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Assessment of the hygienic quality of groundwater for drinking and domestic use in the peri-urban villages of the municipality of Jacqueville in Côte d'Ivoire

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The shortages in the distribution of drinking water from the public network in the municipality of Jacqueville lead the population of the peri-urban villages of the said municipality to turn to well water, the quality of which remains a concern. The objective of this study is to evaluate the hygienic quality of well water used by the population for their domestic needs. The measurement and sampling were carried out on eleven wells in three peripheral villages of the commune. The analysis covered ten physico-chemical parameters (T, pH, EC, Turbidity, salinity, NO_3, NO_2, NH_4, PO_4 and SO_4) and three microbiological parameters (total coliforms, *Escherichia coli* and faecal streptococci). Principal component analysis (PCA) was applied to the data to highlight the phenomena causing the degradation of the water. The calculation of the fecal contamination index (FCI) revealed three classes of water quality: Uncontaminated wells, moderately contaminated wells, and heavily contaminated wells. The study of the general quality shows that most of the wells studied had warm, turbid water with a high population of pathogenic microorganisms. This study highlighted the health risk incurred by the population when consuming the water from these wells without prior treatment.

Key words: Assessment, physicochemistry, microbiology, well, Jacqueville, Côte d'Ivoire.

INTRODUCTION

The importance of water for human existence and ecological sustainability cannot be overestimated as it is essential for life. It is found in virtually all living cells and is essential for life (Adeyemi et al., 2020). Around the world, pressure on water resources and especially on groundwater is increasing, mainly due to growing demand (Ibrahim, 2019). The observed gap between supply and demand and the sectoral competition for

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drinking water supply are problems not only for developing countries but also for industrialised countries (Mwanza et al., 2019). However, the issue of water remains a crucial one, as supplying cities with drinking water has always been a top priority and covers several aspects viz-viz economic, environmental, technical, political, and socio-cultural (Mwanza et al., 2019). In some regions of the world, groundwater is the only drinking water resource for human population; it is dependent on a combination of natural and anthropogenic factors (Joodavi et al., 2021). Groundwater is generally of good quality because it is better protected, but this quality can deteriorate due to inadequate protection and poor resource management (Sadiya et al., 2018). In Côte d'Ivoire, due to the government's difficulties in meeting the ever increasing demand of water by the populace, they resort to alternative sources such as shallow wells to meet their water needs (Mangoua et al., 2021). The use of water from open public wells and unprotected individual wells, combined with the inadequacy of sanitation facilities and the lack of basic hygiene knowledge, favours the spread of faecal diseases and can cause serious illnesses such as gastroenteritis, hepatitis, and typhoid (Ben Hida et al., 2012). The commune of Jacqueville in southern Côte d'Ivoire is faced with problems of access to drinking water. Indeed, the quantity of water supplied by the distribution company seems insufficient to cover the water needs of a constantly growing population. Shortages in the distribution of drinking water from the public network lead the populations of the peri-urban villages of the commune to resort to well water, the quality of which remains a concern. The aim of this study is to assess the hygienic quality of the well water used by the population for their domestic needs. The results of this study will be of great interest to the hygiene and health services, in preventive and curative actions to be taken against water-borne diseases.

MATERIALS AND METHODS

Study area

The study area is in the Grand Pont region, 62 km west of the economic capital Abidjan (Figure 1). The area is made up of low plateaus of continental origin dating back to the pre-Holocene era, formed of clay sands with an altitude varying from 8 to 12 m, and a plain formed by the coastal strips in the eastern part of its southern half (Tastet, 1979). Its tectonic structure is marked by a satellite fault parallel to the major fault (the lagoon fault) of the entire Ivorian sedimentary basin (Tastet and Guiral, 1994). The climate is transitional equatorial, with four seasons (Kpidi, 2017). In the coastal sedimentary basin, there are three important reservoirs in terms of hydrogeology, namely the Quaternary aquifer, the Terminal Continental aquifer of Mio-Pliocene age and the Maestrichtian aquifer (Aghui and Biemi, 1984). The Quaternary aquifer contains the most vulnerable water table. This aquifer, whose piezometric level is very close to the ground surface, floods the coastal plains with each rainfall. It could directly receive pollutants from various sources (Aghui and Biemi, 1984). The quaternary represents four horizons from top to bottom:

Horizon 4: marine sands, coarse sands of the cordons (40 to 50 m).
Horizon 3: fine to coarse sands with little clay (30 m).
Horizon 2: peaty clays (8 to 16 m).
Horizon 1: silty marl (0 to 40 m).

Of these four horizons, only horizons 4 and 3 contain the Nouakchottian water table (coarse marine sands) and the Oogolian water table (fine coarse sands). The permeability of the Quaternary aquifers varies from 10^{-3} to 40.10^{-3} m/s with a flow rate of 2 m^3/h to 22 m^3/h (Jourda, 1987).

Sampling method

The measurement and sampling campaigns were carried out on eleven wells in three villages (Figure 2). These wells were selected according to the frequency of use by the population. The water samples were taken in 1-L polyethylene bottles, which were rinsed three times with the water to be sampled for the physico-chemical parameters. For the microbiological analyses, 1 L glass bottles, preferably borosilicate, with erlenmeyer stopper were used. Before use, these bottles were carefully washed and rinsed to avoid any trace of detergent or antiseptic. They were then dried and capped with carded cotton. The packed stopper and the bottle were wrapped in filter paper and sterilized in an autoclave at 120°C for 15 min. All bottles were filled to the brim and sealed, then stored in a cooler to maintain the temperature at 4°C and transported to the laboratory for analysis.

Methods of analysis

The measurements of certain parameters were carried out *in situ* using a multi-parameter HANNA HI 9829. These are hydrogen potential (pH), temperature, electrical conductivity (EC), salinity and turbidity. In the laboratory, the analysis methods used, and the associated standards are those recommended by Rodier et al. (2009) shown in Table 1.

Data processing

The physico-chemical and microbiological parameters were subjected to a simple statistical analysis for a better exploitation of the data. Descriptive statistical analysis was used to calculate the minimum, maximum, average and standard deviation of each parameter studied. Principal Component Analysis (PCA) was used to determine the typology of the water in the different wells studied. The analyses covered 10 physico-chemical parameters and 3 microbiological parameters. All data were processed using XLSTAT Trial software.

Calculation of the FCI

In the present study, the calculation of the FCI was based on the guide values of the criteria used by Orou et al. (2016). The parameters considered for the elaboration of the FCI are bacteria of faecal origin; *Escherichia coli* (EC), faecal streptococci (FS) and total coliforms (TC) found in the digestive tract of humans and animals. The FCI is calculated by the following equation:

$$FCI = EC + FS + TC \quad (1)$$

The classification of the variables is done by alteration class and

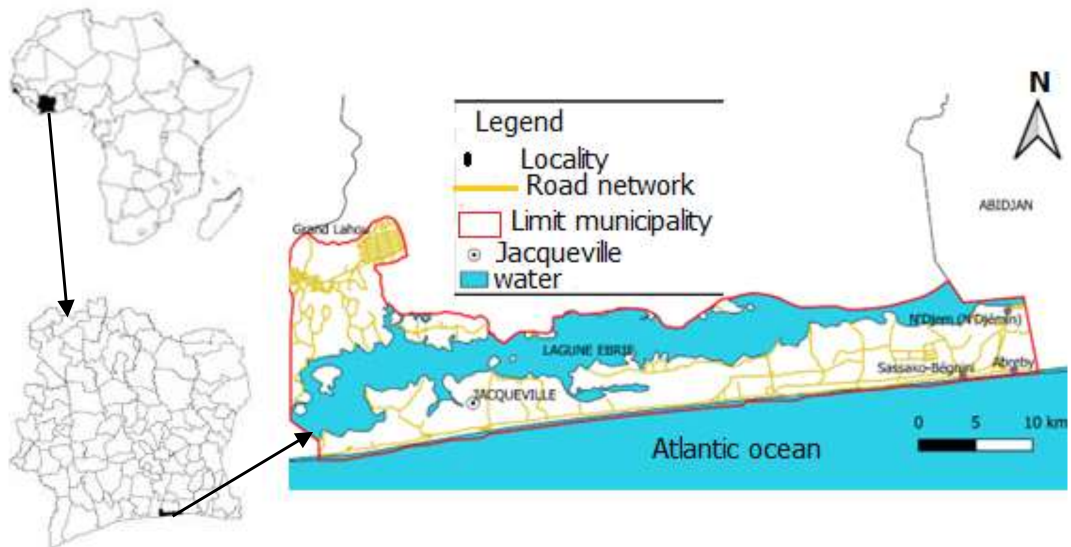

Figure 1. Location of the study area.
Source: Author's 2022

Figure 2. Location of sampling stations.
Source: Author's 2022

Table 1. Methods of analysis of physicochemical and microbiological parameters.

Parameter	Unit	Dosing methods
Ammonium	mg/L	Indophenol blue spectrometric method according to NF T90-015-2.
Nitrite	mg/L	Method by molecular absorption spectrometry (classification index T90-013).
Nitrate	mg/L	Method by molecular absorption spectrometry with sulphosalicylic acid according to NF EN ISO 10304-1
Phosphate	mg/L	Ammonium molybdate spectrometric method (classification index T 90-023).
Sulphate	mg/L	Nephelometric method according to NF T90-040.
Fecal coliforms	CFU/100 ml	Enumeration method by membrane filtration according to NF EN ISO 9308-1.
E. coli	CFU/100 ml	Enumeration method by membrane filtration according to NF EN ISO 9308-1.
Streptococci	CFU/100 ml	Enumeration method by membrane filtration according to NF ISO 7899-2.

Source: Author's 2022

Table 2. Grid for groundwater quality assessment by class (MEDD, 2003).

Class variable	1	2	3	4
EC	0	0-20	20-20000	>20000
FS	0	0-20	20-10000	>10000
TC	0	0-50	50-50000	>50000

FCI = Sum of the class numbers of the three (3) variables.
Source: Author's 2022

Table 3. Fecal contamination index scale for groundwater.

Class	FCI value	Degree of pollution
1	$0 < FCI \leq 3$	No faecal contamination
2	$3 < FCI \leq 6$	Moderate faecal contamination
3	$6 < FCI \leq 9$	Strong faecal contamination
4	$9 < FCI \leq 12$	Excessive or very heavy faecal contamination

Source: Author's 2022

Table 2 shows the concentrations of bacteriological elements by class. The table 3 shows the grid for the degree of faecal contamination of groundwater.

RESULTS

Physical characteristics of the surveyed wells

The main results of the study of the physical characteristics of the wells studied are recorded in Table 4. In the study area, the wells sampled had depths that vary between 2.3 and 6.5 m with piezometric levels that vary between 1.3 and 5.3 m. The piezometric level measurements obtained showed the proximity of the water table to the topographic surface. This proximity would increase the exposure of the water table to pollution phenomena, and this could lead to the degradation of most of the wells in the various peri-urban villages in the municipality of Jacqueville.

Physico-chemical and microbiological characteristics

The results of the descriptive statistics of the physico-chemical and microbiological variables used in this study concerned the minimum, maximum, mean and standard deviation values (Table 5). These results of the different parameters analyzed were compared to the WHO (2017), standards.

Well water temperatures range from 28.29 to 30.72°C with an average of 29.6 ± 0.65°C. The temperatures exceed 25°C, the WHO guideline value for drinking water. The groundwater in the study area was warm at all study points. The wells had turbid water, wells P1, P7 and P8 exceeded the WHO standard for drinking water.

Table 4. Physical characteristics of the surveyed wells.

Station	P (m)	N P (m)	Usage
P1	2.3	1.3	Domestic
P2	3.5	2.7	Drinking water
P3	4	3.2	Domestic
P4	5	4	Domestic
P5	5	4	Domestic
P6	3.7	3	Drinking water
P7	6	4.7	Domestic
P8	4	3.1	Domestic
P9	6.2	5.3	Drinking water
P10	6.5	5.3	Domestic
P11	4.5	3.7	Domestic

P: Depth, NP: Piezometric level.
Source: Author's 2022

Table 5. Descriptive statistics for physico-chemical and microbiological variables.

Variable	Unit	Min.	Max.	Means	Standard deviation	WHO Standards (2017)
NO_2^-	mg/L	0.017	0.118	0.04	0.034	<0.2
NO_3^-	mg/L	9.2	47.8	31.41	11.36	<50
NH_4^+	mg/L	0.07	0.37	0.121	0.08	<0.2
PO_4^{3-}	mg/L	0.30	3.7	1.35	1.10	<5
SO_4^{2-}	mg/L	0.00	44	20	12.76	<250
Turb	NTU	0.00	50	5.90	14.80	<4
T	°C	28.29	30.72	29.60	0.65	<25
pH	-	6,5	8,29	7.07	0.51	6.5-8.5
EC	µS/cm	117	488.00	329.18	97.57	<400
Sal	mg/L	0.05	0.50	0,18	0.11	-
CT	CFU/100 ml	0.00	18000	4010	5976.22	0/100
E. coli	CFU/100 ml	0.00	5800	600	1731.35	0/100
SF	CFU/100 ml	0.00	2800	330	832.02	0/100

Source: Author's 2022

The various wells studied were slightly acidic to basic with pH values ranging from 6.49 to 8.29 with an average of 7.07 ± 0.51. The electrical conductivity of the well water in the study area ranges from 117 to 488 µS/cm with an average of 329.18 ± 97.97 µS/cm. Nine out of eleven wells had conductivity below 400 µs/cm WHO guide value. The concentrations of sulphate ions varied from 0 to 44 mg/l with an average of 20 ± 12.76 mg/l. The Quaternary groundwater in the study area is less rich in sulphate ions. The concentrations of nutrients (NO_3, NH_4, NO_2 and PO_4) are all within WHO standards. The results of the microbiological parameters of the analysed wells showed that wells P4, P5, P9 and P10 are free of pathogenic microorganisms and are fit for drinking according to WHO standards. For the rest of the wells sampled, total coliforms are present in most of them, and their concentration varies from 210 to 18000 CFU/100 ml. *E. coli* was found in wells P1, P6, P7 and P8 with concentrations varying between 130 and 5800 CFU/100 ml. Streptococci were found in wells P1, P6, P7 and P8 with concentrations ranging from 100 to 2800 CFU/100 ml.

Correlation matrix analysis

The various levels of correlations that exist between the variables are shown in Table 6. Its analysis shows that NO_2^- is strongly correlated with turbidity (r= 0.66), *E. coli* (r= 0.69) and enterococci (r= 0.66). Phosphates are significantly correlated with TC (r=0.89), *E. coli* (r= 0.73), enterococcus (r= 0.78) and turbidity (r= 0.78). NO_3^- is significantly correlated with salinity (r = 0.60). Turbidity is significantly correlated with pH (r= 0.79), TC (r= 0.86), *E. coli* (r= 0.99), enterococcus (r= 0.99). pH is significantly correlated with CT (r= 0.74), *E. coli* (r= 0.80),

Table 6. Correlation matrix of variables.

Variable	NO_2^-	NO_3^-	NH_4^+	PO_4^{3-}	SO_4^{2-}	Turb	T (°C)	pH	EC	Sal	CT	*E. coli*	SF
NO_2^-	1.00												
NO_3^-	0.19	1.00											
NH_4^+	0.02	-0.62	1.00										
PO_4^{3-}	0.27	-0.46	-0.12	1.00									
SO_4^{2-}	-0.19	0.02	-0.33	0.18	1.00								
Turb	0.66	-0.25	0.03	0.78	0.17	1.00							
T °C	-0.66	-0.39	0.04	-0.20	-0.01	-0.61	1.00						
pH	0.51	-0.12	0.03	0.77	0.09	0.79	-0.69	1.00					
EC	0.19	0.52	-0.64	0.25	0.43	0.21	-0.38	0.44	1.00				
Sal	-0.09	0.60	-0.37	-0.07	0.31	-0.01	-0.48	0.35	0.64	1.00			
CT	0.49	-0.41	-0.07	0.89	0.15	0.86	-0.36	0.74	0.22	-0.08	1.00		
E. coli	0.69	-0.20	0.06	0.73	0.15	0.99	-0.67	0.80	0.21	0.01	0.82	1.00	
SF	0.66	-0.23	0.04	0.78	0.16	0.99	-0.64	0.83	0.27	0.02	0.86	0.99	1.00

Turb: Turbidity; sal: salinity.
Source: Author's 2022

enterococcus (r= 0.83). EC is correlated with salinity (r= 0.64). *E. coli* is significantly correlated with enterococcus (r= 0.99). Another level of correlation less significant than the previous one is established between NO_2^- pH (r=0.51), NO_3^- and EC (r=0.52).

Principal component analysis (PCA)

Factors F1 and F2 express 47.74 and 23.24% of the variance, respectively. These two factors alone contain 70.98% of the variances expressed and contain the maximum amount of information to allow the interpretation of the results. The representation using the first two factors gives a satisfactory account of the structure of the scatterplots. The examination of the correlations between the axes and the different variables studied makes it possible to explain the significance of each axis in the structured distribution of the scatterplot and the relationship between the typological structure and the environmental variables. The F1 axis is positively correlated with the variables: NO_2, PO_4, turb, pH, CT, *E. coli* and enterococcus and negatively correlated with temperature. This F1 axis groups together most of the parameters that determine the degree of pollution of the water in the different wells. The F2 axis is positively correlated with conductivity, salinity and NO_3 and negatively correlated with NH_4. The F2 factor describes the mineralization of the water in the different wells, which is dominated by the intrusion of salty marine or lagoon water (Figure 3).

Fecal contamination index (FCI)

The results of the FCI of the water samples taken from the different wells are presented in Figure 4. The analysis of this figure shows that the eleven wells studied are divided into three classes of bacteriological quality. Four wells (P4, P5, P9 and P10), that is, 36.4%, present water of good quality for human consumption. These waters do not contain pathogenic germs. Following the first group are waters of average quality with a moderate presence of faecal contamination. These waters concern three wells (P2, P3 and P11), that is, 27.3% of the points sampled, and are of acceptable quality for human consumption, but may be subject to disinfection treatment if necessary. Finally, the last group concerns P1, P6, P7 and P8, that is, 36.4% of the wells sampled. They are characterised by high faecal contamination and are not suitable for human consumption.

DISCUSSION

The quality of groundwater is characterised by ion concentrations and the presence or absence of pathogenic germs. The WHO standard defines the limit for water intended for human consumption. In the well waters studied, these different parameters were found in varying concentrations. The results of the piezometric study of the wells show piezometric levels that vary between 1.3 to 5.3 m. This proximity of the water table to the topographic surface makes the water more vulnerable and predisposed to contamination, especially as the land above the aquifer is permeable (Kanohin et al., 2017). The temperature of the water in the different wells remains high with values above the WHO standard of 25°C. These temperature variations are strongly influenced by the climatic conditions of the locality. This temperature is close to the average temperature of the ambient air in the study area. This would be related to the

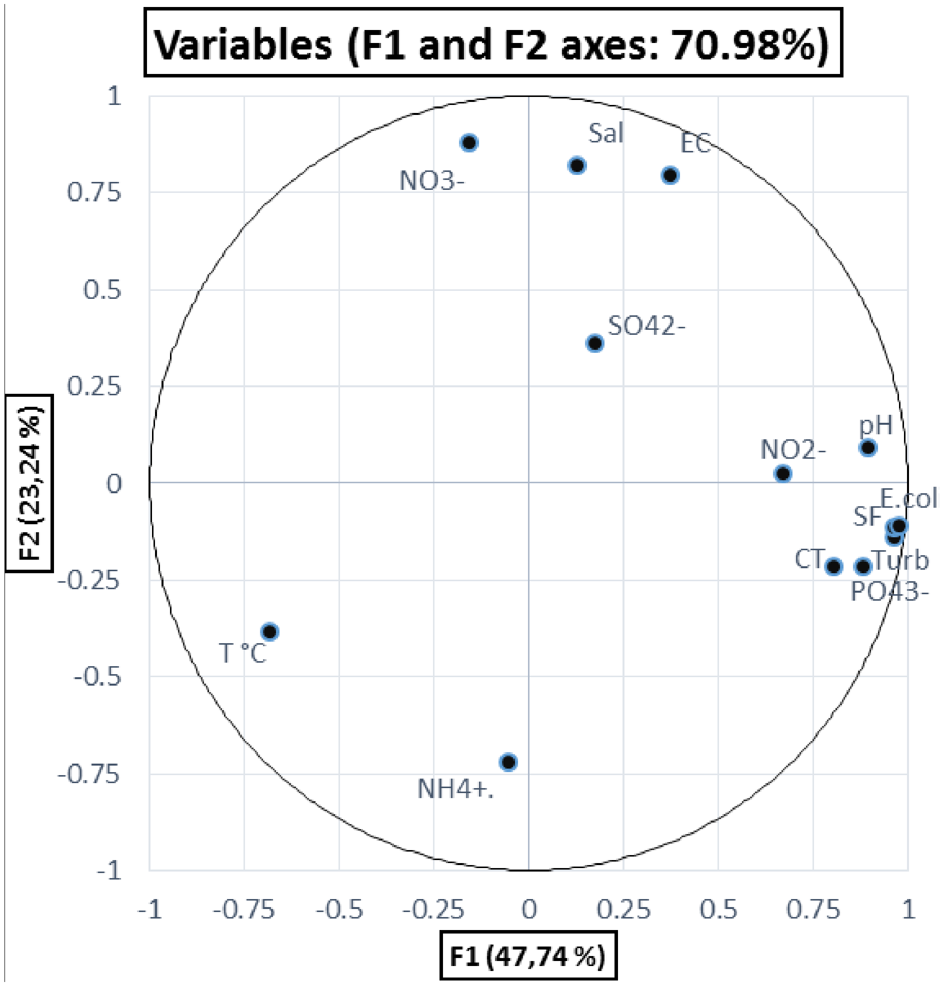

Figure 3. Variable space of the F1-F2 factorial design.
Source: Author's 2022

shallow depth of the wells and the piezometric level which is close to the topographic surface (Mahamat et al., 2021). The turbidity value shows that some wells (P1, P7 and P8) have very turbid water. The water from these wells cannot be consumed according to WHO (2017) recommendations which estimate the turbidity value below 5 NTU. The high turbidity of the water is believed to be caused by the presence of suspended matter such as clay, silt, organic matter and other microscopic organisms (Adongo et al., 2022). Turbidity is related to the content of pathogenic organisms in water from stormwater runoff (Umeh et al., 2020). The significant positive correlation between turbidity and pathogens studied, justifies the surface runoff of soil particles containing microorganisms in the wells studied. The electrical conductivity values were mostly low during the study period. All conductivity values were below the WHO (2017) permisable limits. The low conductivity values suggest the presence of low mineralized water with very little dissolved solid (Magha et al., 2021). This could be due to low dissolution in well water, rapid ion exchange between the aquifer and groundwater or geological rock consisting of insoluble minerals. Salinity is often based on chloride concentration and contributes strongly to conductivity. The significant positive correlation between conductivity and salinity (r=0.64) confirms a saline intrusion in well water. This saline intrusion in the groundwater may be attributed to its proximity to the sea and the Ebrié Lagoon. The different characteristics of the study area, which are the proximity to the ocean and the lagoon, the low sea level, and an aquifer structure consisting of sand, favour the contamination of wells by salts making the water unfit for consumption (Nyakundi et al., 2020). The concentrations of nutrient salts (NO_3, NO_2, NH_4, PO_4 and SO_4) in the well water studied remained low throughout the study period. These concentrations are far below the WHO (2017) standards for water intended for human consumption. This is in contradiction with the work conducted by Douagui et al. (2019) on Quaternary waters in the southern part of Abidjan district.

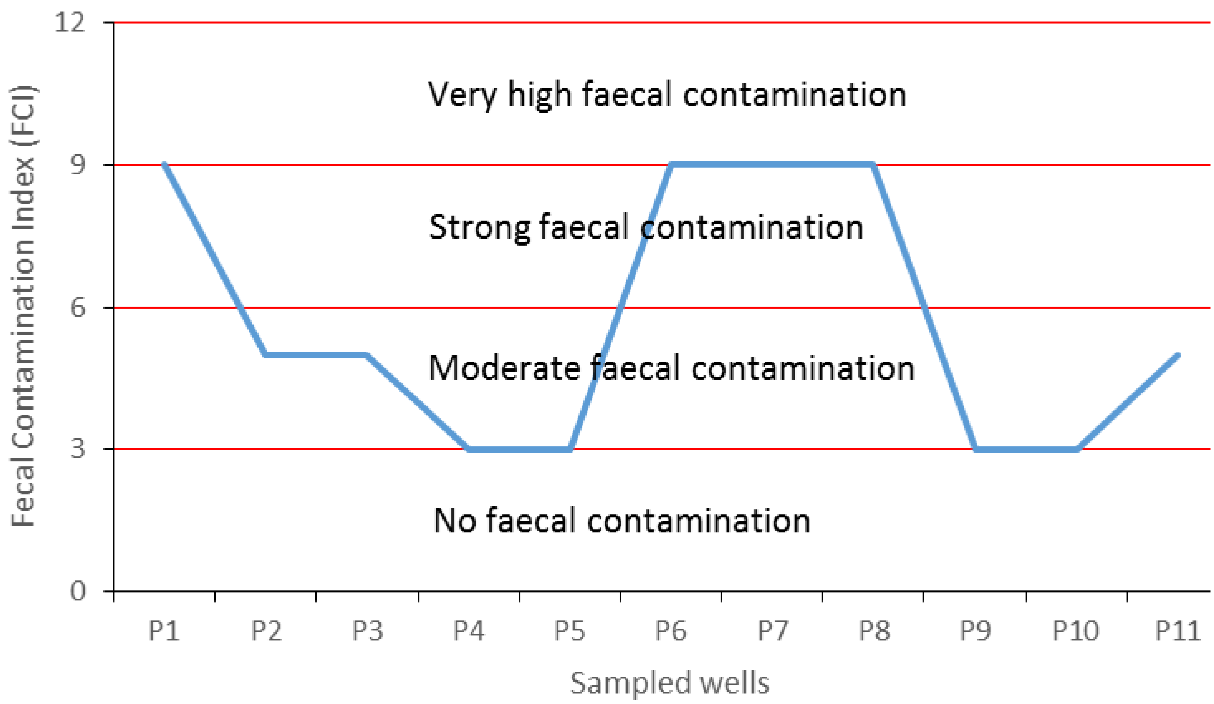

Figure 4. Variation in the faecal contamination index of the wells studied.
Source: Author's 2022

These authors found high concentrations of nutrient salts. In these areas, insalubrity increases with the direct discharge of solid waste and wastewater on the ground. This practice leads to the formation of elements in the soil and their transfer to the water table by runoff. The results of the FCI show three microbiological quality classes of the wells analysed. These quality classes ranged from the highly contaminated class, which is equivalent to poor quality water, to the uncontaminated class, which corresponds to good quality water. In the wells belonging to the high contamination class, high levels of microorganism populations are found in comparison with the WHO standards (2017). This contamination can be caused by domestic discharges, the existence of wells near latrines and surface water infiltration into the wells (Annan et al., 2022). The results of the present study are consistent with Ntep et al. (2021) who reported high numbers of coliforms and faecal streptococci in wells in the upstream catchment of the Biyémé River in Cameroon. The high pathogen values in the wells of the study area are like those found in the groundwater in the city of Anébo in Togo (Poromna et al., 2022).

Conclusion

The evaluation of the hygienic quality of well water used by the population in the commune of Jacqueville for domestic purposes has revealed bacteriological contamination of the water. The main cause of this contamination is human activities, which constitute a major risk for humans and their environment, particularly for water resources. This study has shown the importance and usefulness of the FCI to obtain information on the hygienic quality of water and thus prevent all kinds of contamination originating from domestic activities. The monitoring of the FCI of the water during this study shows that the wells are divided into three classes of bacteriological quality. Most of the wells were found to be unsuitable for drinking water use according to WHO recommendations. This contamination of well water is due to very high turbidity values and microbiological parameters exceeding WHO standards. Thus, to avoid possible serious health risks, the adoption of hygienic measures, including periodic chlorination of well water at family level, is recommended for the population concerned. This study is of great interest to the hygiene and health services, which will be able to implement preventive and curative actions for the population of the commune of Jacqueville. But above all, to establish Informative, Educative, Communicative and Sensitization (IECS) programs for the populations that use these contaminated water sources.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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