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Influence of land use and land cover on the water quality of the Pinacanauan de Tuguegarao River: A multi-buffer zone analysis

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ABSTRACT

The study examined the influence of land use and land cover (LULC) on the water quality of the Pinacanauan de Tuguegarao (PdT) River, a designated Water Quality Management Area in northern Philippines. GIS and Pearson correlation analysis were used to determine the relationship between agriculture, forest, and built-up areas and water quality parameters using 500-m (n = 112), 1-km (n = 88), and 2-km (n = 64) buffer zones. Data used include focus group discussions (FGD), on-site visits, LULC from ESRI Sentinel-2 imagery with a 10-m resolution, and water quality monitoring results from the Environmental Management Bureau (EMB) Regional Office 2. The Kappa coefficient verified the accuracy of the processed LULC maps, ranging from 89% to 94%, indicating reliability for subsequent analyses. Results indicated that built-up areas exhibited positive correlations with nitrate, fecal coliform, TSS, BOD, temperature, and phosphate, and negative correlations with DO. These findings are consistent with the communities' perceptions and field observations, such as direct drainage and sewage discharge, quarrying activities, and improper waste disposal, all of which contribute significantly to the deterioration of water quality. In contrast, forested areas demonstrated a buffering effect, showing negative correlations with nitrate, fecal coliform, TSS, temperature, BOD, and phosphate and a positive correlation with DO. Moreover, agricultural lands displayed negative correlations with temperature, nitrate, and color and a positive correlation with DO, likely mitigated by the presence of riparian vegetation. The study underscores that land use intensity and spatial scale significantly affect the water quality of the PdT River.

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INTRODUCTION

Water pollution is one of the most pressing environmental issues globally due to declining water quality while the need for clean water continues to increase (WB, 2019; Tahiru *et al.*, 2020; Kumar *et al.*, 2024). Every nation is dealing with the effects of the degradation of water quality, which include aquatic ecosystems' gradual decline, reduced agricultural productivity, and the increase in healthcare costs (WB, 2019; WWF, 2023). In Southeast Asia, surface water bodies continue to degrade (ASEAN, 2017), which stresses sectors that depend heavily on clean water (USGS, 2018). Likewise, poorer water quality increases the spread of waterborne diseases (Lin et al., 2022), especially in areas with low economic profiles (Assegide *et al.*, 2022). The continued degradation of water quality slows down the economic growth of a country and can cause a loss of up to one-third (WB, 2019).

One of the primary causes of the decreased in surface water quality is land uses, which alter the runoff patterns, volume of pollutants, and the ability of the surface water body to filter the contaminants from various sources (Huang *et al.*, 2019; Clark *et al.*, 2022). Camara *et al.* (2019) presents the influence of urban, agricultural, and forest land use on surface water body conditions. Poorly managed effluents from settlements and agricultural runoffs discharging into the water bodies increase the levels of nutrients, pathogens, and chemical contaminants (UNESCO, 2018; Chen *et al.*, 2018; Namaalwa *et al.*, 2020). Poor management in agricultural areas tends to increase the level of sediments and nutrient concentrations in nearby waters due to surface runoff carrying soil particles and excess fertilizers (Carpenter *et al.*, 1998; Zhang *et al.*, 2022). Similarly, urban land uses increase the concentration of pollutants (Meyer and Paul, 2001; Walsh *et al.*, 2005; Gan *et al.*, 2021), which are mainly from untreated domestic and industrial wastewater (Giao, 2022). In contrast, maintaining vegetation cover contributes to a healthy ecological condition of surface waters (Uriarte *et al.*, 2011) by filtering runoff carrying pollutants before discharging into the streams (Tong and Chen, 2002; Bu *et al.*, 2014; Allan, 2004).

The quality of surface water continues to suffer with the increasing pressure on land resources (Camara *et al.*, 2019). According to the Global Environment Facility, the increasing population and rapid development put so much pressure on land resources, which are associated with weak land use planning and unsustainable land management practices. This scenario continues largely considering that rural areas depend heavily on natural resources for employment and other sources of livelihood (Ramirez *et al.*, 2019). In the Philippines, 33 million of its population are affected by the reduction of forest cover from around 90% in the 16th century to only about 23% at present because of extensive use of resources and land conversions (Camara *et al.*, 2019). One of the water bodies that was observed to be contaminated already is the Pinacanauan de Tuguegarao (PdT) River, a Water Quality Management Area (WQMA) and a tributary of the Cagayan River in the northern Philippines. Fecal coliform counts across 15 sampling stations were above the water quality guidelines (EMB, 2020), thereby declaring the PdT River as unsafe for recreation. Also, the PdT River recorded a high concentration of sediments (TSS), which can be linked to unsustainable agricultural and construction activities surrounding the water body (Calder, 2000; Newson, 1992).

Therefore, the study investigated the effects of agriculture, forests, and built-up areas on the key water quality parameters of the PdT River through a multi-buffer zone analysis. The outcome of the study is vital in making reasonable decisions and long-term management of the PdT River (Akram *et al.*, 2006). It informs and advises the PdT-WQMA Governing Board, agencies, local government units, communities, and institutions, which have a role in ensuring the healthy ecological status of the PdT River is maintained. Similarly, the study is significant considering that the Metro Tuguegarao Water District (MTWD) will be utilizing the surface water of the PdT River to increase its supply of domestic water. Furthermore, the study might also be applied to evaluate the current programs, projects, and other initiatives of agencies, LGUs, and communities in the PdT River.

MATERIALS AND METHODS

Study area

The PdT River is geographically located at 17°36'16.85"N, 121°43'47.90"E and passes through the municipalities of Peñablanca and Tuguegarao City in Cagayan province. The river is one of the tributaries of the Cagayan River and was designated as a WQMA in 2013. With its designation, the Environmental Management Bureau Regional Office 2 (EMB RO2) regularly monitors the water quality of the PdT River. Sampling stations are found on the downstream part of the river in Tuguegarao City (Stations 1 to 4) and the midstream and upstream parts in Peñablanca (Stations 5 to 15). Fig. 1 shows the location of the study area and sampling stations.

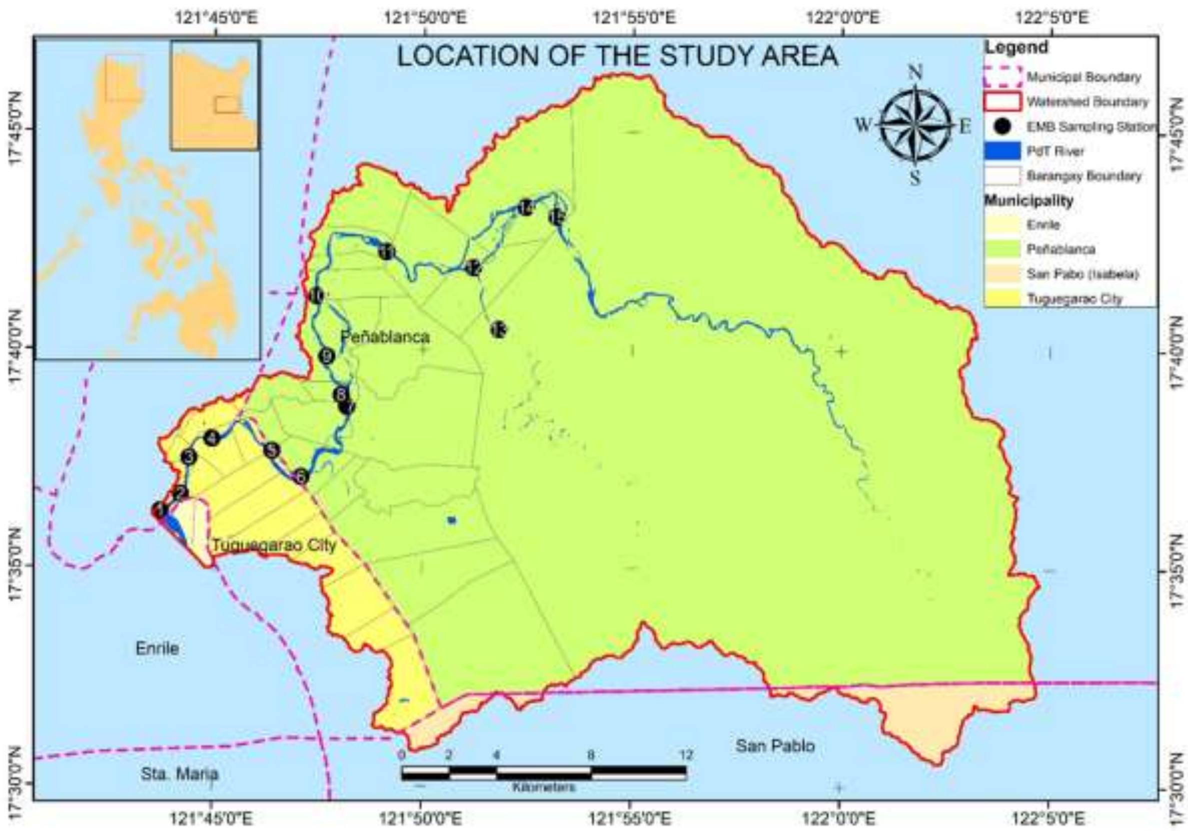

Fig. 1. Location of the Pinacanauan de Tuguegarao River

Data collection

The EMB RO2 provided the water quality data from 2017 to 2024, where the bureau constantly examined the water quality of the PdT River. Such datasets consist of the measurements of the physical parameters (color, temperature, and total suspended solids), chemical parameters (pH, dissolved oxygen, biochemical oxygen demand, nitrate, phosphate, and chloride), and microbiological fecal coliform data. Sampling stations were also provided with geographic coordinates.

For the land use and land cover (LULC) data, raster images of Sentinel-2 with a 10-m by 10-m resolution were accessed through the Environmental Systems Research Institute (ESRI) over the same 8-year span. Focus group discussions (FGD) were conducted in the upstream, midstream, and downstream of the river to have a clearer view of local experiences and practices. The monitoring stations were also visited to complement and confirm the numerical findings.

Data processing and analysis

For each water quality parameter and per station, the 8-year average and coefficient of variation (CV) were analyzed. The 8-year mean was calculated to identify which stations displayed relatively high or low pollution

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rates, along with the CV values to determine the extent to which the parameters varied between 2017 and 2024, as suggested by Gomez and Gomez (1984).

The Quantum Geographic Information System (QGIS) was used to process LULC maps. The raster datasets were categorized into five LULC classes that comprise water bodies, agricultural areas, forested areas, built-up areas, and barren land (Encisa-Garcia *et al.*, 2020). To test the validity of the classification that has been conducted, 100 random points were created every year between 2017 and 2024 within the watershed. Using these points, the Kappa coefficient for each year was calculated according to the principles of Landis and Koch (1977). Subsequently, spatial analyses were performed using only those maps that had a Kappa of greater than 81%. Each sampling station was then used to create 500-m, 1-km, and 2-km buffers (Fig. 2) following the natural flow of the water (Bo *et al.*, 2017; Zhang *et al.*, 2021; Yao *et al.*, 2024; Huang *et al.*, 2019). The established buffers provide the LULC composition necessary in the correlation analysis.

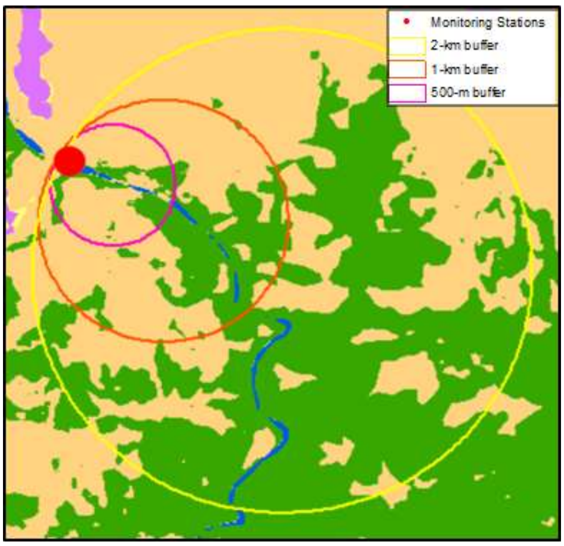

Fig. 2. Delineation of the buffer zones

Correlation analysis

The Pearson's correlation was used in the study to establish the linkage between land use and water quality. The strength and direction of the relationship were measured using the coefficient (*r*). Relatively, the significance of the relationship was determined using *p*-values that are below 0.05. A significant relationship indicates that the pattern could not have occurred out of random variation (Cohen, 1988). Using this method helps pinpoint the type of LULC with the strongest impact on the water quality condition (Kadir *et al.*, 2022; Cheng *et al.*, 2022; Kibena *et al.*, 2014). Information gathered during the FGD and ground observations supplemented the correlation findings.

RESULTS AND DISCUSSION

Study area

The downstream section of the PdT River, encompassing Stations 1–4 in Tuguegarao City, represents the urban areas. The midstream section (Stations 5–10) located in Peñablanca corresponds to the peri-urban zone, whereas the upstream portion (Stations 11–15) represents the rural areas of the river. In terms of land use, Stations 1–6 are predominantly settlement areas, Stations 7–10 are primarily agricultural zones interspersed with residential developments, while Stations 11–15 are characterized by a combination of agricultural, forested, and residential areas (Fig. 3).

Fig. 3. Locations of the sampling stations

Water quality

The variation in the physical water quality parameters across the PdT River seems to have a strong correlation with the nature of land use around each sampling station (Fig. 4).

Stations 1-6 recorded the highest TSS and temperature. Such trends are probably driven by increased surface runoff, soil erosion due to paved and impervious surfaces, and streams of domestic effluents into the river (Meyer and Paul, 2001; Akram *et al.*, 2006). At Stations 7-9, TSS was moderate, probably influenced by quarrying, surrounding farms, and mixed residential development (Huang *et al.*, 2019). At the same time, Stations 10-15, which are mostly rural with agricultural land and forest cover, recorded relatively lower TSS and temperature levels. Additionally, water temperature and color are within the water quality guidelines (WQG) of 25-32°C and 50-75 TCU, respectively.

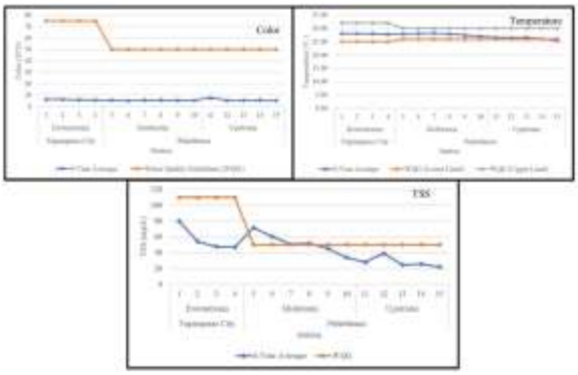

Fig. 4. Average of the physical water quality parameters from 2017-2024

The coefficient of variation (CV) indicates that TSS had high variability, with the majority of the stations registering CV values up to 120% to 140% (Station 15). The high variability of TSS may be explained by differences in land use pressures, erosion, and supply of sediments due to agricultural and construction activities (Akram *et al.*, 2006; Giri and Qiu, 2016). Color and temperature, on the other hand, have CV values ranging from 9% to 22% and 2% to 4%, respectively. Low-to-moderate CV values indicate the inherent stability of the river shaped by climate and hydrological patterns (Meyer and Paul, 2001).

Fig. 5 shows that all of the chemical parameters are below or within the WQG. The downstream stations (1-4), situated in settlement-dominated areas, showed higher concentrations of chloride (5.99-8.29 mg/L), BOD (1.65-2.04 mg/L), nitrate (0.19-0.23 mg/L), phosphate (0.04-0.06 mg/L), and pH (7.62-7.73), with lower DO levels (7.26-7.56 mg/L). These patterns point to stronger human influences in the urban section of the river, likely linked to domestic wastewater and runoff associated with built-up environments (Meyer and Paul, 2001; Giri and Qiu, 2016). Moving toward the midstream peri-urban stretch (Stations 5-10), pollutant concentrations were moderately lower as compared to downstream with a higher DO. This suggests that some dilution and natural self-purification occur as the river passes through areas with mixed residential and agricultural activities. Moreover, the upstream rural stations (11-15), surrounded by agricultural and forested landscapes, recorded the lowest pollutant concentrations. Data shows that the upstream has the lowest values of chloride (5.51-6.13 mg/L), BOD (1.34-1.53 mg/L), nitrate (0.09-0.11 mg/L), phosphate (0.02-0.06 mg/L), and pH (7.41-7.70), and the highest DO values (7.98-8.47 mg/L). These results reflect minimal human disturbance in this section and stronger natural aeration processes (Akram *et al.*, 2006; Bu *et al.*, 2014).

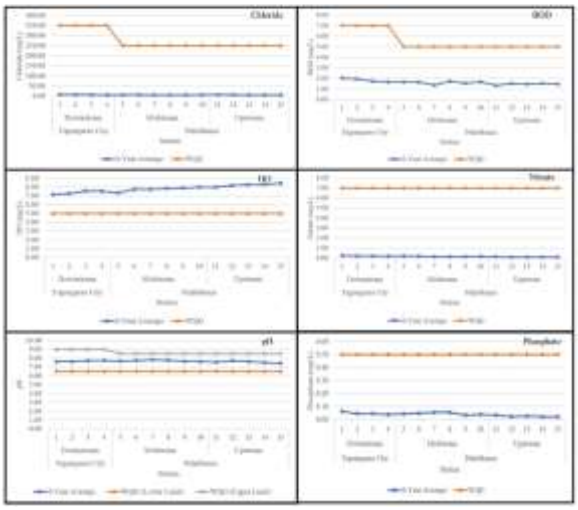

Fig. 5. Average of the chemical water quality parameters from 2017-2024

Chloride, nitrate, and phosphate have high CV values ranging from 21% to 162% due to low baseline levels. Meanwhile, pH and DO show very low variation (CV = <10%), suggesting that the river maintains stable buffering capacity and relatively consistent oxygenation along the river stretch. In contrast, BOD showed moderate variability with CV values ranging from 16% to 42%. This indicates shifts in organic matter loading and nutrient levels, especially in zones affected by settlements and farming activities (Meyer and Paul, 2001; Akram *et al.*, 2006).

Fig. 6 shows that all stations recorded fecal coliform above the water quality guidelines (Class B = 100

MPN/100 mL and Class C = 200 MPN/100 mL). The highest levels of fecal coliform were recorded at the downstream and certain midstream sites (Stations 1–4 and 6).

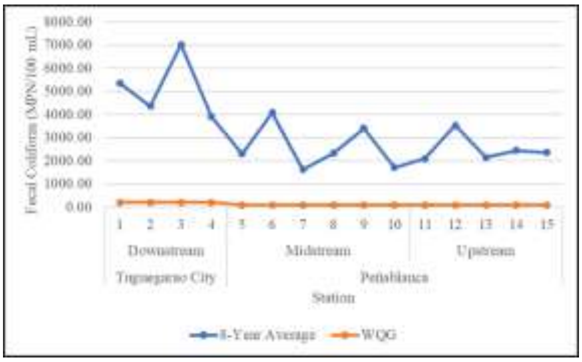

Fig. 6. Average of fecal coliform from 2017-2024

These stations are highly populated with domestic discharges, which enhance microbial contamination (Meyer and Paul, 2001; Akram *et al.*, 2006). Lower levels, as compared to downstream, were noted at the midstream peri-urban stations (Stations 5 and 7-10) in Peñablanca, possibly because of mixed land uses. Livestock and domestic wastewater discharges and inadequate sanitation systems can all contribute to the concentration levels in the midstream (Bu *et al.*, 2014; Giri and Qiu, 2016). The lowest levels of fecal coliform were recorded in Stations 11-15, as compared to downstream and midstream, due to lesser human activities at the upstream part of the river (Olilo *et al.*, 2016).

High CV values vary between 41% and 85% in the settlement-dominated stations (1-6), indicating that fecal coliform levels are quite stable due to the relative consistency of domestic sources in these areas. The CV increases drastically in the midstream peri-urban section of Peñablanca (71-188%), particularly in agricultural zones with residential zones. The significant changes in bacterial levels can be attributed to agricultural activities, varied surface runoff, and human activities. High variability (CV = 75-122%) is also observed at the upstream rural stations (11-15) with agricultural lands, forests, and scattered residences.

Land use and land cover

The values of Kappa coefficients were between 89% and 94% (Fig. 7), which implies that the multi-year LULC maps are reliable and can be used in the subsequent spatial analyses. Equivalent results have been documented in tropical and subtropical watershed studies, with Kappa values above 85% being typical of high-resolution classifications, indicating the robustness and consistency of the method employed (Seto *et al.*, 2012).

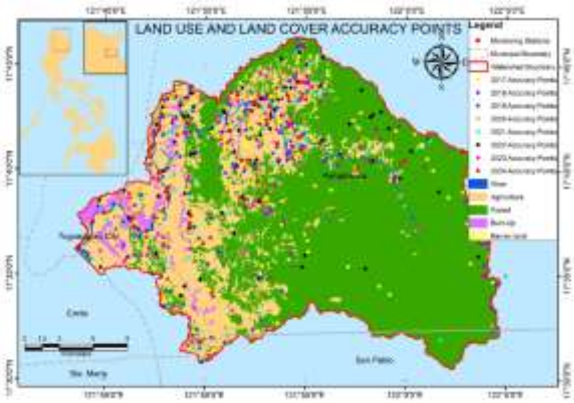

Fig. 7. Accuracy points of the processed LULC maps from 2017-2024

The LULC pattern of the PdT Watershed remained relatively the same between 2017 and 2024. The largest portion is dominated by forest areas with 65% to 67%, and agricultural lands occupy about 28% to 31% of the total areas (Fig. 8). Notable changes were only observed in water bodies, while built-up areas and barren land had almost similar extents, indicating that minimal conversion of land uses took place within the study period.

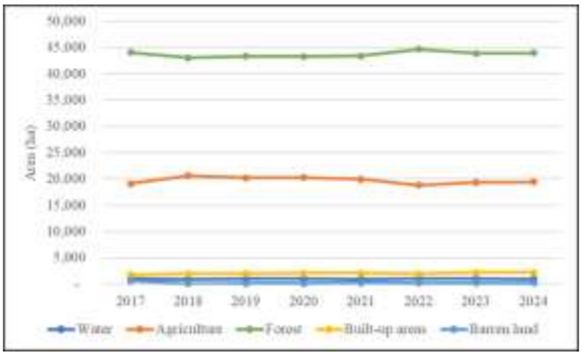

Fig. 8. Land cover composition of the PdT watershed in 2024

Within the 500-meter buffer zones surrounding the sampling stations (Fig. 9), agriculture is the dominant land use (28–81%). A large area of agriculture indicates its strong influence on potential nutrient and sediment runoff to the river (Tong and Chen, 2002; Li *et al.*, 2008). Forest cover is generally sparse, reducing the natural capacity for pollutant filtration (Allan and Castillo, 2007). Built-up areas are localized but may still contribute to water quality degradation through domestic discharges and surface runoff (Allan and Castillo, 2007).

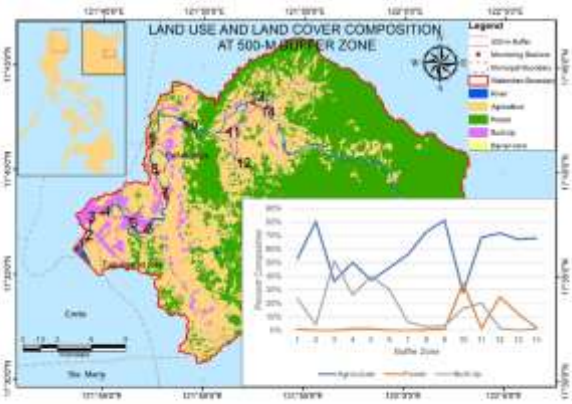

Fig. 9. Land use and land cover composition at 500-m buffer zone

The 1-km buffer zone (Fig. 10) exhibits distinct spatial variability in land use, with agriculture dominating most areas (58-73%). Forest cover is generally sparse, except in Buffers 8 and 9, where higher proportions (29% and 43%) suggest localized vegetation that may aid in runoff control and soil stabilization. Built-up areas are concentrated in Buffers 2 and 3 with an area share of 45% and 49%, respectively, which reflects localized urban influence, while other zones remain largely agricultural.

The land use composition within the 2 km (Fig. 11) indicates that agriculture is the dominant land use. The area ranges from 37% to 70%, suggesting strong agricultural influence on the surrounding river environment. Forest cover is moderate in some zones, particularly Buffers 6 and 7 (40–56%), where vegetation may help reduce runoff and sedimentation. Built-up areas are generally low, except in Buffers 1 and 2 (35–47%), indicating localized urban development that may contribute to point and nonpoint pollution sources.

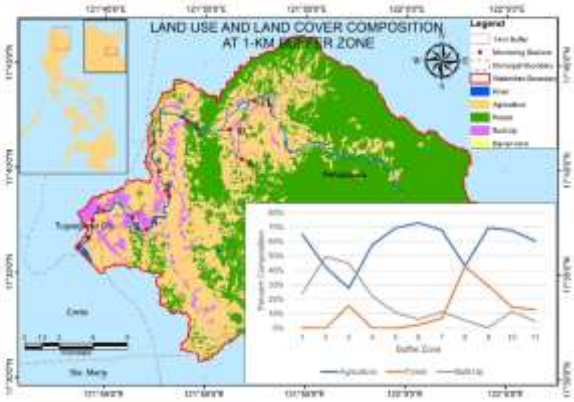

Fig. 10. Land use and land cover composition at 1-km buffer zone

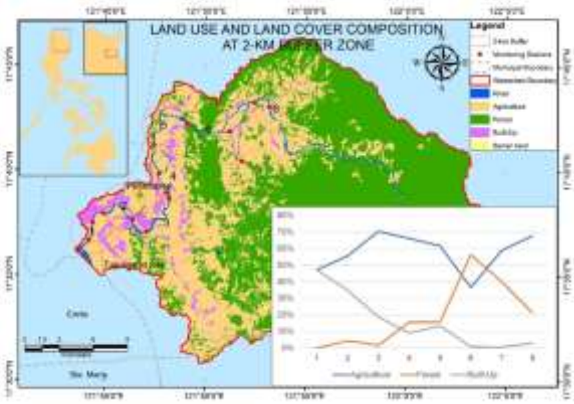

Fig. 11. Land use and land cover composition at 2-km buffer zone

Community perceptions on the effect of land uses on water quality

The findings of the field observations and the community perceptions indicate a definite association between land use and water quality conditions along the PdT River. Three themes were noted during the conduct of FGD at the downstream, midstream, and upstream sections of the river. These include the impacts of built-up and urban areas, agricultural land use, and deforestation.

Across all streams of the river, residents always linked the worsening of the water quality with the growth of built-up areas. Settlements that were common in both the downstream and midstream sections were associated with a higher amount of wastewater discharges and other human activities, such as quarry activities along the river stretch and improper waste disposal. These observations coincide with literature indicating that urbanization tends to increase surface runoff, which transports pollutants like nutrients, sediments, and organic materials into the water bodies (Tong and Chen, 2002). The increased areas of impervious surfaces in developed or urbanized areas decrease infiltration levels and increase the flow of contaminants to the river, which leads to an increase in the level of pollutants like nitrate, TSS, and BOD. Across all streams, drainage and sewage systems (Fig. 12) discharging directly into the river were observed, with most of these found at the downstream section of the river.

Fig. 12. Drainage directly discharging wastewater beside Station 6

Agricultural activities also contribute to water pollution, wherein residents have pointed out its adverse effect, especially during rainy season. The community observation coincides with the expansion of agricultural lands at the upstream section of the river. Other agriculture-related activities like washing of agricultural equipment (i.e., spray) and bathing of carabaos in the river contributed to the increase in nutrient, chemical, and microbial contamination. Other studies have also reported similar results, wherein higher nutrient loading was caused by agricultural runoff, which led to eutrophication and poor water quality (Carpenter *et al.*, 1998).

The continuous deforestation at the upstream region was observed as a contributor to sedimentation and higher turbidity. The communities noticed that during a rainy season muddy water runs down the river. Such observation means that the conversion of forests to agricultural land use increases the transportation of sediments, especially during the rainy season. Giri and Qiu (2016) argue that forested lands are significant in stabilizing soil, sediment filtration, and general water clarity.

The above observations demonstrate how agricultural development, urbanization, and deforestation influenced the water quality of the PdT River. Agricultural expansion leads to deforestation that increases erosion and turbidity. Built-up areas increase the concentrations of nutrient, chemical, and microbial contamination. On the other hand, vegetated areas are linked with purer and cleaner water.

Correlation analysis

Results of the Pearson's correlation analysis revealed the relationships between LULC types and key water quality parameters across multiple buffer zones. For each water quality parameter and corresponding LULC type, a substantial number of paired observations were analyzed across the three buffer distances. A total of 112 observations for the 500-m buffer, 88 for the 1-km buffer, and 64 for the 2-km buffer, which implies more reliable correlation estimates (Schober *et al.*, 2018). Significant correlations ($p < 0.05$) indicate that land use patterns exhibit measurable influences on the water quality, consistent with findings from other watershed studies (Bu *et al.*, 2014; Ding *et al.*, 2016).

Agricultural land use and water quality

Across three buffer zones, agricultural land use showed a positive impact on the water quality of the PdT River (Table 1). Agriculture is negatively correlated with temperature (r = -0.29 and -0.27) and nitrate (r = -0.21 and -0.30) within the 500-m and 1-km buffers. Additionally, significant negative correlation was also observed for color (r = -0.25) at the 2-km buffer.

The negative correlations may seem counterintuitive, as agriculture is typically associated with water quality deterioration due to nutrient and sediment inputs (Rey-Romero *et al.*, 2022; Crasswell and Singh, 2021). However, the presence of riparian vegetation and conservation practices can mitigate these effects by trapping sediments and nutrients and providing shade that reduces stream warming (Mayer *et al.*, 2007; Fuller *et al.*, 2025). Such observation is consistent with field observations indicating the presence of vegetation along the riverbanks, as well as trees serving as lot boundaries, particularly in the upstream areas (Fig. 13).

Table 1. Correlation analysis between agriculture land use and water quality

Water quality parameter	Pearson r-value		
	500 m (n = 112)	1 km (n = 88)	2 km (n = 64)
Color	-0.08	0	-0.25*
Temperature	-0.29*	-0.27*	0.06
TSS	-0.18	-0.12	0.09
BOD	0.06	-0.04	-0.07
Chloride	-0.03	0.02	-0.04
DO	0.19*	0.27*	0.06
pH	-0.16	-0.1	-0.05
Phosphate	-0.12	-0.04	0.07
Nitrate	-0.21*	-0.3*	0.07
Fecal coliform	-0.14	0.01	-0.04

*Significant at $p<0.05$

Fig. 13. Vegetation along riverbank and trees as lot boundary in the upstream area

A significant positive correlation between agriculture and DO was also observed at 500 m (r = 0.19) and 1 km (r = 0.27). At the 2-km buffer zone, correlations between agriculture and most water quality parameters became weak and statistically insignificant. The influence of agricultural activities on water quality diminishes with increasing distance from the river channel, likely due to the accumulated effect of agriculture on a larger scale (Bu *et al.*, 2014; Ding *et al.*, 2016).

Built-up land use and water quality

Built-up areas were positively correlated with temperature, TSS, BOD, nitrate, phosphate, and fecal coliform, while negatively correlated with DO. Table 2 presents the correlation analysis between built-up areas and water quality for the three buffer zones.

Table 2. Correlation analysis between built-up land use and water quality

Water quality parameter	Pearson r-value		
	500 m (n = 112)	1 km (n = 88)	2 km (n = 64)
Color	0.07	0	0.04
Temperature	0.36*	0.46*	0.55*
TSS	0.2*	0.22*	0.32*
BOD	0.05	0.28*	0.29*
Chloride	0.03	-0.11	0.07
DO	-0.3*	-0.5*	-0.57*
pH	0.17	0.03	0.11
Phosphate	0.15	0.14	0.25*
Nitrate	0.38*	0.55*	0.7*
Fecal coliform	0.3*	0.11	0.33*

*Significant at $p<0.05$

At the 500-m buffer, built-up areas were moderately correlated with temperature, TSS, nitrate, and fecal coliform, and negatively correlated with DO, likely due to runoff from impervious surfaces, sewage, and industrial discharges (Meyer and Paul, 2001; Walsh *et al.*, 2005).

At wider buffer zones (1 km and 2 km), the correlations generally intensified. Temperature and TSS showed higher positive correlations, as did BOD and nitrate. The increasing negative correlation with DO (r = -0.50 to -0.57) indicates the cumulative effect of built-up area on larger spatial scales (Bu *et al.*, 2014). The positive correlation of phosphate at the 2 km buffer (r = 0.25) further supports the notion that urban runoff contributes to nutrient concentration, which can enhance eutrophication risks.

Built-up areas were positively correlated with fecal coliform at 500-m and 2-km buffer zones. The relationships reflect the influence of domestic sewage and poor wastewater management associated with urban settlements (Allan, 2004; Meyer and Paul, 2001). These findings align with the "urban stream syndrome," where streams in urbanized catchments experience increased nutrient loading, microbial contamination, suspended solids, and altered thermal regimes (Walsh *et al.*, 2005).

The results emphasize that urban land use is a major driver of water quality degradation, with cumulative effects proportional to the increase in buffer size (Bu *et al.*, 2014). Such findings coincided with field observations and community perceptions. These include drainage and sewage systems discharging directly into the river (Fig. 12), active quarry operations along the river stretch, and other human activities (i.e., washing of clothes and vehicles and bathing carabaos) that contribute to water quality degradation.

Forest land use and water quality

Pearson correlation analysis shows that forested areas are generally associated with improved water quality (Table 3). Across all buffer zones, forest is negatively correlated with temperature, TSS, BOD, nitrate, phosphate, and fecal coliform. Conversely, the positive correlations of forest with DO suggest enhanced oxygenation in forested areas (Allan and Castillo, 2007; Walsh *et al.*, 2005). These relationships reinforce the role of forests in mitigating the impacts of surface runoff and in improving the riverine ecosystem health.

Table 3. Correlation analysis between forest land use and water quality

Water quality parameter	Pearson r-value		
	500 m (n = 112)	1 km (n = 88)	2 km (n = 64)
Color	0.1	0.07	0.13
Temperature	-0.32*	-0.4*	-0.51*
TSS	-0.23*	-0.19	-0.33*
BOD	-0.19*	-0.29*	-0.21
Chloride	-0.02	0.1	-0.03
DO	0.24*	0.31*	0.43*
pH	-0.07	0.03	-0.08
Phosphate	-0.17	-0.17	-0.26*
Nitrate	-0.3*	-0.34*	-0.61*
Fecal coliform	-0.21*	-0.09	-0.25*

*Significant at $p<0.05$

CONCLUSION

The study demonstrates a clear relationship between LULC and the water quality of the PdT River. Built-up areas exhibited the strongest influence on water quality, with significant positive correlations to pollutants such as nitrate, fecal coliform, TSS, BOD, temperature, and phosphate, and negative correlations with DO. These results indicate that urbanization associated with human activities, such as direct drainage and sewage discharge, quarrying operations, improper solid waste disposal, and surface runoff from urban areas, are major contributors to water quality degradation.

In contrast, forested areas acted as natural buffers that help improve and stabilize water quality. Forest zones showed a positive correlation with DO and negative correlations with temperature, fecal coliform, TSS, nitrate, BOD, and phosphate. The positive impact of forest land use reflects its filtering capacity in reducing pollutant transport, regulating temperature, and enhancing oxygenation. The stronger relationships at larger buffer distances highlight the importance of wider forest cover in protecting the river's water quality.

Meanwhile, agricultural areas showed significant negative correlations with temperature, nitrate, and color, and a positive correlation with DO. The beneficial effects of agricultural land use on water quality highlight the critical role of vegetative buffers in reducing pollution loads and increasing oxygenation. However, the negative correlation diminishes with increasing distance from the river, emphasizing the cumulative effect of agriculture at larger spatial scales.

Resting on these findings, efforts to protect and improve the water quality of the PdT River are suggested through promotion of more sustainable agricultural practices, expansion of riparian vegetation, and better management of wastewater in settlement areas.

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