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Indices of Water Quality in Dangău Mare Commune, Cluj County

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Abstract

In rural areas, the reliance on local water resources underscores the importance of ensuring water safety and sustainability. This study explores the interactions between natural factors (e.g., climate and topography) and pollution occurrence that shape water quality dynamics. The research was conducted in Dangău Mare Commune, Cluj County, Romania, over a six-month period (March–September 2024). Monthly water samples were analyzed for selected water indices. The findings reveal distinct patterns of stability and variability. Correlations emphasize specific interdependencies, with PCA identifying three principal factors: environmental conditions (55.82% variance), geographical position (33.03% variance), and pollution sources (11.16% variance). The dominance of environmental and spatial factors underscores their influence on water quality, while pollution-related variability highlights the impact of human activities.

Keywords: interdependencies, pollution sources, spatial and environmental factors, variance.

1. Introduction

Water quality serves as a cornerstone of environmental health, impacting not only the natural ecosystem but also human populations and their economic activities. High-quality water is essential for maintaining biodiversity, supporting aquatic life, and sustaining critical ecosystem services. Furthermore, clean water is a fundamental necessity for human health, playing a pivotal role in drinking water safety, sanitation, and hygiene, which are directly linked to reducing the prevalence of waterborne diseases and ensuring public well-being [10, 12].

In rural areas, the dependence on local water resources, such as surface water (rivers, streams, and lakes) and groundwater (wells and aquifers), is particularly pronounced. These water sources are often the primary, if not the sole, means of meeting the diverse needs of communities [8, 11].

These include domestic consumption for drinking and cooking, agricultural irrigation, and various economic activities such as livestock farming and small-scale industries. This heavy reliance amplifies the need for sustainable management practices and vigilance in ensuring water safety [1, 10, 13, 14].

The quality of water in rural settings is shaped by a dynamic interplay between natural and human-driven factors. Natural elements, such as climate, influence water quality through rainfall patterns, seasonal variations, and temperature changes [4].

For instance, heavy rainfall can increase the amount of runoff, carrying sediments and pollutants into water bodies, while prolonged droughts can concentrate contaminants due to reduced water volumes. Topography also plays a significant role, as the physical landscape affects water flow, erosion rates, and sediment deposition in aquatic systems [3, 7].

Improper waste management in rural areas, including the disposal of household sewage and solid waste, poses another layer of challenge [6]. The lack of adequate infrastructure for treating wastewater and managing solid waste often results in the infiltration of harmful substances such as heavy metals, microbial pathogens, and organic pollutants into water resources. These contaminants can significantly alter the physical, chemical, and biological properties of water, leading to turbidity changes, pH shifts, and the presence of hazardous substances [5, 6, 9].

Our research was conducted to identify water quality indices in Dangău Mare area, Cluj County, Romania Căpușu Mare and through PCA, the interactions between natural factors (e.g., climate and topography) and pollution occurrence that shape water quality dynamics.

2. Material and Method

The research was developed in Dangău Mare Commune, Cluj County, between March and September 2024.

Water samples were collected monthly, and the following indices were measured, and turbidity, conductivity, pH, permanganate index, total hardness, calcium, magnesium, alkalinity, chlorides, phosphates, and nitrates.

All analyses were conducted following standardized methodologies, and the results were compared to the limits established by Romanian regulations [2].

Statistical analysis was carried out using XLSTAT software.

Descriptive statistics were employed to calculate mean values and dispersion parameters Pearson correlation coefficients were calculated, Principal Component Analysis was applied to condense the information from the diverse physicochemical variables used to characterize water quality.

3. Results and Discussions

Turbidity shows moderate variability, with a mean of 0.32, a standard deviation of 0.03, and a coefficient of variation of 9.88%, suggesting relatively consistent water clarity across samples. Conductivity, with a mean of 614.75, exhibits higher variability as indicated by a standard deviation of 160.83 and a coefficient of variation of 26.16%, reflecting significant differences in dissolved ion content. pH values are stable, with a mean of 7.05 and a low coefficient of variation of 3.37%, indicating well-buffered water conditions. The permanganate index, indicative of organic matter, displays moderate variability with a mean of 0.85, a standard deviation of 0.14, and a coefficient of variation of 16.47%.

Total hardness, calcium, and magnesium are relatively consistent, with coefficients of variation of 8.27%, 10.50%, and 11.53%, respectively, suggesting uniformity in mineral content.

Alkalinity shows slightly higher variability, with a coefficient of variation of 14.56%, reflecting some fluctuation in the water's buffering capacity. Chlorides exhibit notable variability, with a mean of 14.25, a standard deviation of 3.40, and a coefficient of variation of 23.85%, indicating differing chloride concentrations among the samples.

Phosphates and nitrates are more stable, with coefficients of variation of 7.69% and 6.70%, respectively, suggesting consistent nutrient levels across the dataset (Table 1).

The conductivity and chlorides are the most variable parameters, reflecting significant spatial or temporal differences in ion concentrations. pH, nitrates, and hardness-related parameters are more stable, indicating consistent baseline conditions for these traits.

These findings underscore the need to monitor high-variability parameters for changes that may indicate environmental shifts or contamination events (Table 1).

Turbidity is positively correlated with conductivity at 0.74 and chlorides at 0.78, indicating that higher turbidity is associated with increased ionic content and chloride presence.

However, turbidity shows a strong negative correlation with magnesium at -0.84 and alkalinity at -0.79, suggesting an inverse relationship with these parameters. Conductivity exhibits strong positive correlations with calcium at 0.85 and total hardness at 0.67, emphasizing its dependence on dissolved mineral content. Conversely, it shares a strong negative correlation with pH at -0.88, reflecting opposing trends between ionic concentration and acidity. pH stands out with extremely strong negative correlations, including -1.00 with calcium and -0.90 with total hardness, highlighting its inverse relationship with water mineral content.

It also has a strong positive correlation with the permanganate index at 0.77, suggesting a potential link between acidity and oxidizable substances. All indices frames within limits accepted by Romanian regulations [2].

Table 1.Basic statistics for the water quality in Dangău Mare Commune, Cluj County

Parameter	N	X	Min.	Max.	s	CV(%)
Turbidity, NTU	10	0.32	0.28	0.35	0.03	9.88
Conductivity, µS/cm	10	614.75	463.00	836.00	160.83	26.16
pH	10	7.05	6.81	7.38	0.24	3.37
Permanganat index, mg O_2/L	10	0.85	0.51	1.26	0.14	16,47
Total hardness, ºG	10	3.75	3.34	4.00	0.31	8.27
Ca, mg/L	10	19.38	16.51	21.32	2.03	10.50
Mg, mg/L	10	4.51	3.94	5.20	0.52	11.53
Alkalinity, mL HCl 0,1N	10	1.03	0.48	2.30	0.15	14,56
Chlorides, mg/L	10	14.25	10.56	20.42	3.40	23.85
Phosphates$^-$, mg/L	10	0.13	0.07	0.17	0.01	7.69
Nitrates, mg/L	10	52.14	48.62	56.43	3.50	6.70

N – number of samples; X – media/mean; s – standard deviation; CV – coefficient of variation;

The permanganate index is strongly negatively correlated with total hardness at -0.97 and calcium at -0.81, indicating its reduction with increased mineral content. This trend is complemented by a moderate negative correlation with magnesium at -0.60, suggesting similar behavior (Table 2). Total hardness exhibits strong positive correlations with calcium at 0.92 and conductivity at 0.67, reflecting its mineral-based composition.

Table 2. The simple correlations between the studied water indices calculated for Dangău Mare area

	Var15	Var16	Var17	Var18	Var19	Var20	Var21	Var22	Var23	Var24	Var25
Var15	1.00	0.74	-0.46	0.19	0.03	0.39	-0.84	-0.79	0.78	0.70	0.39
Var16	0.74	1.00	-0.88	-0.50	0.67	0.85	-0.27	-0.27	1.00	0.87	0.53
Var17	-0.46	-0.88	1.00	0.77	-0.90	-1.00	0.04	-0.16	-0.84	-0.92	-0.15
Var18	0.19	-0.50	0.77	1.00	-0.97	-0.81	-0.60	-0.69	-0.43	-0.48	-0.06
Var19	0.03	0.67	-0.90	-0.97	1.00	0.92	0.40	0.53	0.60	0.67	0.10
Var20	0.39	0.85	-1.00	-0.81	0.92	1.00	0.01	0.23	0.79	0.90	0.10
Var21	-0.84	-0.27	0.04	-0.60	0.40	0.01	1.00	0.82	-0.32	-0.42	0.03
Var22	-0.79	-0.27	-0.16	-0.69	0.53	0.23	0.82	1.00	-0.35	-0.12	-0.48
Var23	0.78	1.00	-0.84	-0.43	0.60	0.79	-0.32	-0.35	1.00	0.84	0.58
Var24	0.70	0.87	-0.92	-0.48	0.67	0.90	-0.42	-0.12	0.84	1.00	0.04
Var25	0.39	0.53	-0.15	-0.06	0.10	0.10	0.03	-0.48	0.58	0.04	1.00

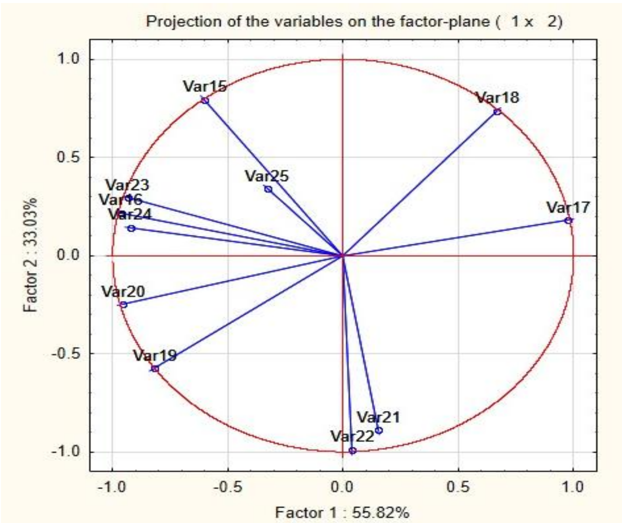
Var 15- Turbidity, NTU; Var 16- Conductivity, µS/cm; Var 17-pH, units of pH; Var 18- Permanganat index, mg O_2/L; Var 19- Total hardness, ºG; Var 20- Ca, mg/L; Var 21- Mg, mg/L; Var 22- Alkalinity, mL HCl 0,1N; Var 23- Chlorides, mg/L; Var 24- Phosphates, mg/L; Var25- Nitrates, mg/L.

It is strongly negatively correlated with pH at -0.90 and the permanganate index at -0.97, indicating inverse relationships with these traits. Calcium shows strong positive correlations with conductivity at 0.85 and total hardness at 0.92, reinforcing its role in overall mineral content. It also exhibits a moderate positive correlation with chlorides at 0.79, suggesting shared influences. Magnesium displays a strong positive correlation with alkalinity at 0.82, reflecting their interconnected buffering roles. However, it shows an inverse relationship with turbidity at -0.84 and chlorides at -0.32, indicating differing behaviors. Alkalinity correlates strongly with magnesium at 0.82 but negatively with turbidity at -0.79 and pH at -0.16, reflecting its role in buffering against pH changes while inversely related to sediment load. Chlorides exhibit strong positive correlations with turbidity at 0.78 and conductivity at 1.00, indicating their connection to ionic and particulate content. They are negatively correlated with alkalinity at -0.35, suggesting contrasting trends. Phosphates correlate strongly with calcium at 0.90 and conductivity at 0.87, emphasizing their linkage with dissolved minerals. They show an inverse relationship with pH at -0.92, consistent with nutrient availability under acidic conditions. Nitrates exhibit weaker correlations overall, with a moderate positive correlation with chlorides at 0.58 and weaker links to other parameters, suggesting a less significant role in defining water traits. The table showsthe pivotal roles of conductivity, calcium, and total hardness in shaping water quality dynamics, as reflected in their strong intercorrelations with turbidity, pH, and the permanganate index. Conversely, magnesium and alkalinity highlight buffering capacities, while phosphates and nitrates reflect nutrient dynamics with weaker overall linkages.

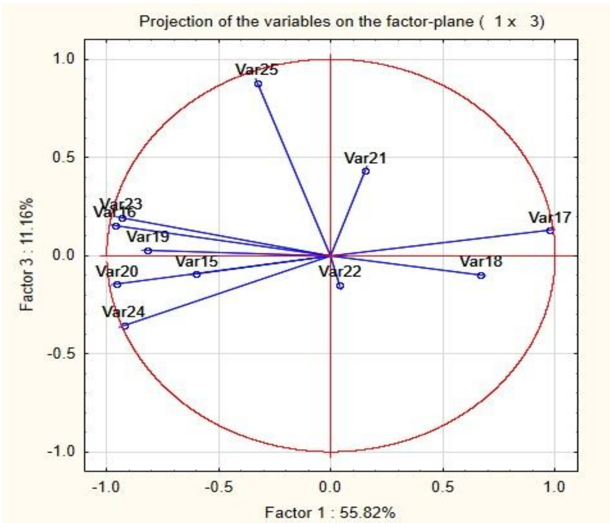
The PCA shows the presence of three factors (Fig. 1, Table 3), the environmental conditions (Factor 1), the geographical position (Factor 2), and pollution sources (Factor 3).

Table 3. The Eigenvalues and total variance corresponding to Dangau Mare water quality

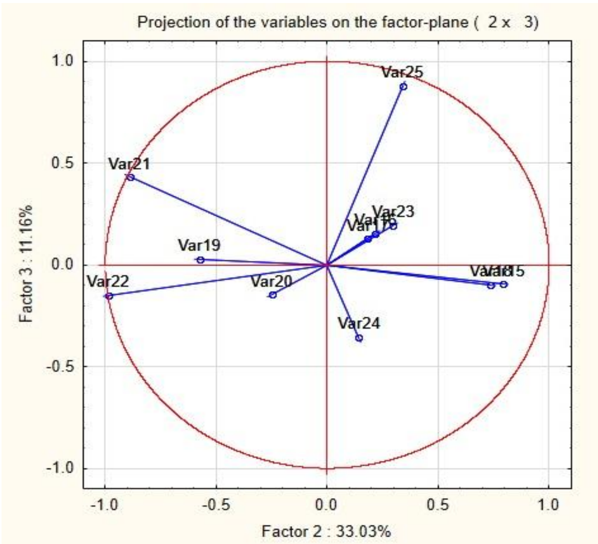
Factor	Eigenvalue	% Total	Cumulative	Cumulative
Factor 1	6.139898	55.81725	6.13990	55.8173
Factor 2	3.633006	33.02732	9.77290	88.8446
Factor 3	1.227097	11.15542	11.00000	100.0000



a.PC1 x PC2 plan



b.PC1 x PC3 plan



c.PC2 x PC3 plan

Var 15- Turbidity, NTU; Var 16- Conductivity, µS/cm; Var 17-pH, units of pH; Var 18- Permanganat index, mg O_2/L; Var 19- Total hardness, ºG; Var 20- Ca, mg/L; Var 21- Mg, mg/L; Var 22- Alkalinity, mL HCl 0,1N; Var 23- Chlorides, mg/L; Var 24- Phosphates, mg/L; Var25- Nitrates, mg/L.

Figure 1. The studied water traits representation on principal components plans

Factor 1 has the highest eigenvalue of 6.14, accounting for 55.82% of the total variance. This indicates that it captures the majority of the variation in the dataset and is likely the most influential in explaining the underlying relationships among the variables. Factor 2, with an eigenvalue of 3.63, explains an additional 33.03% of the total variance. Combined with Factor 1, these two factors cumulatively account for 88.84% of the variance, suggesting that the first two factors sufficiently represent the majority of the dataset's structure. Factor 3, with an eigenvalue of 1.23, contributes only 11.16% to the total variance, bringing the cumulative explained variance to 100%. Its relatively low contribution implies that it captures residual variability not explained by the first two factors.

The dominant roles falls to environmental conditions (Factor 1), and geographical position (Factor 2) in explaining the dataset's variance, while Factor 3 plays a minor supplementary role. This distribution suggests a strong dimensional reduction, where the first two factors encapsulate the majority of the information contained within the dataset.

The projections of all three factors identified reveal distinct relationships and the multidimensional nature of the water quality variables, offering insights into their interactions and contributions to overall variability.

pH (Var17) and permanganate index (Var18) are strongly correlated with the environmental conditions (Factor 1), responsible for 55.82% of variance, indicating their significant contribution to the primary source of variability in the dataset. Turbidity (Var15) and nitrates (Var25) are primarily aligned with the geographical position (Factor 2), responsible for 33.03% of variance, suggesting their variability is more influenced by this secondary dimension. Conductivity (Var16), chlorides (Var23), calcium (Var20), and hardness (Var19) cluster together in the negative half of Factor 1, suggesting a strong positive relationship among them, all contributing similarly to the dataset's variability. Alkalinity (Var22) and magnesium (Var21) oppose conductivity and hardness on Factor 1, indicating an inverse relationship (Fig. 1a).

Magnesium (Var21) and nitrates (Var25) align strongly with pollution sources (Factor 3), responsible for 11.16% of variance, emphasizing their unique contribution to this component. pH (Var17) and permanganate index (Var18) remain dominant contributors to the environmental conditions (Factor 1), similar to Fig. 1a. Turbidity (Var15), phosphates (Var24), and chlorides (Var23) remain grouped on the negative side of Factor 1 but exhibit a neutral association with Factor 3 (Fig. 1b).

Magnesium (Var21) and nitrates (Var25) again demonstrate a strong relationship with pollution sources (Factor 3), while other variables like chlorides (Var23) and turbidity (Var15) exhibit weaker associations. Turbidity (Var15) and nitrates (Var25) show a high alignment with), the geographical position (Factor 2), reinforcing their role in explaining variability in this secondary dimension. Calcium (Var20) and hardness (Var19) contribute minimally to Factor 3, showing limited alignment in this plane (Fig. 1c).

Thus, Factor 1 captures the major variance in the dataset, strongly influenced by pH (Var17) and permanganate index (Var18), Factor 2 reflects contributions from turbidity (Var15) and nitrates (Var25), suggesting their distinct patterns in the dataset, while magnesium (Var21) and nitrates (Var25) emerge as key contributors to Factor 3, highlighting their unique variability compared to other variables. Conductivity (Var16), calcium (Var20), hardness (Var19), and chlorides (Var23) form tight clusters, indicating similar trends, while alkalinity (Var22) and magnesium (Var21) show opposing patterns, suggesting distinct behavior (Fig. 1).

4. Conclusions

The analysis of water quality parameters reveals distinct patterns of stability and variability among the measured traits, providing valuable insights into their interactions and environmental significance. Correlations among the parameters reveal strong interdependencies. The principal component analysis (PCA) identifies three factors shaping the dataset's variability: environmental conditions as Factor 1, geographical position as Factor 2, and pollution sources as Factor 3. Factor 1, responsible for 55.82 percent of the total variance, captures the primary source of variability, strongly influenced by pH and the permanganate index, suggesting these parameters' dominant roles in the dataset. Factor 2, accounting for 33.03 percent of the variance, reflects contributions from turbidity and nitrates, indicating distinct patterns influenced by spatial variation. Factor 3, contributing 11.16 percent of the variance, highlights unique variability linked to magnesium and nitrates, emphasizing their roles in pollution dynamics. Our study emphasizes the dominance of environmental conditions and geographical position in explaining water quality variability, while pollution sources provide supplementary insights. The tight clustering of mineral-related parameters contrasts with the distinct behavior of buffering and nutrient-related traits, highlighting the multidimensional nature of water quality and the intricate interplay of environmental and anthropogenic influences shaping the dataset.

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