World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Influence of Agricultural Inputs and Urban Waste on the Physicochemical and Metal Profile of Surface Waters in Man, Côte d'Ivoire

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World Journal of Advanced Research and Reviews, 2025, 28(01), 1668-1680

Publication history: Received on 08 September 2025; revised on 19 October 2025; accepted on 22 October 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.1.3548

Abstract

Water pollution is a major environmental and public health issue. In the city of Man, located in western Côte d'Ivoire, this problem is exacerbated by the coexistence of intensive agricultural zones and precarious urban neighborhoods, often lacking proper sanitation infrastructure. This study aims to assess the physicochemical quality of surface waters in relation to anthropogenic activities within the municipality of Man. The methodological approach combined field surveys on agricultural practices, in situ measurements of physical parameters, and laboratory analyses of major ions and trace metals. Pollution indices (contamination factor and degree of contamination) were used to characterize the contamination status. The results show elevated concentrations of trace metals such as cadmium (Cd), zinc (Zn), iron (Fe), manganese (Mn), and phosphorus (P), exceeding WHO guideline or aesthetic values. Nitrite pollution, above recommended standards despite low nitrate levels, suggests localized organic contamination from domestic wastewater and leachates from illegal dumpsites. Major cations (Ca^{2+}, K^{+}, Mg^{2+}) also present high concentrations, linked both to anthropogenic inputs (fertilizers) and local lithology. Pollution indices confirm a high level of water contamination across all sampled sites.

These findings reveal a concerning degradation of surface water quality in Man and call for urgent, integrated water resource management, including better regulation of agricultural practices, improved waste management, and more sustainable urban planning.

Keywords: Urban agriculture; Metal pollution; Contamination indices; Surface waters; Tonkpi Region

1. Introduction

Water pollution has become a major global environmental issue, impacting human health, aquatic biodiversity, and ecosystem sustainability [1]. Metallic residues present in water bodies or sediments can harm aquatic life by accumulating in microorganisms, plants, and animals, and can also affect human health through water use for drinking or recreational purposes [2-3].

In the context of rapid population growth, uncontrolled urbanization, and the intensification of agricultural activities, pressures on aquatic environments are continuously increasing. The infiltration of organic, chemical, and microbiological pollutants into surface and groundwater resources compromises their quality and limits their usability—particularly in developing countries where waste and wastewater management infrastructures are often inadequate or entirely lacking [4].

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In West Africa—and more specifically in Côte d'Ivoire—water pollution poses a growing threat, exacerbated by several factors including unplanned urban expansion, intensive agricultural practices, and the low efficiency of sanitation systems. Despite having a relatively dense hydrographic network, the country faces a gradual degradation of water quality. River basins such as the Sassandra, Bandama, and Comoé are frequently impacted by anthropogenic pollution. Several studies have highlighted contamination from trace metals, pesticide residues, and high organic loads resulting from domestic and industrial discharges [5-8].

In western Côte d'Ivoire, research has identified significant impacts on water quality related to agricultural and mining activities. In the sub-prefecture of Zouan-Hounien, [9] reported physicochemical and microbiological contamination of groundwater, attributed to agricultural practices and uncontrolled domestic uses. Furthermore, [10] identified mercury pollution in the waters of Zouan-Hounien, associating its presence with artisanal gold mining activities. In the Bangolo department, [11] documented metal pollution of water bodies stemming from both mining and agricultural sources.

Similarly, just south of the Tonkpi region, pollutants from intensive agriculture, gold mining, and urban discharges have been identified as a significant threat to water quality upstream of the Buyo Dam [8]. These studies underscore the urgency of enhanced monitoring and integrated water resource management, especially in areas facing intense human pressure.

The city of Man, located in the Tonkpi region in western Côte d'Ivoire, exemplifies a space subject to dual environmental pressure: on one hand, a rapidly growing urban area characterized by disorganized development and limited sanitation infrastructure [12 - 14]; on the other, a dominant agricultural landscape where the cultivation of coffee, cocoa, rice, and vegetables involves the uncontrolled use of chemical inputs. This situation increases the risk of pollution in rivers and aquifers, with potential consequences for local ecosystems and public health.

Within this context, the present study aims to characterize the water quality status in urban and peri-urban areas of Man in relation to surrounding human activities. It relies on a combined approach that includes an assessment of environmental pressures, physicochemical analysis of water samples, and estimation of pollution indices to determine the level of contamination.

2. Material and methods

2.1. Geographical Location

The study area is located in the Tonkpi region, in western Côte d'Ivoire. It covers a surface area of 4,140.7 km^2 and lies between latitudes 07°20'00" and 07°35'N, and longitudes 07°25' and 07°45'W (Figure 1). It is bordered to the north by the municipality of Biankouma, to the south by Bangolo, to the east by Kouibly and Facobly, and to the west by Danané.

The city of Man is the regional capital of the Montagnes District and is nicknamed the "city of 18 mountains" due to the surrounding mountain ranges. The region is home to numerous waterfalls, making the municipality of Man a popular tourist destination in Côte d'Ivoire. The municipality is made up of twenty-nine (29) neighborhoods and twenty-eight (28) villages [14].

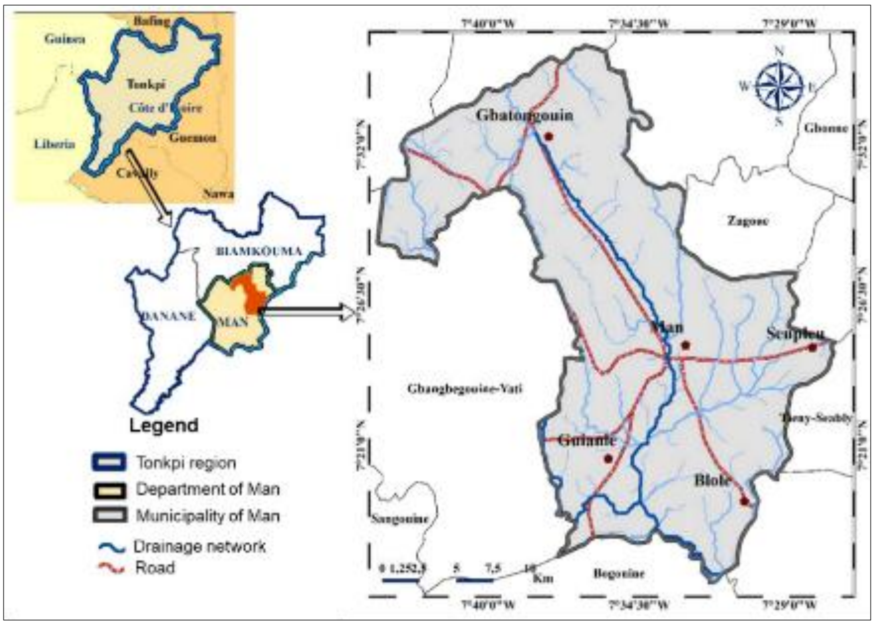

Figure 1 Geographical location of Man municipality

2.2. Natural Environment and Population

The climate of the municipality of Man is characteristic of western Côte d’Ivoire. It is tropical, hot, and humid, and is locally referred to as a "Mountain climate" [15]. The rainy season extends from April to the end of October, while the dry season runs from November to the end of March. The rainy season is generally wet and cloudy, whereas the dry season is marked by very high temperatures. Throughout the year, temperatures typically range between 19°C and 34°C. The terrain is mountainous, with elevations reaching around 1,300 meters. The city of Man is located in a natural basin surrounded by mountains and hills, creating a landscape dominated by steep relief [16]. The main watercourse in the municipality of Man is the Kô River (a tributary of the Sassandra River), which flows from north to south, passing through the entire city. To the south of the municipality, near Guianlé, the Kô merges with the Koué River to form the N’zo River. Other smaller watercourses are found throughout the area—some are perennial, while others are seasonal (Figure 2). The structure of these rivers is influenced by geological faulting as well as external factors such as geomorphology and climate. The area’s geomorphology offers favorable conditions for the development of vegetable farming in its many wetland zones. While cash crops such as coffee and cocoa are cultivated on the forested mountain slopes, subsistence crops (including rice, tomatoes, eggplant, beans, lettuce, cabbage, etc.) are primarily grown in lowlands that cross or border urban and peri-urban areas. The municipality of Man, which is primarily agricultural, has experienced rapid and significant population growth over the years. This increase is partly due to immigration and the city's location within densely populated rural areas. Between 1998 and 2014, the population grew from approximately 148,171 to 164,449 residents, reaching an estimated 241,970 inhabitants in 2021 [14].

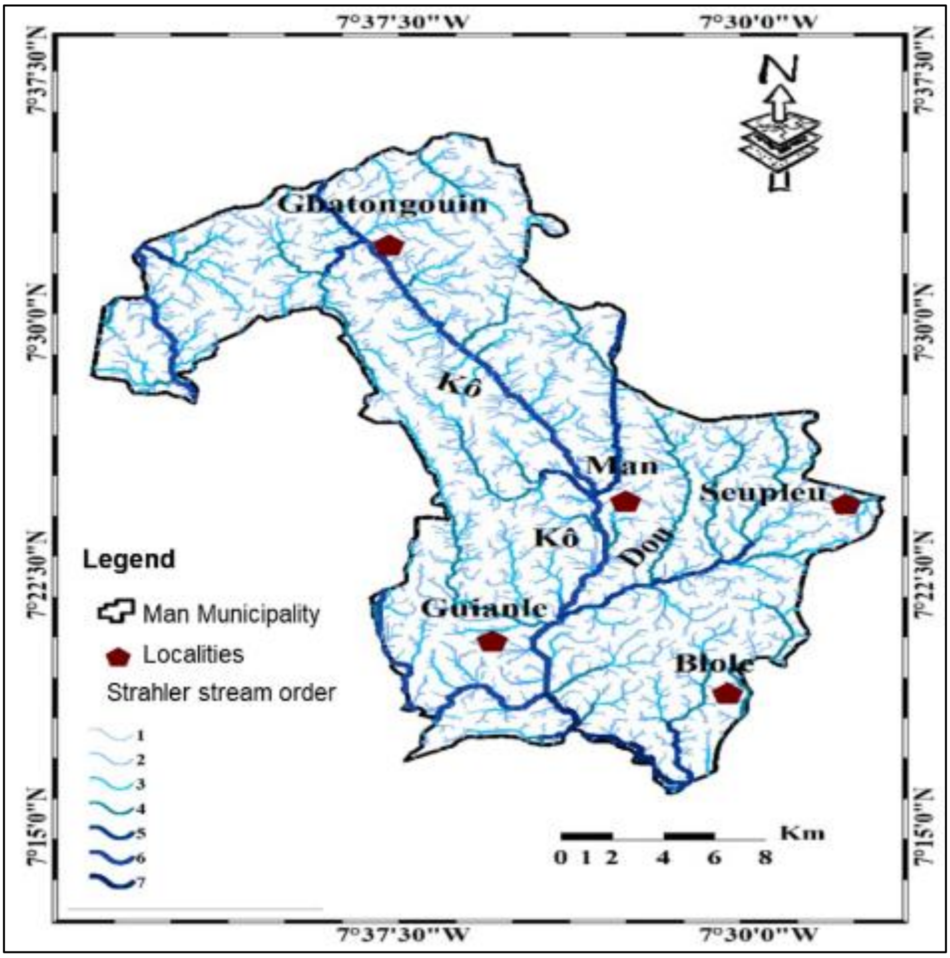

Figure 2 Hydrographic network of the Municipality of Man

2.3. Materials

In order to identify the types of crops and the main chemical products used by farmers (particularly vegetable growers), a structured questionnaire was employed during field visits conducted in March 2025. This questionnaire was designed to collect comprehensive information from the field.

Water samples were collected from streams and rivers using 250 mL polyethylene bottles. Prior to sampling, the bottles were rinsed several times with the water to be analyzed, then filled to the brim and tightly sealed to avoid the presence of air bubbles. For each sampling site, two types of bottles were used. One bottle was used for storing water intended for the analysis of major ions and some nutrients (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, NO_3^{-}, SO_4^{2-}, HCO_3^{-}, NO_2^{-}, PO_4^{3-}), and the other for the analysis of trace metals (Cd, Cu, Pb, Hg, Zn, Fe, Mn, P, and As).

Samples designated for trace element analysis were acidified with ultrapure 6M nitric acid (HNO_3) to a pH ≤ 2, in order to maintain the metals in their ionic form. All samples were stored at low temperature in coolers with ice packs and transported to the Chemistry Laboratory of the Houphouët-Boigny National Polytechnic Institute (INPHB) in Yamoussoukro.

Physical parameters (pH, oxidation-reduction potential, temperature, electrical conductivity, and dissolved oxygen) were measured in situ using a multi-parameter probe.

In the laboratory, chemical parameters were analyzed using a UV-Visible spectrophotometer, while trace metals were quantified using an ICP-MS (Inductively Coupled Plasma Mass Spectrometry). The raw results of the chemical analyses were processed using the Statistica 7.1 software.

2.4. Methods

The methodological approach consisted of three main components:

- Identification of the main agricultural practices and chemical products used by vegetable farmers in the city of Man;
- Analysis of the physicochemical parameters of the collected water samples;
- Evaluation of water quality and its suitability for irrigation purposes.

2.4.1. Field Survey

To document vegetable crops and the main techniques used for the production of vegetables and cereals, we selected areas within the municipality of Man where agricultural activity is most intense. Priority was given to zones with easy access to water and favorable geomorphological conditions for farming activities. To identify the chemical products used by vegetable growers, a survey form was developed. Equipped with this form, several field missions were conducted in the lowland areas of the Man municipality from January 20 to 28, 2025. The survey questions were carefully designed to avoid influencing respondents' answers, and were either open-ended or closed, depending on the context. Based on the identified agricultural zones, along with the cataloged farming techniques and chemical inputs (fertilizers and pesticides), several water sampling sites were selected.

2.4.2. Collection of Physicochemical Data

To determine the water quality in the vegetable farming areas, seven surface water samples were collected on March 19, 2025. The sampling sites were selected to provide a representative picture of the studied waters. The spatial distribution of these sampling points is illustrated in Figure 3. The main neighborhoods concerned include: Municipal, La Sari, Lycée-Santé, Petit Paris, Camp SEA, Grandes Endémies, Lycée-Village, Sainte Thérèse, Mindéba, Domoraud, Saint Pierre, Lycée-Club, Fraternité, and Belle Étoile, located along the road to Biankouma, north of the city of Man.

Figure 3 Distribution of Sampling Points

2.4.3. Assessment of the Impact of Agricultural Activities on Surface Water Resources

The laboratory analysis data were processed using descriptive statistical methods. In addition, to evaluate the quality of the studied water samples, two pollution indices related to drinking water quality were calculated: the Contamination Factor (CF) and the Degree of Contamination (Cd).

Contamination Factor (CF)

The Contamination Factor is an index introduced by [17]. It is a simple and effective tool for monitoring environmental contamination by trace metals [18]. This index helps determine whether or not the environment is contaminated by trace elements and provides the level of contamination. The CF is expressed as the ratio between the concentration of a given element measured in the environment and its reference concentration (Equation 1). In this study, the World Health Organization guideline values for drinking water [19] were used as the reference concentrations.

The Contamination Factor is calculated using the following equation:

$$\text{FC} = \frac{C_{metal}}{C_{reference}} \quad (1)$$

Where:

C_{metal} is the concentration of the element *i* in the water sample;

$C_{reference}$ is the guideline concentration proposed by the World Health Organization [19] for drinking water.

According to [17], the interpretation of CF values is as follows:

CF ≤ 1: Low contamination
1 < CF < 3: Moderate contamination
3 ≤ CF < 6: Considerable contamination
CF ≥ 6: Very high contamination

Degree of Contamination (Cd)

The Degree of Contamination is used as a reference to assess the overall contamination level of water with trace metals [20]. It is calculated as the sum of all individual contamination factors:

$$\text{DC} = \sum_{i=n}^{n} FC_i \quad (2)$$

Where:

CF, is the contamination factor for element *i*;

n is the number of trace metals considered.

According to [21-22], the degree of contamination is classified into three categories:

Cd<1 : Low

1 < Cd < 3 : Moderate

Cd>3 : High

3. Results

3.1. Agricultural Practices in the Municipality of Man

Various field surveys helped to identify the main agricultural practices, including the types of crops grown and the chemical products used for crop management. Analysis of Table 1 shows that the main vegetable crops cultivated in the lowland areas of Man include: cabbage, lettuce, bell pepper, spinach, cucumber, chili pepper, carrot, okra, green beans, spring onions, purple eggplant, sweet potato leaves, zucchini, tomato, rice, and groundnut. Some of these crops are illustrated in Figure 4. To ensure high yields, farmers use several fertilizers such as urea, NPK 15, and Renfort+. In addition, a wide range of pesticides is applied to protect crops from insect pests and weeds. The pesticides used include: Top Lambda, Sababu 210wp, Callicuivre, Ivory 80wp Arysta, Filalforce, K-Optimal, Cofenrin 100 EC, Furadent 500wp, Maneb 800wp, Manco Top 800wap, and Cotzeb 80%wp.

Table 1 Main Crops Cultivated and Types of Chemical Products Used in the Municipality of Man

Crops Grown	Types of Pesticides Used	Metal Content in Fertilizers
Lettuce	Calli cuivre	Cu
Cabbage	Ivory 80WP Arysta	Cu
Parsley	Nematyl (Oxamyl 30 g/kg)	S
Bell pepper	Filalforce 75WP	Zn
Spinach	Kapaas	-
Chili pepper	K-Optimal	K, Pb, Cd, Hg
Cucumber	Coton clair	-
Okra	Cofenrin 100 EC	Cu
Carrot	Furadent 500 WP	S
Green beans	Maneb 800 WP	Mn
Spring onions	Mancotop 800 WAP	Mn, Cu

Figure 4 Diversity of Crops and Chemical Products Used in Agricultural Practices in the Municipality of Man

3.2. Physicochemical Quality of the Studied Waters

Physical Parameters of Surface Waters

The results of the physical parameters of the studied waters are presented in Table 2.

The temperature of the water samples varied slightly, with values ranging from 25.4°C to 26.7°C, and an average of 25.54°C, which reflects the tropical climate of the study area. These values are consistent with the natural thermal regime of surface waters in humid equatorial zones. The surface waters are generally neutral, with a mean pH of 6.87 ± 0.61. However, samples E3 and E6 exhibited acidic pH values of 6.13 and 6.22, respectively. The electrical conductivity (EC) of the surface waters ranged from −24 to 73 µS/cm, with an average of 30.85 ± 32.27 µS/cm. Dissolved oxygen (DO) concentrations varied widely, from 0.60 mg/L to 10.30 mg/L, with a mean of 3.22 ± 3.29 mg/L. In addition, the oxidation-reduction potential (Eh) ranged from 55.30 to 161.60 mV, with an average of 99.48 ± 50.62 mV.

Table 2 Physical Parameters of Surface Water

Variables	Surface waters			
	Mean	**Minimum**	**Maximum**	**Std. Dev.**
Temperature	25.54	25.4	26.7	0.1
pH	6.87	6.13	7.90	0.61
Electrical Conductivity ((µS/cm)	30.86	-24.00	73.00	32.27
Redox Potential (mV)	99.49	55.30	161.60	50.62
Dissolved Oxygen (mg/L)	3.23	0.60	10.30	3.30

Chemical Parameters (Major Ions and Metals)

The descriptive statistics for the chemical parameters of the studied surface waters are presented in Table 3. The results show that potassium (K^+) is the dominant cation, followed by calcium (Ca^{2+}) and magnesium (Mg^{2+}), with average concentrations of 270.34 mg/L, 215.34 mg/L, and 188.79 mg/L, respectively. Regarding anions, the concentrations follow the decreasing order: Sulfates (SO_4^{2-}) > Nitrates (NO_3^-) > Bicarbonates (HCO_3^-) > Chlorides (Cl^-).

Table 3 Chemical Parameters of the Studied Waters

Parameters	Mean	Minimum	Maximum	Std. Dev.	Guideline values [19]
Ca2+	187.66	247.25	215.34	21.59	100
K+	233.88	311.29	270.23	26.39	12
Mg2+	185.84	192	188.79	2.35	50
Na+	12.26	102.23	43.93	33.14	150
NO2-	0.15	0.95	0.53	0.27	0.2
PO43-	0.02	0.09	0.05	0.03	5
Cl-	0.12	0.35	0.21	0.08	200
HCO3-	1.48	4.17	2.39	1.07	250
SO4-	27.24	93.42	54.26	25.64	250
NO3-	2.72	5.45	4.26	0.87	50

Table 4 presents the concentrations of trace metals in surface waters (expressed in mg/L). Analysis of this table reveals a predominance of zinc, iron, and phosphorus compared to the other elements. Zinc concentrations are particularly high, especially in samples E1, E3, and E6, with respective values of 396.18, 409.4, and 328 mg/L. Cadmium and manganese concentrations exceed the guideline values recommended by the World Health Organization (WHO).

However, copper levels remain below the WHO guideline value (see Table 4). The abundance of metals in the water follows the order: Zn > Fe > P > Mn > Cd > Cu > Pb. The elevated zinc concentrations suggest significant contamination from both agricultural and domestic sources. Sample E1 was collected near an open dumpsite containing mixed waste. Samples E3 and E6 were taken from the Kô River, which borders areas cultivated with crops such as okra, maize, spinach, and cabbage.

Table 4 Statistical Parameters of Trace Metal Elements (mg/L) in Surface Waters

Sample	**Concentration of trace metals (mg/L)**						
	Cd	Cu	Fe	Mn	P	Pb	Zn
E1	0.15	0.21	248.35	2.33	27.88	0.01	396.18
E2	0.21	0.00	172.56	1.80	36.38	0.00	242.53
E3	0.06	0.16	176.79	0.12	32.04	0.02	409.39
E4	0.21	0.00	165.02	2.69	21.22	0.00	311.90
E5	0.26	0.18	175.44	2.78	61.34	0.07	278.33
E6	0.22	0.00	175.92	0.88	94.24	0.02	327.99
E7	0.28	0.00	176.70	2.56	5.65	0.00	259.52
Mean	0.20	0.08	184.40	1.88	39.82	0.02	317.98
Minimum	0.06	0.00	165.02	0.12	5.65	0.00	242.53
Maximum	0.28	0.21	248.35	2.78	94.24	0.07	409.39
Std. Dev.	0.07	0.10	28.50	1.02	29.31	0.02	64.92
WHO guideline (2017)	0.003	2	-	0.4	-	0.01	-

Surface Water Pollution Indices

The results of the pollution indices are presented in Table 5. Phosphorus was excluded from this pollution assessment because no WHO guideline value exists for it. Similarly, iron and zinc were not considered toxic and therefore lack health-based guideline values from the WHO. However, the WHO does recommend aesthetic threshold values for both iron and zinc due to their undesirable effects on water quality. These thresholds were used to calculate the contamination factors (CF) and the degree of contamination (Cd).

The results show that the studied waters exhibit no contamination by copper, as all CF values are below 1. The waters are slightly contaminated by lead, with a mean CF of 1.8. However, for cadmium, iron, and zinc, all water samples are extremely contaminated, with CF values well above 6. Regarding manganese, the waters are moderately contaminated, with a mean CF of 4.7.

The degree of contamination (Cd), used as a reference to estimate the overall intensity of water contamination, indicates a high level of pollution, with a mean value of 793.6.

Table 5 Surface Water Pollution Indices

Samples	**FC**							**DC**
	Cd	**Cu**	**Fe**	**Mn**	**P**	**Pb**	**Zn**	**1018.28**
E1	51.17	0.11	827.83	5.82	-	1.30	132.06	731.54
E2	70.90	0.00	575.19	4.50	-	0.10	80.84	749.80
E3	21.21	0.08	589.30	0.30	-	2.45	136.46	731.92
E4	71.08	0.00	550.06	6.71	-	0.09	103.97	777.42
E5	86.00	0.09	584.80	6.95	-	6.81	92.78	772.64

E6	72.70	0.00	586.39	2.19	-	2.03	109.33	773.91
E7	91.93	0.00	589.00	6.39	-	0.07	86.51	793.65
Mean	66.43	0.04	614.65	4.70	-	1.84	105.99	1018.28

4. Discussion

Field surveys revealed several anthropogenic activities that may contribute to the degradation of water quality. Notably, informal waste dumps were observed either within or near riverbeds. In underdeveloped neighborhoods (such as Si Tu Veux, Blockhauss, Petit Paris, and Sari), dwellings were identified in close proximity to surface water bodies. This situation results in the direct discharge of various types of domestic waste into the waterways. The elevated concentrations of phosphorus, nitrites, and nitrates can be attributed to this pollution. The persistent proliferation of aquatic vegetation also indicates a continuous nutrient input from upstream activities, promoting the eutrophication of surface waters, as previously reported by [23-24]. Among the cultivated crops observed in the area were lettuce, cabbage, parsley, rice, tomatoes, and sweet potatoes—species that demand high inputs of water and fertilizers, especially since the same plots are exploited season after season and year after year.

The mean water temperature was 25.54 °C, which falls within the normal temperature range (25–29 °C) for inland waters in Côte d'Ivoire [25] [23]. Overall, the waters were neutral, with pH values between 6.5 and 8.5, consistent with WHO guidelines, except for samples E3 and E6, collected respectively in the Belle Étoile district near an eggplant field and in the Sari neighborhood near an open dumpsite. The acidity of these samples is likely due to leachate infiltration from solid waste [26]. [27] demonstrated that the decomposition of organic matter in waste sites can reduce the pH of surface waters receiving leachate. Similarly, [28-29] linked pH declines in surface water to intensive agricultural activity surrounding watercourses.

The concentrations of nitrates, phosphates, bicarbonates, sulfates, and chlorides were low and remained below [19] guideline values. In contrast, major cations (Ca^{2+}, K^{+}, Mg^{2+}, and Na^{+}) exceeded recommended thresholds. Elevated levels of Ca^{2+}, K^{+}, and Mg^{2+} may result from both the lithological composition of the area—rich in silicate minerals—and anthropogenic inputs, such as fertilizer use and domestic discharges [30]. While major anions remained within acceptable limits—indicating good water quality with respect to chlorides, sulfates, nitrates, and bicarbonates—the waters were found to be polluted with nitrites, which greatly exceeded WHO admissible limits for drinking water. The high nitrite concentrations, contrasted with relatively low nitrate levels, may be explained by the point-source pollution from untreated domestic wastewater and leachate runoff. This could result in nitrite spikes, while nitrate contamination tends to originate from more diffuse sources or may undergo slower transformation processes [31-32].

The concentrations of trace metals in the surface waters were generally high—except for copper and, to a lesser extent, lead. Cadmium, iron, manganese, phosphorus, and zinc were detected at levels above WHO guideline values (for Cd and Mn) and above WHO aesthetic thresholds (for Zn, Fe, and P). Although the local geology may naturally release iron via minerals such as hematite (Fe_2O_3) or siderite ($FeCO_3$), the high iron levels in the water are primarily due to anthropogenic inputs. The lowlands where samples were taken act as receptors for domestic wastewater and leachate from illegal dumpsites. Domestic wastewater, landfill leachates, industrial effluents, and open dumping have all been identified as significant sources of iron contamination in water bodies [33-35]. Similarly, elevated concentrations of Zn, P, Mn, and Cd are closely tied to human activities, especially fertilizer and pesticide use by local vegetable growers. Analysis of commonly used agricultural products revealed the presence of Zn in Filalforce 75 WP, Mn in Maneb 800 WP and Mancotop 800 WAP, and Cd in K-Optimal. Studies by [34] [36-37] confirmed that Cd contamination in water is often linked to phosphate fertilizer application. Moreover, [34-35] attributed high levels of Mn and Zn in water to agricultural activities and waste dumping.

In conclusion, the high concentrations of trace metals indicate that the surface waters in the Man municipality are heavily polluted. The calculated pollution indices are significantly elevated, confirming a serious level of contamination.

5. Conclusion

This study assessed the physicochemical quality and trace metal concentrations in surface waters of the Man municipality in Côte d'Ivoire, in relation to agricultural practices and domestic waste discharge. The results revealed significant anthropogenic pressure on water resources, characterized by elevated concentrations of several pollutants. While parameters such as nitrates, chlorides, sulfates, and bicarbonates remained below WHO guideline values, nitrite concentrations exceeded the recommended limits, indicating contamination from domestic wastewater and leachate.

Major cations (Ca^{2+}, K^+, Mg^{2+}, Na^+) also showed levels above WHO thresholds, likely influenced by both natural lithology and fertilizer use. Trace metals presented the most alarming results. Cadmium, manganese, zinc, and iron were found at concentrations well above WHO health-based or aesthetic guideline values, particularly in areas near agricultural fields and informal waste dumpsites. Pollution index calculations confirmed a high degree of contamination, especially for cadmium, manganese, and zinc.

Overall, the findings highlight a pressing need for integrated water management strategies in the region. This includes regulating agricultural inputs, improving waste collection and treatment, and establishing buffer zones around water bodies. Without immediate mitigation measures, the quality of surface water in Man will continue to deteriorate, posing risks to both environmental and public health.

Compliance with ethical standards

Acknowledgments

The authors express their gratitude to the Directorate of the Training and Research Unit in Geological and Mining Sciences for their support and for providing logistical resources during the fieldwork missions.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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