GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

(Research Article)

Check for updates

Hydrochemical Characterization and Water Pollution Indices of Groundwater in Urban Farming Areas: The Case of the Municipality of Man, Western Côte d'Ivoire

Kouadio Assemien François YAO [1,*], Moussa OUEDRAOGO [1], Konan Richmond BROU [1], Léréyaha COULIBALY [1], Ismaïla OUATTARA [1], Odon Clément N'CHO [1] and Koffi Blaise YAO [2]

[1] *Department of Geological and Mining Sciences, University of Man, Man, Cote d'Ivoire.*

[2] *Department of Soil, Water, and Geomaterials Sciences, Félix Houphouët-Boigny University, Abidjan, Cote d'Ivoire.*

GSC Biological and Pharmaceutical Sciences, 2025, 33(02), 001–012

Publication history: Received on 21 September 2025; revised on 30 October 2025; accepted on 01 November 2025

Article DOI: https://doi.org/10.30574/gscbps.2025.33.2.0424

Abstract

The objective of this study was to assess the physicochemical and metallic quality of groundwater used in urban farming areas of the Man municipality, western Côte d'Ivoire. Nine water samples were collected in March 2025 and analyzed for key physical, chemical, and trace metal elements (TME). The results showed pH values ranging from 4.9 to 9.3 and an average electrical conductivity of 60.9 µS/cm. The groundwater exhibited high concentrations of major ions (K^+, Mg^{2+}, Ca^{2+}) and nitrites (up to 101.7 mg/L), exceeding WHO standards. Trace metal concentrations were dominated by zinc (mean = 303.2 mg/L), iron (186.9 mg/L), and cadmium (0.31 mg/L). Contamination factor (CF) values indicated extreme pollution by Cd, Fe, and Zn, with an overall contamination degree (CD) of 793.6. Statistical analysis revealed two main sources of mineralization: natural (geochemical alteration) and anthropogenic (agricultural inputs and waste disposal). Overall, groundwater in the urban farming zones of Man is unsuitable for human consumption and requires regular monitoring and the implementation of sustainable water resource management measures.

Keywords: Groundwater; Heavy metals; Urban farming; Pollution index; Côte d'Ivoire

1. Introduction

Access to high-quality groundwater is a major challenge for public health and sustainable development, particularly in urban areas where agriculture develops within limited spaces [1-3]. According to the United Nations, despite ongoing efforts, nearly 2 billion people still lack access to safe water, and water-related diseases continue to cause millions of deaths each year [4].

Urban aquifers are subject not only to natural processes of mineralization and geochemical alteration but also to increasing anthropogenic pressures such as pollutant infiltration, intensive use of agricultural inputs, and changes in urban recharge, which may compromise their suitability for drinking and irrigation. For example, the widespread use of pesticides in agricultural areas is now recognized as a potential source of groundwater contamination [5, 6].

In West Africa, urban farming zones are a critical component of local food production systems but raise specific challenges regarding water management and hydrochemical quality [7-9]. In the Man municipality, western Côte d'Ivoire, farmers frequently use chemical fertilizers and pesticides for legume and cereal cultivation, raising concerns about the impact of these practices on groundwater quality for irrigation and, in some cases, for human consumption [10]. More than twenty pesticides and chemical fertilizers have been reported to be in use by farmers in the area.

* Corresponding author: Kouadio Assemien François YAO

In this context, it is crucial to assess the compliance of groundwater with drinking water standards and to identify the processes responsible for mineralization and the presence of trace metal elements (TMEs).

This study aims to (i) determine the physicochemical quality and TME content of groundwater, (ii) compare the results with WHO drinking water standards to assess their suitability for human consumption or irrigation, (iii) identify the sources of mineralization and contamination using principal component analysis (PCA), and (iv) quantitatively evaluate overall water quality through a Water Quality Index (WQI).

This work makes an original contribution by combining groundwater quality assessment in an urban farming context in West Africa, the application of multivariate tools to interpret contamination sources, and a quantitative evaluation of water quality relative to drinking water standards.

2. Material and methods

2.1. Study area

2.1.1. Geographic Location

The Man municipality is part of the Tonkpi region in western Côte d'Ivoire. It covers an area of 4,140.7 km², between latitudes 7°20′00″ and 7°35′N and longitudes 7°25′ and 7°45′W (Figure 1). It is bounded to the north by Biankouma, to the south by Bangolo, to the east by Kouibly and Facobly, and to the west by Danané. The town of Man serves as the administrative center of the Montagnes District and is nicknamed the "city of 18 mountains" due to the surrounding mountain ranges. The municipality comprises twenty-nine (29) neighborhoods and twenty-eight (28) villages [11].

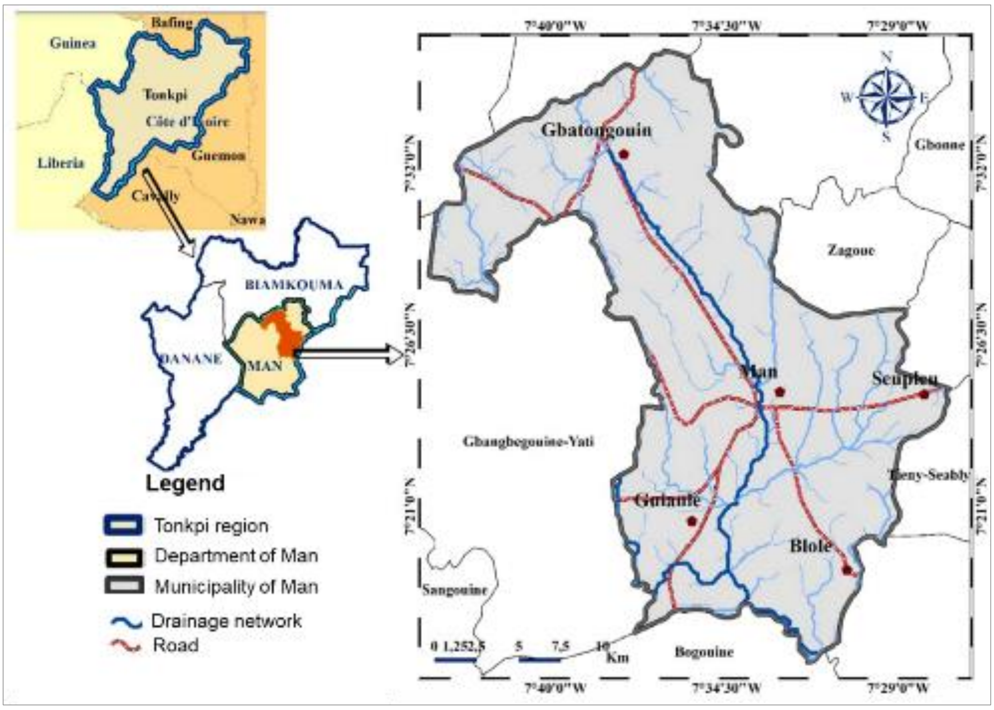

Figure 1 Geographical location of Man municipality

2.1.2. Natural Environment and Population

The climate of the Man municipality is typical of the mountainous western region of Côte d'Ivoire, characterized by a hot and humid tropical climate [12]. Temperatures range from 19 °C to 34 °C depending on the season. The terrain is mountainous, reaching an altitude of approximately 1,300 m, and the town is located in a basin surrounded by hills [13]. The main watercourse is the Kô River, a tributary of the Sassandra River, which joins the Koué River in the south to form the N'zo River (Figure 2). Numerous secondary streams, influenced by geological fracturing and climate, feed wetlands favorable to vegetable farming. Predominantly agricultural, the municipality has experienced rapid population growth, increasing from 148,171 inhabitants in 1998 to approximately 242,000 in 2021 [11].

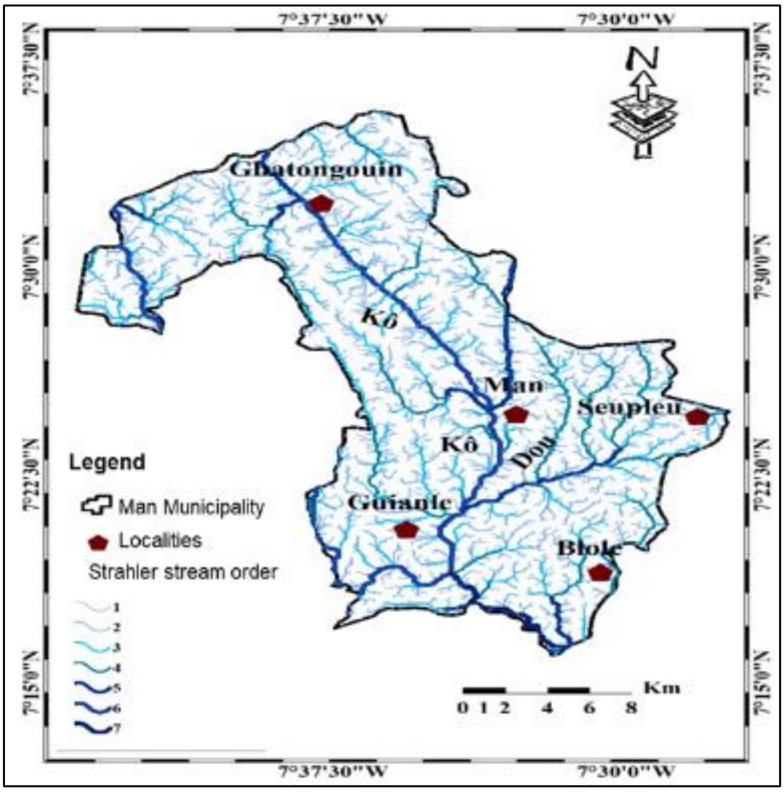

Figure 2 Hydrographic network of the Municipality of Man

2.2. Sampling and Laboratory Analysis

Water samples were collected from nine wells in March 2025 within the vegetable farming areas. Sampling points were selected to obtain representative samples of the groundwater under study. The spatial distribution of the sampling points is shown in Figure 3. The main neighborhoods included Municipal, La Sari, Lycée-Santé, Petit Paris, Camp Sea, Grandes Endémies, Lycée-Village, Domoraud, Lycée-Club, Fraternité, and Belle Étoile along the Biankouma road to the north of Man city. Samples were collected in 250 mL polyethylene bottles, each rinsed three times with the water to be sampled, filled to the top, and tightly sealed, avoiding air bubbles. Samples were transported in coolers at 4 °C to the laboratory. Two samples were collected at each site: one for major ion analysis and one for trace metal analysis. For trace metal samples, one to two drops of nitric acid were added to stabilize the metals.

Field measurements of physical parameters—including temperature, pH, conductivity, and dissolved oxygen—were performed in situ using a multiparameter probe. Major ions and trace metals were analyzed at the Chemistry Laboratory of the National Polytechnic Institute Houphouët-Boigny (INPHB), Yamoussoukro. Cations analyzed included Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and total hardness (TH), while anions included PO_4^{3-}, HCO_3^{-}, NO_3^{-}, NO_2^{-}, and Cl^{-}. Analyses were performed following AFNOR standards (1997) or equivalent methods. Trace metals analyzed included Cd, Cu, Pb, Hg, Zn, Fe, Mn, P, and As. Major ions were measured using a UV-visible spectrophotometer, while trace metals were quantified using ICP-MS. Raw analytical data were processed using Statistica 7.1 software.

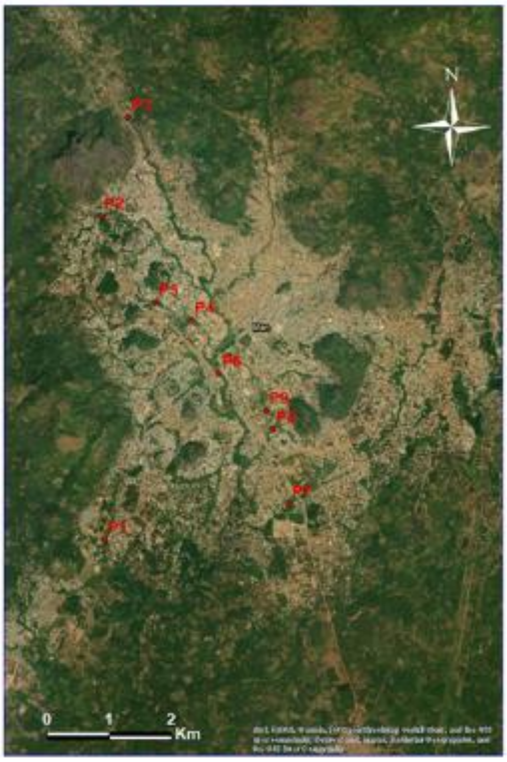

Figure 3 Distribution of Sampling Points

2.3. Statistical Analysis

Laboratory data were initially processed using descriptive statistical methods. To understand the relationships between variables and identify groupings among observations, multivariate statistical analyses were applied. Principal Component Analysis (PCA) was performed to determine the main processes controlling groundwater mineralization in the commune of Man.

2.4. Water Quality Assessment

To evaluate the quality of the studied groundwater, two pollution indices related to drinking water quality were calculated: the Contamination Factor (CF) and the Degree of Contamination (DC).

The Contamination Factor, introduced by [14], is an effective index for monitoring environmental contamination by trace elements [15]. It indicates whether a medium is contaminated by trace elements and quantifies the level of contamination. CF is calculated as the ratio of the measured concentration of an element in the medium to a reference concentration (Equation 1). For this study, the World Health Organization guideline values for drinking water were used as the reference concentrations [16].

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

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 [16] for drinking water.

The CF values are interpreted according to [14] as follows:

CF ≤ 1: Low contamination

1 < CF < 3: Moderate contamination

3 ≤ CF < 6: Considerable contamination

CF ≥ 6: Very high contamination

The contamination degree (CD) is used as a reference to assess the overall level of metal contamination in water [17]. It is calculated using Equation 2:

$$\mathrm{DC} = \sum_{i=n}^{n} FC_i \qquad (2)$$

Where:

CF, is the contamination factor for element i;

n is the number of trace metals considered.

According to [18, 19], the degree of contamination is classified into three categories:

Cd<1 : Low

1 < Cd < 3 : Moderate

Cd>3 : High

3. Results

3.1. Physicochemical Quality of the Studied Waters

3.1.1. Physical Parameters of Groundwater

The results indicate that the groundwater is generally neutral, with a mean pH of 6.55 ± 1.2. However, sample P9 is acidic, with a pH of 4.9, while P4 exhibits a basic pH of 9.32 (Table 1). Electrical conductivity (EC) ranges from 0.307 µS/cm to 113.90 µS/cm, with an average of 60.90 ± 45.68 µS/cm. Dissolved oxygen (DO) concentrations vary between 1.6 mg/L and 10 mg/L, with a mean of 4.93 ± 2.26 mg/L. The redox potential (Eh) ranges from -108 mV to 137 mV, averaging 55.22 ± 70.87 mV.

Table 1 Physical Parameters of groundwater

Variables	Groundwater			
	Mean	Minimum	Maximum	Std. Dev.
T	25.30	25.00	25.60	0.19
pH	6.55	4.90	9.32	1.20
CE	60.90	0.31	113.90	45.68
Eh	52.22	-108.00	137.00	70.88
OD	4.93	1.60	10.00	2.26

3.1.2. Chemical Parameters (Major Ions and Metals)

Table 2 presents the statistical summary of the chemical parameters. The results show that potassium (K^+) is the dominant cation, followed by magnesium (Mg^{2+}) and calcium (Ca^{2+}), with mean concentrations of 247.02 mg/L, 187.94 mg/L, and 182.30 mg/L, respectively. The concentrations of Ca^{2+}, K^+, and Mg^{2+} all exceed the respective WHO guideline values. Regarding sodium, only sample P9 shows a concentration (152.6 mg/L) above the recommended limit.

Among the anions, concentrations decrease in the following order: nitrites (NO_2^-) > nitrates (NO_3^-) > sulfates (SO_4^{2-}) > chlorides (Cl^-) > bicarbonates (HCO_3^-). Of these, only nitrite concentrations exceed the WHO standard (0.2 mg/L).

The predominance of cations—particularly potassium—suggests a strong influence of human activities, notably domestic and agricultural discharges, in the study area.

Table 3 presents the concentrations of trace metals in the groundwater samples. Analysis of the data reveals a predominance of zinc, iron, and phosphorus over the other elements. Zinc concentrations are particularly high, especially in samples P3, P4, and P9, with respective values of 366.2, 332.0, and 529.69 mg/L. Cadmium and manganese concentrations exceed the WHO guideline limits, whereas copper levels remain below the recommended threshold (Table 3). Overall, the metals occur in the following decreasing order of abundance: Zn > Fe > P > Mn > Cd > Cu > Pb.

Table 2 Chemical Parameters of the Studied Waters

Parameters	**Mean**	**Minimum**	**Maximum**	**Std. Dev.**	**Guidelines values [16]**
Ca^{2+}	101	234.82	182.3	49.89	100
K^+	226.71	302.01	247.02	21.74	12
Mg^{2+}	184.24	190.58	187.94	1.98	50
Na^+	17.62	152.58	55.36	52.43	150
NO^{2-}	4.9	101.67	39.03	30.28	0.2
PO_4^{3-}	0.49	4.08	1.71	1.41	5
Cl^-	0.32	4.31	1.44	1.35	200
HCO_3^-	0.17	1.72	0.47	0.5	250
SO_4^-	0.49	4.79	2	1.53	250
NO_3^-	0.37	38.35	4.85	12.56	50

The elevated zinc concentrations suggest significant zinc pollution of both agricultural and domestic origin. The samples with the highest Zn levels (P3, P4, and P9) were collected near vegetable cultivation areas (lettuce, cabbage, spinach, maize, etc.). Furthermore, several uncontrolled waste disposal sites were observed around these agricultural zones, likely contributing to the metal enrichment of the groundwater.

Table 3 Statistical Parameters of Trace Metal Elements (mg/L) in groundwaters

Samples	**Concentration of trace metals (mg/L)**						
	Cd	Cu	Fe	Mn	P	Pb	Zn
P1	0.34	0.00	177.57	2.33	82.93	0.00	164.73
P2	0.12	0.00	161.46	0.75	52.91	0.00	242.20
P3	0.35	0.00	181.45	2.33	68.24	0.00	366.20
P4	0.32	0.16	276.18	1.54	32.54	0.00	331.99
P5	0.58	0.16	177.08	1.69	20.16	0.00	281.24
P6	0.29	0.17	171.80	0.15	77.87	0.00	231.46
P7	0.40	0.00	175.44	1.20	37.00	0.00	282.56
P8	0.28	0.00	173.67	2.16	53.32	0.00	298.45
P9	0.13	0.17	187.30	0.31	33.35	0.02	529.69
Mean	0.31	0.07	186.88	1.38	50.92	0.00	303.17
Minimum	0.12	0.00	161.46	0.15	20.16	0.00	164.73
Maximum	0.58	0.17	276.18	2.33	82.93	0.02	529.69
Std. Dev.	0.14	0.09	34.22	0.84	21.93	0.01	103.12
WHO guideline [16]	0.003	2	-	0.4	-	0.01	3

3.1.3. Correlations Among the Studied Variables

Table 4 presents the correlation matrix of the analyzed variables. The analysis shows strong positive correlations between pH and potassium (r = 0.54), pH and magnesium (r = 0.61), pH and nitrites (r = 0.75), and pH and iron (r = 0.78). Calcium is also well correlated with bicarbonates (r = 0.51), sulfates (r = 0.79), and phosphorus (r = 0.80). Additionally, notable correlations were observed between nitrates and copper (r = 0.54), potassium and iron (r = 0.65), as well as magnesium and iron (r = 0.53).

Conversely, negative correlations were recorded between pH and lead (r = −0.54), and between sulfates and nitrates (r = −0.63). The strong positive correlations observed between calcium and bicarbonates, sulfates, and between magnesium and iron suggest a common geochemical origin or a shared process responsible for their mobilization and dissolution in groundwater.

3.2. Water Pollution Indices

The results of the calculated pollution indices are presented in Table 5. Phosphorus was excluded from this evaluation due to the absence of a WHO guideline value. Similarly, no toxicity-based limits exist for iron and zinc; however, the WHO provides aesthetic thresholds for these elements, which were used to compute the contamination factors (CF) and the contamination degree (CD).

The results indicate that groundwater samples show no contamination from copper, as all CF values are below 1. Stations P6 and P8 are moderately contaminated with lead.

Table 4 Correlation Matrix of Physicochemical Parameters

Variables	**PH**	**CE**	**ORP**	**Ca^{2+}**	**K^{+}**	**Mg^{2+}**	**Na^{+}**	**NO_2^-**	**PO_4^{3-}**	**Cl^-**	**HCO_3^-**	**SO_4^{2-}**	**NO_3^-**	**Cd**	**Cu**	**Fe**	**Zn**	**Mn**	**P**	**Pb**
PH	1.00																			
CE	0.14	1.00																		
Eh	-0.94	-0.15	1.00																	
Ca^{2+}	0.16	0.21	-0.23	1.00																
K^{+}	0.54	0.46	-0.53	-0.10	1.00															
Mg^{2}	0.61	-0.08	-0.53	0.16	0.05	1.00														
Na^{+}	0.02	0.02	-0.02	-0.29	-0.45	-0.52	1.00													
NO_2^-	0.75	-0.18	-0.78	-0.03	0.18	0.30	0.27	1.00												
PO_4^{3-}	-0.28	-0.37	0.42	-0.48	-0.30	0.38	-0.37	-0.42	1.00											
Cl^-	0.04	0.49	-0.07	0.28	-0.35	-0.03	-0.37	-0.01	-0.25	1.00										
HCO_3^-	-0.22	-0.07	0.24	0.51	-0.33	0.41	-0.30	-0.28	0.18	-0.09	1.00									
SO_4^{2-}	0.05	-0.22	-0.11	0.79	-0.48	0.13	-0.21	0.11	-0.30	0.35	0.50	1.00								
NO^{3-}	0.00	-0.06	0.10	-0.39	0.22	0.26	-0.26	-0.26	0.64	-0.45	-0.22	-0.63	1.00							
Cd	-0.24	-0.52	0.22	-0.31	-0.45	0.14	-0.49	-0.15	0.39	0.01	0.07	-0.03	-0.03	1.00						
Cu	-0.02	0.14	0.07	-0.37	0.15	0.39	-0.22	-0.04	0.36	-0.35	0.22	-0.63	0.54	0.12	1.00					
Fe	0.78	0.29	-0.76	-0.22	0.65	0.53	0.02	0.56	-0.15	-0.05	-0.22	-0.41	0.09	0.03	0.43	1.00				
Zn	-0.24	-0.28	0.20	-0.34	0.13	-0.04	0.02	-0.19	0.14	-0.48	-0.18	-0.33	-0.01	0.66	0.38	0.24	1.00			
Mn	0.23	0.33	-0.17	0.01	0.20	0.06	0.12	-0.11	0.05	0.48	-0.14	0.16	-0.28	-0.12	-0.54	0.10	-0.27	1.00		
P	-0.10	0.54	0.02	0.80	-0.20	-0.21	-0.28	-0.23	-0.53	0.68	0.21	0.58	-0.43	-0.34	-0.41	-0.34	-0.49	0.16	1.00	
Pb	-0.54	-0.23	0.48	-0.47	-0.17	-0.34	-0.10	-0.30	0.14	-0.24	-0.05	-0.43	0.05	0.71	0.40	-0.01	0.83	-0.47	-0.34	1.00

In contrast, all samples show extreme contamination by cadmium, iron, and zinc, with CF values far exceeding 6. Manganese contamination ranges from low to high, with an average CF of 3.6.

The overall contamination degree (CD), used as an indicator of total metal pollution, reveals a very high contamination level, with a mean CD value of 793.6.

Overall, groundwater samples collected from the urban farming zones of Man are heavily contaminated and therefore unsuitable for human consumption.

Table 5 Groundwater Pollution Indices

Samples	FC						DC
	Cd	Cu	Fe	Mn	Pb	Zn	
P1	112.37	0.00	591.90	5.82	0.00	54.91	765.01
P2	41.52	0.00	538.21	1.88	0.00	80.73	662.35
P3	115.69	0.00	604.83	5.82	0.00	122.07	848.41
P4	108.25	0.08	920.61	3.85	-0.04	110.66	1143.41
P5	192.39	0.08	590.26	4.22	0.10	93.75	880.80
P6	98.30	0.08	572.66	0.38	2.33	77.15	750.90
P7	133.41	0.00	584.81	3.01	0.00	94.19	815.41
P8	94.36	0.00	578.90	5.39	1.00	99.48	779.13
P9	43.10	0.08	624.35	0.79	0.00	176.56	844.88
Mean	104.38	0.04	629.04	3.57	0.34	90.49	838.04

4. Discussion

The results of this study highlight a strong spatio-chemical variability of groundwater in the municipality of Man, closely linked to anthropogenic activities within the urban farming areas. The pH values, ranging from 4.9 to 9.32, reflect the combined influence of natural geochemical processes (such as mineral dissolution and ion exchange) and external inputs related to agricultural practices [20-22]. The presence of slightly acidic water (sample P9) may result from the decomposition of organic matter and the infiltration of acidic leachates from cultivated soils, as similarly reported by [9] in West African urban environments.

The relatively low electrical conductivity (mean value of 60.9 µS/cm) indicates moderate mineralization of the groundwater, suggesting that geological weathering processes remain limited. However, the predominance of the cations K^+, Mg^{2+}, and Ca^{2+}, along with nitrites among the anions, reveals a major anthropogenic influence. The elevated potassium concentration, far exceeding the WHO guideline value of 12 mg/L, clearly reflects the intensive use of potassic fertilizers in vegetable farming, consistent with the findings of [10] in the same area.

The mean nitrite concentration (39.03 mg/L) greatly exceeds the WHO guideline of 0.2 mg/L, indicating likely agricultural or domestic pollution. Nitrites often originate from the reduction of nitrates under anaerobic conditions, a process enhanced by the accumulation of organic matter and wastewater discharges. Moreover, the strong positive correlation observed between pH, nitrites, and iron ($r = 0.75–0.78$) suggests a common origin related to redox processes within the aquifer system [23-25].

The trace metal concentrations (TMs) reveal an alarming level of contamination. The extremely high levels of Zn (up to 529.7 mg/L) and Fe (up to 276.18 mg/L) far exceed the WHO aesthetic thresholds (3 mg/L for Zn and 0.3 mg/L for Fe), indicating substantial inputs from fertilizers, pesticides, and metallic waste in cultivated and surrounding areas [26]. Likewise, the significant concentrations of Cd (mean 0.31 mg/L) and Mn (mean 1.38 mg/L), both above drinking-water standards (0.003 and 0.4 mg/L, respectively), point to potentially toxic contamination. These findings are consistent with those of [5, 6, 27, 28], who attribute high metal levels to agricultural soil leaching and atmospheric deposition.

Principal Component Analysis (PCA) and the correlation matrix confirm the presence of two main processes governing groundwater quality. The first is a geogenic process, characterized by the dissolution of carbonate minerals (Ca^{2+}–HCO_3^-–SO_4^{2-} correlation). The second is an anthropogenic process dominated by agricultural inputs (K^+–Fe–NO_2^- and Zn–Cd–Pb associations), indicating contamination from fertilizer and waste sources.

The contamination indices further substantiate these observations. The contamination factor (CF) shows extremely high values for Cd, Fe, and Zn (CF > 100), indicating severe pollution. The overall degree of contamination (DC = 793.6) classifies these waters as highly polluted. These values are much higher than those reported for other urban or peri-urban areas in Africa [29-30], underscoring the urgent need for stricter regulation of local agricultural practices.

From a public health perspective, the high levels of heavy metals pose chronic health risks, including hepatic accumulation, neurological disorders, and carcinogenic effects. Environmentally, contamination of shallow aquifers threatens groundwater sustainability and urban food security. These findings call for the implementation of an integrated water quality monitoring program that includes the management of agricultural inputs, control of domestic discharges, and increased awareness among local farmers.

5. Conclusion

This study conducted in the municipality of Man highlights a significant deterioration in the quality of groundwater used for both agricultural and domestic purposes. The elevated concentrations of major ions (K^+, Mg^{2+}, Ca^{2+}) and trace metals (Zn, Fe, Cd, Mn) reflect the combined impact of intensive agricultural activities, waste disposal practices, and local geochemical processes. The overall contamination degree (DC > 700) categorizes all groundwater samples as highly polluted and unfit for human consumption without prior treatment.

These findings emphasize the urgent need for immediate action, including:

- The strict regulation of fertilizer and pesticide use in urban farming areas;
- The installation of appropriate treatment or pre-filtration systems for wells; and
- Awareness campaigns targeting farmers and local residents to promote groundwater protection.

An integrated and sustainable groundwater management approach is essential to safeguard this vital resource and ensure the health security of the population in Man.

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.

References

[1] Foeken D, To subsidise my income, urban farming in an east-African town. African Student Centre Series. Leiden: Brill, 2006.

[2] Kana AA, Heavy metal assessment of groundwater quality in part of Karu, Central Nigeria. Water Practice and Technology. 2022; 17(9): 1802–1817.

[3] Sanusi IO, Olutona GO, Wawata IG, Onohuean H. Heavy metals pollution, distribution and associated human health risks in groundwater and surface water: a case of Kampala and Mbarara districts, Uganda. Discover Water. 2024 ; 4(27): 1-14

[4] Kokobou, K.H.J., Konan-Waidhet, A.B., Soro, T.D. and Biemi, J. (2022) Mapping of

[5] Potential Recharge Areas of Fractured Aquifers in the Departments of Yamoussoukro and Toumodi (Central Côte D'ivoire). Journal of Geographic Information System, 14, 527-545.

[6] Olowoyo JO, and Lion GN. Urban farming as a possible source of trace metals

[7] in human diets. S Afr J Sci. 2016; 2016;112(1/2): 1-6.

[8] Acharya LK, Paramaguru PK, Tripathi K, Bhoi TK, Kumar T, Seth P, and Birah A. Pesticide contamination in groundwater: processes, risks, and mitigation strategies. Discover Agriculture. 2025; 3: 1-25.

[9] Vermeiren K, Adiyia B, Loopmans M, Tumwine FR, Van Rompaey A. Will urban farming survive the growth of African cities: A case study in Kampala (Uganda)? Land Use Pollut. 2013; 35:40–49.

[10] Levasseur V, Pasquini MW, Kouamé C, Temple L. A review of urban and peri urban vegetable production in West Africa. SHS Acta Horticulturae 762: International Symposium on Horticultural Plants in Urban and Peri-Urban Life. 2007.

[11] Lapworth DJ, Nkhuwa DCW, Okotto-Okotto J, Pedley S, Stuart ME, Tijani MN, Wright J. Urban groundwater quality in sub-Saharan Africa: current status and implications for water security and public health. Hydrogeol J. 25:1093–1116.

[12] Yao KAF, Coulibaly L, Ouattara I, Ouédraogo M, Komien AM, Kouakou KE. Influence of Agricultural Inputs and Urban Waste on the Physicochemical and Metal Profile of Surface Waters in Man, Côte d'Ivoire. World Journal of Advanced Research and Reviews. 2025; 28(01): 1668-1680.

[13] Institut National de la Statistique- INS, Recensement Général de la Population et de l'Habitat, Résultats Globaux. 2021.

[14] Goula Bi A, Issiaka S, Brou K, Vamoryba F and Gnamien BK. Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'ivoire (Afrique tropicale humide). Revue en Sciences de l'Environnement Vertigo. 2006; 7 : 20-24.

[15] Brou KM. Croissance urbaine et risques naturels en milieu de montagne : L'exemple de Man (Côte d'Ivoire) [Thèse pour le Doctorat unique en Géographie], Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire. 2015.

[16] Hakånson L. Ecological risk index for aquatic pollution control, A sedimentological approach. Water Res. 1980; 14, 975–1001.

[17] Shen F, Mao L, Sun R, Du J, Tan Z, Ding M. Contamination evaluation and Source Identification of Heavy Metals in the Sediments from the Lishui River Watershed, Southern China. International Journal of Environmental Research and Public Health. 2019; 16: 1-14

[18] WHO (World Health Organization). Guidelines for Drinking-water Quality. Fourth edition incorporating the first Addendum. 2017

[19] Belkhiri L, Tiri A, Mouni L. Assessment of Heavy Metals Contamination in Groundwater: A Case Study of the South of Setif Area, East Algeria. In: Achievement and Challenges in Integrated Basin Management, Ed. Dejan Komatina. IntechOpen, chapter 2, 2018; 17–31.

[20] Yari AR et Sobhanardakani S. Water Quality Assessment of Ground water Resources in Qaleeh Shahin Plain Based on Cd and HEI. International Archives of Health Sciences, 2016; 3: 101-106.

[21] El-Hamid HTA et Hegazy TA,. Evaluation of Water Quality Pollution Indices for Groundwater Resources of New Damietta, Egypt. MOJ Eco Environ Sci. 2017; 2: 1–5.

[22] Lü X, Han Z, Li H, Zheng Y, and Liu J. Influence of Urbanization on Groundwater Chemistry at Lanzhou Valley Basin in China. Minerals. 2022; 12: 2-16.

[23] Nenkam TLLJ, Kringel R, Fantong WY, Pierre Nbendah P, Alain Fouépé Takoundjou AF, Elisabeth Z, Kamtchueng BT. Hydrochemistry of nutrients in groundwater under farmland in the Benue River Basin, North-Cameroon. Environmental Earth Sciences. 2022 ; 81: 1-22.

[24] Asmoay A. Evaluating groundwater quality and salinity dynamics in the Western-west area of El Minya Governorate, Egypt, based on geochemical modelling and multivariate analysis. Journal of Umm Al-Qura University for Applied Sciences. 2024; 10:91–101.

[25] Claon JS, Kouassi KS, Sérikipré L, Seka MA, N'guettia KR, Traoré A, Djamananallico J, Kouadio KL. Assessment of Nitrates and Nitrites in Borehole Water from the Southern and the Northern Region of Côte d'Ivoire (West Africa). Open Journal of Modern Hydrology. 2024; (14): 87-105.

[26] Smith RL, Kent DB, Repert DA, Böhlke JK. Anoxic nitrate reduction coupled with iron oxidation and attenuation of dissolved arsenic and phosphate in a sand and gravel aquifer. Geochimica et Cosmochimica Acta. 2017; 196: 102-120.

[27] Glodowska M, Ma Y, Smith G, Kappler A, Jetten M, Welte CU. Nitrate leaching and its implication for Fe and As mobility in a Southeast Asian aquifer. FEMS Microbiology Ecology. 2023; 99: 1–14.

[28] Martin S, Griswold W. Human health effects of heavy metals. Environ Sci Technol Briefs Citizens. 2009; 15:1–6.

[29] Alloway BJ, Jackson AP. The behaviour of heavy metals in sewage sludge-amended soils. Sci Total Environ. 1991; 100:151–176.

[30] Panda B, Chidambaram S, Thilagavathi R, Ganesh N. Prasanna MV, Vasudevan U. Source governed trace metal anomalies in groundwater of foothill aquifer and its health effect. Applied Water Science. 2020.10: 1-10.

[31] Belkhiri L, Tiri A, Mouni L. Assessment of Heavy Metals Contamination in Groundwater: A Case Study of the South of Setif Area, East Algeria. In: Achievement and Challenges in Integrated Basin Management, Ed. Dejan Komatina. IntechOpen, chapter 2, 2018; 17–31.

[32] Yari AR et Sobhanardakani S. Water Quality Assessment of Ground water Resources in Qaleeh Shahin Plain Based on Cd and HEI. International Archives of Health Sciences, 2016; 3: 101-106.