Water samples were collected at nine sampling points along the Densu River. These points were selected based on their different land use types within the basin. The river was sampled once every month from October 2018 to January 2019. Duplicate samples were taken at each station, between the hours of 6:00–10:00 a.m., at a depth of 15–20 cm. Sampling bottles were soaked in nitric acid and rinsed with distilled water before sampling. The samples were analysed for conductivity (Cond), turbidity (Turb), total suspended solids (TSS), pH, total dissolved solids (TDS), temperature (Temp), total hardness (TH), sodium (Na), chloride (Cl), nitrate-nitrogen (NO_3-N), phosphate (PO_4-P), ammonia-nitrogen (NH_3-N), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD_5) and iron (Fe). Temperature and conductivity were measured in-situ with a WAGTECH (Micro 600) conductivity meter. Measurement of pH was done by using a pH 3000 series multi-parameter (Eutech Instruments, Singapore). Turbidity and TSS were measured with a HACH 5200 turbidimeter. Nitrate-nitrogen was measured using the hydrazine reduction method and PO_4-P was determined using the stannous chloride method. Alkalinity was determined using the strong acid titration method. Ammonia-nitrogen was determined using the direct nesslerisation method. Chloride were measured using the argentometric method. The EDTA titration method was used to determine total hardness. COD was determined with the closed tube reflux method. BOD_5 was determined using the dilution method by using five day incubation at 20 °C followed by DO determination. DO was determined by using the azide modification of the Winkler method. All measurements followed *Standard Methods for the Examination of Water and Wastewater* (APHA 2012). Quality control measures were done by calibrating all the instruments before use in the field and the laboratory. Blanks and quality control sample analyses were performed on the samples for quality assurance purposes. The laboratory analyses were done in duplicate and the mean values recorded. Ionic error balance was checked from the analytical results and >10% ionic balance error was rejected.

Land cover analysis

Landsat 8 satellite image for 2018 was obtained from the United States Geological Survey (USGS Earth Explorer). Maximum likelihood classification was used for supervised classification. Samples were trained based on their spectral reflectance and field references including Google maps and Bing maps. Five land use types (i.e. agriculture, forest, grassland, built-up/bare land and water bodies) were categorised based on the field references from Google maps and the reconnaissance survey. Anderson's level 1 classification scheme was adopted in this study for the land use classification (Table 1). The land use types were forest, agriculture, grassland, and built up/bare land; water bodies including rivers, lakes and wetlands were also captured in the classification. The overall accuracy of the classified image was 80% with a kappa coefficient of 0.86. Buffer widths of 50 and 150 m were created from the stream network at each water quality monitoring site. The buffer zone widths were selected based on the recommended Design Standards for Riparian Buffer Zones in Ghana. This procedure was performed to compare the influence of land use on water quality both at the sub-basin scale and the various buffer scales. Aster DEM data with 30 m × 30 m resolution was used for the delineation of the Densu Basin. For catchment delineation, the Wang and Liu algorithm (Wang & Liu 2006) was used in identifying and filling surface depressions in the DEM. Subsequently, the processed DEM was used in the Soil and Water Assessment Tool (SWAT) employing the automatic catchment delineator, to extract the sub-catchments of the Densu Basin. Random samples of the various types of land uses were collected through ground-truthing and Google visual observations to aid in the land cover classification and validation process.

Table 1 | Land-use classification scheme after Anderson *et al.* (1976)

Land cover class	Description
Grassland	Herbaceous, shrub and bush and mixed rangeland
Water	Lakes, reservoirs, streams
Agriculture	Crop fields and pastures
Forest	Deciduous, commercial and mixed forest
Built-up	Residential, commercial services, industrial, transportation, communication, mixed urban or built-up lands

Statistical analysis

One-way analysis of variance (ANOVA) with post hoc test was used to determine the differences in water quality among the sampling sites at a significance level of 0.05. The Kolmogorov–Smirnov goodness-of-fit test (K-S test) was used to examine the characteristics of the distribution inherent in the water quality and land use variables. Non-normal variables were log-transformed to get the distribution closer to normal before the ANOVA analysis was carried out.

The relationship between land use and water quality was performed with multiple regression analysis and Pearson correlation. The correlation analysis developed a correlation matrix between the land use types and water quality in order to determine the type of interaction between them. Moreover, the multiple regression analysis explained the magnitude and influence of the land use (predictor variables) on water quality parameters (response variables). The statistical analysis was performed at two buffer scales (i.e. 50 m and 150 m) and also at the sub-basin level (Figure 2). Stronger positive correlation showed values closer to 1 and those closer to −1 showed a stronger negative correlation between variables. Factor analyses were used to determine the pollution factors affecting the water quality among the sampling sites. According to Liu *et al.* (2015), factor loading value >0.75 is described as 'strong' loading, 0.75–0.50 is 'moderate' and 0.50–030 is described

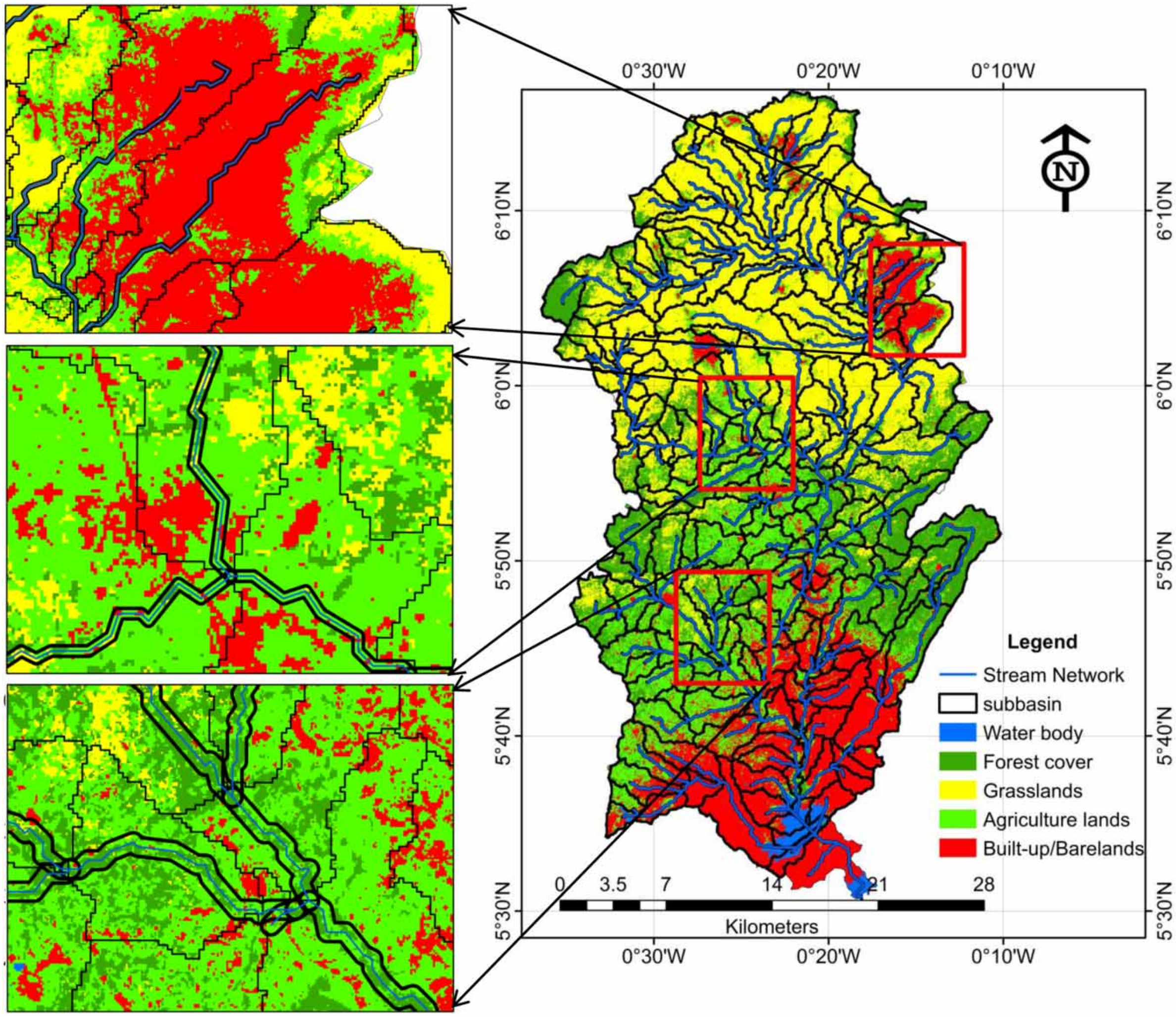

Figure 2 | Land use classification of the Densu Basin showing the riparian buffer zones and the sub-basins.

as 'weak'. Water quality was initially standardised with z-scale transformation. Kaiser–Meyer–Olkin (KMO) and Bartlett's sphericity tests were performed to determine the adequacy of the water quality data for the analysis. The analysis was performed using SPSS 25.

RESULTS AND DISCUSSION

Spatial variation of water quality and land use characteristics

Physicochemical parameters of water samples were analysed using descriptive analysis. Mean and standard deviation values at different sampling sites are presented in Table 2. The K-S test of normality is presented in Table 3. Variables with significant test ($p < 0.05$) indicated that the data were not normally distributed whereas those with less significant test ($p > 0.05$) showed a normal distribution of the variable. Subsequently, non-normal variables (i.e. pH, forest and grassland) were log-transformed. One-way ANOVA test indicated that most of the parameters are significantly different ($p < 0.05$) among the sampling sites with the exception of pH, TH, NO$_3$-N, NH$_3$-N, DO, COD and Fe. The correlation matrix from Table 4 indicates high positive correlation between conductivity, turbidity, TSS, PO$_4$-P, temperature, Na, Cl and TDS. These parameters indicate the main contaminants within the basin. High

Table 2 | Descriptive analysis of physicochemical parameters at different sampling sites

	WEIJA	ASHALAJA	AFUAMAN	NSAWAM	PAKRO	MANGOASE	AKWADUM	KOFORIDUA	POTROASE
pH	8.1 ± 0.3	7.8 ± 0.3	7.6 ± 0.2	8.1 ± 0.5	7.8 ± 0.4	7.8 ± 0.2	7.8 ± 0.3	7.8 ± 0.2	7.7 ± 0.3
Cond (μS/cm)	305 ± 40.6	410 ± 169	493 ± 243	414 ± 46.2	399 ± 164	372 ± 163	234 ± 29	247 ± 38.5	189 ± 27.5
Turb (NTU)	15.5 ± 7.5	44.8 ± 24.7	40.8 ± 5.6	51.3 ± 30.6	34.3 ± 11.9	23.5 ± 16.9	19.3 ± 8.6	17.0 ± 9.8	8.3 ± 4.3
TSS (mg/L)	16.3 ± 8.3	44.5 ± 18.0	37.5 ± 6.6	45.3 ± 25.5	33.3 ± 12.7	27.0 ± 16.2	17.8 ± 6.2	15.3 ± 5.7	9.3 ± 5.4
Temp (°C)	29.7 ± 0.4	28.3 ± 0.7	29.6 ± 0.7	28.1 ± 1.2	28.6 ± 0.9	27.3 ± 1.6	26.7 ± 1.7	27.6 ± 1.3	25.1 ± 0.5
TDS (mg/L)	183 ± 24.3	246.0 ± 102	296 ± 146	248 ± 27.7	239 ± 98.4	223. ± 98.3	141 ± 17.3	148 ± 23.1	113 ± 16.5
TH (mg/L)	92.3 ± 14	123.3 ± 46.4	140 ± 54.3	115 ± 2.2	128 ± 46.3	121 ± 42.5	93.5 ± 8.9	97.4 ± 11.1	69.7 ± 6.6
Na (mg/L)	30.1 ± 4.1	37.9 ± 15.0	49.5 ± 29.8	36.3 ± 6.8	38.0 ± 16.1	34.3 ± 19.7	16.1 ± 3.9	15.9 ± 0.8	11.7 ± 1.9
Cl (mg/L)	29.5 ± 7.4	36.1 ± 20.9	52.8 ± 36.4	28.6 ± 8.9	29.8 ± 14.0	26.1 ± 16.1	15.5 ± 1.9	14.8 ± 3.8	12.8 ± 2.7
NO_3-N (mg/L)	0.04 ± 0.03	0.03 ± 0.02	0.03 ± 0.01	0.14 ± 0.17	0.06 ± 0.04	0.07 ± 0.02	0.04 ± 0.03	0.02 ± 0.02	0.04 ± 0.06
PO_4-P (mg/L)	0.1 ± 0.03	0.3 ± 0.04	0.2 ± 0.04	0.3 ± 0.2	0.3 ± 0.05	0.3 ± 0.1	0.1 ± 0.04	0.2 ± 0.03	0.1 ± 0.02
NH_3-N (mg/L)	0.4 ± 0.1	0.4 ± 0.1	0.3 ± 0.2	1.0 ± 0.3	0.5 ± 0.6	0.4 ± 0.3	0.8 ± 0.8	0.3 ± 0.2	0.3 ± 0.2
DO (mg/L)	7.1 ± 0.2	6.2 ± 1.2	6.3 ± 1.2	5.9 ± 2.9	7.9 ± 0.3	7.7 ± 0.6	6.6 ± 1.1	7.7 ± 1.3	6.0 ± 1.8
BOD (mg/L)	2.8 ± 1.1	1.0 ± 0.4	2.3 ± 0.5	3.7 ± 2.6	3.2 ± 0.9	3.2 ± 1.9	1.3 ± 1.1	2.9 ± 1.0	1.0 ± 0.7
COD (mg/L)	22.7 ± 2.6	29.0 ± 7.8	25.9 ± 7.9	28.1 ± 10.2	32.3 ± 2.1	25.6 ± 3.7	19.9 ± 10.9	28.5 ± 13.2	20.3 ± 6.1
Fe (mg/L)	0.1 ± 0.03	1.8 ± 1.4	1.4 ± 0.9	2.0 ± 1.0	1.6 ± 0.8	1.4 ± 1.1	1.3 ± 0.8	1.0 ± 0.9	0.7 ± 0.3

mean values of conductivity, TDS, TH, Na, and Cl were observed at Afuaman, which could be due to the sediment runoff from bare lands and agricultural fields or the leaching of ions from the soil beneath into the water. Lower values were observed at Potroase, which is located upstream the basin. A similar observation at Potroase has been reported by other studies (Karikari & Ansa-Asare 2006; Darko *et al.* 2013). A high concentration of NO_3-N (0.14 ± 0.17 mg/L), turbidity (51.3 ± 30.6 mg/L), TSS (45.3 ± 25.5 mg/L), and minimum DO concentration of 5.9 ± 2.9 mg/L were recorded at Nsawam. The sampling site is located near market communities and highly dense residential and agricultural fields, therefore sewage sludge, chemicals from fertilisers and sediment runoff may explain the high TSS and nitrate leaching into the Densu River. Fianko *et al.* (2009) reported similar findings at the same area. Also, phosphate showed a strong significant correlation with conductivity, turbidity, TSS, TDS, TH and NO_3-N. The observed correlation could be a good indication of nutrient and sediment leaching from agricultural fields and runoff from urban areas. Chemical oxygen demand (COD) significantly correlated with TH and PO_4-P, which indicates a high contribution of oxidizable organic and inorganic pollutants (Otukune & Biukwu 2005). Pakro recorded high COD concentration (32.3 ± 2.1 mg/L). Additionally, BOD significantly correlated with NO_3-N, which indicates the contribution of organic matter and nutrient enrichment from domestic and agricultural sources. Iron (Fe) showed high positive correlation with turbidity, TSS and PO_4-P.

The land use characteristics in Figure 3 indicate the proportion of land use types (i.e. built-up/bare land, agriculture, forest land, grassland and water body) within the 50 m buffer scale, 150 m buffer scale and the sub-basin of the nine sampling sites. Built-up/bare land and agricultural lands were the dominant land use at the downstream parts of the Densu River Basin. Within the 50 m buffer, built-up/bare land occupied the highest percentage area of 51% at Ashalaja. Agricultural lands occupied the highest percentage area of 54% and 47% at Nsawam and Afuaman, respectively. This could contribute to the high concentration of NO_3-N, turbidity, and TSS at Nsawam and conductivity, TDS, TH, Na, and Cl at Afuaman, respectively. Potroase and Pakro occupied the highest proportions of 74% and 55% of forest cover within the 50 m buffer. This could contribute to the low water quality values at Potroase. The dominant land use within the 150 m buffer was agricultural

Table 3 | The Kolmogorov–Smirnov test of normality for water quality parameters and land use characteristics

Water quality	**K-S test**	**Sig.**
pH	**0.290**	**0.028**
Cond	0.178	0.200*
Turb	0.181	0.200*
TSS	0.207	0.200*
Temp	0.113	0.200*
TDS	0.178	0.200*
TH	0.166	0.200*
Na	0.196	0.200*
Cl	0.199	0.200*
NO_3	0.253	0.101*
PO_4	0.225	0.200*
NH_3	0.257	0.088*
DO	0.199	0.200*
BOD	0.223	0.200*
COD	0.153	0.200*
Fe	0.185	0.200*
50 m buffer	**K-S test**	**Sig.**
Forest	**0.314**	**0.011**
Grassland	**0.519**	**0.000**
Built-up/bare land	0.253	0.100*
Agriculture	0.155	0.200*
150 m buffer	**K-S test**	**Sig.**
Forest	**0.243**	**0.002**
Grassland	**0.253**	**0.006**
Built-up/bare land	0.307	0.114*
Agriculture	0.181	0.200*
Sub-basin	**K-S test**	**Sig.**
Forest	**0.336**	**0.004**
Grassland	**0.321**	**0.008**
Built-up/bare land	0.253	0.100*
Agriculture	0.155	0.200*

*indicates normal distribution of data ($p > 0.05$), bold values indicate non-normal distribution.

land use, which was evidenced at Afuaman (58%), Ashalaja (51%), Nsawam (51%), and Koforidua (45%). This could influence the relatively high turbidity (44.8 ± 24.7 NTU; 51.3 ± 30.6 NTU) and PO_4 (0.3 ± 0.04 mg/L; 0.3 ± 0.2 mg/L) concentration at Ashalaja and Nsawam respectively, due to runoff from unconventional farming activities and soil erosion (Amoako *et al.* 2010). The percentage area of grassland was high at Akwadum (55%) and Mangoase (47%). The dominant land use at the sub-basin was built-up/bare land. Large proportions of built-up/bare land uses were found at Nsawam (85%), Ashalaja (85%), Afuaman (68%) and Weija (68%). This could be due to the increase in population and rate of urbanisation in these areas. Grassland was dominant at Mangoase (87%) and Akwadum (84%) and forest cover was dominant at Potroase (93%) and Pakro (50%).

Principal Component Analysis (PCA) in Table 5 shows extractions of four factors. Factor 1 accounted for 40% of the total variance in water quality parameters, with strong loadings of conductivity, temperature, total dissolved oxygen, total hardness, sodium and chloride. The concentration of these ions could be due to seawater intrusion from the sea. A similar result was reported by Osei *et al.* (2010). Factor 2 accounted for 27% of the total variance with strong factor loadings of phosphate (PO_4-P) and iron (Fe), which indicates human influence on the water quality, especially agricultural activities. Factor 3 accounted for 14.41% of the total variance in the water quality parameters and depicted high loadings of DO and BOD from domestic waste discharge. Factor 4 accounted for 12.90% of the total variance and showed strong loading of pH and ammonia (NH_3-N) from agricultural fields.

Relationship and influence of land use on water quality

The relationships between land-use and water quality at the buffer and sub-basin scales are presented in Table 6, using the Pearson correlation. The results explain that built-up/bare lands within the 50 m buffer showed a significant positive correlation with conductivity ($r = 0.68$, $p \leq 0.05$), turbidity ($r = 0.76$, $p \leq 0.05$), TSS ($r = 0.72$, $p \leq 0.05$), TDS ($r = 0.68$, $p \leq 0.05$) and Cl ($r = 0.71$, $p \leq 0.05$). Agriculture showed a significant positive correlation with turbidity ($r = 0.83$, $p \leq 0.01$), TSS ($r = 0.77$, $p \leq 0.05$) and Fe ($r = 0.82$, $p \leq 0.01$). Built-up/bare land within the 150 m buffer scale had high positive correlation with conductivity, turbidity, TSS, temperature, TDS and total hardness but this was not statistically significant. Agriculture showed significant positive correlation with turbidity ($r = 0.81$, $p \leq 0.01$), TSS ($r = 0.77$, $p \leq 0.05$) and Fe ($r = 0.80$,

Table 4 | Correlation analysis of water quality parameters at the Densu River Basin

	pH	COND	TURB	TSS	TEMP	TDS	TH	Na	Cl	NO_3-N	PO_4-P	NH_3-N	DO	BOD	COD	Fe
pH	1															
Cond (μS/cm)	0.015	1														
Turb (NTU)	0.183	.861**	1													
TSS (mg/L)	0.146	.889**	.987**	1												
Temp (°C)	0.361	.715*	0.502	0.500	1											
TDS (mg/L)	0.015	1.000**	.861**	.889**	.715*	1										
TH (mg/L)	− 0.121	.945**	.790*	.826**	0.657	.945**	1									
Na (mg/L)	0.031	.986**	.786*	.824**	.768*	.986**	.915**	1								
Cl (mg/L)	− 0.117	.914**	.686*	.709*	.773*	.914**	.822**	.942**	1							
NO_3-N (mg/L)	0.514	0.299	0.394	0.407	− 0.004	0.299	0.164	0.288	0.031	1						
PO_4-P (mg/L)	0.083	.783*	.827**	.853**	0.413	.783*	.873**	.697*	0.497	0.360	1					
NH_3-N (mg/L)	0.625	0.062	0.366	0.307	0.032	0.062	0.039	0.017	− 0.157	0.619	0.316	1				
DO (mg/L)	0.041	− 0.051	− 0.306	− 0.254	0.215	− 0.051	0.173	− 0.017	− 0.165	− 0.113	0.193	− 0.144	1			
BOD (mg/L)	0.524	0.393	0.276	0.255	0.473	0.393	0.387	0.381	0.166	0.535	0.470	0.283	0.501	1		
COD (mg/L)	0.135	0.617	0.639	0.654	0.477	0.617	.695*	0.557	0.379	0.166	.771*	0.030	0.387	0.514	1	
Fe (mg/L)	− 0.074	0.600	.823**	.820**	0.044	0.600	.669*	0.475	0.309	0.383	.875**	0.416	− 0.151	0.177	0.598	1

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

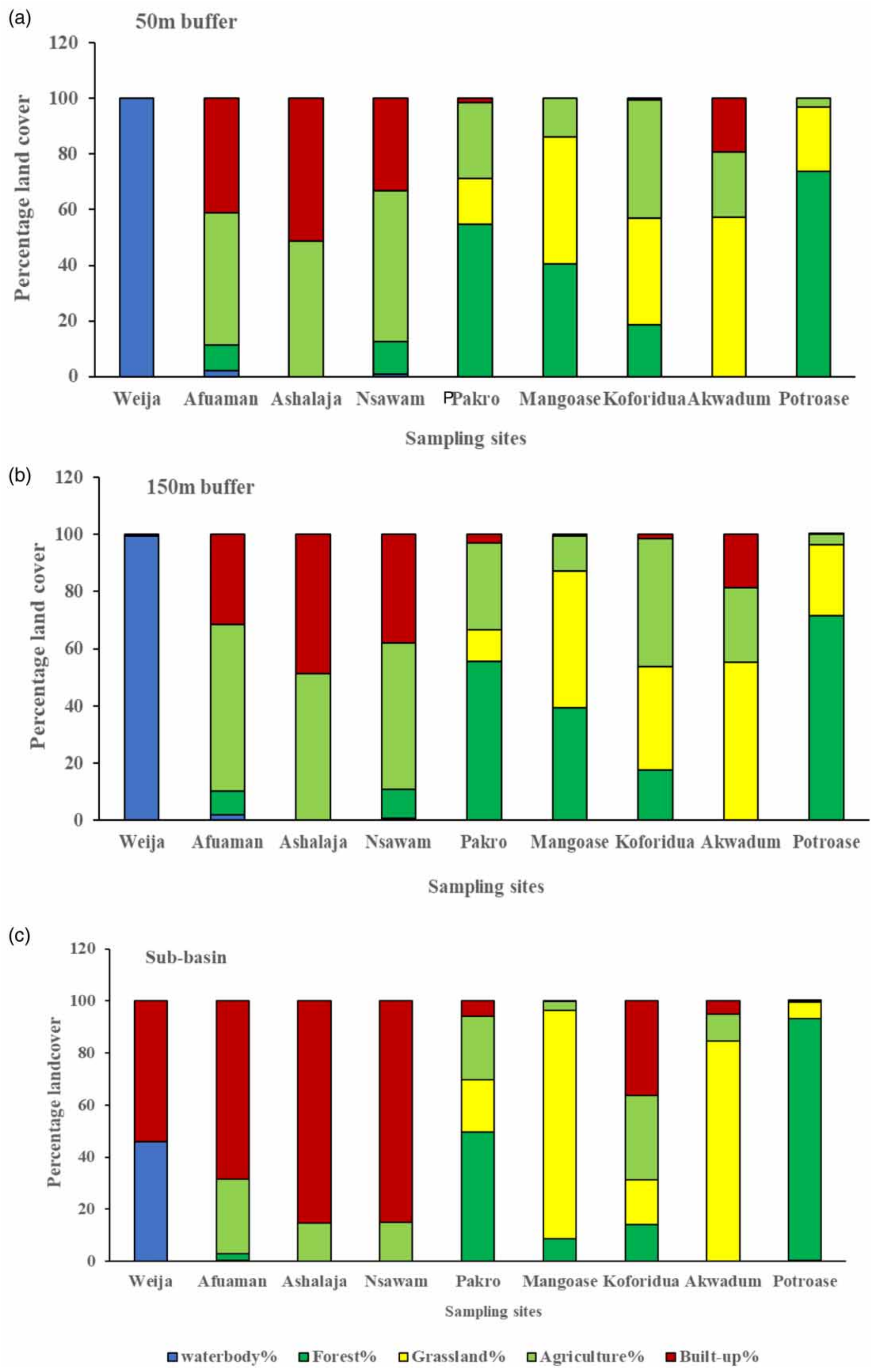

Figure 3 | Land use proportion among the sampling sites within (a) 50 m buffer, (b) 150 m buffer and (c) sub-basin scales of the DRB.

Table 5 | Factor scores of water quality parameters from principal component analysis

Parameters	Factor 1	Factor 2	Factor 3	Factor 4
pH	0.022	– 0.115	0.134	**0.934**
Cond (μS/cm)	**0.894**	0.431	0.057	0.011
Turb (NTU)	0.669	0.667	– 0.195	0.212
TSS (mg/L)	0.686	0.681	– 0.149	0.154
Temp (°C)	**0.897**	– 0.174	0.256	0.212
TDS (mg/L)	**0.894**	0.431	0.057	0.011
TH (mg/L)	**0.794**	0.514	0.206	– 0.142
Na (mg/L)	**0.93**	0.307	0.085	0.009
Cl (mg/L)	**0.973**	0.089	– 0.101	– 0.14
NO_3-N (mg/L)	0.05	0.662	0.496	0.383
PO_4-P (mg/L)	0.371	**0.822**	0.343	0.022
NH_3-N (mg/L)	– 0.113	0.444	– 0.28	**0.774**
DO (mg/L)	– 0.09	– 0.072	**0.938**	– 0.137
BOD (mg/L)	0.266	0.191	**0.704**	0.523
COD (mg/L)	0.429	0.585	0.509	– 0.037
Fe (mg/L)	0.232	**0.947**	– 0.145	0.017
Eigenvalue	6.2	4.3	2.3	2.1
% Variance	40	27	14	13
Cumulative %	40	66	80	93

Bold values indicate factor loading >0.75, which is described as 'strong' loading.

$p \leq 0.01$). At the sub-basin level, built-up/bare land had a significant positive correlation with turbidity ($r = 0.71$, $p \leq 0.05$), TSS ($r = 0.66$, $p \leq 0.05$), and Cl ($r = 0.69$, $p \leq 0.05$). Forest cover correlated negatively with water quality parameters at the different scales but this was not statistically significant. However, grassland had a significant negative correlation with temperature ($r = -0.73$, $p \leq 0.05$) and total hardness ($r = -0.67$, $p \leq 0.05$).

Several researchers have reported trends of the impact of urban, agricultural and forest land use on water quality (Sliva & Williams 2001; Ou *et al.* 2016; Gu *et al.* 2019; Yadav *et al.* 2019). For example, Yadav *et al.* (2019) revealed a positive correlation of total phosphorus (TP) with urban land use at both sub-basin and buffer-zone scale and attributed it to point sources such as treatment plants, domestic sewers, wastewater treatment plants and industries. In this study, built-up and agricultural land appeared to be the most important predictors of water quality variability at both the buffer-zone and sub-basin scales. The positive correlation between built-up/bare land and TDS, conductivity,

Table 6 | Results of Pearson correlation between land use types and water quality within the buffer zones and sub-basin scale of the sampling sites in the Densu Basin

	Forest	Grassland	Agriculture	Built-up/bare land
50 m buffer				
pH	– 0.409	– 0.383	– 0.022	– 0.136
Cond	– 0.091	– 0.559	0.581	**0.680***
Turb	– 0.185	– 0.503	**0.829****	**0.758***
TSS	– 0.082	– 0.505	**0.772***	**0.720***
Temp	– 0.463	– **0.729***	0.255	0.444
TDS	– 0.091	– 0.559	0.581	**0.680***
TH	– 0.042	– **0.665***	0.601	0.597
Na	– 0.066	– 0.540	0.469	0.605
Cl	– 0.193	– 0.436	0.461	**0.710***
NO_3-N	0.241	– 0.035	0.080	– 0.160
PO_4-P	– 0.019	– 0.573	0.635	0.488
NH_3-N	– 0.293	– 0.357	0.446	– 0.126
DO	0.195	– 0.414	– 0.406	– 0.480
BOD	– 0.168	– 0.499	– 0.011	– 0.029
COD	0.131	– 0.496	0.365	0.392
Fe	0.077	– 0.367	**0.820****	0.514
150 m buffer				
pH	– 0.368	– 0.304	– 0.079	0.165
Cond	– 0.316	– 0.589	0.570	0.524
Turb	– 0.337	– 0.605	**0.813****	0.596
TSS	– 0.286	– 0.592	**0.768****	0.500
Temp	– 0.644	– 0.576	0.264	0.524
TDS	– 0.316	– 0.589	0.570	0.524
TH	– 0.283	– 0.351	0.604	0.528
Na	– 0.297	– 0.637	0.463	0.435
Cl	– 0.403	– **0.681***	0.474	0.456
NO_3-N	0.133	– 0.266	– 0.029	0.191
PO_4-P	– 0.105	– 0.211	0.612	0.438
NH_3-N	– 0.113	– 0.187	0.362	0.286
DO	0.083	0.517	– 0.388	– 0.078
BOD	– 0.171	0.007	– 0.117	0.468
COD	– 0.106	– 0.186	0.396	0.411
Fe	– 0.016	– 0.134	**0.798****	0.443
Sub-basin				
pH	– 0.395	– 0.383	– 0.091	0.307
Cond	– 0.221	– 0.559	0.244	0.616
Turb	– 0.290	– 0.503	0.489	**0.713***
TSS	– 0.227	– 0.505	0.467	**0.663***

(*continued*)

Table 6 | continued

	Forest	Grassland	Agriculture	Built-up/bare land
Temp	– 0.511	**– 0.729***	0.101	0.587
TDS	– 0.221	– 0.559	0.244	0.616
TH	– 0.196	**– 0.665***	0.388	0.426
Na	– 0.190	– 0.540	0.174	0.602
Cl	– 0.281	– 0.436	0.150	**0.693***
NO_3-N	0.039	– 0.107	– 0.100	0.240
PO_4-P^-	– 0.077	– 0.573	0.413	0.294
NH_3-N	– 0.287	– 0.300	0.437	0.344
DO	0.137	– 0.414	– 0.093	– 0.621
BOD	– 0.165	– 0.499	– 0.289	0.020
COD	0.043	– 0.496	0.297	0.073
Fe	– 0.046	– 0.367	0.622	0.299

**indicates significance at $p \leq 0.01$ and *indicates significance at $p \leq 0.05$.

Table 7 | Results of multiple regression of the effect of land use on water quality at the buffer scales and sub-basin

Water quality (responses)	**Predictors**				
50 m buffer	**Forest**	**Grassland**	**Agriculture**	**Built-up/bare land**	R^2
Temperature		–			0.76
Turbidity			+	+	0.84
TSS			+	+	0.72
Fe			+		0.85
150 m buffer	**Forest**	**Grassland**	**Agriculture**	**Built-up/bare land**	R^2
Turbidity			+		0.74
TSS			+		0.59
Fe			+		0.64
Cl		–			0.47
Sub-basin	**Forest**	**Grassland**	**Agriculture**	**Built-up/bare land**	R^2
Temperature		–			0.60
Turbidity				+	0.62
TH		–			0.54
TSS				+	0.63
Cl				+	0.50

(+) indicates positive significant correlation ($p < 0.05$, $p < 0.01$) and (–) indicates negative significant correlation, blank space represents no correlation.

Cl, turbidity and TSS at both buffer zones and sub-basin are most likely to be ascribed to sediment runoff from construction sites, weathering of rocks and erosion from bare areas (Kusimi 2009). Road salts can be a great contributor to chlorides in receiving waters (Granato *et al.* 2015). The positive correlation between agricultural lands and turbidity, TSS and Fe at the 50 m and 150 m buffer zones could likely be attributed to the sediment runoff from loose soils on agricultural lands into the river (Lintern *et al.* 2017; Yadav *et al.* 2019). Forest and grassland depicted negative correlation with water quality parameters. This indicates that as forest land increases, degraded water quality decreases and vice-versa. According to Sliva & Williams (2001), vegetation can improve water quality deterioration by absorbing nutrients and blocking sediment runoff. Tu (2011) revealed similar results, indicating forest and grasslands as indicators for good water quality. One of the main effects of riparian forests on streams is shading, which influences water temperature and aquatic productivity (Sugimoto *et al.* 1997; Newton & Ice 2016).

Evaluation of the complex relationship between land use and water quality

There have been several reports on the complex relationship between land use types and water quality. Many researchers have debated whether the influence of land use on water quality at the buffer scale is more important than at the sub-basin level. Sliva & Williams (2001) reported that the correlation at the catchment scale was better than at the 100 m buffer scale. Other studies including Hunsaker & Levine (1995) indicated that 200 m or 400 m buffer strips are considered to better describe the influence of land use on water quality. Johnson *et al.* (1997) also reported that land use within a 100 m buffer has better influence on water quality than the whole catchment. Moreover, Chang (2008) indicated that the land cover and topographic factors at the riparian-buffer scale better explained the variations in BOD, COD, SS, TN and TP than the whole basin. This study used a multiple regression model to determine the effects of land use types on water quality at both buffer and sub-basin scales. The four land use types were regressed against the water quality parameters with significant correlation, with results summarised in Table 7. Turbidity ($R^2 = 0.84$), TSS ($R^2 = 0.72$), temperature ($R^2 = 0.76$) and Fe ($R^2 = 0.85$) were highly influenced by built-up/bare land and agricultural activities within the 50 m buffer zone. At the 150 m buffer, agriculture showed as a positive contributor to turbidity ($R^2 = 0.74$), TSS ($R^2 = 0.59$) and Fe ($R^2 = 0.64$). Grassland correlated with Cl ($R^2 = 0.47$), while forest cover did not show any significant correlation. At the sub-basin scale, turbidity ($R^2 = 0.62$), TSS ($R^2 = 0.63$) and Cl ($R^2 = 0.50$) were influenced by built-up/bare land. Total hardness ($R^2 = 0.54$) and temperature ($R^2 = 0.60$) were influenced by grassland. Comparing the correlation coefficient (R^2) of the response variables (water quality variables) at the different spatial scales, the water quality variable that had the highest multiple regression coefficient was turbidity ($R^2 = 0.84$) and was better correlated with the 50 m buffer zone. Hence it indicates the largest effect on water quality. This corresponds with results from several studies that suggested that land use within riparian buffer zones has greater impact on water quality than at the sub-catchment or catchment scales (Sliva & Williams 2001; Ou *et al.* 2016; Zhang *et al.* 2019). The influence of built-up/bare land and agricultural land use within the 50 m buffer indicates that anthropogenic activities contribute more pollution at the buffer-zone scale than at the sub-basin. Therefore, more management strategies should be given at different buffer-zone scales than in a whole-catchment scale approach.

Land use and water management strategies

The Densu River is one of the major rivers in Ghana, fundamental to water supply and food safety. Therefore, land use and water management measures should effectively be promoted to improve the catchment ecology and water quality. This study indicates the influence of both land use and landscape patterns on water quality. The wide distribution of forest cover and grassland at the upstream parts of the basin improved water quality while built-up/bare land and agricultural activities at the midstream and downstream parts led to water quality deterioration. Hydrologically, these land uses influence the degree of runoff generation (Gyamfi *et al.* 2016b; Kwarteng *et al.* 2020) which has the propensity to carry contaminants to the Densu River. According to WRC (2007), human activities have overwhelmingly impacted on the ecosystem, and there is total loss of riverine forest, and hence surface water resources are vulnerable to pollution. Damaged forest areas should be restored to support the water treatment capacity in the region. From the result, water quality is affected more greatly at the buffer-zone than at the sub-basin scale, and the primary proportion of land use types affecting water quality are built-up/bare land and agricultural land. These suggest that catchment management should incorporate and implement better land use planning to improve water quality within riparian buffer zones.

CONCLUSION AND RECOMMENDATION

We conclude that the water quality of the Densu River is not only affected by land use types but is also dependent on multi-spatial scales. Land use types within the river basin showed high correlation with water quality at both buffer and sub-basin scales. Turbidity, TSS, conductivity, Cl and TDS were better correlated with the 50 m and 150 m buffer scales due to the agricultural and domestic activities within the riparian buffer zones. Turbidity, TSS and Cl were better correlated with the sub-basin, which could also be from point and non-point sources of pollution such as leachate from landfills, septic system discharges, salt water influx and road construction. Forest was negatively correlated with water quality but not significantly. Grassland correlated significantly with temperature, Cl and total hardness. This indicates that grassland and forest lands are indicators for good water quality by reducing erosion, absorbing nutrients and also improving aquatic productivity. Comparing the influence of the three landscape metrics on water quality and turbidity indicates high correlation coefficients ($R^2 = 0.84$) and ($R^2 = 0.74$) at the 50 m buffer and 150 m buffer zones respectively, which explains that turbidity is highly influenced by activities within the buffer zones rather than at the sub-basin. Therefore, the influence of water quality at the sub-basins is slightly better than that within the riparian buffer zones. We also highlighted that human activities from point and non-point sources resulted in water quality deterioration, using principal component analysis. These findings and methods used could be useful to identify the sources of pollution and improve water management and land use planning within the basin. Due to the landscape effect on water quality, we recommend that land use planners and water managers should demonstrate Best Management

Practices at different spatial scales, especially at the riparian zones, rather than in a whole catchment management approach. Moreover agricultural activities, construction and residential areas within 50 and 150 m riparian buffers should be banned and relocated. Further investigations will require natural factors such as population, topography, soil and climate to deeply disclose the reasons for water quality variability within the watered. Also, further work will require both spatial and temporal sampling regime and high-resolution maps for the analysis.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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