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Investigation of Groundwater Quality Control in Adamawa-Cameroon Region

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Abstract: According to the standard method recommended by the American Public Health Association (APHA), 34 samples were collected and analyzed for various parameters such as pH, temperature, color, turbidity, total hardness, electrical conductivity, total dissolved solids, dissolved oxygen, total alkalinity, iron, manganese, major ions chloride, calcium, sulfate, nitrate, phosphate, sodium and potassium in order to master the hydro-chemical changes of water quality in the Adamawa-Cameroon region. This analysis indicates that, some parameters such as pH, dissolved oxygen, iron, turbidity and temperature are in alarming proportions in certain samples compared to the standards recommended by the World Health Organization (WHO). Also, ordinary Kriging analysis was conducted to investigate the spatial distribution of these non standard parameters. The global water quality index for the region has been calculated and its value is equal to 82.11. The approach used in this study can be recommended to control the evolution in time and space properties of groundwater and can be conducted in other areas for the study of similar phenomena.

Key words: Distribution map, groundwater quality index, Kriging, physico-chemical parameter

INTRODUCTION

Presently in the world, nearly 885 million people die every year for non-access to water and more than 4 million for drinking unsafe water (WHO, 2003). In some countries in the world, the statistics are not generally demonstrative and the problem remains complaining. Scientists are also unanimous in all sectors, specifically in the area of housework, that water quality is more important than its quantity (CPHEEO, 1998; Patnaik *et al*., 2002; Tanriverdi *et al*., 2010). Because of the restriction and saturation (deficiency) of the network performed by the public organizations in charge of the matter (production and distribution), many individuals have turned to the use of groundwater (Nouck *et al*., 2013b). However, population growth and the expansion of agriculture, the development of units of poultry, cattle and pigs farms as well as the use of uncontrolled septic tanks cause a major problem of the alteration of groundwater resources, already in limited quantities. The development of these human activities coupled with the phenomenon of climate change and the nature of geological formations makes the groundwater increasingly infected and therefore, very dangerous to health when used for foodstuff (Laferriere *et al*., 1996; Conway, 2009). In order to reduce the magnitude of waterborne diseases, the World Health Organization (WHO) has established the standards for drinking water (WHO, 1996). These standards help to establish and monitor permanently the water quality in a given region (Chhabra, 2008; Chandra *et al*., 2010; Srivastava and Ramanathan, 2008). Water quality parameters thus have a threshold not to cross as this would make water contaminated and hazardous to health (Islam *et al*., 2003; Cobbina *et al*., 2010; Fulazzaky *et al*., 2010). It is therefore, important to know the different standards and indicators of quality and potability of groundwater to edify officeholders in charge of the sector on the importance of controlling water quality to reduce the spread of waterborne diseases. This study therefore aims to conduct an analysis of the physico-chemical parameters of groundwater in the region of Adamawa-Cameroon using the standard method advised by the American Public Health Association (APHA) and then to study their spatial distribution in order to develop a comprehensive report on the groundwater quality in this region.

MATERIALS AND METHODS

Study area: Adamawa region is located in the heart of Central Africa between 6-8° North latitude and 11-16° East longitude (Fig. 1). It extends over a length of about 410 km

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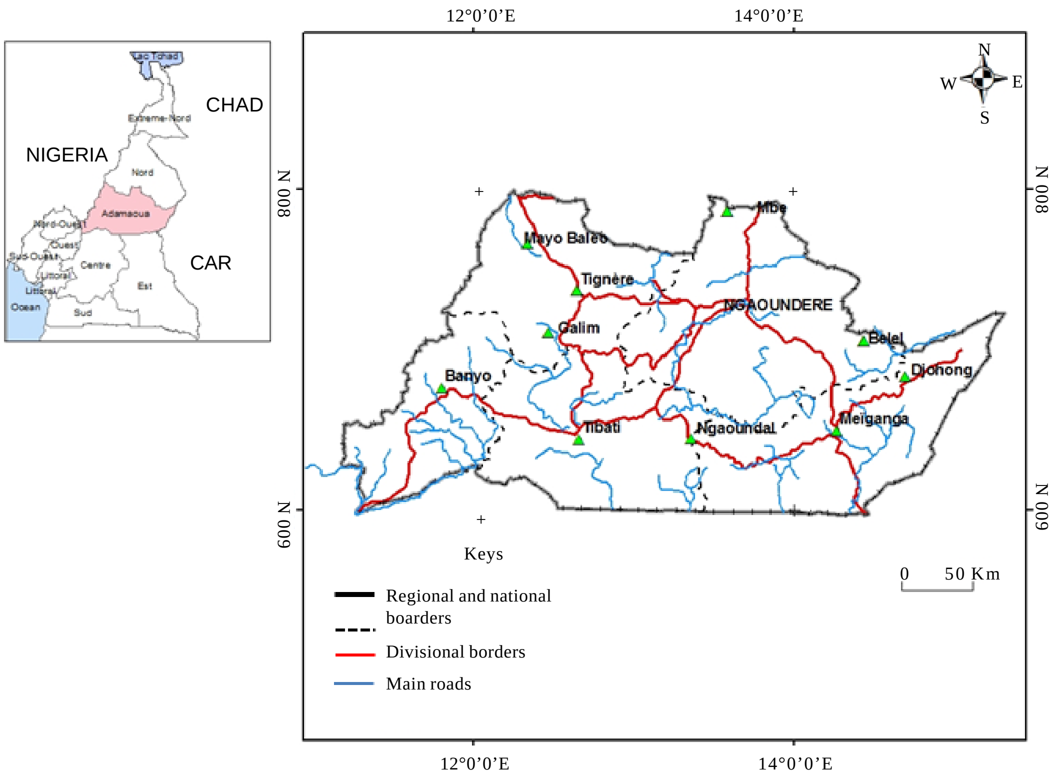


Fig. 1: Study area

from West to East between Nigeria and the Central African Republic, for a total area of 67,827 Km^2. The region receives an average of 1,540 mm of rainfall per year, from March to October. The temperature is moderate with an annual average around 25°C (Bring, 2005). On hydrological level, the Adamawa region is called “the water tower of Cameroon” because it feeds three of the four major watersheds of this country, namely the lake Chad Basin, the Niger basin in the North and the Sanaga Atlantic basin in the South (Djeuda-Tchapnga, 1988).

Sampling and physico-chemical analysis: This study focuses on 34 groundwater samples collected mainly from hand pumps in March 2013. The samples, packaged in cleaned and screw capped polythene which were brought to the laboratory where they were analyzed using the standard method defined and advised by the American Public Health Association (APHA, 1995). Just before the sampling, each tube was thoroughly washed and rinsed three times using the water to be sampled. The chemical test and indicator used depend on the parameter to be analyzed. Different methods and chemical tests are shown in Table 1.

Geostatistics: Geostatistics can be defined as a set of techniques or tools used to estimate or predict the content of a variable distributed in space or in time. It is used to analyze samples of data, develop models of variograms and produce spatial distribution maps (Nijmeijer *et al*., 2001; Meli’i *et al*., 2013; Nouck *et al*., 2013a). Ordinary Kriging called best linear unbiased estimator for having zero mean square error, is widely used in Geostatistics for optimal estimation of variables in geology , hydrology, environmental sciences and other areas where spatial interpolation of data is required (Stein, 1999).

Kriging has two main tasks: Quantifying the spatial structure of the data and producing a predicted surface. In order to predict an unknown value for a specific location, Kriging will use the fitted model from variography, the spatial data configuration and the values of the measured sample points around the prediction location (Sarangi *et al*., 2005). With the recent advances in computation facilities and the availability of geostatistical softwares, the use of Kriging in the spatial analysis of environmental data is increasingly popular. Several types of Kriging have also been developed and

Table 1: Different methods and indicators used for the analysis

Method	Indicator	Parameters Number	Designation
Water analyzer	Systronic–371	6	Electrical Conductivity (EC) pH Total Dissolved Solids (TDS) Dissolved Oxygen (DO) Salinity Turbidity
Complexometric EDTA	Eriochrome black–T	1	Total Hardness (TH)
Complexometric EDTA	Eriochrome murexide	1	Calcium hardness
titrametric method	Phenolphthalein	1	Total Alkalinity (TA)
titrametric method	Methyl–orange	1	Carbonate and bicarbonate
Argentometric method	K_2CrO_4	1	Chloride concentration
Spectrophotometer	Zirconyl	1	Fluoride concentration
Spectrophotometer	Brucine	1	Nitrate concentration
Spectrophotometer	Turbidimetric	1	Sulfate concentration
Flame–photometric		3	Sodium Potassium Calcium
Calculated from total and calcium hardness		1	Magnesium

are currently used: Simple Kriging, ordinary Kriging, universal Kriging, block Kriging, co-Kriging and disjunctive Kriging. Ordinary Kriging for proving its reliability in similar studies (Yamamoto, 2000), will be used in this study for interpolation and spatial analysis of physico-chemical parameters. In a trivial way, the semi- variogram is given by Eq. 1:

$$\gamma(h)=\frac{1}{2}E\left[z(x)-z(x+h)\right]^2 \tag{1}$$

For discrete variables, this function can be written as shown in Eq. 2:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[z(x_i)-z(x_i+h)\right]^2 \tag{2}$$

Where $z(x_i)$ is the value of the variable Z at location x_i and N(h) the number of pairs of points separated by lag distance h. The experimental variogram obtained is adjusted to a theoretical model. Hence, Kriging allows estimating the value of a variable through Eq. 3:

$$Z^*(x_0)=\sum_{i=1}^{n}\lambda_i z(x_i) \tag{3}$$

Where, $z^*(x_0)$ is the estimated value at location x_0, $z(x_i)$ the measured value at location x_i and λ_i its weight.

Interpolation: For each parameter, different variogram models were tested. Through cross-validation, the model with the smallest Root Mean Square Error (RMSE) is selected for interpolation (Johnston *et al*., 2001).

Overall index of water quality in the region: This index helps to reduce the wide number of physico-chemical parameters used to characterize a water sample (Gorai and Kumar, 2013). Many researchers have used in its barycentric version as a weighted arithmetic mean function (Dinius, 1987; Dee *et al*., 1973; Ott, 1978; Ball and Church, 1980; Egborge and Benka-Coker, 1986; Stambuk-Giljanovic, 1999; Prasad and Bose, 2001; Bordalo *et al*., 2001; Gorai and Kumar, 2013). But this study is limited insofar as it does not efficiently address parameters with minimum standard value such as Dissolved Oxygen (DO) or Positive Hydrogen ions (pH). For this reason, this study instead uses the global groundwater quality index established in 2001 by the Canadian Council of Ministers of the Environment (CCME, 1999). This index comprises three factors: F_1, F_2 and F_3 which represent respectively extent, frequency and amplitude of the water alteration.

The extent F_1 represents the percentage of parameters including at least one measure which doesn't meet the standard during the study period (Eq. 4). The frequency F_2 is the percentage of nonconforming analytical results (Eq. 5). The amplitude F_3 is the difference between nonconforming analytical results and the standards to which they relate. This last factor is computed in three steps:

- **First:** The difference coefficient which represents the magnitude by which an individual concentration is greater than the standard (or lower when this standard is a minimum). When the analytical result should not exceed the standard, the difference coefficient is given by Eq. 6 and 7
- **Second:** The normalized sum of the difference coefficients which is the overall level of nonconforming (Eq. 8)
- **Third:** The term F_3 can be calculated using an asymptotic function that scales the normalized

sum of deviation from standards within a range of values from 0 -100 (Eq. 9)

These three factors are then used to compute the global groundwater quality in the overall region in Eq. 10:

$$F_1 = \left(\frac{\text{No. of nonconforming parameters}}{\text{Total No. of parameters}}\right) \times 100 \quad (4)$$

$$F_2 = \left(\frac{\text{No. of nonconforming analytical results}}{\text{Total No. of analytical results}}\right) \times 100 \quad (5)$$

$$\alpha_i = \left(\frac{\text{Nonconforming result}_i}{\text{Standard}_i}\right) - 1 \quad (6)$$

$$\alpha_i = \left(\frac{\text{Standard}_i}{\text{Nonconforming result}_i}\right) - 1 \quad (7)$$

$$\beta = \frac{\sum_{i=1}^{n} \alpha_i}{\text{Total No. of results}} \quad (8)$$

$$F_3 = \frac{\beta}{0.01\ \beta + 0.01} \quad (9)$$

$$WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (10)$$

RESULTS AND DISCUSSION

Temperature: Temperature is an important parameter in the quality of groundwater insofar as it influences several physico-chemical properties such as the density and the viscosity of water, the solubility of gases in the water and the rate (speed) of chemical and biochemical reactions (HCWFFAD, 2006). Results obtained in the study area show a rather wide variation in the temperature, from 19.7-28.5°C with an average of 25.4°C (Table 2).

pH: pH affects a large number of physico-chemical equilibrium between water, dissolved carbon dioxide, carbonates and bicarbonates. It also indicates the acidity level of the water and mainly depends on the origin of the water and the geological nature of the substrate of the watershed's own (Dussart, 1966; Bremond and Vuichard, 1973; Shyam and Kalwania, 2012). In our study area, the recorded values range from 5.2-7.7 with an average of 6.7 (Table 2).

Electrical Conductivity (EC): EC is the Electrical conductance of 1 cm^3 column of water. It provides information on the origin of the water reservoirs regarding the mineralization and the amount of dissolved salts in water (HCWFFAD, 2006). The values recorded during the study period range from 0.02-336 μ Sm^{-1} with an average of 72 μSm^{-1} (Table 2).

Total Hardness (TH): The total hardness of a water is produced by calcium, magnesium, barium and strontium salts. Its primarily results from contact of groundwater with rock formations (WHO, 1995). Calcium for example derives from the attack of dissolved carbon dioxide by limestone rocks or their dissolution as sulfate in gypsum. It thus provides information on the geological structure of the soil overlapped by the water during infiltration. In the analyzed samples, this parameter varies from 2.5-180 mg L^{-1} with an average of 50.6 mg L^{-1} (Table 2).

Sulfate (SO_4^{2-}): Sulfate ions originate from runoff or infiltration into the land drywall or oxidation of hydrogen sulphide which is highly toxic (HCWFFAD, 2006). In this study, the concentration of sulphate ions ranges from 0.2 -112.6 mg L^{-1} with an average of 4.5 mg L^{-1} (Table 2).

Dissolved Oxygen (DO): DO is the main factor which provides information on the amount of oxygen in the water. It originated in the ventilation of the surrounding air. Generally, running or cold water is more oxygenated than stagnant or hot one. Its low rate bodes poor water quality for drinking (Jena *et al*., 2003). According to WHO, the superior water contains an amount of DO greater than 7 mg L^{-1}. It is good when DO ranges from 5 -7 mg L^{-1} andis moderate when the amount of DO is less than 3 mg L^{-1} (WHO, 2003). In our study area, its concentration varies from 1.55-7 mg L^{-1} with an average of 2.8 mg L^{-1} (Table 2).

Nitrate (NO_3^-): The nitrate ions present in water find their origin in the leaching of nitrogen in the soil, through use of fertilizers and in the decomposition of some organic matters (Samake, 2002). Concentration in this region is generally low with an average value of 5.2 except one sample where it reached 118 mg L^{-1} (Table 2).

Calcium (Ca^{2+}): This parameter varies as TH and its concentration in water also depends on the overlapped geological substrate. This concentration ranges from 0.3-95 mg L^{-1} with an average of 13.6 mg L^{-1} (Table 2).

Sodium (Na^+): The presence of sodium in water may be due to leaching of geological formations containing sodium chloride, to the decomposition of mineral salts such as sodium silicates and aluminum to the infiltration

Table 2: Overall results of the physico-chemical analysis of groundwater in the area of Adamawa-Cameroon

Pump	pH	T	[1]TA	[1]TDS	[1]DO	[1]Cl^-	[1]Ca^{2+}	[1]SO_4^{2-}	[1]NO^{3-}	*Fe	[1]Mn	[1]PO_4^{3-}	[1]Na^+	[1]K^+	[2]TH	[3]Turbidity	[4]Color	[5]EC
P-1	6.13	24.6	8	60.8	2.98	1.8	7.2	2	0	0.09	0.005	1.4	1.2	0.5	72	2	4	127.8
P-2	6.8	27	1	60.2	2.87	0.1	7.3	2	0.2	0.05	0.05	0.81	0.8	0.1	61	4	3	0.08
P-3	7.3	28	2	60.7	2.75	0.1	7.4	1.2	0.2	0.05	0.05	0.82	0.9	0.3	42	5	6	0.08
P-4	7.3	23.2	0.8	60.5	1.55	0.2	7.1	0.5	0.1	0.1	0.1	0.86	1	0.2	22	1.5	9	6.55
P-5	6.5	28.5	0.3	59	2.18	24.6	48	0.5	1.3	0	0	0.89	1.1	0.4	31	3	6	297
P-6	6.9	28.1	3	60	2.1	0.01	7	0.7	0.01	0.01	0.01	1	1.2	0.5	24	2	3	4.51
P-7	7.7	23.8	40	62	2.13	37.8	95	0.9	4.9	0	0	1.2	1	0.4	17.5	2.5	2	4.51
P-8	6.5	24.9	3.2	61	2.1	0.1	36	0.4	17.32	0	0.5	1.3	1.3	0.3	20	4	2	270
P-9	5.8	28	8	60.4	2.13	0.9	6.9	0.2	0.5	0.35	0.002	1.4	0.8	0.3	19	2	6	126.8
P-10	7.4	20.6	6	62	6.4	0.1	6.9	1.1	0.2	0.05	0.05	1.5	1.4	0.2	18	6	5	0.3
P-11	5.7	24.5	0.4	60.9	2.01	0.1	8	1.2	1.2	0.2	0.1	0.7	1.5	0.1	17	2	5	26.6
P-12	7.32	23.4	4	66	3	87.66	71.55	112.61	12.89	0.05	0.009	0.81	1.2	0	16	5.12	3	193.55
P-13	7.2	22.4	7	64	2.18	1	6.8	1.3	0.01	0.01	0.01	0.9	0.8	0.1	18.5	8.5	5	17
P-14	6.28	24.2	8.1	61.4	2.1	1.9	7.5	1.4	0	0.04	0.009	0.79	1.2	0.5	2.497	0	2	129.8
P-15	5.59	24.9	7.4	58.6	2.32	2.9	5.7	0.9	1.7	0.25	0.001	0.9	1.2	0.4	15	1	2	124.4
P-16	7.2	25.9	3	81	2.7	0.1	6.7	0.7	0.2	0.05	0.05	1.1	0.7	0.2	53.04	3	4	0.19
P-17	5.22	29.1	2.9	165	4	1.1	10.9	2.8	6.9	2.01	0.008	1.2	2.1	0.6	14	7	28	336
P-18	6.8	26	1	45	2.65	0.1	6.6	0.8	0.2	0.05	0.05	1.14	0.5	0.3	71.2	7	4	0.064
P-19	6.22	25	2.4	22	2.1	0.2	0.8	0.8	0.1	0.07	0.004	0.9	0.2	0	112.8	1	2	45
P-20	7.5	23.8	3	27	2.12	0.1	6.5	0.8	0.2	0.05	0.05	1.15	1.5	0.4	54	6	2	0.056
P-21	7.3	20.9	0.9	44	2.66	1.94	6.4	0.7	0.01	0.05	0.05	1.02	0.3	0.5	180	1.9	3	26.6
P-22	5.8	23.5	0.3	55	1.98	0.4	8	0.5	11.9	0	0.2	0.89	0.8	0.6	116.17	5	4	34
P-23	6.81	21.8	1.2	8.6	2.21	0.2	2	0.9	0.1	0.07	0.004	0.9	0.9	0	126	1	2	15.8
P-24	6.12	24.6	5.5	44.2	2.75	1.8	3.9	0.8	2	0.04	0.007	1.9	0.8	0.2	13	1	3	88.6
P-25	7.2	24.9	10	69	2.4	8.6	6.3	0.7	0.2	0.05	0.05	1.1	1.2	0	106.8	1.7	4	0.76
P-26	7.4	24.3	4	62	2.17	0.3	6.2	1	0.1	0.1	0.01	1.25	1.3	0.1	90	1.2	6	14.9
P-27	7.5	24.6	7	72.3	2.12	0.35	6.1	1.1	0.01	0.05	0.05	1.96	1.1	0.2	12	1.8	5	12.1
P-28	6.33	27	12.3	100.4	2.54	2.2	11.5	3	0.8	0.01	0.007	1.25	1.7	0.4	144	3	8	210
P-29	5.54	24.8	8.2	73.3	7	2.8	9.4	1.2	2.8	0.1	0.004	1.1	1.3	0.5	116.6	0	1	155.6
P-30	7	25.1	4	46	6.3	0.1	5.4	1.1	0.2	0.05	0.05	0.87	0.9	0.3	4.99	4	4	0.021
P-31	6.8	19.7	1.5	71	2.05	0.1	5.3	1.2	0.01	0.01	0.01	1.58	0.8	0.4	24.62	5	3	2.7
P-32	7.2	26.1	5	69	2.36	0.01	5.2	1.3	0.01	0.01	0.01	1.62	1.1	0.2	18.22	4.5	7	19.4
P-33	7.2	24.7	11	64	2.12	0.01	5.1	1.4	0.01	0.01	0.01	0.69	1	0.1	18.22	4.1	4	17.6
Minimum	5.22	19.7	0.3	8.6	1.55	0.01	0.8	0.2	0	0	0	0.69	0.2	0	2.49	0	1	0.02
Maximum	7.7	28.5	40	165	7	0.2	95	112.6	118.8	2.01	0.2	1.96	2.1	0.6	180	7	28	336
Average	6.71	25.4	5.53	61.7	2.76	0.05	13.35	4.48	5.25	0.12	0.03	1.07	1.06	0.28	50.64	3.07	4.76	72
Standard	7-8.5	20-24	200	600	5-7	250	100	200	50	1	0.5		10-100		12	200	50	1400

[1]Values expressed in mg L^{-1}, ppm, NTU (0-5: Colorless, 5-30: little colored; 30-50: colorful), HU and µS cm^{-1}

of waste water from industry or to the intrusion of seawater (Rodier, 1996). Its presence is really tiny in this region with an average concentration of 1 mg L^{-1} (Table 2).

Chloride (Cl^-): Abundant presence of chloride ions in the water makes it laxative and corrosive. Based on the results of analysis of the water samples, the chloride concentration ranges from 0.01-373 mg L^{-1} with an average of 16 mg L^{-1} (Table 2).

Iron (Fe): The presence of iron in the water can promote the proliferation of certain strains of bacteria, it also causes corrosion of the pipes. Highly ferruginous water requires suitable treatment before consummation (Guillemin and Roux, 1992). The average iron concentration in the study area is 0.12 mg L^{-1} (Table 2).

Turbidity: Turbidity is due to the presence of active and detrital mineral or organic particles in the water. Thus, more water is loaded in phytoplankton biomass or sediment particles, more it is turbid (www.wikipedia.com). High turbidity can allow microorganisms to attach to particles in suspension. Its value reaches 7 NTU (Nephelometric Turbidity Unit) with an average of 3 NTU in the study area (Table 2).

Color: The color of a small amount of water is caused by the presence of the metal particles (iron and manganese) dissolved or suspended, humus, plankton, etc. Its presence in water does not necessarily compromise its potability. In this study, the color varies from 1-28 HU (Hazen units) with an average of 4.8 HU.

Total Alkalinity (TA): Alkalinity is not a criterion of pollution. It expresses the total rate of substances capable of neutralizing the acidity of water. It essentially originates from rocks that contain carbonate groups, bicarbonate, hydroxide, silicate, borate and phosphate. In reality, it does not represent a danger to water consumption but in significant amount, the water becomes bitter-tasted. It ranges from 0.3- 40 mg L^{-1} with an average of 5.5 mg L^{-1} in the region.

Total Dissolved Solids (TDS): The term TDS describes the overall solids (particularly minerals) that are dissolved in water. This is an important parameter since it impacts the taste and drinkability of the water. Its concentration ranges from 8.6-165 mg L^{-1} with an average of 62 mg L^{-1}.

Manganese (Mn^{2+}), potassium (K^+) and phosphate (PO_4^{3-}) ions have also been analyzed. Their maximum concentrations (respectively 0.2l, 0.6 and 1.96 mg L^{-1}) do not exceed the WHO standards.

All these results are summarized in Table 2 where they are compared with the standards recommended by the World Health Organization (WHO, 2004).

This table shows that for all the samples, some parameters such as TA, TDS, Cl^-, Ca^{2+}, SO_4^{2-}, Na^+, K^+, Mn, TH, turbidity, EC and the color are within the proportions acceptable or allowable by the World Health Organization.

However, other parameters have abnormalities on some samples. At locations P-1, P-2, P-9, P-11, P-14, P-15, P-17, P-19, P-22, P-24, P-28 and P-29, the pH value is below the WHO standard. The average temperature (25.4°C) is greater than the permissible standard WHO. Its values are higher on the samples P-2, P-3, P-5, P-6, P-9, P-16, P-17, P-18, P-19, P-28, P-30, P-32 and lower on site P-31. All samples have a dumpy concentration of DO except P-10 (6.4 mg L^{-1}), P-17 (4 mg L^{-1}), P-29 (7 mg L^{-1}) and P-30 (6.3 mg L^{-1}). Nitrate ions have a very low concentration except the sample P-22 (118.8 mg L^{-1}). Generally, the iron concentration is acceptable according to the WHO standards except Site F-22 which is twice greater than the standard.

Spatial distribution of parameters with undesirable (nonconforming) concentration: According to the above analysis, certain parameters have anomalous values in some samples. It is therefore, necessary to analyze their spatial distribution in order to predict their behavior on locations where sampling was not performed. For each parameter containing at least one undesirable value (pH, DO, Fe, turbidity and temperature), seven variogram models (linear, circular, Gaussian, exponential, spherical, cubic, logarithmic) were tested for the selection of the best fitted model on the basis of cross-validation tests. Following the development of the cross-validation, spatial distribution maps were produced to provide a visual representation of the distribution of these parameters (Fig. 2). RMSE is calculated by Eq. 11 and characteristics (nugget, range and sill) for each selected model of variogram are shown in Table 3.

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n}\left(\gamma_{i\text{th}} - \gamma_{i\text{ex}}\right)^2} \quad (11)$$

In this equation expressing the root mean square error, γ_{ith} and γ_{iex} represent, respectively theoretical and experimental values of the variogram at the location x_i.

Models described and shown in table 3 are used to perform the spatial distribution maps of the nonconforming parameters (Fig. 2).

Using the guidelines of the World Health Organization (WHO, 2004), it appears that the turbidity varies from 1.4-6.8 NTU (Fig. 2a) which means that the water is clear and colorless everywhere except Tibati where it is slightly colorful (turbidity more than 5).

The temperature hovers around 25°C (Fig. 2b) make the water quality moderate. Indeed, when the temperature is high, some water parameters such as viscosity, DO, etc., are spoiled.

With a DO rate ranged between 1.8 and 7 mg L^{-1}, the water is usually very little hydrogenous in the region except in Dankali, Meiganga, Beka and Bantoua-Godole (Fig. 2c and Table 4).

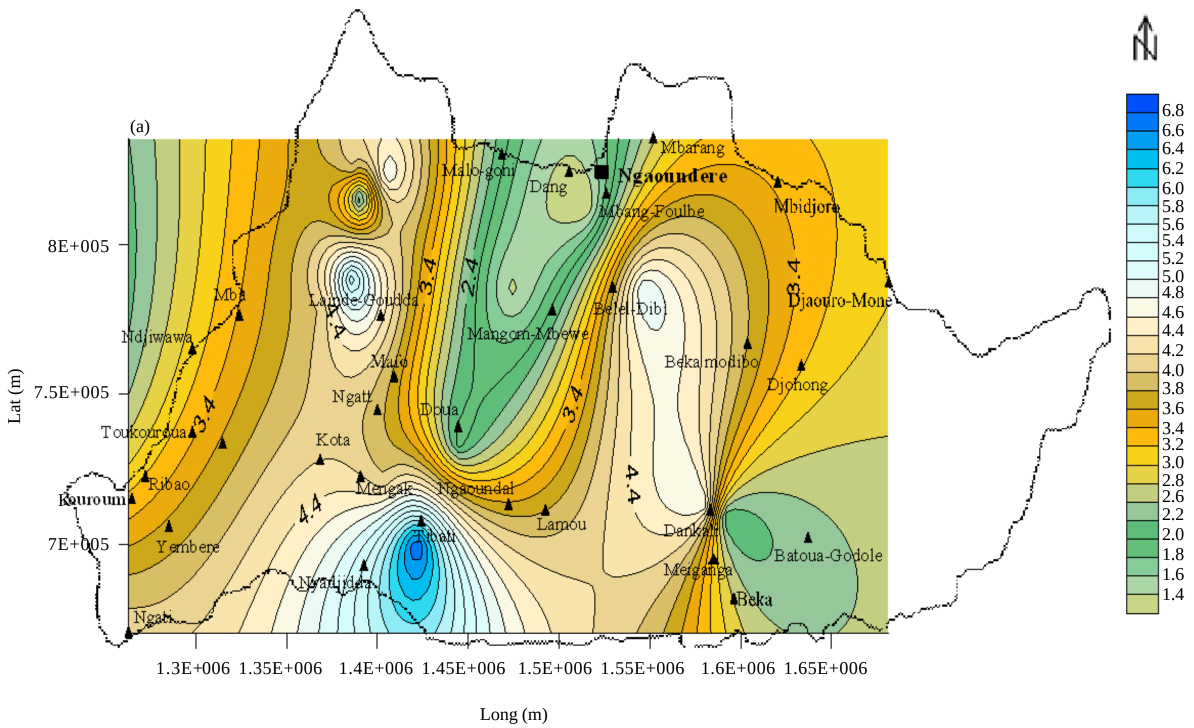
The pH ranges from 5.7-7.3 (Fig. 2d). In western (Yemberé, Ngati) and Southeast (Dankali, Meiganga, Beka, Bantoua-Godole) regions of the study area, water would be acid-tasted and neutral in the North region (Ngaoundere, Belel-Dibi).

In the locality of Ngati and surroundings, the iron concentration is greater than the 1 mg L^{-1} standard (Fig. 2e). The presence of this metal is associated with sedimentary rocks deposited in a reducing environment (marls, clays) and metamorphic rocks. Several consequences will be the corrosion (rusting) of the boreholes slab and the alteration of the water taste.

EC values show that, water is moderately mineralized in Mbanti and Djambare (with EC values ranging from 80-100 μS cm^{-1}), mineralized in Beka, Modiba, Djaouro-Mone and Belel-Dibi where EC values are higher than 300 μS cm^{-1} (Fig. 2f). However, its minerality is sensitive to that of rain water in the localities of Ngaoundere, Doua and Ngaoundal where EC values range between 10 and 80 μS cm^{-1}.

Overall index of groundwater quality in the region: There are 5 nonconforming parameters for 72 nonconforming results on a total of 594 (Table 4).

Results supplied by Table 4 are used to compute the global groundwater quality index in the region. We obtained an extent value (F_1) of 27.78, a frequency value (F_2) of 12.12 and an amplitude value (F_3) of 6.45. Therefore, the global ground Water Quality Index (WQI) in the region is equal to 82.11. According to this result, the



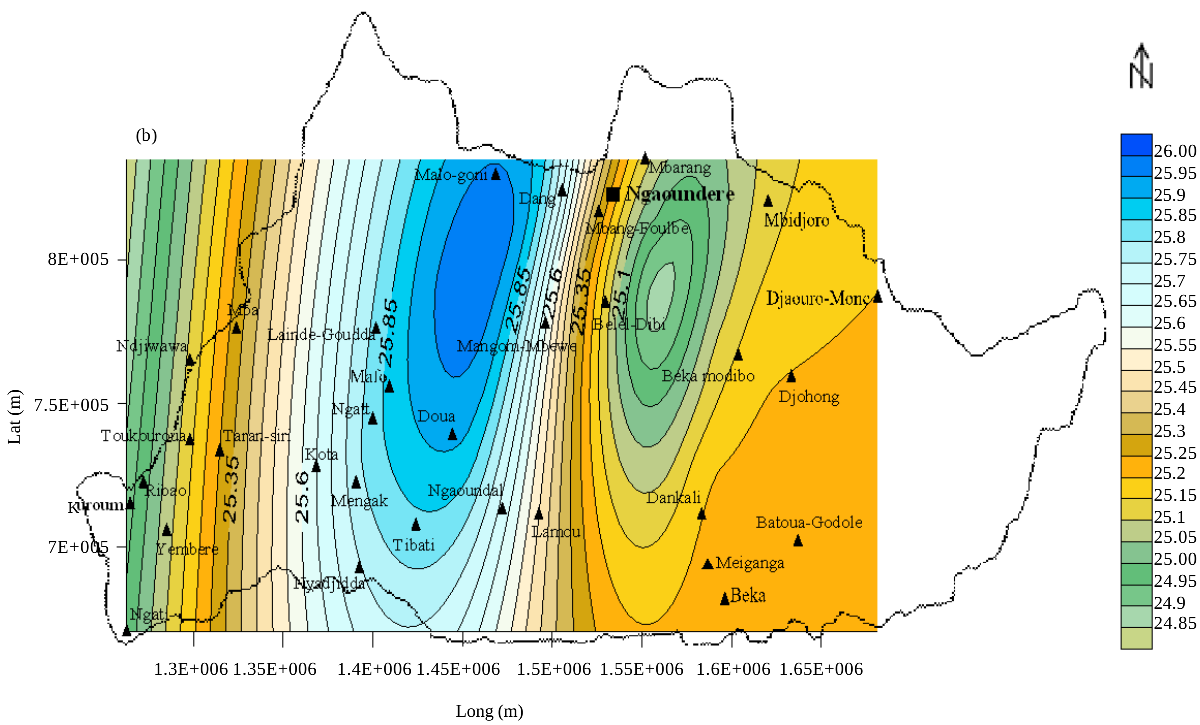
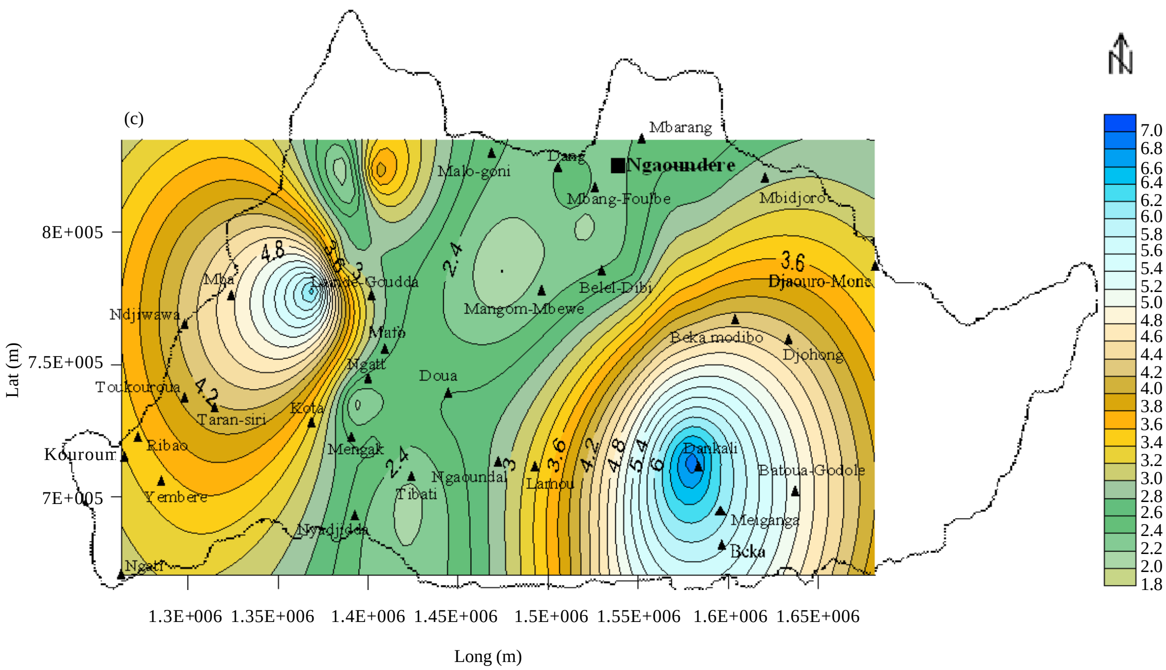


Fig. 2(a-f): Countinue



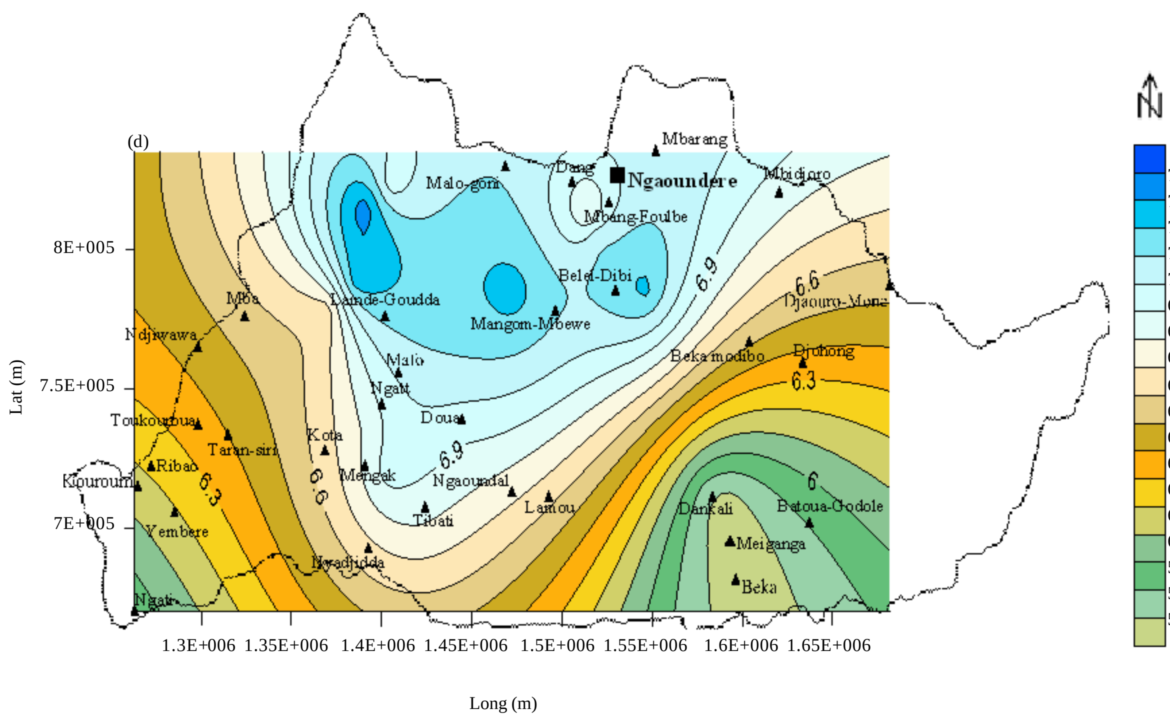


Fig. 2(a-f): Countinue

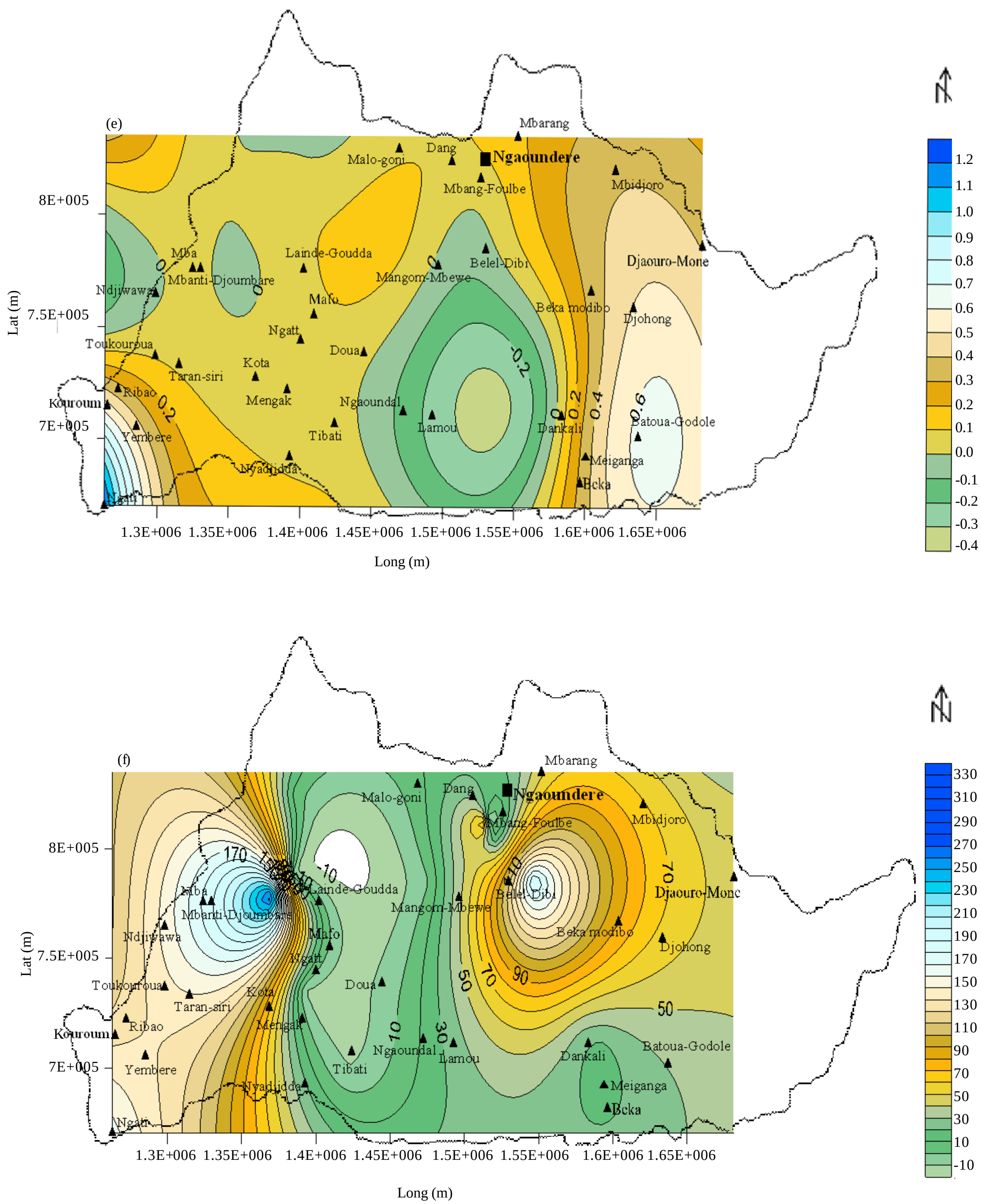


Fig. 2(a-f): Spatial distribution map of physico-chemical parameters of water quality, (a) Turbidity (NTU), (b) temperature, (c) DO (mg L^{-1}), (d) pH, (e) Iron (mg L^{-1}) and (f) EC (μS cm^{-1})

Table 3: Best fitted models variograms and their characteristics

Parameters	Models	Nugget	Sill/Slope	Range	RMSE
pH	Linear	0.14	0.02	-	0.54
DO	Spherical	6.47	3.01	190	0.61
Iron	Cubic	0.64	0.21	190	0.97
EC	Exponential	125	10210	140	0.44
Temperature	Linear	5.18	156	-	1.65
Turbidity	Exponential	0	5.08	130	0.60

Table 4: Summary of non-compliant analytical results

Nonconforming parameters	Nonconforming results
pH	P-1, P-9, P-11, P-14, P-15, P-17, P-19, P-22, P-24, P-28, P-29
T	P-1, P-2, P-3, P-5, P-6, P-8, P-9, P-11, P-14, P-15, P-16, P-17, P-18, P-19, P-24, P-25, P- 26, P-27, P-28, P-29, P-30, P-31, P-32, P- 33
DO	P-1, P-2, P-3, P-4, P-5, P-6, P-7, P-8, P-9, P-11, P-12, P-13, P-14, P-15, P-16, P-17,P- 18, P-19, P-20, P-21, P-22, P-23, P-24, P-25, P-26, P-27, P-28, P-31, P-32, P-33
Fe	P-17
Turbidity	P-10, P-12, P-13, P-17, P-18, P-20
Total 5	72

groundwater in this area can be broadly classified acceptable quality. However, an appropriate treatment of each nonconforming parameters is recommended in every concerning locality before consummation.

CONCLUSION

The physico-chemical analysis of groundwater quality was conducted in the region of Adamawa-Cameroon using the standard method defined by the American Public Health Association (APHA) in 1995. Results showed that among 18 parameters analyzed, 6 namely pH, DO, Fe, turbidity and temperature have abnormalities in some samples. To this end and for an optimal management of groundwater resources, the geostatistical method (ordinary Kriging) was used to analyze the spatial distribution of these parameters that are not compliant (nonconforming) to the WHO standards. Inspite of the presence of these nonconforming results, the overall groundwater quality index calculated in conformity with the Canadian Council of Ministers of the Environment recommendations reveals the suitability of groundwater quality for drinking purposes in the Adamawa (Central Africa) region. This study allows the follow-up of groundwater and can be conducted in other areas for the study of similar phenomena.

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