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# Linking Land Use and Land Cover with Water Quality in the Pinacanauan de Tuguegarao River: Evidence from a Riparian Scale Analysis for Watershed Management

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## ABSTRACT

The study examined the impacts of agriculture, forests, and built-up areas on the water quality indices 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 land use and land cover (LULC) and the water quality parameters using a 500-m buffer zone around the sampling station. Data used in the study 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. Built-up areas were directly associated with temperature, TSS, nitrate, and fecal coliform, while negatively correlated with DO. Observations on the ground, such as drainage and sewage systems directly discharging wastewater into the river, quarrying activities, poor waste management, and other anthropogenic activities, negatively affect the water quality of the river. Conversely, riparian vegetation was negatively correlated with temperature, nitrate, TSS, BOD, and fecal coliform, while positively correlated with DO. Unexpectedly, agricultural areas had an inverse relationship with temperature and nitrate, while there was a positive correlation with DO. Correlation results of forest and agriculture highlight the critical role of riparian vegetation in maintaining the ecological condition of the PdT River. Further studies may consider a multi-buffer zone analysis to capture the cumulative effects of land uses at broader spatial scales.

## 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 (Land use and land cover (LULC) changes significantly affect water quality and ecosystem health. Human activities such as urbanization, agriculture, and deforestation can increase pollution and alter hydrological processes. Several studies have highlighted the strong relationship between LULC changes and water quality degradation (World Bank, 2019; Tahiru et al., 2020; Kumar et al., 2024). Every nation is dealing with the effects of water quality degradation, including the gradual decline of aquatic ecosystems, reduced agricultural productivity, and increased 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 sources of the decreased 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.*, 2020; 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 runoff discharging into water bodies increase nutrient, pathogen, and chemical contaminant levels (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 & 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 contribute to a healthy ecological condition of surface waters (Uriarte *et al.*, 2011) by filtering runoff carrying pollutants before discharging into the streams (Tong & 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 (2019), 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

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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, due to extensive resource use and land conversions (Camara *et al.*, 2019).

One of the water bodies that was observed to be contaminated already is the PdT River, a Water Quality Management Area and a tributary of the Cagayan River in the northern Philippines (DENR-EMB, n.d.). Fecal coliform counts across 15 sampling stations were above the water quality guidelines (EMB, 2020), thereby declaring the PdT River as unsafe for recreation (PIA, 2022). 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 primary water quality parameters of the PdT River, based on a riparian scale analysis. The outcome of the study is vital to 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 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 in order to increase its supply of domestic water. Furthermore, the study provides an assessment to the current programs, projects, and other initiatives of agencies, LGUs, and communities in the PdT River.

## LITERATURE REVIEW

### Water Quality Indicators

In assessing the ecological condition of the river, physicochemical and biological parameters are used to see how natural processes as well as human influences affect surface water. Such indicators provide a clearer picture of how water quality is being affected by land cover changes such as deforestation associated with agricultural expansion and rapid urbanization (Meybeck & Helmer, 1989). In the Philippines, primary parameters that include TSS, temperature, color, BOD, DO, chloride, nitrate, phosphate, pH, and fecal coliform are used to assess the pollutant concentration of water bodies (DENR, 2016). Said parameters are included in the Water Quality Guidelines (WQG) and General Effluents, which were established to monitor the ecological condition of surface waters, especially for the Water Quality Management Areas. The WQG for freshwater, is presented in Table 1. Additionally, DENR (2016) provided a classification of water bodies by beneficial use, with Classes AA to D for freshwater. The PdT River was classified as Class B in Peñablanca and Class C in Tuguegarao City (DENR-EMB, n.d.). Said classification is used to monitor if these water bodies exceed the limit set by the DENR (2016), as shown in Table 1. Moreover, the PdT River's midstream and upstream sections are intended for primary contact recreation (Class B), while the downstream portion (Class C) is being used for fishery propagation, no-contact recreation activities, and other uses such as irrigation and livestock watering (DENR, 2016).

**Table 1:** Water quality guidelines for freshwater

| Parameter | Unit | Water Body Classification | | | | |
|---|---|---|---|---|---|---|
| | | AA | A | B | C | D |
| BOD | mg/L | 1 | 3 | 5 | 7 | 15 |
| Chloride | mg/L | 250 | 250 | 250 | 350 | 400 |
| Color | TCU | 5 | 50 | 50 | 75 | 150 |
| DO (minimum) | mg/L | 5 | 5 | 5 | 5 | 2 |
| Fecal Coliform | MPN/100mL | <1.1 | <1.1 | 100 | 200 | 400 |
| Nitrate | mg/L | 7 | 7 | 7 | 7 | 15 |
| pH | | 6.5-8.5 | 6.5-8.5 | 6.5-8.5 | 6.5-9.0 | 6.0-9.0 |
| Phosphate | mg/L | <0.003 | 0.5 | 0.5 | 0.5 | 5 |
| Temperature | °C | 26-30 | 26-30 | 26-30 | 25-31 | 25-32 |
| TSS | mg/L | 25 | 50 | 65 | 80 | 110 |

*Source: (DENR, 2016)*

### Influence of Land Use on Different Spatial Scales

Multiple studies indicate that riparian land uses provide a clearer pattern of water quality conditions as compared to the entire area of the watershed (de Mello *et al.*, 2018). Assessment within 100 m and 200 m of the river substantially affects water quality indices (Tran *et al.*, 2010; Shen *et al.*, 2015). A concrete example is that nutrient levels, BOD, and TSS from agricultural and built-up areas influence water quality more strongly (Tran *et al.*, 2010; Shen *et al.*, 2015) as compared to larger spatial scales. On the other hand, other scales (sub-watershed and watershed scales) are employed to describe the process of washing away and storing pollutants (Zhou *et al.*, 2012; Ding *et al.*, 2016). For instance, turbidity and DO may be well observed on the watershed level, while nitrogen and fecal coliform were more sensitive on the sub-watershed scale (Uriarte *et al.*, 2011).

The correlation between land use and water quality is different at various spatial scales (Tanaka *et al.*, 2016; Wang *et al.*, 2013). These observations suggest that one needs to study both spatial scales in detail, which entail watershed, sub-watershed, and riparian buffer at all, to gain a comprehensive understanding of how water quality responds to land uses.

### Statistical Approaches Linking Land Use and Water Quality

Several geostatistical methods are used to examine the relationship between water quality and land use (Cheng *et al.*, 2022). These methods include the redundancy analysis that is capable of linking the seasonal variations, the land use features, and the water quality behavior (Chen *et al.*, 2016). The other tool is the correspondence analysis (CA), used to display the spatial trends and group the sampling stations with similar observations (Damanik-Ambarita *et al.*, 2016). Such an approach is significant in establishing the sources of pollution (Tanriverdi *et al.*, 2010). Conversely, correlation analysis is used to assess the linear relationship between land use and water quality, with higher absolute values indicating stronger correlation (Cheng *et al.*, 2022). Two highly effective techniques for regression and complex analysis are Geographically Weighted Regression (GWR) and Bayesian hierarchical linear regression (BHLR). Both methods are useful in cases when the study is characterized by a complex correlation between land use and water quality, whereby different locations and periods exist (Huang *et al.*, 2015; Wan *et al.*, 2014; Ullah *et al.*, 2018). The GWR and BHLR eliminate the challenge of the complexity of the spatial difference and interactions of different geographic extents that cannot be determined with basic methods (Wan *et al.*, 2014).

However, in cases of data scarcity, say when the study is narrowed to a limited number of sampling stations, then the complex processes are not practical as compared to the Pearson correlation (Schober *et al.*, 2018). Correlation analysis provides simpler and less expensive approaches over the complex ones. In the article by Panda *et al.* (2018), the correlation technique was utilized to determine the relationship between water quality and land use with few sampling stations.

## MATERIALS AND METHODS

### Study Area

The (PdT) River passes through the province of Cagayan and flows through the municipalities of Peñablanca and Tuguegarao City (17°36’16.85”N, 121°43’47.90”E). The river is one of the tributaries of the Cagayan River and was proclaimed as a WQMA will suffice in 2013 (DENR-EMB, n.d.). Likewise, EMB RO2 regularly monitors the water quality of the PdT River as a designated WQMA. Monitoring 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). Figure 1 shows the location of the study area.

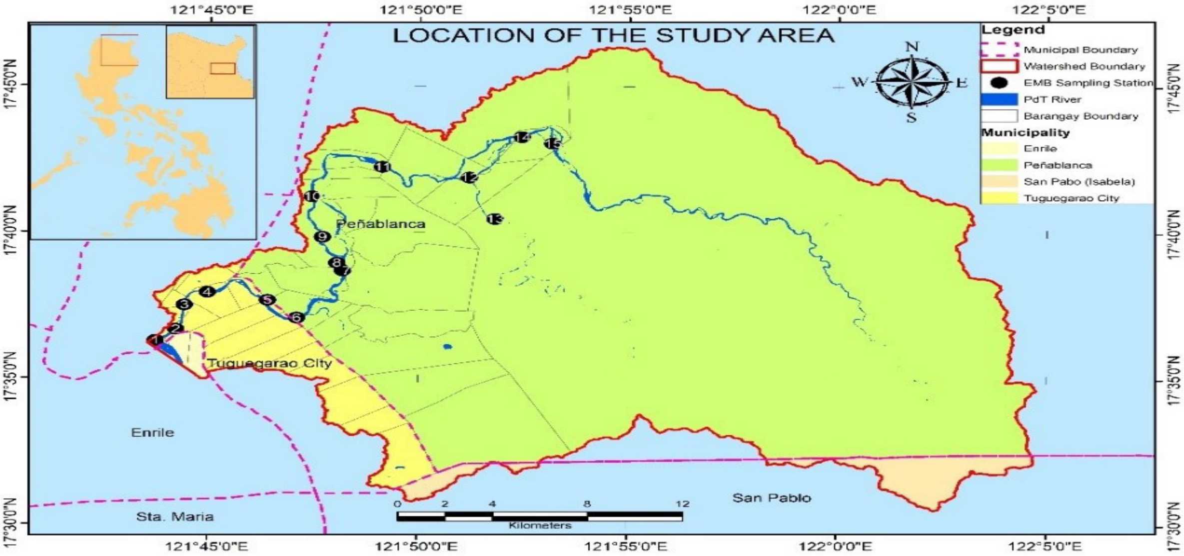


**Figure 1:** Location of the Pinacanauan de Tuguegarao River

### Data Collection

The DENR-EMB RO2 provided the water quality records between 2017 and 2024, where the agency constantly examine the water quality of the PdT River. Such datasets consist of the measurements of physical parameters (color, temperature, and TSS), chemical parameters (pH, DO, BOD, nitrate, phosphate, and chloride), and microbiological fecal coliform data. Sampling stations were also provided with geographic coordinates. In relation to the LULC component, the raster images of Sentinel-2 with a 10-m resolution were accessed through 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, the average and coefficient of variation (CV) of the 8-year period at each station were analyzed. The 8-year mean was calculated to identify which stations displayed relatively high or low pollution 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 zones, forested zones, built-up zones, 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. The Kappa coefficients were calculated using these points each year 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 a 500-meter buffer (Figure 2) following the natural flow of the water (Bo *et al.*, 2017; Zhang *et al.*, 2021; Huang *et al.*, 2019; Yao *et al.*, 2024). The established buffers provide the LULC composition necessary in the correlation analysis.

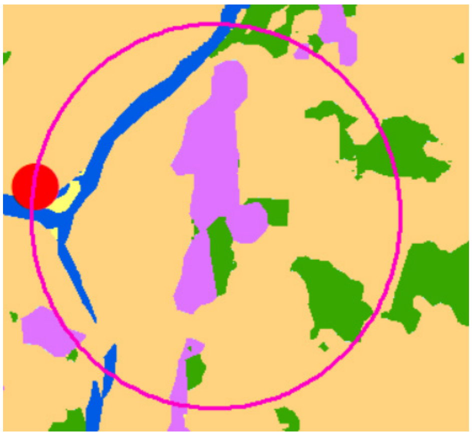


**Figure 2:** Delineation of the 500-m buffer zone

### Correlation Analysis

The Pearson's correlation was used in the study to correlate 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 water quality changes (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 PdT River, a WQMA, is being monitored by the EMB RO2 on a regular basis through its 15 sampling stations. These are situated at the downstream within Tuguegarao City (Stations 1-4), midstream (Stations 5-10), and upstream (Stations 11-15) located in Peñablanca. The established 15 sampling stations are shown in Figure 3. The downstream section of the PdT River, comprising

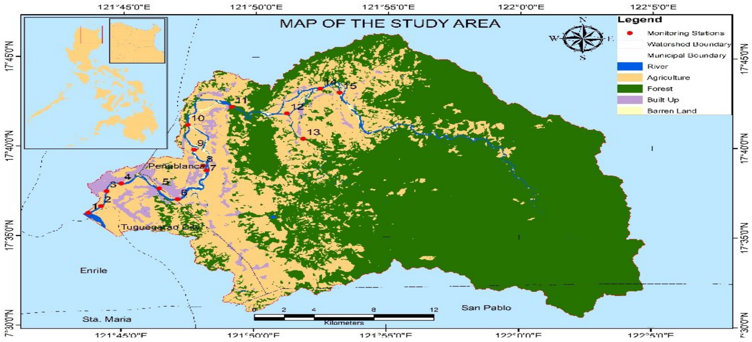


**Figure 3:** Locations of the sampling stations

the barangays Centro 10, Capatan, Tanza, and Caggay in Tuguegarao City, is a mixture of residential, vegetation, and agricultural land. The riverbanks have vegetation, which is predominantly grasslands and bamboo stands. The farmland is located on the east, and the settlements are located on the western side. Additionally, fishing activities are present around the mouth of the river, and this implies that the community relied on the river resources.

The midstream is characterized by agricultural land and quarry areas with sparse riparian vegetation. Farmlands are found on both sides of the river. The riverbank is covered with grasses and few trees, being thicker at the end of Station 10 (Tawi Bridge). There are several quarrying operations (Stations 5 and 7-9) that may result in an increase in sediments. Other observations include drainage directly discharging wastewater into the river, bathing of carabaos, and washing of laundry.

The upstream section is composed of forested, agricultural, and residential land uses, where forest cover is predominant in Stations 11 and 13 and farmlands occupy the large part of Stations 12, 14, and 15. Settlements are located distant from the river, except for Station 11, where households directly discharge domestic wastewater into the river. In contrast, Stations 12-15 (Barangays Manga, Buyun, and Lapi), on the other hand, have settlements more distant along the river. Drainage flows out through creeks, which drain into the river.

## Water Quality Parameters

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 (Figure 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 & Paul, 2001; Akram *et al.*, 2006). At midstream stations (7-9), located in the peri-urban area, TSS was moderate, which can be attributed to quarrying, surrounding farms, and mixed residential development (Huang *et al.*, 2020). At the same time, the upstream 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 set standards of 25-32°C and 50-75 TCU, respectively.

The result of 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 or construction activities (Akram *et al.*, 2006; Giri & 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 & Paul, 2001).

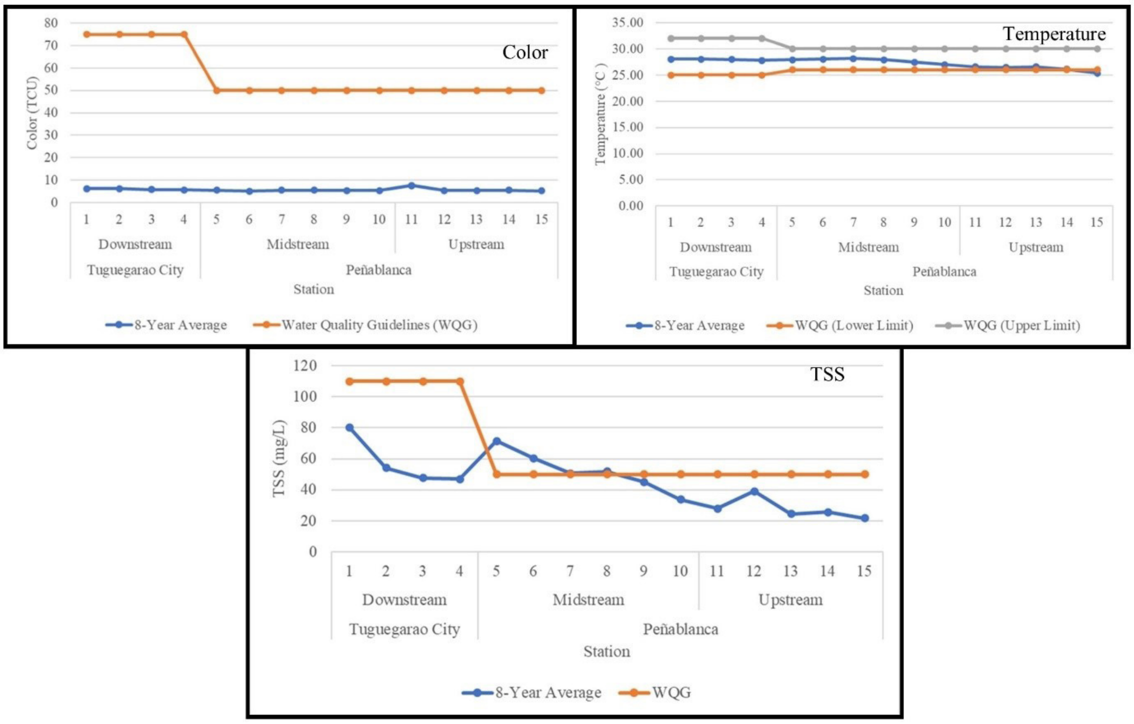


**Figure 4:** Average of the physical water quality parameters from 2017-2024

All the chemical parameters are below or within the water quality guidelines (Figure 5). The chloride levels are between 5.51 and 8.29 mg/L, which is below the water quality guidelines (250 mg/L for Class B and 350 mg/L for Class C). In addition, the chloride levels are a little higher in downstream stations (5.99-8.29 mg/L), which is natural in any urban area where drainage and domestic discharges directly to the river introduce small but measurable amounts of dissolved ions, including chloride (Meyer & Paul, 2001; Giri & Qiu, 2016). A downward trend can be observed, suggesting lesser influences in the upstream area. Furthermore, the concentrations of chloride exhibit high variability over time, with a range of coefficient of variation (CV) ranging between 46% and 63% across all stations due to low baseline levels.

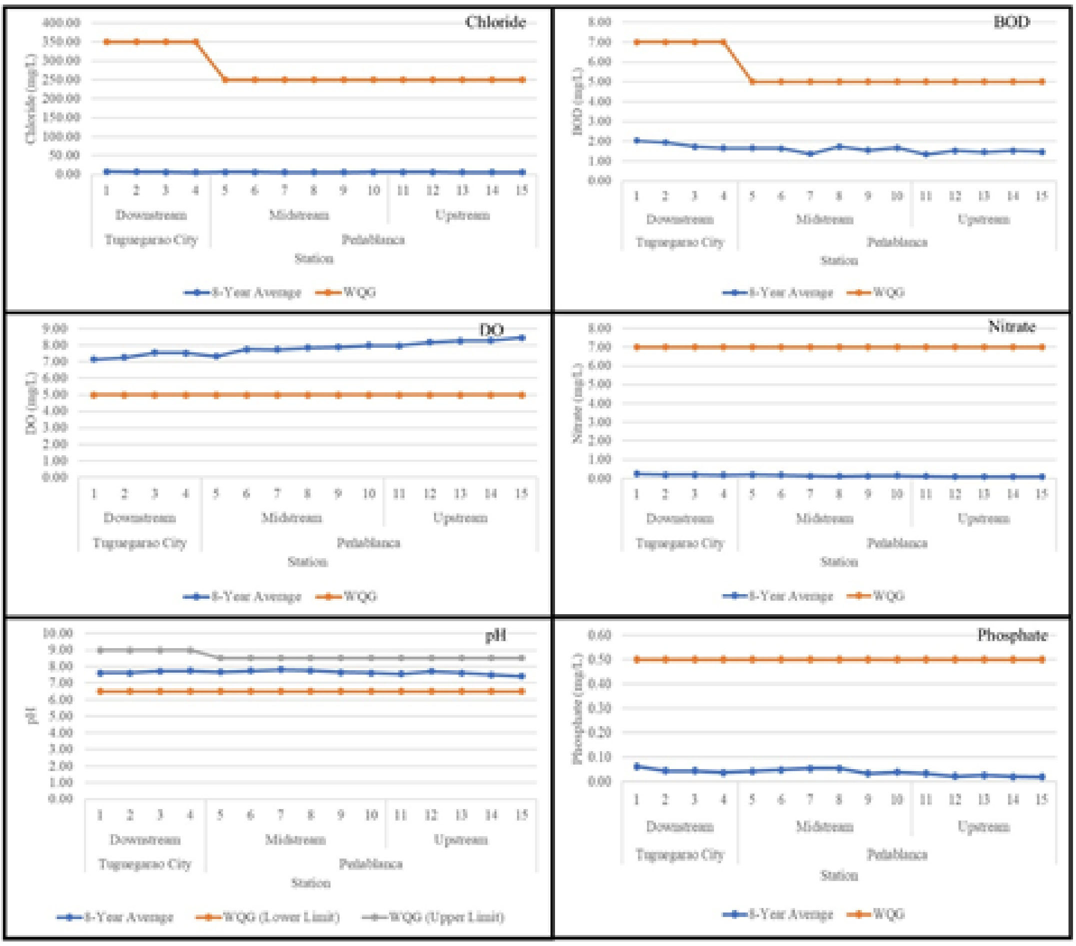


**Figure 5:** Average of the chemical water quality parameters from 2017-2024

Biochemical oxygen demand ranges from 1.34 to 2.04 mg/L, which is significantly lower than the water quality standards of 5 and 7 mg/L for Class B and C, respectively. The concentrations are slightly higher (1.65-2.04 mg/L) in the downstream urban stations, probably due to the urban runoff and drainage releases (Meyer & Paul, 2001; Giri & Qiu, 2016). The midstream and upstream stations exhibit lower BOD (1.54-1.73 mg/L and 1.34-1.53 mg/L), reflecting lesser human activities and the buffering effect of riparian vegetation (Akram *et al.*, 2006; Bu *et al.*, 2014). Meanwhile, the CV values (16-42%) show low-to-high variability over the 8-year period. Low-to-moderate variability is observed in downstream stations sustained by a consistent supply of organic matter through domestic wastewater. High variability is recorded in midstream stations and upstream stations, which may be affected by changes in agricultural practices, infrequent runoff, and change of seasons.

The concentration of DO is between 7.15 and 8.47 mg/L, higher than the standard of 5 mg/L, indicating normal levels of oxygen in the river. The decreased DO levels downstream (7.26-7.56 mg/L) can be linked to urban and residential impacts (Meyer & Paul, 2001; Giri & Qiu, 2016). Sources such as domestic wastewater and agricultural runoff increase the index of microbial activity and oxygen use in the decomposition process (Rice *et al.*, 2011). Urban and densely populated areas are likely to have lower levels of DO as the BOD is higher and because of low re-aeration when channels are altered or slowed down. Mid stations related to agriculture (7.34-8.00 mg/L) and upstream forested stations (7.98-8.47 mg/L) exhibit a little higher DO, probably because of decreased organic loading, riparian shading, and forested catchment effects, which improved oxygen retention (Akram *et al.*, 2006; Bu *et al.*, 2014). On the other hand, the variability of DO is very low (CV = 4.20-8.10%) at all stations, which means stable oxygen conditions over the years.

The levels of nitrate are between 0.09 and 0.23 mg/L, which is far less than the water quality standard of 7 mg/L, implying that there is minimal concentration of nutrients along the river. Nitrate levels are somewhat higher in the downstream urban stations (0.19-0.23 mg/L), probably due to urban runoff and drainage discharges (Meyer & Paul, 2001; Giri & Qiu, 2016). There is a slight increase in the levels in midstream agricultural stations (0.12-0.19 mg/L), probably because of fertilizer use and domestic sources. The lowest concentration of nitrate is in the upstream forested stations (0.09-0.11 mg/L) because of the natural forested catchments and intact riparian buffers that restrict the runoff of the nutrient (Akram *et al.*, 2006; Bu *et al.*, 2014). Additionally, the concentrations of nitrate exhibit high-to-moderate variability over time, with a range of coefficient of variation (CV) ranging between 21% and 63% across all stations due to low baseline levels.

Phosphate levels (0.02-0.06 mg/L) are below the limit of 0.5 mg/L. Downstream stations recorded little bit higher levels (0.04-0.06 mg/L), which can probably be attributed to urban runoff and drainage releases (Meyer & Paul, 2001; Giri & Qiu, 2016). Midstream agricultural stations show the slight contributions (0.03-0.05 mg/L) from fertilizer use and residential sources. Upstream forested stations have the lowest levels of phosphate (0.02-0.03 mg/L), implying a small anthropogenic contribution and strong nutrient retention by forested catchment and riparian vegetation (Akram *et al.*, 2006; Bu *et al.*, 2014). Moreover, there is a high variation of the phosphate levels (CV = 42-162%), which represents the effect of hydrological changes and low baseline concentrations.

The pH readings within the 8-year period are between 7.41 and 7.81, which falls within the WQG of 6.5 to 9.0 in the downstream stations and 6.5 to 8.5 at the midstream and upstream stations. The values of pH (7.62-7.73) at downstream urban stations are slightly higher, possibly due to urban runoffs and small amounts of effluents. Besides, the relative variability of all monitoring stations is very low (CV = 2.18-5.56%), which means that the pH conditions are highly stable.

Figure 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). These are highly populated with domestic discharges, likely to be the cause of enhanced microbial contamination (Meyer & 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 influenced 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 & 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).

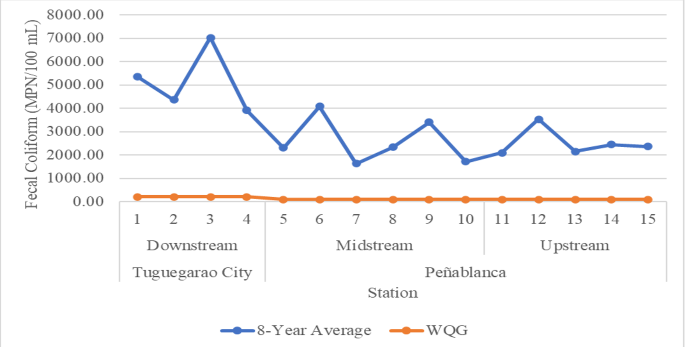


**Figure 6:** Average of fecal coliform from 2017-2024

High CV values vary between 41% and 85% in the settlement-dominated stations (1-6), indicating that the levels of fecal coliform 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, which are probably caused by 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% (Figure 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).

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%-67%, and agricultural lands occupy about 28%-31% of the total areas (Figure 8). Notable changes were only observed in water bodies, while built-up areas and barren land had almost similar sizes, indicating that minimal conversion of land uses took place within the study period.

The 500-m buffer zone comprises mostly agricultural lands, approximately 28% to 81% of the total land area of the buffer (Figures 9 and 10). This dominance

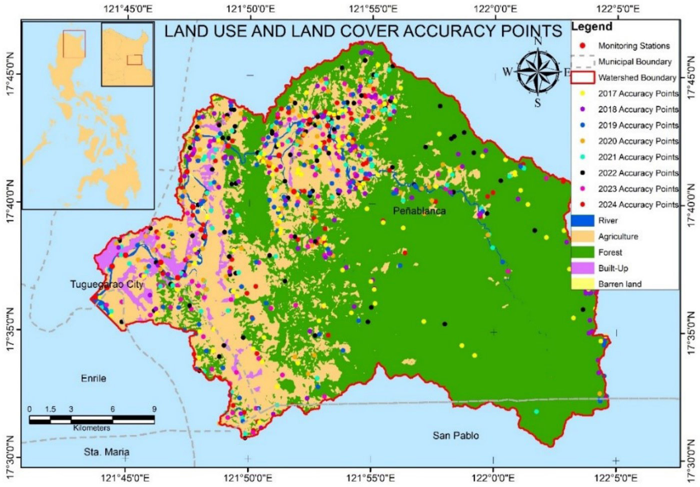


**Figure 7:** Accuracy points of the processed LULC maps (2017-2024)

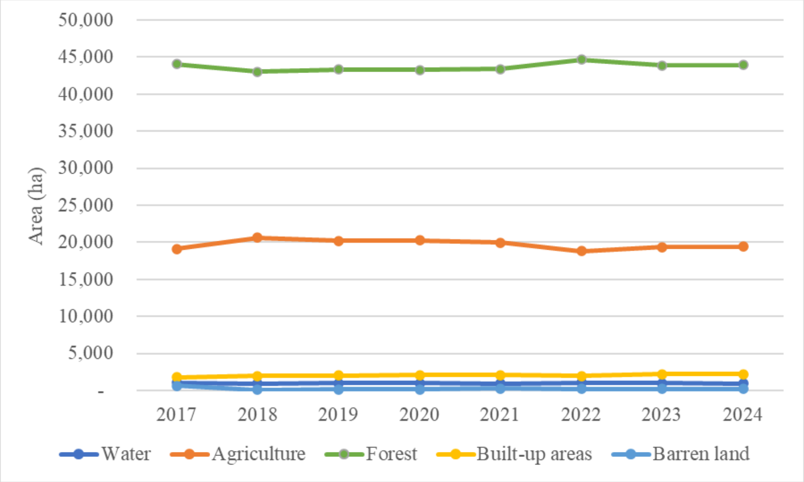


**Figure 8:** Land cover composition of the PdT Watershed in 2024

indicates exposure of the river to nutrient, sediment, and agrochemical concentrations, which can cause eutrophication and high turbidity (Allan, 2004; Meyer & Paul, 2001). Buffer zones 2 and 9, with agricultural cover of 80% and 81%, are more susceptible to such effects due to the lack of vegetative buffers to assist in filtering runoff.

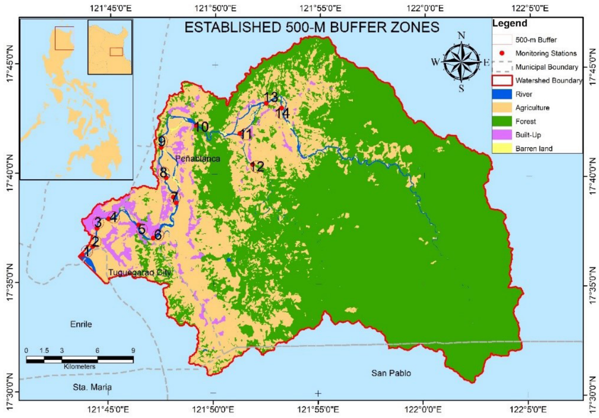


**Figure 9:** Established 500-m buffer zones

Forest cover is mostly minimal in all buffer zones. Large areas of forest can only be observed in Buffers 10 and 12, with 35% and 25% composition, respectively. Such a small area of vegetation decreases the capacity of the riverbank to filter runoff, resulting in increased sediment enrichment, enhanced nutrient contributions, and more pronounced temperature shifts within the river (Burt *et al.*, 2002). Conversely, areas with a greater percentage of forest cover contribute to the moderation of water quality through shading, enriching of soil, and organic material. The density of built-up areas also differs across the buffer zones, with larger percentages in Buffer 3 (51%) and Buffer 5 (40%). Such high percentages can be linked to increased imperviousness, more runoff, and potential sewage or industrial contributions (Walsh *et al*., 2005). These areas can be hotspots of water quality problems, especially in areas where there are small vegetation buffers or none at all.

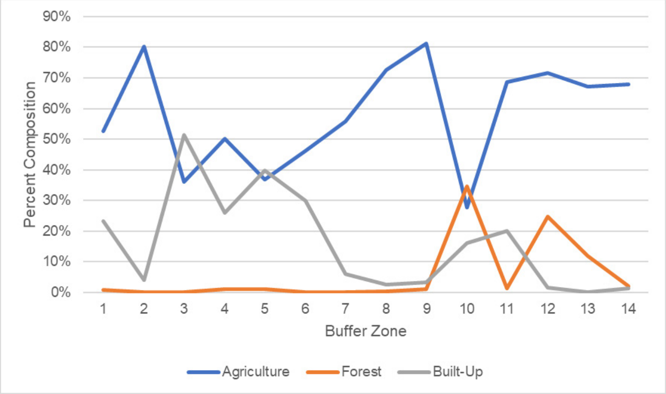


**Figure 10:** Land use and land cover composition at 500-m buffer zone

### 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. The 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 transport pollutants like nutrients, sediments, and organic materials into the water bodies (Tong & Chen, 2002). The increased areas of impervious surfaces in developed or urbanized areas decreases infiltration levels and increases the flow of contaminants to rivers which leads to an increase in the level of pollutants like nitrate, TSS, and BOD. In addition, field observations show that there exist drainage and sewage systems (Figure 12) that drain into the river across all streams, with most of these are found at the downstream section of the river.

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 increased 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).

Likewise, the continuous deforestation of the upstream region was characterized as a contributor to sedimentation and water turbidity. The communities noticed that during a rainy season muddy water runs down the river, and during hot seasons the river is clear. Such observation means that the conversion of forests to agricultural land use increases the transportation of the sediments, especially during 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 and built-up areas that increase nutrient, chemical, and microbial contamination. On the other hand, vegetated areas are linked with purer and cleaner water.

### Community-Perceived Solutions

The result of the FGD shows the community's clear understanding of the effect of different land uses on the ecological condition of the river, wherein residents enumerated several solutions to reduce the pollution of the PdT River. Upstream, the community supports strategies that include proper solid waste management, reforestation, and sustainable farming in order to mitigate pollution and erosion along the river. The suggested tree-planting initiative reflects the clear understanding of the function of vegetation (i.e., trees and grasses) to ensure soil stability and sediment filtration (Giri & Qiu, 2016). Upland farmers also underscored the necessity to preserve vegetation in the riverbanks and farmlands to prevent further scouring and erosion.

In the midstream, residents identified the importance of increasing the awareness of the communities residing near the river through clean-up drives along the river stretch and information and education campaigns (IEC). These interventions ensure the participation of the community, which is consistent with the suggestion of Ongley (1996) that local action was important in managing water pollution.

Meanwhile, the downstream communities pointed out the necessity of having different drainage and sewage systems and proper waste disposal along the river stretch. The awareness of the urban population depicts that there is a clear understanding of urban-related pollution. Similarly, to reduce the discharge of wastewater into the river, infrastructure planning has to be done in a collective manner (Zhou & Qianqian, 2014).

The outcomes of the FGD indicated the role of both infrastructure (i.e., separate drainage and sewage systems) and non-infrastructure (i.e., proper waste management, reforestation, and forest conservation) as central in maintaining the ecological state of the PdT River.

### Pearson's Correlation Analysis

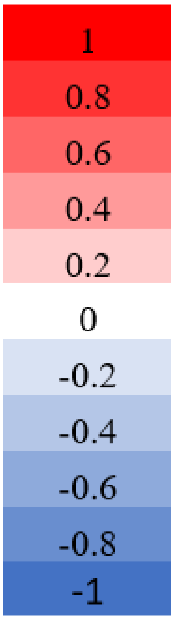
The Pearson correlation analysis (n = 112) indicated that the correlation between LULC types (agriculture, forest, and built-up areas) and water quality parameters varied in the 500-m buffer zone (Table 2). The significant correlation ($p < 0.05$) between land use and the water quality indicates that the effect is substantial, which is consistent with similar research findings (Bu *et al.*, 2014; Ding *et al.*, 2016).

### Agriculture Land Use and Water Quality

**Table 2:** Results of the Pearson's correlation analysis at 500-m buffer zone (2017-2024)

| Water Quality Parameter | Agriculture | Forest | Built-Up |
|---|---|---|---|
| Color | -0.08 | 0.1 | 0.07 |
| Temp. | -0.29* | -0.32* | 0.36* |
| TSS | -0.18 | -0.23* | 0.2* |
| BOD | 0.06 | -0.19* | 0.05 |
| Chloride | -0.03 | -0.02 | 0.03 |
| DO | 0.19* | 0.24* | -0.3* |
| pH | -0.16 | -0.07 | 0.17 |
| Phosphate | -0.12 | -0.17 | 0.15 |
| Nitrate | -0.21* | -0.3* | 0.38* |
| Fecal Coliform | -0.14 | -0.21* | 0.3* |

**Pearson *r*-value**



**Significant at p<0.05*

Agricultural areas showed negative correlations with temperature (r = -0.29) and nitrate (r = -0.21), along with a positive correlation with dissolved oxygen (r = 0.19). The negative correlations may appear unexpected since agriculture is often linked to water quality degradation through nutrient and sediment runoff (Rey-Romero *et al.*, 2022; Crasswell & Singh, 2021). Nevertheless, the riparian vegetation and other conservation strategies can mitigate these effects by filtering sediments and nutrients and covering the water to avoid warming (Mayer *et al.*, 2007; Fuller *et al.*, 2025). The results are consistent with field observations such as the presence of vegetation along the riverbanks and trees subdividing parcels of farmland found at the upstream section of the river (Figure 11).

### Built-Up Land Use and Water Quality

**Figure 11:** Vegetation along riverbank and trees as lot boundary in the upstream area

Built-up areas were found to be positively correlated with temperature (r = 0.36), TSS (r = 0.2), nitrate (r = 0.38), and fecal coliform (r = 0.3), while negatively correlated with DO (r = -0.3). The results of the correlation indicate that impervious surfaces, urban runoff, and sewage discharge increase nutrient levels, microbial contamination, and reduced oxygen levels (Walsh *et al.*, 2005; Meyer & Paul, 2001). Field and community observations showed sources of contamination from direct drainage and sewage systems discharging into the river (Figure 12), quarry operations, and other human activities (i.e., washing clothes and vehicles and bathing carabaos) along the river stretch.

### Riparian Vegetation and Water Quality

Riparian vegetation is inversely associated with major pollutants, highlighting its critical role in controlling the water temperature, reducing nutrient and sediment load, and decreasing microbial contamination. Correlation results indicated that riparian vegetation is negatively correlated with temperature (r = -0.32), TSS (r = -0.23), nitrate (r = -0.3), BOD (r = -0.19), and fecal coliform (r = -0.21). The positive relationship with DO (r = 0.24) underscores the importance of riparian vegetation for oxygenation of the river, bank stabilization, and pollutant filtration (Sweeney *et al.*, 2004; Allan & Castillo, 2007; Walsh *et al.*, 2005). Figure 13 shows the riparian vegetation along the riverbank

**Figure 12:** Drainage directly discharging wastewater beside Station 6

**Figure 13:** Buffer vegetation at Stations 5 and 14

## CONCLUSIONS

Correlation analysis (n = 112) within the 500-m buffer zone displayed the relationship of agriculture, forest, and built-up areas with the water quality conditions of the PdT River. Agricultural areas showed weak negative relationships with temperature and nitrate and a very weak positive relationship with DO, which indicates that the riparian vegetation and conservation efforts are possibly counteracting the typical effects of agriculture on water quality degradation. Such observations are reinforced by vegetation along the riverbanks and trees serving as lot boundaries, particularly in the upper segments of the river. Built-up areas were positively correlated with the increase in temperature, TSS, nitrate, and fecal coliform, accompanied by low levels of DO. These adverse relationships were attributed to direct drainage and sewage outflows, quarry activities, poor waste management practices, and other anthropogenic activities. Conversely, forest zones were negatively correlated with temperature, nitrate, TSS, BOD, and fecal coliform, while increasing DO. The small portion of forest within the 500-m landscape demonstrates the critical role of riparian vegetation in filtering runoff and in maintaining the ecological health of the river in general. Such results confirm that even in a limited 500-m riparian buffer analysis, LULC significantly affects the quality of water. For future assessments, larger scales can be considered to analyze the cumulative effect and the upstream contribution of land uses (i.e., 1 km, 2 km, or even the entire watershed). 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 urban wastewater in settlement areas.

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