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Case Report

Spatiotemporal dynamics of a peri-urban stream water quality and its relationship with land use

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A B S T R A C T

This study evaluated the impact of land use/land cover patterns on the water quality of a stream in a periurban zone. For this, the water quality was determined by the NSF-WQI, Dinius-WQI, and Heavy Metal Pollution Index (HPI). On the other hand, land uses were obtained from "RapidEye" satellite images, including green, urban, commercial and industrial areas. The land uses were grouped, and the different degrees of association with the chosen water quality parameters were found. The results indicated that the physicochemical parameters were negatively correlated with the "green areas" and positively correlated with the "intervened areas".

1. Introduction

Water bodies are typically diverse and represent biologically productive environments [1,2]. Specifically, streams in urban areas serve as natural corridors for the urban population [3]. Land use/land cover (LULC) transformation processes have been found to result in increased degradation of stream water quality degradation through deposition of point and nonpoint source pollutants [4]. Therefore, information on the relationship between the LULC patterns and water quality in streams, makes it possible to establish the need for restoration of urban and peri-urban streams, as well as the urban management of these water bodies [5,6]. Despite the aforementioned, it has not been given the necessary attention to streams and other low-order water bodies, especially in large cities [7,8]. In this sense, the need for studies to analyze the relationship between water quality and LULC patterns in a given territory is emphasized [9]. This study evaluated the impact of land use patterns on the water quality of a stream in a peri-urban area of the city of Cuenca, Ecuador.

The most recent research highlights that, in order to find the relationship between water quality and LULC patterns, spatial analysis tools are useful when extracting information to establish land use categories: from land use of aerial and space images in resolutions from 1.5 to 30 m, as well as GIS tools for geoprocessing, it is possible to obtain a categorization of the LULC patterns and the subsequent relationship of the categories with water quality parameters [10–12]. Complementarily, multivariate analysis techniques have helped to find the influence of land cover on suspended sediments, nutrients, and ecological integrity of the stream [13]. This allows to explain that the contribution of pollutants from a given land use to a water body brings with it changes in its dynamics [14,15].

In studies analyzing the relationship between water quality and land use, conditions have been defined such that agricultural LULC has been characterized by having a strong influence on water quality due to the nitrate and phosphate load it provides. Likewise, urban LULC (generally classified as residential, commercial and industrial) is associated with the presence of heavy metals and fecal coliforms [4]. The impact of activities such as urban, agricultural and industrial expansion, has been considered an important factor that conditions the water quality of nearby water bodies and at the level of watersheds [4]. Also, forested and shrubby areas are related to good water quality due to the ability to act as a biological filter, just like grassland areas [4,8]. Specifically, the discharge of black and greywater to nearby water bodies, derived from discontinuous urban land where there is no coverage of basic services such as an optimal sewerage system, results in water contamination by biological agents (waterborne diseases), due to a high organic load contained in wastewater [16].

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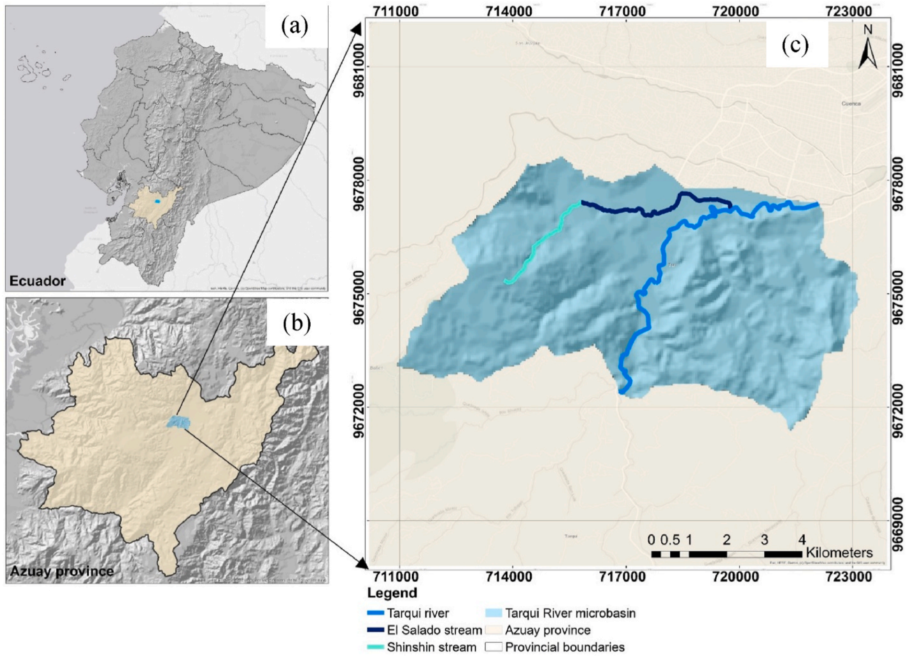


Fig. 1. Geographic delimitation map of the study area. a) Map of the country Ecuador, b) Map of the Azuay province, c) Map of the microbasin where the "El Salado" stream is located.

Other consequences like eutrophication of water bodies due to the high presence of nutrients (nitrates and phosphates) in agricultural LULC, where the intensive use of pesticides with these pollutants allows them to fun off into surface water bodies [17]. Other main sources of nutrient enrichment are attributed to effluents derived from industrial land use, domestic wastewater, and construction work (urban uses) [18]. As a result, this causes an intensive growth of algae and a higher oxygen demand, which leads to death and decomposition of the rest of aquatic flora and fauna [14]. Likewise, a change in the use of natural land for urban, industrial, and commercial uses, can reduce the water retention property of soils such as moorland and natural forest, and generate an increase in surface runoff that in turn triggers floods, especially in rainy seasons [19]. These consequences can cause the alteration of the quality of life of the surrounding population [14].

On the other hand, the El Salado stream is the main body of water that crosses the Baños populated center located to the southwest of the city of Cuenca; it has been used for decades as a source for irrigating crops and livestock activities. These productive activities have frequently ceased to be carried out due to the discharge of effluents, mainly of domestic origin, which is complemented by the fact that the upper areas of Baños do not have a sewage system. Additionally, the inadequate management of solid waste in the surrounding areas and margins of the stream has been evidenced, as well as the lack of cleaning and maintenance by the municipality (personal observation). Areas surrounding the El Salado stream have been affected in recent years by the lack of availability of water sources for irrigation, lack of sanitation, and exposure to health problems.

Several studies worldwide have examined the variation of water quality over time, as well as the relationship between urban and sub-urban population and the different land uses that influence surface water quality [20,21]. However, there are few studies that evaluate the influence of land use patterns on the water quality of small urban water bodies, such as streams. Neither have studies been carried out that consider how their results would help municipalities make responsible decisions in improving the management of urban streams [22]. To conduct an analysis of the spatiotemporal dynamics of the water quality of the El Salado stream and its relationship with the use of the soil, research related to the study of the relationship of water bodies with land uses in peri-urban sectors has been used [22–24].

Based on the above, the main objective of the present study is to determine the relationship between the water quality of a peri-urban stream and the land uses of its area of influence. Other objectives of the study were: to evaluate the water quality of the stream through physical, chemical, and microbiological parameters at various points in El Salado, by applying the NSF-WQI, Dinius-WQI and Heavy Metal Pollution Index (HPI), as well as to determine the relationship between water quality variables and LULC through statistical tools that associate the index and its variables with each land use. The results allowed to generate information that will contribute to subsequent studies to cover issues related to the protection of peri-urban streams, with the purpose of providing a reference for the generation of sufficient guidelines for improvements in territorial planning, and implementation of control measures to prevent contamination of bodies of water. The results will also allow obtaining an orientation for the formulation and reinforcement of public policies, which translates into an improvement in the management of water and soil resources.

2. Materials and methods

2.1. Study area

El Salado stream is an affluent of the Tarqui river, located in the southwest of the city of Cuenca in Azuay province, Ecuador, (2° 56′ 29″ south latitude and 79° 3' 45" west longitude). (Fig. 1). The study zone includes a peri-urban area, which means a rural and urban characterized area, and has an elevation range from 2580 to 4200 m.a.s.l. It is located in the south-western foothills of the Andean Mountain range. The study zone is characterized as an important source of tourism due to its volcanic hot springs.

In climatological terms, the area of influence is determined by the equatorial mesothermal semi-humid climate, characterized by temperatures between 12 and 20 °C, where rainy and dry seasons are generally heterogeneous in duration and location, as indicated by Ref. [25]. Slopes range from 0% to 50%. In the area where the beginning of the El Salado stream is located, there is the highest slope range, while in areas with greater urbanization, the slope ranges are the lowest and predominant.

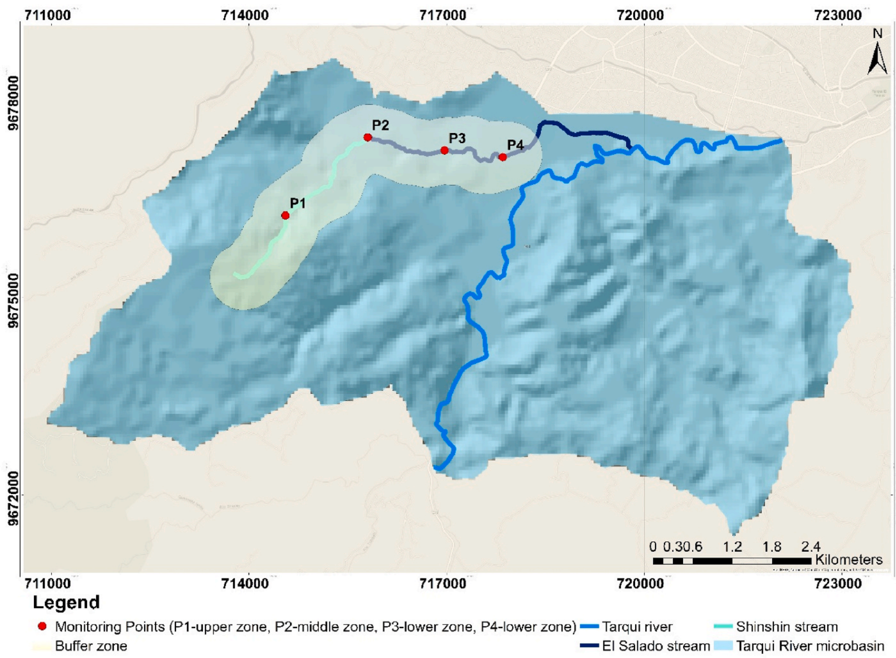


Fig. 2. Geographic delimitation map of the area of influence and location of sampling points.

2.2. Water sampling and analytical methods

To analize the relationship between LULC and water quality in the El Salado stream, it was considered a 500 m buffer zone, covering an area of 624.17 ha (Fig. 2), which is in line with what has been mentioned by various authors [26–28]. Studies, support that there is a better probability to evidence alterations in water quality by analyzing a buffer width directly adjacent to the water body [29,30]. Against this background, the area of influence was mapped, considering the beginning of the stream under study at about 180 m upstream from sampling point 1 or P1 (upper part of the stream), due to the contribution of important sources of pollution such as houses without sewerage, and agricultural areas. Sampling point 2 was located in the middle part of the El Salado stream. Finally, the study area ends in a section of an artificial open channel where sampling points 3 and 4 (lower part). From this section, the stream flows through an underground aqueduct until it flows into the Tarqui River, in a 7.98 km long route (Fig. 2).

In this study area, there is evidence of the existence of sources of contamination of the stream caused by the discharge of untreated wastewater from homes, thermal pools, car workshops and washes, located mainly in the middle (P2) and lower zone of the stream (P3 and P4), as well as from farming areas located mainly in the middle (P2) and upper part of the stream (P1).

Monitoring process was conducted at the four sampling points mentioned above (P1, P2, P3 and P4) (Fig. 2). At each of the points, sampling was carried out at a monthly frequency for 5 consecutive months (October 2019 to February 2020). At each point, 15 physical, chemical and microbiological parameters were analyzed, as well as 4 heavy metals required for the application of water quality indices. The following parameters were measured in situ: pH (pH), total solids (TS), dissolved oxygen (DO), electrical conductivity (EC), and temperature (T); a laboratory analysis was also carried out on the parameters: color (Col), turbidity (Turb), alkalinity (Alk), chlorides (Cl-), total hardness (TH), 5-day biochemical oxygen demand (BOD_5), total phosphate (PT-PO_4^{-3}), nitrates (NO^{3-}), fecal coliforms (FC) and total coliforms (TC), arsenic (As), cadmium (Cd), chromium (Cr) and Zinc (Zn).

The choice of heavy metals was made based on the relevance in terms of environmental and human health effects even in small concentrations, as indicated by Ref. [31], as well as based on the volcanic scenario of the study area.

Table 1
Equipment and methods used for the analysis of water quality parameters.

Measurement	Parameter	Equipment/Regeants	Method
In-situ	pH	Multiparameter	MNE 4500-B
	EC		2510-B
	DO		MNE 4500-G
	TS		MNE 2540-B
	T		MNE 2550-B
Ex-situ	Cl-	Reagent pillows for detection.	MNE 4500-G
	PT-PO4-3	Spectophotometer.	MNE 2320-C
	NO3-		MNE 4500-B
	Cd		MNE 3500-D
	Cr		MNE 3500-E
	Zn		MNE 3500-F
	As	Inorganic As detection reagent package	MNE 3500-C
	Alk	Sulfuric acid titration	MNE 2320-B
	BOD_5	Inoculation. Dissolved Oxygen Meter	MNE 5210-B
	TH	Ehylenediaminetetraacetic acid sodium salt	MNE 2340-C
	Col	Pt–Co reference solution	MNE 2120-B
	Tur	Portable Turbidimeter	MNE 2130-B
	FC	Multiple tube series	Most Probable Number (MPN)
	TC		

Sampling for physical, chemical and microbiological analysis was conducted according to the methodology of the Standard Normalized Methods [32], where simple samples were taken manually with 1 L containers, which were hermetically sealed, refrigerated and transported to the laboratory for analysis. It is important to emphasize that central points were selected for the collection of the samples, where there is no water stagnation or proximity to the banks of the stream. In-situ and ex-situ laboratory measurements were made to obtain the values of the water quality parameters: for in-situ measurements, a portable multiparametric water quality meter was used to measure pH, EC, DO, TS, and T. The ex-situ analysis of the water samples collected was carried out at the Water Analysis Laboratory of the University of Cuenca, following the procedure specified in Table 1 [32]:

The analysis was carried out under the following established laboratory conditions: temperature of 18 °C at 2530 m.a.s.l, at an atmospheric pressure of 530 mmHg.

2.3. Estimation of water quality indices (WQI)

The NSF-WQI index was calculated using the methodology provided by Refs. [33,34] for each monitoring point on a monthly basis. The second quality index Dinius-WQI was calculated using the methodology provided by Ref. [35]. For the calculation of the heavy metal pollution index (HPI), the methodology recommended by Refs. [36,37] was used. The relevance of the Dinius-WQI index lies in the determination of water quality according to the specific use and needs of the study (agricultural use), so the values that make up this index were compared with the water quality criteria for agricultural of irrigation use (pH, DO, and FC). This last index, by allowing the evaluation of water quality according to a specific water use, is in line with the uses that the stream under study was used in the past: crop planting.

2.4. LULC analysis

Cartographic information corresponding to the land use and land cover map of the local Development and Land Use Plan of Cuenca was used, whose information corresponds to the set of RapidEye 2010 satellite images at a local level, with a spatial resolution of 5 m, using the geoprocessing toolset of GIS software to map LULC, presenting a UTM WGS 84 Zone 17 South projection. It was recognized that the land use patterns do not show a substantial change for the most recent years. The buffer area was divided into four small zones, drawn based on the beginning and end of the location of the selected water monitoring points P1, P2, P3 and P4. This division allowed to obtain the percentage areas of land uses in each of the 4 zones, and was performed prior to statistical analysis due to the implication of correlation as an analysis between two datasets with the sample size "n": water quality parameters (4 sampling points) and land uses (4% areas) following similar methodologies [38].

2.5. Statistical analysis of correlation between water quality and land use

For this purpose, 16 out of 19 analysis parameters were considered: Col, T, Turb, pH, TS, DO, BOD_5, PT-$PO_4^{-3,}$ NO_3^-, EC, Alk, TH, As, Cd, Cr and Zn. This choice was based on the relevance for the present study according to personal observation and according to commonly used parameters found in the reviewed literature [39], where FC and TC were excepted because their concentration remained constant throughout the monitoring, preventing the applicability for this type of variables, as established by the statistical program used.

Six analyses of variance, including ANOVA, Kruskal – Wallis and Wlech's test of ANOVA, were used to identify the influence of spatio – temporal variables (sampling point and month of monitoring) on the results of water quality indices. The tests were performed at a significance level of $p < 0.05$. The analyses of variance were grouped into two categories: "spatial variable or sampling point" and "temporal variable or monitoring month". For those data sets where the parametricity conditions were met, ANOVA was applied and a posteriori or post-hoc test was additionally performed to compare means and categorize them into groups. The Bonferroni technique was used, one of the methods applicable when the number of observations is small [40].

The multivariate principal component analysis (PCA) tool was used to perform land use categories and subsequently carry out the analysis of the degree of linear association between water quality parameters and the values of each principal component. The PCA was performed using the XLSTAT 2020 software, where eigenvalues and eigenvectors were obtained to establish the number of principal components and the quality of the projection. The relationship between each principal component and each land use was interpreted. Then, Pearson's correlation coefficient method was applied to find the relationship between the 16 individual water quality variables, with land uses and principal components, at a 95% confidence level. Prior to the correlation method, the largest number of variables was found to be normally distributed, thus excluding the possibility of choosing non-parametric correlation coefficient methods, since the Shapiro-Wilk normality test showed that most of the water quality and LULC data followed a normal distribution. The choice of method based on a majority of non-normally distributed values was supported by Ref. [41]. This coefficient was also used because is one of the most common methods for the analysis of continuous data [39].

3. Results

3.1. Water quality characteristics

The results of the analysis of the water quality parameters indicated that temperature values ranged from 14.1 °C to 23.3 °C, with high temperatures being recorded from December to January, due to the evident local climatic variability during the last few years. In relation to pH, values ranged from 5.74 to 8.64 in the dry season and from 5.42 to 8.47 in the rainy season, indicating that in both seasons the stream water was acidic at specific sampling sites, but alkaline water predominated. This predominance can be attributed to a high concentration of ions in the water due to the natural presence of mineral salts in volcanic waters. Likewise, there was a higher alkalinity in the dry season, derived from a lower dilution of minerals in the water due to a decrease in precipitation. Tur presented mean values of 23.3 and 17.39 UNT in dry and rainy season respectively, showing the accumulation of suspended materials and sediments. A total of 419.05 mg/L of TS was presented during the dry season and 551.19 mg/L during the rainy season, which is attributed to the dragging of solids along the stream thanks to the precipitation evidenced, close to the fourth monitoring (January).

Regarding DO, higher values were obtained in the dry season (6.94 mg/L) than in the rainy season (4.29 mg/L). These values derive from a greater presence of salts in the rainy season than in the dry season, through the inversely proportional relationship with the EC values obtained (619.15 μS/cm in the dry season and 727.29 μS/cm in the rainy season), where oxygen depletion promotes the release of ions, increasing the EC [42]. There was no evidence of turbulent flows in the water, which could have a negative influence on water quality in terms of oxygenation. This in turn would explain a lower aerobic activity of aquatic microorganisms that may be present in the water, which may indicate that these values affected the BOD_5 results, corresponding to 6.72 mg/L in the dry season and 4.35 mg/L in the rainy season. A possible explanation for the relationship between DO and BOD_5 values is that the presence of forested areas from point 1 allow the accumulation of refractory organic matter derived from decomposing plant material, which then flows to the next sampling sites via surface runoff, implying that such BOD_5 values exist, thus implying that the rate of oxygen consumption depends on the organic material in the sample, and may also be linked to the characteristics of the microorganisms present (organic matter consumption rate). This occurs in studies such as [43], where forested areas are positively related to both DO and COD_{Mn}.

PT-PO_4^{-3} concentration (1.39 mg/L in the dry season and 0.46 mg/L in the rainy season) were relatively low, indicating the absence of algae formation. On the other hand, the values of total nitrogen expressed as NO^{3-}, (0.64 mg/L in the dry season and 2.65 mg/L in the rainy season) can be explained by the drag of natural and synthetic nitrogen compounds derived from fertilizers and chemical fertilizers coming from the crop plots, especially in the rainy season, as established by Ref. [44]. With respect to the parameter Col, 68.54 UC was obtained in the dry season and 62.88 UC in the rainy season. This parameter characterized the water with a very light brown color associated with the content of humic substances, due to the contact of the stream water with soil organic matter. The Cl-parameter in both seasons was present in low concentrations in a constant way, with a value of 0.04 mg/L (dry season)

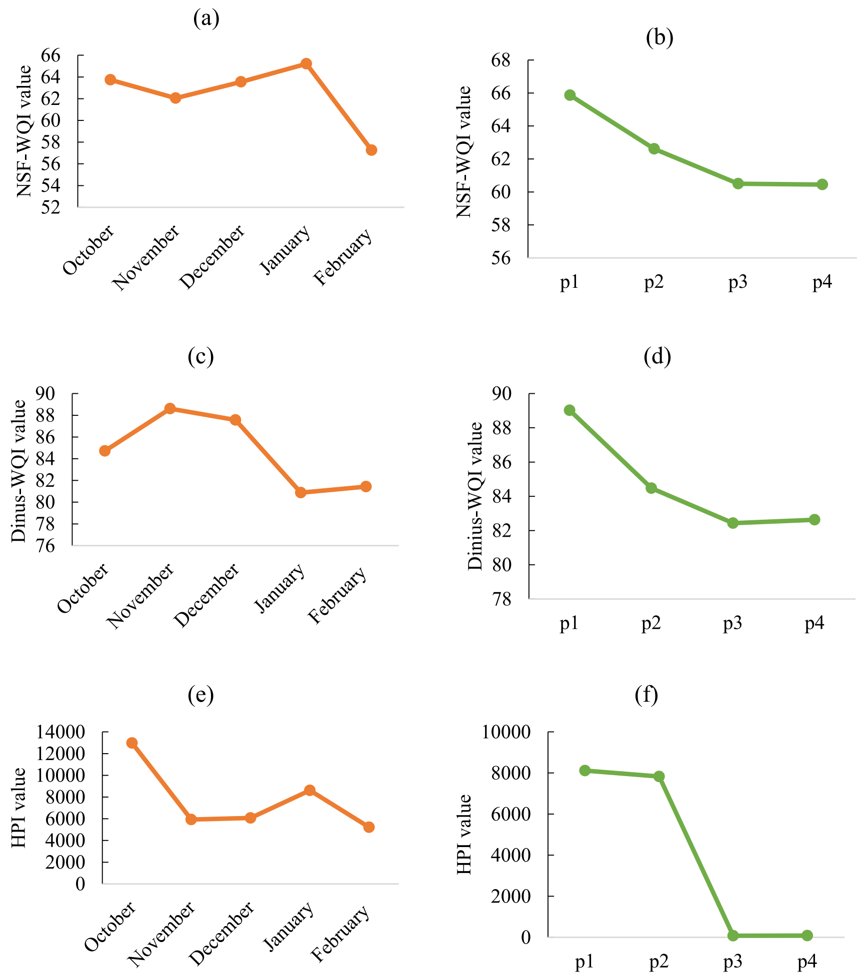


Fig. 3. Results of the applied water quality indices.

and 0.06 mg/L (rainy season), which can be attributed to the fact that natural waters have chlorides. The EC values, as mentioned above, presented an average value of 619.5 µS/cm in the dry season, and an increase was reported in the rainy season with an average value of 727.29 µS/cm, this is due to the existence of natural factors such as volcanological factors that cause an extreme mineralization of the water, since, as mentioned above, the study area has thermal waters of volcanic origin. This led to the assumption that this increase in the concentration of dissolved electrolytes was due to natural ionic dissolution processes, which is clearly corroborated by the drop in pH that occurred during the rainy season [45]. The average alkalinity value was 146.46 mg/L $CaCO_3$ in the dry season and 140 mg/L $CaCO_3$ in the rainy season. This was one of the relevant parameters that made it possible to evaluate the existence of alkaline substances of carbonates, bicarbonates, and hydroxides, mainly Ca and Mg [46]. The TH as $CaCO_3$ had a mean value of 85 mg/L, which qualified the water as slightly hard in both seasons, which is attributed to the content of salts, whose sources correspond to minerals, natural rocks and thermal waters present in the area, thus providing a conductivity capacity in the aquatic environment [46]. The presence of FC in all the points during all the monitoring months is due to the direct discharge of domestic wastewater into this stream in areas that do not have access to the sewerage system, this occurs in some houses located in zones adjacent to the points 1 and 2 that do not have this service. In addition, the presence of PVC pipelines discharging untreated domestic wastewater into the stream was observed in points 3 and 4. In this case, despite the existence of sewage systems in these areas, there are some households which, due to their geographical location, cannot discharge their wastewater into the sewage system, which is why it is deduced that they discharge such effluents into the stream.

In relation to heavy metals, in the first monitoring corresponding to October (dry season), the highest concentrations of As of 252.50 µg/L and Cd of 510.50 µg/L were found. In the rainy season, the concentrations of As and Cd were a little lower than those witnessed in the dry season, however, these two metals were consistently found in excessive amounts considering that the WHO presents a standard value for As, Cd, Cr and Zn concentrations of 10, 3, 50 and 300 µg/L respectively, in surface water for water destined for human consumption [47]. The mean concentration of the heavy metals expressed in µg/L had the following order: Cd (324.50) > As (196.67) > Zn (35.83) > Cr (5.83) in the dry season, and of the same order Cd (264) > As (247.63) > Zn (27.50) > Cr (13) in the rainy season. The mean concentration of all heavy metals throughout the study period was highest at P3, followed by P4, results attributable to its location (downstream of the stream), specifically within the fully urbanized area. The next value corresponded to P2, which is upstream of the reference stream within the peri-urban zone, while the lowest concentration of these heavy metals was at P1, also upstream and located at the highest point of the stream, where a higher proportion of natural areas were evident, which can be corroborated in the land use maps of the area of influence, although in general the presence of heavy metals was high along the entire length of the stream. These results indicate that concentrations of As and Cd are significantly toxic to the aquatic environment and to the health of the people living in this study area, especially if they are consumed directly

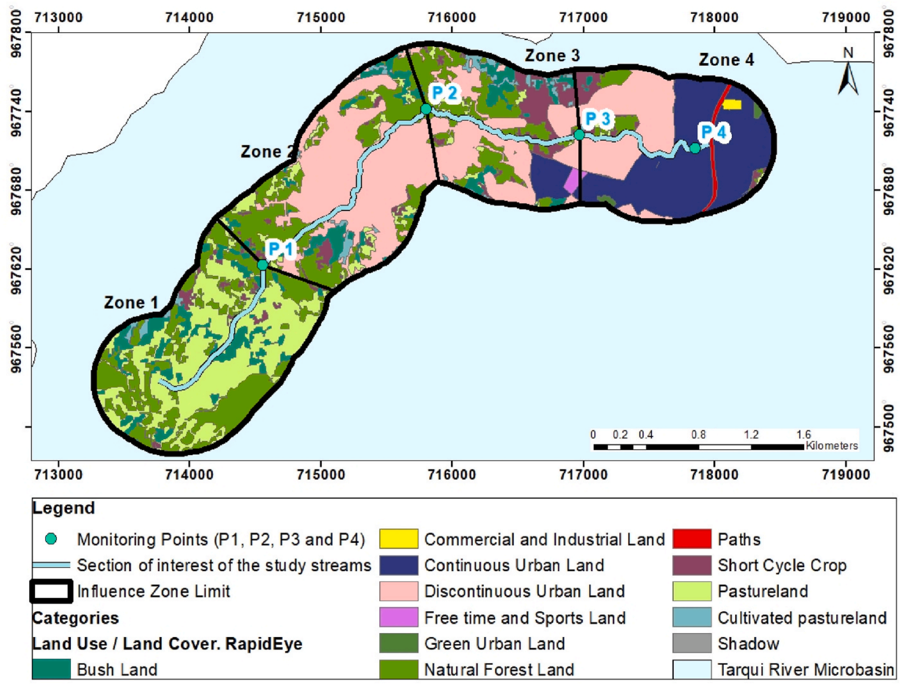


Fig. 4. Subdivision of zones of the area of influence.

or indirectly because of the uses studied.

With respect to water quality indices, the overall water quality through the NSF-WQI index had an average value of 61.23, indicating a "medium" quality criterion. The temporal variation of NSF-WQI is shown in Fig. 3 (a). In both seasonal periods, all index values remained in the range of 51–70, except for P1 in December (dry season) where a value of 72.80 was obtained, mainly due to lower values for ST and BOD_5 compared to the rest of the values measured for the following points in the remaining months, as P1 corresponds to the point upstream closest to forested areas and shrubby areas. The spatial variation of NSF-WQI is presented in Fig. 3 (b). It is observed that water quality decreases from P1 to P4, because as natural areas decrease, urban and peri-urban areas increase, where the contribution of wastewater from direct anthropogenic activities has been evidenced.

When analyzing the conditions and background of the stream, it was relevant to apply Dinius-WQI because it allows the evaluation of water quality according to the water use, in this case study the use is agricultural. As with the previous index, an overall average of the individual ratings was used to qualitatively interpret water quality. The average monthly variation of quality with this index is presented in Fig. 3 (c). The month of January (rainy season) had the lowest value than the other months with 80.88, and the month of November (dry season) had the highest value with 88.61. The average scores had a high value (range 71–100) with a mean of 84.64, which categorized the agricultural water quality in the category "No purification necessary", for all months monitored. Therefore, the Dinius-WQI indicated that the water was found to be in a relatively acceptable state for agricultural purposes. In summary, the water quality was found to be relatively better in the dry season (86.96) than in the rainy season (81.15), indicating that the stream water does not need any purification treatment to be used for crops. The difference between the two seasonal periods did not vary significantly as their values are within the same classification range. With respect to spatial variation, the water quality decreased equally from P1 to P4, showing that although there were slight differences between the values of the results, the contamination of the stream water increased as it approaches the urban area, due to the influence of livestock, agricultural, domestic, and commercial activities (personal observation) (Fig. 3 d).

The application of the HPI index determined an overall average value of 7627.42, indicating that the results from all sampling sites greatly exceeded the WHO critical limit for drinking water (100); the analysis of the above was performed considering that the water from this stream was collected for drinking water treatment; however, in a conventional drinking water treatment plant these metals are not removed. The water was therefore characterized as "with high levels of heavy metal contamination" (above a value of 30). The mean HPI for the El Salado stream in the dry season was 8326.63, and subsequently decreased in the rainy season with a value of 6928.21 (Fig. 3 e). Therefore, in both seasons the water of the stream contained heavy metals in a large and constant amount. The slight variations with respect to the seasonal period can be explained by a higher dilution of the pollutants during the rainy season (higher flows). In relation to the monitoring point, the HPI values at P1 can be mainly attributed to the high concentrations of Cd and As, because these elements are naturally occurring, as mentioned previously (Fig. 4 f). Specifically, As passes into an aqueous state in hydrothermal waters or precipitates and accumulates in the sediments of water bodies. As for Cd, it was determined that it could also be introduced into the stream by anthropogenic sources, through the use of agricultural products (phosphate fertilizers), discharges from urban establishments found along the route (P3 and P4) such as galvanizing plants, automotive mechanics, lubricators and washing machines, and in smaller quantities through the incineration of waste, wood, plastics, coal and tire rubbers that were observed along the stream [44,48]. Based on these considerations, it is presumed that the high concentrations of heavy metals obtained are mainly due to the presence of natural sources, to which the various anthropogenic sources are also added, the latter being a possible explanation for the difference in concentrations between one sampling point and the other. This can be attributed to the presence of heavy metals that are deposited in the mineral rocks of volcanic origin in the Baños area, which are incorporated into the hydrothermal waters once natural weathering of these rocks occurs, as well as the erosion of soils and geological formations. Of this group, the most common metals found in the water include those of interest for the present study [49]. Specifically, the presence of As has been reported in local water bodies, this is due to factors such as the Tertiary and Quaternary volcanism characteristic of the Andes Mountains that is

Table 2
Results of analysis of variance.

Quantitative Dependent Variable	Qualitative Independent Variable			
	Sampling Point		Sampling Month	
	Value	Interpretation	Value	Interpretation
NSF-WQI	0.2811	No Significant Difference ($p > 0.05$)	0.1895	No Significant Difference ($p > 0.05$)
Dinius -WQI	0.2125	No Significant Difference ($p > 0.05$)	0.119	No Significant Difference ($p > 0.05$)
HPI	0.9129	No Significant Difference ($p > 0.05$)	0.0683	Significant Difference ($p < 0.05$)

manifested in these thermal waters [50]. Cd, Cr and Zn, on the other hand, are naturally distributed in the earth's crust, which represents a natural source of these metals in water bodies due to soil erosion processes and sedimentary and igneous rocks [51].

To determine whether the spatio-temporal difference is significant, ANOVA results showed that the distribution of water quality indices data per sampling point was of an independent, normal nature (except for the Dinius-WQI index values) and their variances were homoscedastic. For this reason, the data of the NSF-WQI and HPI indices were analyzed using the ANOVA method, and the Dinius-WQI data were analyzed using the Kruskal-Wallis method. Based on the analysis performed, the significance level was higher than 0.05 ($p > 0.05$), which showed that there were no significant differences between the means of the data set. The slight differences explained better water quality at higher altitude (point 1) for the NSF-WQI and Dinius-WQI. It was also corroborated that the heavy metal content was relatively constant along the stream despite the different land uses encountered, which is attributed to a natural type of input. As for the temporal analysis of the monthly determined water quality indices, the distribution of the data was independent, normal (except for the HPI values) and homoscedastic (except for the Dinius-WQI values). Therefore, the ANOVA analysis was applied for the NSF-WQI index, the Welch method of ANOVA for Dinius-WQI, and the Kruskal-Wallis method for the HPI index. After the analyses, it was determined that water quality did not present a statistically significant difference in its values according to the month of monitoring ($p > 0.05$), which are subject to seasonality. Therefore, it was established that the difference in water quality according to the climatic conditions presented in each month, defined for the rainy and dry seasons, did not represent a significantly influential variable in the water quality of the El Salado stream.

In summary, for the six analyses of variance, there were no statistically significant differences. The results of the analysis of variance are shown in Table 2:

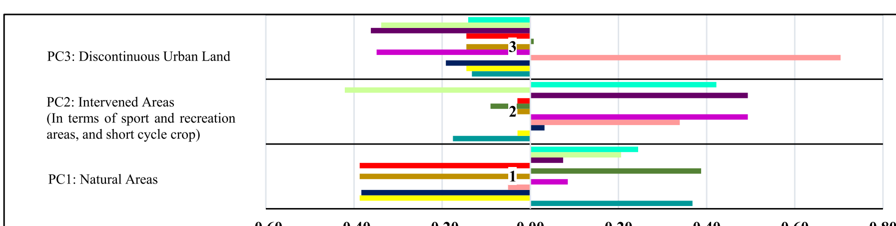
3.2. LULC categorization

Fig. 4 shows the results of the area of influence with the corresponding land uses divided into 4 zones, each zone encompassing a monitoring point. In accordance with the slope map, a decreasing trend of urban LULC was revealed as the slope increases in the area of influence. The LULC with the largest surface area for the entire area of influence corresponded to the discontinuous urban land (185.63 ha), followed by natural forest land (145.20 ha), pastureland (108.6 ha) and consequently continuous urban land (92.28 ha). It can be seen that there is a strong predominance of urban and natural LULC adjacent to the El Salado stream.

3.3. Linkages between water quality and land use parameters

The 11 land use categories were grouped using PCA, resulting in 3 components: PC1, PC2 and PC3. These components agglomerated all the original land use categories and were defined after finding the eigenvalues greater than 1. The cumulative values, on the other hand, determined that the three principal components explained 100% of the variation in the data set, meeting the acceptability (minimum 90%) for using such a component size (minimum 90%) (3). It was shown that the three principal components (PC) explained the total variability in the data, since the cumulative percentage reached 100%, which is why they were chosen for further correlation with the water quality parameters. In addition, the remaining components represented a practically null proportion of the variability. The visual representation of the PCA eigenvectors is shown in Fig. 5. The influence plots or "biplots" are also shown for the principal component axes 1 and 2, which explained 88.93% of the variability of the data (Fig. 6), and for the principal component axes 1 and 3, which explained 69.96% of the variability of the data (Fig. 7).

The figures allowed to explain the most influential variables for the formation of each principal component, through their eigenvalues and eigenvectors: The category that indicated a large positive influence on PC1 corresponded mainly to natural forest land, with an eigen vector of 0.388, followed by bushland with a vector of 0.368. On the contrary, land uses such as commercial and industrial land, continuous urban land, green urban land, and roads, had a negative effect on this component by obtaining values around −0.38. With respect to PC2, the



	1	2	3
Cultivated Pastureland	0.245	0.422	-0.141
Pastureland	0.206	-0.421	-0.338
Short Cycle Crop	0.074	0.494	-0.362
Paths	-0.387	-0.029	-0.145
Natural Forest Land	0.388	-0.090	0.008
Green Urban Land	-0.387	-0.029	-0.145
Free time and Sports Land	0.085	0.494	-0.349
Discontinuous Urban Land	-0.051	0.339	0.704
Continuous Urban Land	-0.383	0.032	-0.192
Commercial and Industrial Land	-0.387	-0.029	-0.145
Bush land	0.368	-0.176	-0.132

Fig. 5. Principal component analysis eigenvectors.

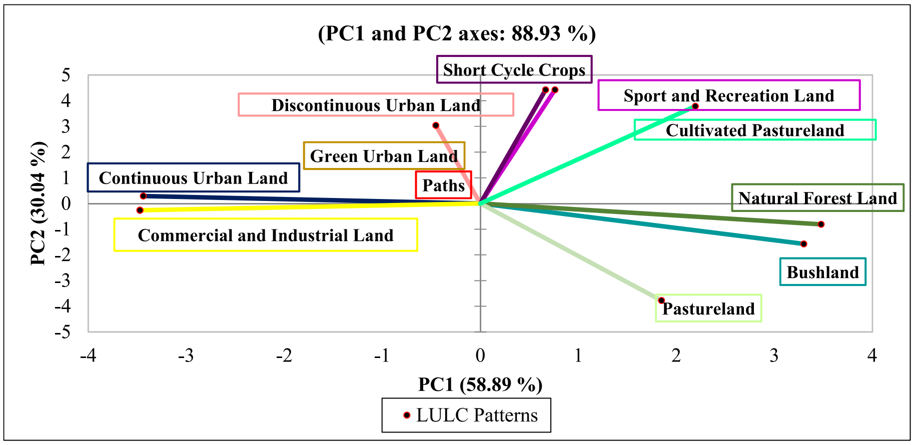


Fig. 6. Biplot (PC1 and PC2 axes).

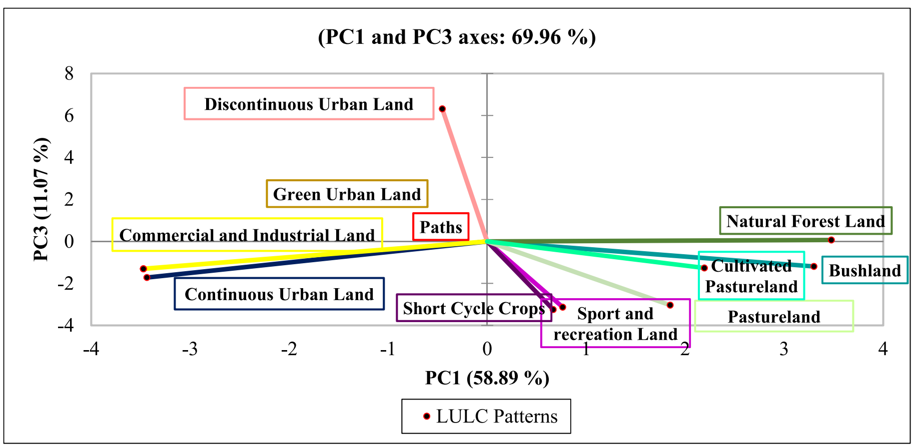


Fig. 7. Biplot (PC1 and PC3 axes).

most positively influenced categories were short cycle crops, sport and recreation (0.494), followed by cultivated pastureland (0.422). In contrast, the natural pastureland category had a negative relationship with PC2 (−0.421). Based on these results, it could be established that the second component is positively correlated with certain intervened areas, because of the similarities between the short cycle crop land and

Table 3
Pearson correlation coefficients between water quality parameters, PC1, PC2, PC3 and LULC patterns.

LULC Pattern / Parameter	pH	TS	DO	BOD_5	PT-PO_4^{-3}	NO_3^-	EC	Alk	TH	As	Cd	Cr	Zn	PC1	PC2	PC3
Bushland	**-0.995**	-0.742	-0.292	-0.357	-0.167	-0.942	-0.635	-0.650	-0.696	-0.756	0.940	-0.351	0.578	0.936	-0.319	-0.146
Commercial and Industrial Land	0.838	0.355	0.457	0.595	-0.143	0.674	0.210	0.219	0.277	0.414	**-0.954**	0.728	-0.867	-0.986	-0.053	-0.160
Continuous Urban Land	0.856	0.424	0.536	0.651	-0.023	0.705	0.283	0.280	0.330	0.497	-0.934	0.656	-0.872	-0.976	0.059	-0.211
Discontinuous Urban Land	0.514	0.830	-0.440	-0.531	0.437	0.705	0.878	0.920	0.921	0.710	-0.224	-0.556	0.482	-0.129	0.616	0.777
Sport and recreation Land	0.025	0.504	0.560	0.360	**0.974**	0.157	0.550	0.452	0.381	0.605	0.291	-0.673	0.080	0.216	0.897	-0.385
Green Urban Land	0.838	0.355	0.457	0.595	-0.143	0.674	0.210	0.219	0.277	0.414	**-0.954**	0.728	-0.867	-0.986	-0.053	-0.160
Natural Forest Land	**-0.950**	-0.585	-0.395	-0.493	-0.039	-0.843	-0.457	-0.468	-0.520	-0.624	**0.971**	-0.535	0.737	0.986	-0.164	0.008
Paths	0.838	0.355	0.457	0.595	-0.143	0.674	0.210	0.219	0.277	0.414	**-0.954**	0.728	-0.867	-0.986	-0.053	-0.160
Short Cycle Crops	0.047	0.511	0.582	0.385	**0.973**	0.172	0.554	0.454	0.384	0.616	0.266	-0.651	0.051	0.189	0.897	-0.399
Pastureland	-0.830	**-0.996**	-0.098	-0.028	-0.610	-0.939	**-0.975**	**-0.976**	**-0.982**	**-0.971**	0.554	0.295	0.046	0.524	-0.765	-0.374
Cultivated Pastureland	-0.334	0.289	0.178	-0.049	0.854	-0.140	0.397	0.321	0.238	0.329	0.657	-0.909	0.512	0.622	0.767	-0.156

1 0.9 0.75 0.5 0.25 0.00 -0.25 -0.5 -0.75 -0.9 -1

Table 4
Pearson correlation coefficients between water quality parameters, PC1, PC2, PC3 and LULC patterns.

	pH	TS	DO	BOD_5	$PT\text{-}PO_4^{-3}$	NO_3^-	EC	Alk	TH	As	Cd	Cr	Zn
PC1	−0.907	−0.460	−0.338	−0.469	0.124	−0.772	−0.323	−0.346	−0.407	−0.491	**0.989**	−0.657	0.770
PC2	0.348	0.819	0.327	0.140	**0.974**	0.519	0.860	0.798	0.748	0.858	0.024	−0.706	0.168
PC3	0.236	0.343	−0.882	−0.872	−0.190	0.368	0.394	0.493	0.525	0.152	−0.143	−0.265	0.615

sport and recreation areas, while natural areas such as pastureland had a negative influence on it. As for PC3, the discontinuous urban land presented a strong positive correlation whose value had the largest magnitude in relation to the rest of the categories (0.704). For this component, the rest of the categories showed a negative correlation except for the land use corresponding to natural forest land, whose value close to 0 indicated that the influence is very insignificant (0.008). The most negatively influenced land uses were short cycle crops, sport and recreation area and natural pastureland, respectively. From these data, it was determined that PC3 referred to the discontinuous urban land, while the rest of the variables showed negative or non-significant influence (Figs. 5–7).

Based on the results generated, the principal components were categorized according to the eigenvectors that had the greatest influence on the construction of each of them. Therefore, the principal components were classified into natural areas such as natural forest land (PC1), intervened areas in terms of cultivated soils (short cycle crops) and soils for recreational purposes (sport and recreation) (PC2), and discontinuous urban land (PC3). The purpose of extracting the components was to use them in the correlation analysis, to simplify the interpretation in terms of the association of individual water quality variables with the new land use categories.

The results of the Shapiro-Wilk test for water quality parameters, land use categories, and scores of the three principal components determined that the majority of values (16 out of 26 values) corresponded to a significance greater than 0.05, which is why the Pearson correlation coefficient was chosen (Table 3).

The interpretation of the Pearson correlation results was divided according to land use categories and allowed to explain the results obtained in Table 3:

- Bushland: Natural areas such as bushes, which represent spaces without anthropogenic intervention, did not present a significant adverse impact on water quality with the exception of naturally occurring heavy metals in the upper part of the stream, as mentioned above.
- Commercial and industrial area: For this category, there was a positive correlation with most of the water quality parameters, with pH in first place, followed by Cr, NO^{3-}, and BOD_5 mainly. In relation to CPs, there was evidently a strong negative correlation with CP1, which is represented by natural areas.
- Continuous urban land: It showed positive correlations for most of the water quality parameters, such as pH, DO, BOD_5, NO_3- and Cr. This can be understood by the existence of anthropogenic sources of pollutants derived from this land use, which include domestic wastewater discharged directly into the stream or ending up in it. As for the commercial and industrial area, there was a strong negative correlation with PC1.
- Discontinuous urban land: This land use also showed a strong influence on stream water quality by correlating positively with most variables: strong positive correlations were found with Alk and TH, and moderate correlations with TS and EC. There were no strong negative correlations, and evidently, there was a positive correlation with PC3 because this component is represented by this land use.
- Sport and recreation land: Positive correlations were obtained with almost all parameters as it is a recreational area within the urban area, mainly with $PT\text{-}PO_4^{-3}$, due to the fact that the PCA method related and grouped this use with the areas of short cycle crops and pasture, which leads to similar correlations with the parameters. Therefore, the correlation with phosphates is attributable to the fact that crops are characterized as contributing uses of pollutants such as nutrients. Evidently, there was a positive correlation with PC2, which is represented by this land use as well as short cycle crops because of their similar characterization.
- Green urban land: The effect of this land use is negative on water quality because many moderate positive correlations were obtained with the parameters, mainly with pH, NO_3^-, BOD_5 and Cr; while Cd showed a significant negative value, as well as Zn, again showing the difference between the sources of heavy metals with the rest of the parameters. There was a strong negative correlation with PC1, i.e. with natural areas, which corroborates the negative effect on water quality.
- Natural forest: Cd showed a strong positive correlation and Zn a moderate one. This again emphasizes that the high concentrations of Cd in the stream water are due to natural contamination that may come from these areas, which contributes to the degradation of the water quality. The other correlations with the remaining variables were negative, especially with pH and NO_3^-. As it is a natural area, it presented a strong positive correlation with PC1.
- Roads: It is an urban land use type that is present in greater quantity within the continuous urban land, which implies a negative role in influencing overall water quality because of the number of moderate positive correlations it had with most water quality variables. Being a local area of the urban area, it had a significant negative correlation with PC1.
- Short cycle crops: There were several positive relationships between the area under short cycle cultivation with most of the water quality variables, especially with $PT\text{-}PO_4^{-3}$ which showed a significant strong correlation with this land use. This can be attributed to the agriculture developed in the study area and the application of fertilizers that contribute to the contamination of this water, which can enter through runoff processes until it reaches the stream and finally flows into the Tarqui River. On the other hand, its relationship with NO_3^- is weak positive and can be explained by the capacity of absorption and retention of pollutants that the vegetation has on the soil surface of the cultivated land. These results allowed to determine that short cycle crops play a complex role in influencing water quality. It is related to PC2 through a positive association.
- Pastureland: Natural pastureland had a significant positive influence on water quality. Strong negative correlations were found with TS, NO_3^-, EC, Alk, TH and As, and moderate negative correlations with pH and $PT\text{-}PO_4^{-3}$. This is supported by similar results obtained in another study by Bahar et al. (2008), which states that pastureland helps in the reduction of nitrogen and phosphorus pollutants, thus allowing natural regulation of water quality. In addition, this LULC can effectively reduce nutrient salts introduced into the stream by surface runoff, leading to a possible improvement in water quality. The cultivated pastureland, on the other hand, showed influence on water quality because of the positive correlations found. Natural pastureland showed a strong negative correlation with PC2, represented by disturbed areas. Cultivated pastureland, on the other hand, showed a strong positive correlation with it.

Pearson's correlation was applied to establish the degree of association between the principal components grouping the land uses and the water quality variables studied. The most relevant variables for the

Table 5
Studies of land use impact on water quality: a comparison.

Author	Main parameters influencing water quality	Main land uses influencing water quality	Main results
[52]	FC, TC, TSS, TDS, BOD_5, ammonia nitrogen COD, nitrate, T, pH	Industrial and urban land use, agricultural land use, rivers with plantation effluents exposed to pesticides and herbicides, recreational land use, "lightly disturbed" land use (protected areas).	It was found that rivers with industrial and urban land use registered the highest level of pollution (positive correlation with all water quality parameters studied), followed by agricultural land use (positive correlation with BOD_5 influenced by high levels of nitrogen and phosphorus that increase this parameter, COD, nitrate, high temperatures and low pH due to the presence of coliforms) and recreational land use (FC and TC), while protected areas registered the lowest level of pollution (positive correlation with DO, low temperature).
[12]	NO_3^- N, TP, TS, DO, EC T, pH	Urban land use and forested area	Higher concentrations of EC, NN, pH, TP, TS and T are positively associated with urban land use, especially in areas with low elevations. The forested area was positively associated with DO.
[27]	COD, TP y TN	Forested and grassland area, building area, "impervious" surface (roads and structures), crops, water bodies, and other areas (bare soil).	The urban area (impervious) and other areas (bare soil) were positively related to COD and TP, due to the fact that organic matter and phosphorus loss are related to runoff content and concentration. The crop area showed a strong positive correlation with TP, in this case TN had no significant correlation, and showed a negative correlation with COD. Forest, grassland, and water bodies were negatively correlated with TN and TP.
[43]	pH, EC, DO, COD, COD_{Mn}, NH_3–N, NO_3^- N, TN, TP, SO_4^{2}-	Arable land, forest, grassland, water bodies, urban land use (residential, commercial and industrial), and bare soil.	Forest area was found to be positively related to DO and negatively related to NH_3–N, TP, and TN. It was reported that it was unexpected that the forested area was positively related to COD_{Mn}. A speculation of this phenomenon is that the presence of forest generates an accumulation of refractory organic matter derived from decomposing plant material, which then flows into the water through surface runoff. Added to this is the fact that on high slopes, as was the case in the study area where this phenomenon occurred, there is a higher rate of water flow which contributes to soil erosion and rates of particulate matter and pollutants, thus increasing oxygen demand. On the other hand, arable land was positively associated with nutrients and negatively associated with DO, serving as a source of pollution. The grassland area showed a positive relationship with pH and SO_4^{2}-. The urban land use revealed a positive correlation with COD and NH_3–N. Water bodies were correlated with EC and COD. Bare soil was positively correlated with NO_3^-N.
[22]	As, Hg, Cu, Zn, Pb, Cr, Cd	Agricultural and urban industrial land use	The results showed that a peri-urban area with a high percentage of industrialization generated a much higher risk of contamination by heavy metals such as Cu, Zn, Pb and Cd, than in other areas such as agriculture, which although related to a high content of As, Hg, Pb and Cr, remained below the local limits established to protect agricultural production and maintain human health.
Present study	pH, As, Cd, Cr, Zn, FC, NO_3^-, PT-PO_4^{-3}, EC, TS, TH, Alk, DO, BOD_5	Natural areas (natural forest, shrubs, grassland), intervened areas (recreation areas and crops), and urban area (discontinuous).	Natural areas showed a strong positive correlation with Cd and a moderate positive correlation with Zn, as well as a strong negative correlation with pH and moderate correlation with NO_3^- and Cr. Intervened areas showed strong positive correlations with PT-PO_4^{-3} and moderate positive correlations with ST, EC, As, and NO_3^-. In addition, there were weak positive correlations with pH, DO, BOD_5, Zn and Cd, in order as described, and

(continued on next page)

Table 5 (*continued*)

Author	Main parameters influencing water quality	Main land uses influencing water quality	Main results
			a moderate negative correlation with Cr. Urban land use showed positive correlations with Zn, TH and Alk, and negative correlations with DO.

present study were considered (Table 4).

The values in bold highlighting maintain a significance level of 5%. Those values in blue indicate a moderate to strong positive correlation between variables (0.5–0.9 and 0.9 to 1, respectively), and those in red indicate a moderate to strong negative correlation with the same ranges. The other values express weak positive or negative correlations.

PC1 showed a strong positive correlation only with Cd, and a moderate positive correlation with Zn, as well as a strong negative correlation with pH and moderate with NO_{3-} and Cr. The other values explained weak correlations. PC2 showed a strong positive correlation with PT-PO_4^{-3} and PC3 did not show strong significant positive correlations with any of the water quality parameters. However, it did explain moderate positive correlations with Zn, Du TH and Alk. This means that all three components played a negative and significant role in overall water quality.

As previously determined, natural areas such as forests (PC1) act as sinks, and therefore did not contribute certain pollutants that alter the water conditions of the stream. In addition, there is less presence of point-source pollution in these areas. However, it was possible to identify that, within this surface, there is a source of natural pollution that deteriorates the quality of the water, mainly due to considerable contribution of heavy metals.

On the other hand, the cultivated land surfaces, including urban areas such as sports and recreation (PC2), also generated negative effects on water quality, representing a source of anthropogenic pollution and showing positive relationships with all the pollutant variables studied for all parameters except for Cr.

The urban land (PC3) has proven to be a LULC that interacts positively with most of the pollutant variables, thus degrading the water quality, attributable to domestic and productive activities coming from the population that settles around the stream, mainly due to a finding of nutrients as well as biological pollutants.

Based on the results obtained, it can be confirmed that the main changes in land use/land cover in the study area are due to the conversion of natural areas into intervened areas such as crops and recreational areas, and mainly discontinuous urban areas.

The results show that studies of the relationship between land use and water quality are influenced by regional differences because the effects of anthropogenic land use can overlap with the primitive characteristics of the natural terrain [43].

Table 5 presents the results of this study compared to other similar studies. In this table, it can be seen that the main parameters influencing water quality were pH, DO, BOD_5, phosphates, nitrates, and heavy metals, while the main land uses that influenced water quality are generally agricultural areas (crops), urban land uses that usually present subclassifications such as residential, commercial and industrial areas, and/or continuous and discontinuous urban areas. This research also supports that areas such as pastureland and natural forest contribute positively to water quality [12,22,24,43,52].

4. Conclusions

The land use category that had the greatest effect on the water quality of the El Salado stream was the discontinuous urban land. This is because it turned out to be the most predominant category in the area of influence in terms of proportion and heterogeneity, a reason to be considered for further investigation.

According to the values of the water quality indices, the general water quality of the El Salado stream was categorized as "medium quality" and showed scores that determined a favorable agricultural use, while the heavy metal index HPI determined that the water body presents elevated levels of contamination due to excessive concentrations of Cd and As, which remained constant during the monitoring period and along the whole stream. It was noted that agricultural areas are distributed throughout the area of influence, where the use of pesticides containing heavy metals, especially Cd, represented an important factor in the continuous presence of heavy metals along the El Salado stream.

Despite minor variations in the water quality results between the dry and rainy seasons, it was determined that there was no statistically relevant spatio-temporal influence on the water quality of the stream during the monitoring period.

The study of the relationship between land use categories and water quality in the El Salado stream showed that both natural and intervened areas generated significant impacts on water quality through correlation analysis, where it was possible to identify that the contamination of the stream is not only caused by anthropogenic sources (FC) but is also affected by sources of natural origin, mainly because they are strong contributors of phosphates, Cd and As.

The results provided useful and public information for improved decision making by the competent authorities in order to carry out prevention and mitigation measures for the local control of water pollution for the protection of water bodies as well as for the optimization of land use.

Future research concerning water quality should have a greater focus on water bodies located in rural and peri-urban areas that have not been studied, and which may be severely affected by point and diffuse sources of pollutants, especially when people in the area use water according to their needs and under a resource scarcity scenario. It is important to consider this aspect since most of the similar studies reviewed are based only on an analysis of the water quality of raw water bodies or catchments that are apparently fit for human consumption after being subjected to treatment and purification processes, and even after the application of quality control indices. The aim of this approach is to study the effects of water pollution in a holistic way, contributing to the control of water pollution through proper management of water systems.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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