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Statistical Evaluation of Dugwell Construction and Placement Parameters on Groundwater Contamination in the Sandstone Phreatic Aquiferous Formations in Garoua, North Region Cameroon: Seasonal Variations

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Abstract Dugwell construction parameters (Apron, collar, and cover), and dugwell placement parameters (distance to toilets and distance to dumpsites) could be important factors that may increase the vulnerability of dugwells in phreatic aquiferous formations to biological contamination in Garoua. The objective of this study was to elucidate the role of well construction and well placement parameters on the coliform contamination of groundwater from dugwells in Garoua. According to Cheesbrough classification, coliform bacteria ranged (MPN) from; 0-3000 Wet season, 0-3000 Wet-Dry Season, 2-3000 Dry Season and 1-3000 in the Dry-Wet Season; thus groundwater samples were grossly polluted to unacceptable with coliform present in all seasons. Based on WHO classification most of the groundwater sampled was unfit for domestic purposes in all seasons due to pollution by potentially harmful microorganisms. Hierarchical Cluster Analysis (HCA) performed on dugwell construction and placement parameters in Garoua produced three clusters based on spatial similarities and dissimilarities. Pearson's Correlation Analysis (PCA) showed that significant correlations exists between distances from the nearest toilets and dump sites, wells without Aprons, wells without cover, wells without collars and the bacteriological loads in the dugwell groundwater samples which are thus the parameters responsible for the coliform contamination of the aquiferous formations in Garoua.

Keywords: *Statistical-evaluation, Dugwell-construction-parameters, Groundwater-contamination, Garoua-Cameroon*

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1. Introduction

Dug wells are still widely used in developing countries where hand dug wells are promoted as practical, low-cost, low-technology domestic water supplies [1]. In Sub-Saharan Africa it is estimated that 155 million people rely on dug wells and springs for their domestic water [2]. Dugwells wells are manually dug holes in the ground (using shovels, picks, etc.) with the exception of modern wells. Typically dugwells have three construction component parts (Apron, Collar and Cover or lid) as depicted in Figure 1 and two placement (distance to) parameters: i) Toilets (Latrines/Septic-tanks/Soak-ways) and ii) Dumpsites/Dustbins (Figure 1).

Dugwells are generally not very deep (between 8 and 20 meters). Because they are so shallow, these wells are at higher risk for contamination. Anthropogenic factors for the contamination of groundwater in dugwells refers to changes in groundwater quality caused or influenced by humans especially those factors relating to dugwell; placement, construction, maintenance and exploitation amongst others.

According to [4] well-constructed dug wells protect aquifers from any external contamination.

Well Aprons, well Collars and well covers prevent entry of contaminants into dugwells from runoff and re-entry of spills and splatters. They play a key role in the protection of phreatic aquifers from runoff. Wells with shorter collar heights maybe more susceptible to pollution than those with higher collars. How close or far a dugwell is from latrines or dumpsites may determine its exposure to biological contamination from surficial sources in phreatic settings.

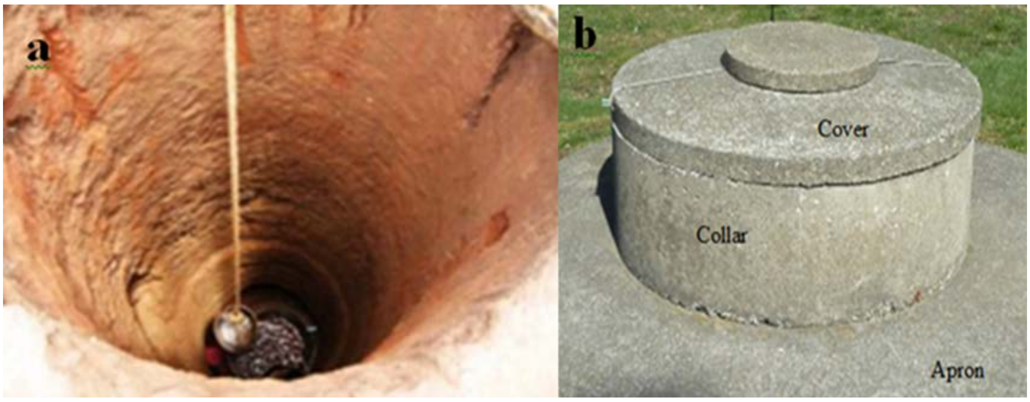

Figure 1. (a) dug well; (b) Dugwell component parts (well apron, well collar and well cover)[2]

In urban areas in Cameroon, there are three major types of wastes: Household wastes, industrial wastes and feces. Household wastes are disposed in one of three ways; burial in pits behind the house, open dumpsites around the corner or waste bins in-front of the house which is periodically emptied. Industrial wastes are collected and disposed of pretreated or untreated. Feces are disposed of mostly in latrines and septic tanks; to a lesser extent via soak away pits, in the open fields (bushes) and streams/river banks.

Groundwater pollution has been the focus of many researchers [5]. Groundwater pollution is partly responsible for low access to potable water and sanitation problems especially in many developing countries.

Dumpsites are sources of groundwater and soil pollution due to the production of leachate and its migration through the aquifer. In recent times, the impact of leachates on groundwater and other water resources has attracted a lot of attention because of its overwhelming environmental importance. Leachates migrate from waste dumpsites and release pollutants into sediments which under certain conditions may pose a high risk to groundwater resource if not adequately managed [6]. The practice of dumpsite systems as a method of waste disposal in many developing countries is usually far from standard recommendations. Waste if not properly disposed could lead to a wide diversity of contaminants affecting groundwater resources.

Pit latrines are common methods of excreta disposal in the developing world. It is popular and widely used in urban slums as well as rural areas probably because it is the simplest, cheapest and the most efficient excreta disposal method that is within the reach of poor people.

Published data on the burden of diseases in Cameroon shows that diarrheal diseases (commonly due to fecal contamination of water) cause 15% to 20% of all deaths in the country, annually [7].

The unavailability of well covers may act as pathways to pollution from external sources into dugwells.

Coliform bacteria are a class of gammaproteobacteria, group of enteric bacteria found in the lower intestines of warm-blooded organisms that includes Enterobacteriaceae family and Escherichia coli species. They are gram negative, facultative anaerobic, non-sporing rods that may be motile or not. They are generally not harmful themselves; they however indicate the probable presence of pathogenic bacteria, viruses and protozoans [8]. Coliforms are used as indicators to monitor the microbiological quality of drinking-water [9]. Their detection is easy to determine so as to evaluate water quality especially in resource limited countries like Cameroon.

According to [10], bacterial distribution in groundwater undergoes spatio-temporal fluctuations and it is influenced by physicochemical and meteorological factors. Waterborne diseases occur every year in rural and urban areas in the northern region of Cameroon. Diarrheal diseases due to E. coli, Salmonella and Shigella are almost endemic in this region. Epidemiological data shows the highest incidence (25.3% of prevalence) of gastroenteritis in the northern region of Cameroon [7].

From the reports of Ministry of Public Health, during the wet season of the year 2010, there was an epidemic of cholera in this area with 9447 cases and 602 deaths [11]. The traditional latrine practices and the lack of wastewater treatment in these communities are major factors of contamination to wells.

In the northern region safe drinking water is available only within urban residential areas. However these areas lack basic data on drinking water quality and related sanitary risks, poverty, illiteracy and research. The supply of potable water by Camwater in Garoua is irregular and in some areas not available. Thus, traditional water points in Garoua (streams, rivers and wells) are widely used by poor communities which only evaluate water quality by the subjective criteria of odor and color. Here, drinking water is one of the main transmission pathways for diarrheal diseases. It has been established that improving the bacteriological quality of drinking water significantly reduces the risk of waterborne diseases [12]. Consequently, the spread and transmission of waterborne diseases could therefore be due to the concentration of people in anarchic urbanization, poor hygiene, poverty and the lack of safe drinking water [13].

According to the WHO, unsafe drinking-water represents significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Therefore, microbial, chemical and other acceptability aspects of drinking-water should fit with guidelines for drinking-water quality [14].

The greatest risk to public health from microbes in water is associated with consumption of water contaminated with human and animal excreta, although other sources of exposure may also be significant [15]. This is because outbreaks of waterborne disease have the capacity to cause simultaneous infection of a large number of people [16].

Several methods are used to determine biological water quality such as; multiple tube method, ATP testing, plate count, membrane filtration and pour plate method [17]. The most reliable methods are direct plate count method and membrane filtration method. In this study the direct plate count method was used because it is fast, cost effective and coliform bacteria acts as a good indicator for contamination.

The population of Garoua is made up of mostly low income subsistence farmers and herders who depend on groundwater for drinking and domestic activities; there is currently sparse information and understanding of the importance of groundwater protection from anthropogenic contamination in this area. Since very few water quality studies have been documented in Garoua, this study sought to elucidate the probable factors responsible for the contamination of wells in the phreatic aquiferous formations in Garoua.

1.2. Description of the Study Area

Garoua the capital of the Northern region of Cameroon is situate between latitude 4.00 - 4.15 and longitude 9.65 - 9.95 and covers a total surface area of about 4,700 km^2 (Figure 2). Groundwater is the major source of water. It is characterized by a tropical climate having a dry season from October to April and a rainy season from May to September. The mean monthly temperatures vary from 26.1°C in December-January to 32.7°C in April, with a mean annual value of 29°C. The mean annual precipitations 1018 m and mean annual potential evapotranspiration is 1855 mm.

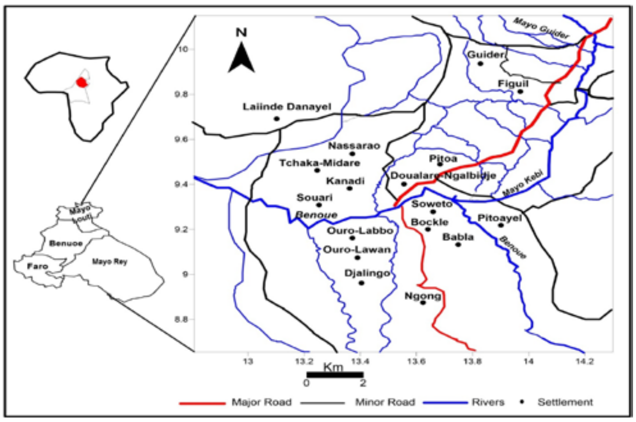

Figure 2. Garoua and environs (insert Africa, Cameroon and Northern Region with four Divisions)

1.3. Geological settings of the Garoua Basin

The Northern region of Cameroon belongs to the mobile zone of Central Africa. This mobile zone is situated between the Western African craton and the Congo craton. The Benue trough is one of the most interesting sedimentary basins of West Africa because of the tectonic movements that account for the marine and continental sediments found there, and also because of the presence of volcanism and the intrusion of plutonic rocks. This trough is directed NE-SW and extends a distance of about 1000 km, with a width of 50–150 km [18]. It consist a great part of the sedimentary basin of North Cameroon, including the Garoua basin. Its origin is related to the opening of the South Atlantic during the Cretaceous, which led to the separation of the African and South American continents [19]. It is made of the sedimentary marine, continental series and is divided into three parts: the low, middle and high Benue. The high Benue includes the Gongola rift and the Yola-Garoua rift. The Yola-Garoua rift extends into Cameroonian territory and is directed E-W while the Gongola rift goes to Niger and is directed N-S. The area of this study (Figure 3) is situated in the Cameroonian territory of the Benue rift (Yola Garoua branch) and especially in the formation known as Garoua sandstone. Its base is made up of two great lithological sets which underwent a metamorphic and tectonic evolution. The Garoua basin is an intracratonic basin and part of the Benue Sedimentary Basin that was formed during the opening of the Gulf of Guinea. It is the eastward continuation of the Yola arm of the northern Benue Trough of Nigeria into the north Cameroon.

The Benue trough is a NE-SW trending basin that spans from the Niger delta basin to Lake Chad. The trough strikes approximately NE–SW and is about 1000 km long and 100 km wide. This basin was formed over the Berremian-Aptian age and it is the biggest of a series of basins formed in northern Cameroon and south-western Chad at this time bounded to the north by the Mokolo Plateau and the south by the Adamawa Plateau. The structures are asymmetrical syn-sedimentary synclines superimposed on half-graben structures [20]. This basin-like many other sedimentary basins that belonged to the West and Central African Rift System is believed to have potential for hydrocarbons generation and accumulation. The Garoua basin is an E-W to N120 trending trough that is filled by Middle to Upper Cretaceous marine sandstones (Serge et al. 2019) [21]. The Basin is filled by continental sediments of Middle to Upper Cretaceous age. The bedrock is made up of igneous and metamorphic rocks of the basement complex, and volcanic rocks of the Tertiary age. This formation is characterized by sandstone sequences which are intercalated by clayey layers. X-Ray diffraction analyses carried out by [22] indicated that the sandstones are dominated mainly by quartz, feldspars, and kaolinite, but also include minor amounts of illite and calcite. The Garoua Sandstone formation is overlain by quaternary alluvial deposits of the Benue River and its tributaries, which are made up mainly of gravel, sand, silt and clay [22].

The dominant sedimentary facies in Garoua are indurated conglomeratic to coarse-grained alluvial sandstones with siliceous cement often rich in iron oxides and in some localities numerous intercalations of reddish ferruginous sandstones are seen. The depth of the basement is 4.4 km to 8.9 km. This represents the thickness of the sedimentary formation overlying the basement complex. Western parts of the basin exhibits numerous volcanic necks of the Cenozoic age while veins of basic rocks are outcrop to the east. The Garoua basin has outcrops of sandstone and intrusive granites, which form the basement complex below the sediments, and intrusive diorites along the Poli-Lere axis. Some hypo volcanic dykes are found within the Garoua sandstones (Figure 3). The basaltic lavas of this area are similar to those of the Cameroon volcanic line.

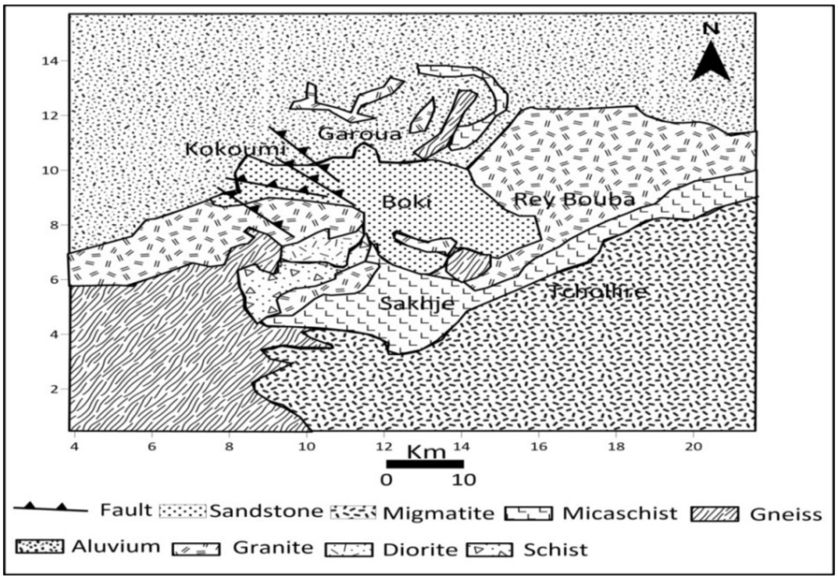

Figure 3. Geology of Garoua basin after [23]

The Precambrian gneisses, migmatite, and schist outcrop in the southern part of Garoua Basin with an extension of the gneisses to the northeast. The intrusive granites outcrop extensively in the Garoua Basin in the northeast and southwest. These rock units from the basement complex below the sediments are referred to as the gneissic-granitic basement. Intrusive diorites also occur along the Poli-Lere axis [23].

The regional structural setting of the Garoua Basin is characterized by three major normal faults striking mainly in the NW-SE to NNE-SSW direction [24]. The continental crust underneath the basin (about 24 km) is thinner than the normal crust, but may be a little thicker to the east [21]. This thinning of the crust is due to extensional regional stress and the uplift of the Asthenosphere is as a consequence and this result to isostatic compensation, this lead to an average sedimentary pile thickness of about 6km from results obtained by [24,25].

1.4. Hydrogeology

The Garoua basin has two aquifers; (1) The Garoua alluvial aquifer which is extensively utilized for water supply through hand-dug wells; it is of limited lateral extent. Aquifer tests results indicate that transmissivity in the upper part of the aquifer varies between 10^{-1} and 10^{-5} $m^2 s^{-1}$ and the hydraulic conductivity ranges from 10^{-4} to $10^{-5}ms^{-1}$ [22]. Groundwater mainly occurs under water-table conditions. (2) The Garoua Sandstone aquifer with a permeability of around 8 to 80 m/day; transmissivity of 300 to1700 m²/day; and a storage coefficient of 0.025. Typically boreholes are between 40 and 200 m deep. According to [22], the Garoua Sandstone aquifer constitutes the most extensive aquifer in the Garoua basin. The thickness of Garoua Sandstone aquifer increases towards the central part of the basin. The crystalline bedrock acts as boundaries of the groundwater reservoir. The presence of many lenses of clay within the sandstone sequences imposes local confinement. The natural hydraulic gradients are low, owing to the low topography of the basin. The groundwater flow is generally towards the Benue River. Recharge is through precipitation. The discharge of groundwater takes place by evapotranspiration wherever the water table is closer to the land surface, by the Benue River and its tributaries, and by several boreholes tapping the water reservoir.

2. Methodology

Laboratory Method

Two hundred and six (206) uncased representatives dug wells, were selected, measured, tested and sampled insitu for coordinates of wells, surface elevation, well water level, wells depths, well diameter, electrical conductivity (EC), pH, total dissolved solids (TDS) and temperature (°C).

For Coliform bacteria (CB); Fifty (50) representative wells sampled and two hundred (200) groundwater samples collected for four hydrogeological seasons (50 samples per season); Wet (July to September); Wet-Dry (October to December); Dry (January to March) and Dry-Wet (April to June). At each well, a clean polyethylene bottle was rinsed thrice with well water and filled two thirds its capacity, these samples were placed in an ice packed cooler to ensure the survival of microorganisms and sent to the Life Science Laboratory of the University of Buea for microbial analysis. Microbial analysis to determine total coliform bacteria using Violet Red Bile Agar method was done.

Preparation of samples using the Violet Red Bile Agar method: [26,27].

41.35 grams of Violet Red Bile Agar was suspended in 100 ml distilled water to form the medium.

i). The medium was heated while stirring to dissolve the Agar completely.
ii). 10ml of groundwater sample was cooled to 45°C and poured into each petri dish.
iii). 10ml of Agar medium solution was added to each petri dish with sample and carefully swirled to mix at 48°C.
iv). The mixture was allowed to solidify and then incubated at 35°C for 18-24 hours.

v). Purple-red colonies were examined for 0.5mm diameter (or larger) circles, surrounded by a zone of precipitated bile acids.

Statistical analysis

Eight parameters were considered, measured and recorded; two well placement parameters: i) The distance of each well to toilet; latrines/Septic-tanks/Soak-pits (DT) ii) Distance from dumpsites/dustbins (DS) and six well construction parameters: i) Wells with cover (WC); ii) wells with no cover (WOC); iii) wells with aprons (WA), iv) wells no Aprons (WOA); v) wells with collar (CH) and vi) wells no collar (COH). DT, DS, WA and CH were subdivided to segments that enabled a detailed quantification of the coliform present in groundwater sample with distance and collar heights (Table 1).

Table 1. Segments of parameters for detailed occurrence of coliform in groundwater

Parameters	Range (m)
Distance to toilet (DT)	0-4.9
	5-9.9
	10-14.9
	15-20
	>20
Distance to dump site (DS)	0-4.9
	5-9.9
	10-14.9
	15-20
	>20
Wells Apron Height (WA)	0-0.29
	0.3-0.59
	0.6-1
Wells Collar Height (CH)	0-0.29
	0.3-0.59
	0.6-1

Statistical applications

The Principal Component Analysis (PCA): Bivariate Pearson's correlation analysis and Hierarchical cluster analysis (HCA) were the two main statistical tools to the data set.

i). Principal Component Analysis (PCA)

The principal component analysis converts a set of possibly uncorrelated variables into a set of linearly correlated ones through an orthogonal transformation. The resulting principal components (PCs) are linear combinations of the original set of variables. Pearson's correlation coefficient r measures the statistical relationship, or association, between two continuous variables. It is the best known method of measuring the association between variables of interest based on the method of covariance giving information about the magnitude of the association or correlation, as well as the direction of the relationship. A positive correlation signifies direct proportion meaning that if variable x increases, then y will also increase, both ions will go into or out of solution simultaneously whereas if the value of the correlation is negative, then if x increases, y decreases; If one ion goes into solution the other is precipitated. It is based on the following assumptions; i) Independence of case: Cases are independent to each other; ii) Linear relationship: The two variables are linearly related to each other, assessed by bivariate scatterplots which should yield relatively straight lines; iii) Homoscedasticity: The residual scatterplots should be roughly rectangular-shaped and iv) Symmetry: The r-value between two variables should be symmetrical, meaning between X and Y or Y and X, the coefficient's value should remain the same [28]. The r values express the degree of correlation which ranges from +1 to -1, where if r is ± 1= Perfect; between ± 0.8 to ±0.9 = extremely strong; between ± 0.7 to ±0.8 = Very strong; between ± 0.6 to ± 0.7 = significantly strong; Greater than ±0.5 = Strong; between ±0.3 to ±0.5 = moderate; between ± 0 to ± 0.3 = Weak and 0 = No correlation. It is independent of the units of measurements.

The formula used to calculate the Pearson's correlation r is:

$$r_{xy} = \frac{n\sum xiyi - \sum xi \sum yi}{\sqrt{n\sum\left(xi^2\right) - (\sum xi)^2}\sqrt{n\sum yi^2 - (\sum yi)^2}}$$

r_{xy} = Pearson correlation coefficient (r) between x and y; n = number of observations, x_i = value of x (for ith observation), y_i = value of y (for ith observation)

ii). Hierarchical cluster analysis (HCA)

Hierarchical cluster analysis is a method of data mining in statistics that seeks to build a hierarchy of clusters group of variables affected by common processes or undergoing common or dissimilar evolution. Strategies for hierarchical clustering generally fall into two categories: i) Agglomerative: This is a "bottom-up" approach: Each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy. ii) Divisive: This is a "top-down" approach: All observations start in one cluster, and splits are performed recursively as one moves down the hierarchy [29]. In general, the merges and splits are determined in a greedy manner. The results of hierarchical clustering are usually presented in dendrograms [30]. In this study the divisive strategy is used.

PCA and HCA were done by mounting field data on the SPSS V25 statistical software and Surfer V17 GIS software platforms.

3. Results

3.1. Physicochemical Parameters

The In-situ physicochemical tests of groundwater samples from 206 wells for; pH, Temperature, EC and TDS vary with seasons are shown in Table 2, indicating seasonal influence on the phreatic aquifer. Highest Temperatures are in Wetdry, Dry and Drywet seasons. Highest pH value (12.5) occurs in the Wetdry season while the highest TDS (1990) and EC (3170) occur in the Wet season. This means in the wet season inorganic content is dissolved and transported into the wells (Table 2).

3.2. Measured Well Placement and Construction Parameters

The well placement and well construction parameters with their resultant coliform content variations and basic statistics are presented in Table 3.

3.3. Coliform Bacteria

The total coliform bacteria ranged from 0-3000 wet season, 0-3000 wet-dry season, 2-3000 dry season and 1-3000 in the dry-wet season shown in Table 4 indicating gross pollution of groundwater in all seasons. This indicates that the water is polluted by potentially harmful microorganisms as shown in Table 4. These pathogens may be of fecal origin and water that contains them is not suitable for domestic purposes.

The presence of coliform bacteria in drinking water increases the risk of contracting water-borne illnesses. The presence of these coliform bacteria could be as a result of the following; a missing or defective well cap, contaminant seepage through the well casing, contaminant seeping along the outside of the well casing and well flooding.

3.4. Binary Plots of Biological Contamination Parameters

The binary plots indicate no significant associations exist between wells with covers, wells with aprons and wells with collars with the bacteriological loads in the groundwater samples. Whereas well distances to the nearest toilets DT, well distance to dumpsites DS, wells without collars COH, wells without aprons WOA, and wells without covers WOC have extremely strong associations with the occurrence of coliform bacteria in wells (Figure 4).

3.5. Pearson Correlation Analysis (PCA)

The correlation of individual well construction, well placement parameters and coliform bacterial present in groundwater are shown in table’s 5a-d.

3.6. Hierarchical Cluster Analysis (HCA)

The R-mode Hierarchical Cluster Analysis HCA performed on well placement and well construction parameters that might contribute to the contamination of groundwater in Garoua produced three clusters based on spatial similarities and dissimilarities: Cluster one consist of coliform bacteria whose presence or absence causes groundwater to be unfit for domestic use; Cluster two made up of collar height the presence of which prevents well contamination; Cluster three; distance from toilet, distance from dumpsite, absence of collar height, absence of well covers, absence of well aprons and wells without covers. Cluster 1 consists of the indicator organism which is coliform bacteria whereas cluster 2 and cluster 3 consists of the well placement and well construction parameters whose deficiency controls the entry of contaminants into the wells.

Table 2. Basic statistics for physicochemical parameters of 206 wells during four hydrogeological seasons

Parameter	Wet			Wet-Dry			Dry			Dry-Wet			WHO (2017)
	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	
pH	4.36	9.36	6.83	4.4	8.92	6.07	4.8	9.1	7.26	4	12.5	7.28	6.5-9.5
EC (µS/cm)	45	3170	383.15	12	2500	311.08	40	2600	222.59	17	1900	223	400
T (°C)	22.9	36.1	29.71	24.4	38.6	29.88	27.9	38.9	30.28	24	38.4	30.29	30
TDS (mg/L)	22	1990	770.94	8	1675	208.42	28	1690	149.25	11	1273	150.1	1000

Table 3. Basic statistics of well placement and construction parameters for 50 spatially representative wells DT, DS, WA, WOA, CH, COH, WC, WOC, and CB variations in groundwater with seasons

Parameters	Range (m)	No. of wells	%	Coliform ranges with Season							
				Wet		Wet/Dry		Dry		Dry/Wet	
				Min	Max	Min	Max	Min	Max	Min	Max
Distance to toilet (DT)	0-4.9	15	30	0	3000	0	3000	0	3000	0	3000
	5-9.9	10	20	3	3000	2	3000	2	2500	0	3000
	10-14.9	11	22	0	3000	19	3000	23	3000	22	3000
	15-20	7	14	31	3000	29	3000	54	870	0	200
	>20	7	14	7	240	10	3000	2	550	4	500
\ Distance to dumpsite (DS)	0-4.9	15	30	0	3000	0	3000	1	3000	0	3000
	5-9.9	12	24	0	3000	86	3000	2	3000	0	2000
	10-14.9	10	20	0	3000	0	380	0	344	1	3000
	15-20	7	14	46	3000	0	204	40	708	31	500
	>20	6	12	7	300	10	480	2	200	0	360
Wells with Apron (WA)	0-0.29	2	4	0	3000	0	5000	0	2500	0	5000
	0.3-0.59	4	8	0	3000	8	3000	19	3000	0	3000
	0.6-1	3	6	0	3000	0	3000	0	2300	5	3000
Wells without Apron WOA)	-	41	82	17	3000	22	3000	8	3000	25	3000
Wells with Collar (CH)	0-0.29	14	28	0	3000	2	3000	0	3000	0	3000
	0.3-0.59	16	32	0	3000	0	3000	4	3000	0	3000
	0.6-1	4	8	0	3000	0	3000	0	3000	0	3000
Wells without Collar (COH)	-	16	32	26	3000	29	3000	17	3000	7	3000
Wells with Cover (WC)	-	14	28	1	3000	0	3000	1	1200	0	3000
Wells without Cover (WOC)	-	36	72	20	3000	13	3000	28	3000	33	3000

Table 4. Coliform bacterial classification of groundwater in Garoua using [40] and [22] guidelines

	Wet Season			Wet-Dry Season			Dry Season			Dry-Wet Season		
SN	CB	CBC	WHO	CB	CBC	WHO	CB	CB	WHO	CB	CBC	WHO
1	4	GP	UF	73	U	UF	194	U	UF	200	U	UF
2	0	A	F	2	U	UF	8	U	UF	270	U	UF
3	60	U	UF	52	U	UF	44	U	UF	880	U	UF
4	25	U	UF	93	U	UF	109	U	UF	3000	GP	UF
5	50	U	UF	59	U	UF	3000	GP	UF	3000	GP	UF
6	90	U	UF	114	U	UF	2800	GP	UF	46	U	UF
7	0	U	UF	0	A	UF	5	U	UF	100	U	UF
8	440	U	UF	750	U	UF	1200	GP	UF	220	U	UF
9	58	U	UF	34	U	UF	55	U	UF	3000	GP	UF
10	70	U	UF	87	U	UF	23	U	UF	60	U	UF
11	31	U	UF	29	U	UF	54	U	UF	70	U	UF
12	100	U	UF	120	U	UF	210	U	UF	250	U	UF
13	3000	GP	UF	3000	GP	UF	3000	GP	UF	31	U	UF
14	400	U	UF	630	U	UF	100	U	UF	22	U	UF
15	60	U	UF	55	U	UF	90	U	UF	46	U	UF
16	27	U	UF	13	U	UF	17	U	UF	1	U	UF
17	3000	GP	UF	3000	GP	UF	2500	GP	UF	9	U	F
18	0	A	F	0	A	F	2	U	UF	3	U	UF
19	3000	GP	UF	3000	GP	UF	3000	GP	UF	204	U	UF
20	200	U	UF	223	U	UF	269	U	UF	26	U	UF
21	3	U	UF	2	U	UF	1	U	UF	280	U	UF
22	200	U	UF	210	U	UF	201	U	UF	7	U	F
23	270	U	UF	340	U	UF	490	U	UF	7	U	UF
24	880	U	UF	3000	GP	UF	3000	GP	UF	4	U	F
25	3000	GP	UF	3000	GP	UF	3000	GP	UF	106	U	UF
26	3000	GP	UF	3000	GP	UF	2100	GP	UF	500	U	UF
27	46	U	UF	75	U	UF	133	U	UF	42	U	UF
28	100	U	UF	108	U	UF	200	U	UF	270	U	UF
29	220	U	UF	300	U	UF	344	U	UF	200	U	UF
30	3000	U	UF	3000	GP	UF	3000	GP	UF	4	U	UF
31	60	U	UF	88	U	UF	3000	GP	UF	1	U	UF
32	70	U	UF	86	U	UF	89	U	UF	60	U	UF
33	250	U	UF	759	U	UF	880	U	UF	25	U	UF
34	31	U	UF	50	U	UF	41	U	UF	50	U	UF
35	22	U	UF	33	U	UF	23	U	UF	90	U	UF
36	46	U	UF	76	U	UF	67	U	UF	0	A	F
37	1	U	UF	0	A	F	3	U	F	440	U	UF
38	0	A	F	0	A	F	2	U	UF	58	U	UF
39	3	U	UF	13	U	UF	18	U	UF	70	U	UF
40	204	U	UF	270	U	UF	550	U	UF	31	U	UF
41	26	U	UF	7	U	UF	10	U	UF	100	U	UF
42	280	GP	UF	480	U	UF	3000	GP	UF	3000	GP	UF
43	0	A	F	19	U	UF	500	U	UF	400	U	UF
44	7	U	UF	10	U	UF	2	U	UF	60	U	UF
45	0	U	F	0	A	F	8	U	F	27	U	UF
46	106	U	UF	190	U	UF	580	U	UF	3000	GP	UF
47	500	U	UF	650	U	UF	870	U	UF	5	U	F
48	42	U	UF	54	U	UF	90	U	UF	3000	GP	UF
49	270	U	UF	309	U	UF	708	U	UF	200	U	UF
50	200	U	UF	312	U	UF	387	U	UF	3	U	UF

A: (Acceptable). GP: (Grossly polluted). U (Unacceptable) F: (Fit) UF: (Unfit) TCB: (Total coliform bacteria) CB: (Cheesbrough)

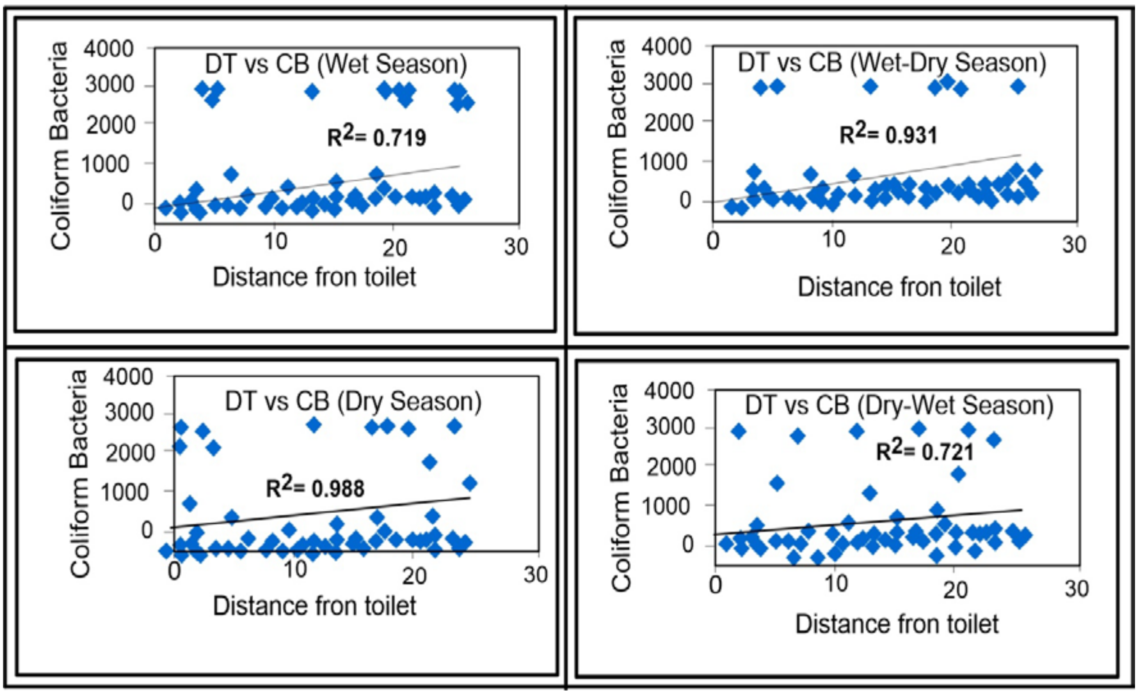

Figure 4. Bivariate plot of DT vs. CB for four seasons in Garoua; r values range from 0.72 Wet; 0.72 Dry/Wet; 0.93 Wet/Dry and 0.99 Dry seasons, implying extremely strong to almost perfect correlation between the distance to toilet and the presence of coliform bacteria in groundwater in all seasons

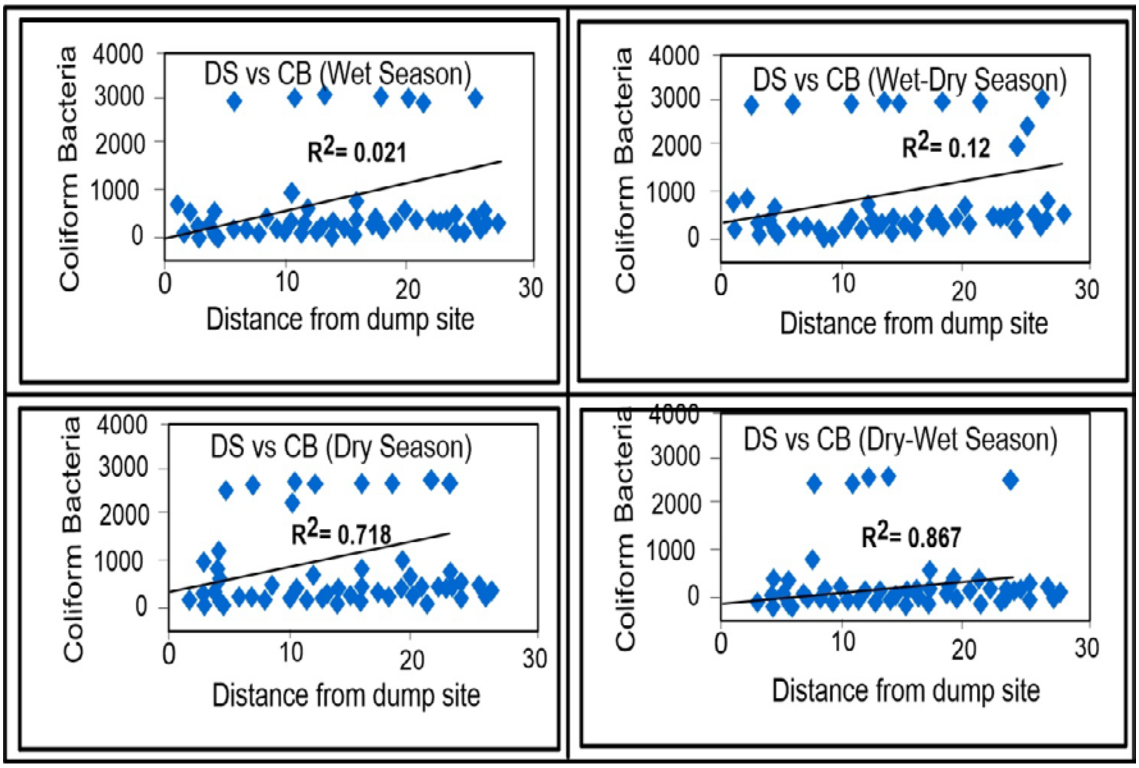

Figure 5. Bivariate plot of DT vs. CB for four seasons in Garoua; r values range from 0.021 poor correlation in Wet; 0.12 poor correlation in Wet/Dry; ; 0.72 very strong correlations in the Dry and 0.87 extremely strong in Dry/Wet seasons, between distance from dumpsites and the presence of coliform bacteria in wells

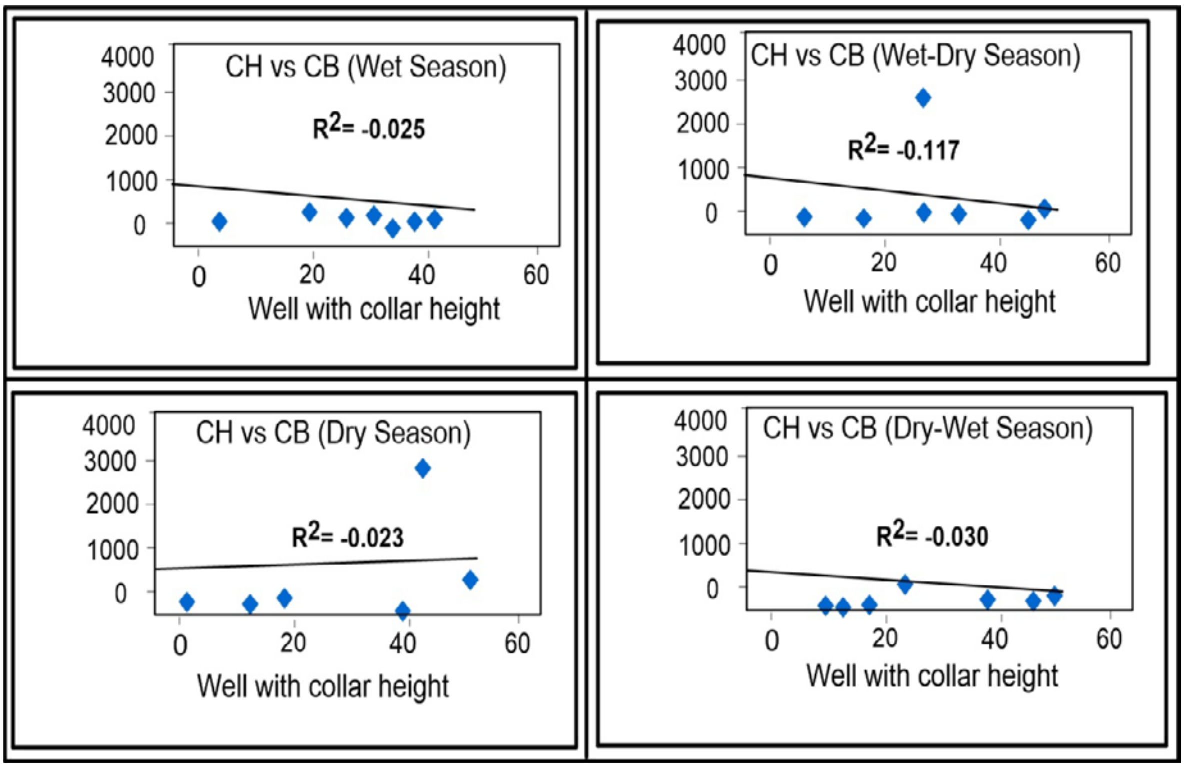

Figure 6. Bivariate plot of WC vs. CB for four seasons in Garoua; r values range from 0.03 (poor) Dry/Wet; 0.03 (poor) in Wet; 0.12 (poor) Wet/Dry; and 0.02 (poor) in Dry seasons, between distance well with cover and the presence of coliform bacteria in wells ; wells with collar are not associated with coliform contamination

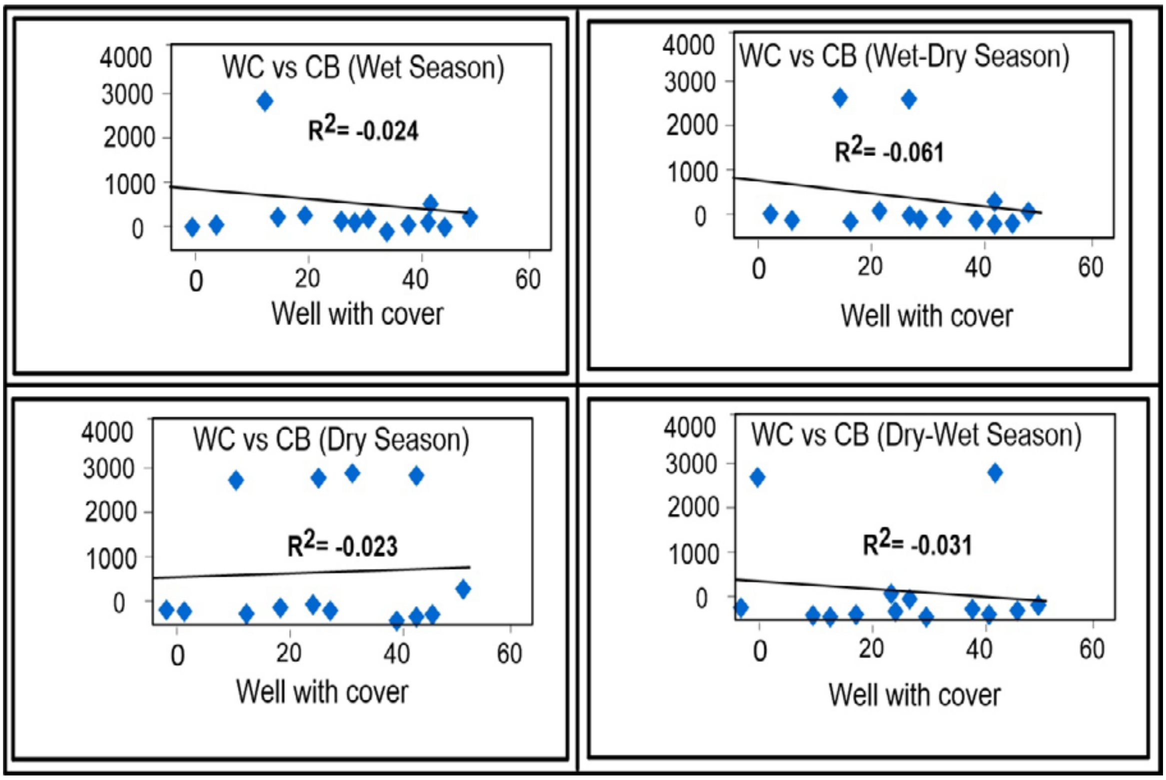

Figure 7. Bivariate plot of WC vs. CB for four seasons in Garoua; r values range from 0.03 (poor) Dry/Wet; 0.02 (poor) in Wet; 0.06 (poor) Wet/Dry; and 0.02 (poor) in Dry seasons, between wells with cover and the presence of coliform bacteria; wells with covers are not associated with coliform contamination

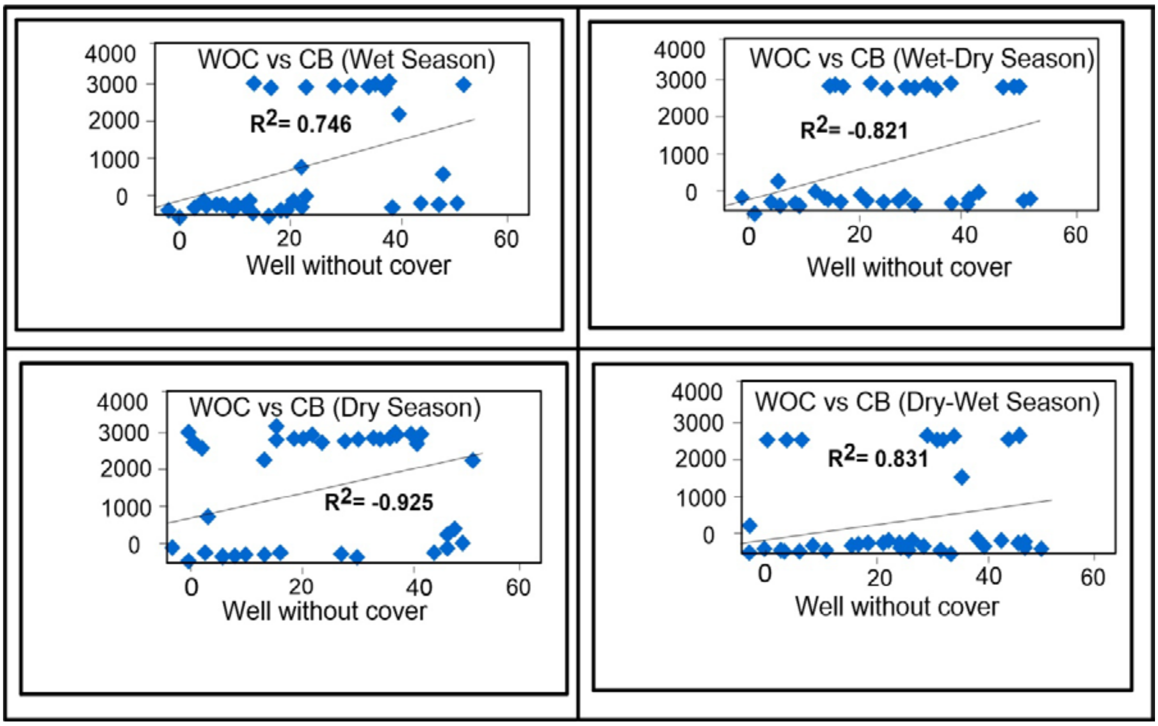

Figure 8. Bivariate plot of WOC vs. CB for four seasons in Garoua; r values range from 0.746 (extremely strong) in Wet; -0.82 (inversely extremely strong) in Wet/Dry; and 0.93 (extremely strong) in the Dry seasons 0.83 (extremely strong) in Dry/Wet; there is extremely strong association between wells without cover and the presence of coliform bacteria in wells

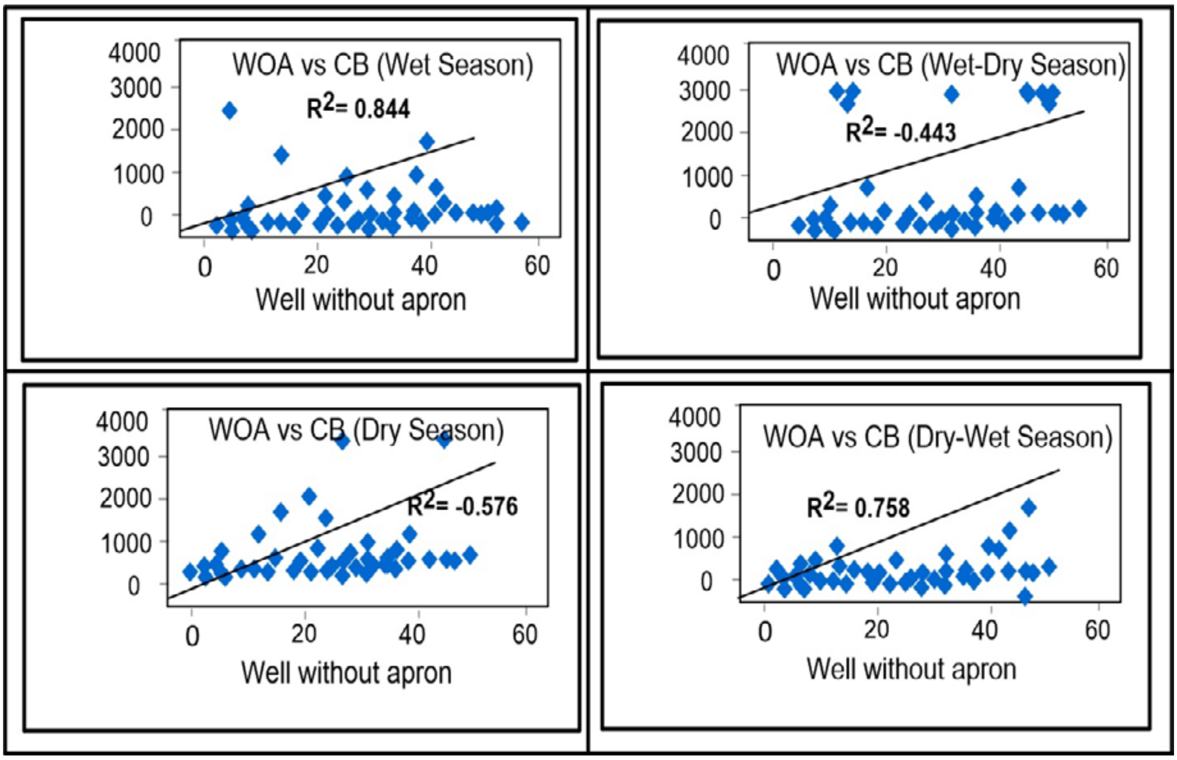

Figure 9. Bivariate plot of WOA vs. CB for four seasons in Garoua; r values range from 0.84 (extremely strong) in Wet; -0.44 (negatively poor) in Wet/Dry; - .58 moderately strong correlation in the Dry seasons and 0.76 extremely strong in Dry/Wet; there is extremely strong association between wells without apron and the presence of coliform bacteria

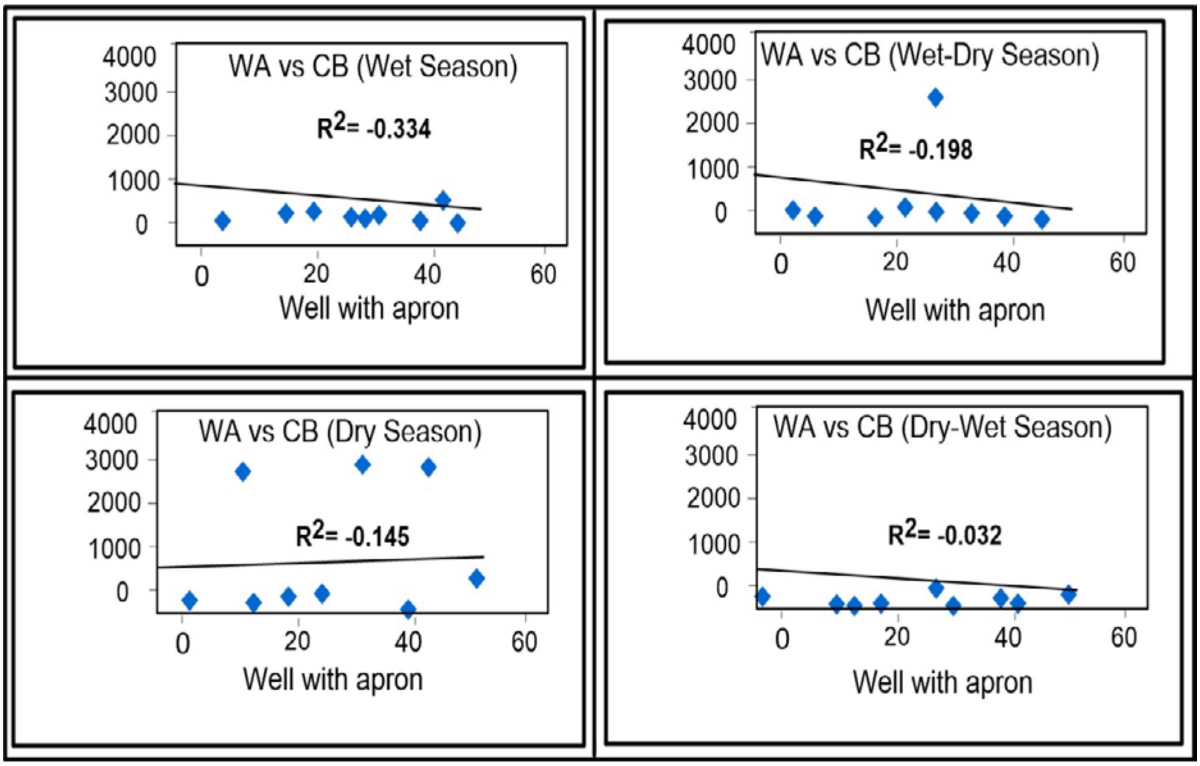

Figure 10. Bivariate plot of WA vs. CB for four seasons in Garoua; r values range from -0.20 (negatively poor) in Dry/Wet; -0.33 (negatively poor) in Wet; -0.19 (negatively poor) in Wet/Dry and -0.20 negatively poor correlations in the Dry seasons; there is extremely negatively strong association between wells with aprons and the presence of coliform bacteria in wells

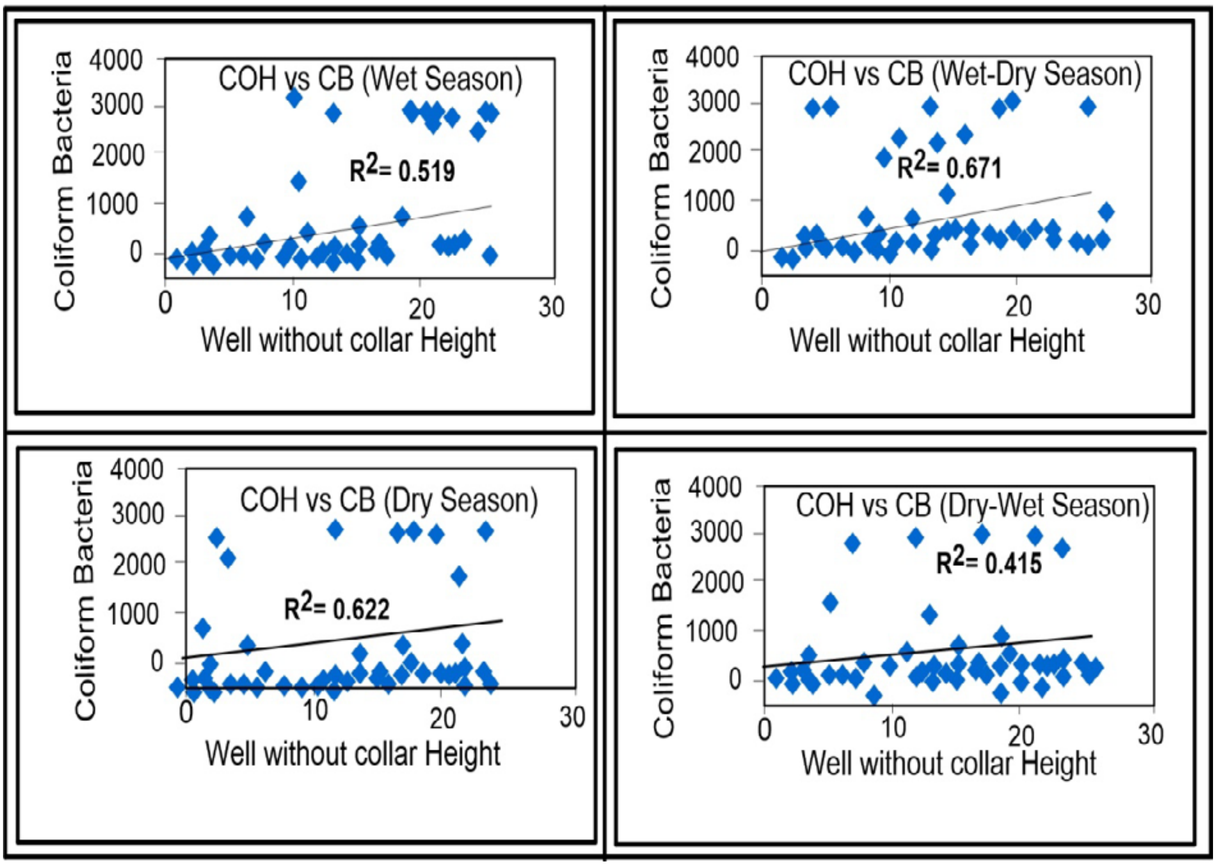

Figure 11. Bivariate plot of COH vs. CB for four seasons in Garoua; r values range from 0.52 (strong) in Wet; 0.42 (poor) in Dry/Wet ; 0.67(significantly strong) in Wet/Dry and 0.62 in the Dry seasons, wells without collar and the presence of coliform bacteria in wells

Table 5a. Pearson Correlation Matrix Garoua (Wet Season): CB; DT, and COH have significantly strong r with WOA, WOC having very strong correlations (bold).

	CB	DT	DS	CH	WC	WOC	WOA	WA	COH
CB	1								
DT	0.72	1							
DS	0.03	0.26	1						
CH	-0.13	0.01	-0.39	1					
WC	-0.02	-0.05	0.03	-0.06	1				
WOC	0.75	0.66	0.71	-0.10	-0.40	1			
WOA	0.85	0.79	0.67	0.59	0.70	0.48	1		
WA	-0.33	-0.05	0.02	-0.04	0.01	-0.13	0.24	1	
COH	0.53	-0.29	0.45	0.32	-0.59	0.02	0.00	0.24	1

Table 5b. Pearson Correlation Matrix Garoua (Wet-Dry Season): CB and COH have significantly strong to very strong, while WOA, WOC and DT have extremely strong correlations (bold)

	CB	DT	DS	CH	WC	WOC	WOA	WA	COH
CB	1								
DT	.93	1							
DS	.01	.46	1						
CH	-.12	.00	-.30	1					
WC	-.06	-.00	.01	-.02	1				
WOC	.82	.21	.21	-.08	-.20	1			
WOA	.49	.97	0.72	.81	.69	.75	1		
WA	-.19	.47	-.34	-.29	-.03	-.35	-.08	1	
COH	.68	.26	.45	.42	-.55	.19	-.25	-.04	1

Table 5c. Pearson Correlation Matrix Garoua (Dry Season): CB, DS and COH have significantly strong to very strong, while WOA, WOC and DT have extremely strong correlations (bold)

	CB	DT	DS	CH	WC	WOC	WOA	WA	COH
CB	1								
DT	0.99	1							
DS	0.73	0.20	1						
CH	-0.02	0.01	-0.50	1					
WC	-0.02	-0.03	0.00	-0.00	1				
WOC	0.92	0.16	0.06	-0.19	-0.21	1			
WOA	0.56	0.85	0.73	0.94	0.64	0.35	1		
WA	0.16	-0.01	0.20	0.21	-0.06	0.11	0.28	1	
COH	0.63	-0.45	-0.51	-0.60	-0.39	0.47	0.09	-0.43	1

Table 5d. Pearson Correlation Matrix Garoua (Dry-Wet season): CB and CH have significantly strong to very strong, while DS, WOA, WOC and DT have extremely strong correlations (bold)

	CB	DT	DS	CH	WC	WOC	WOA	WA	COH
CB	1								
DT	0.72	1							
DS	0.87	0.11	1						
CH	-0.13	0.00	-0.39	1					
WC	-0.03	-0.07	0.03	-0.06	1				
WOC	0.87	0.10	0.81	-0.18	-0.30	1			
WOA	0.73	0.84	0.90	0.76	0.92	0.64	1		
WA	-0.07	-0.34	0.09	0.18	-0.02	0.20	-0.08	1	
COH	0.41	0.03	0.52	-0.16	0.33	0.25	0.05	-0.06	1

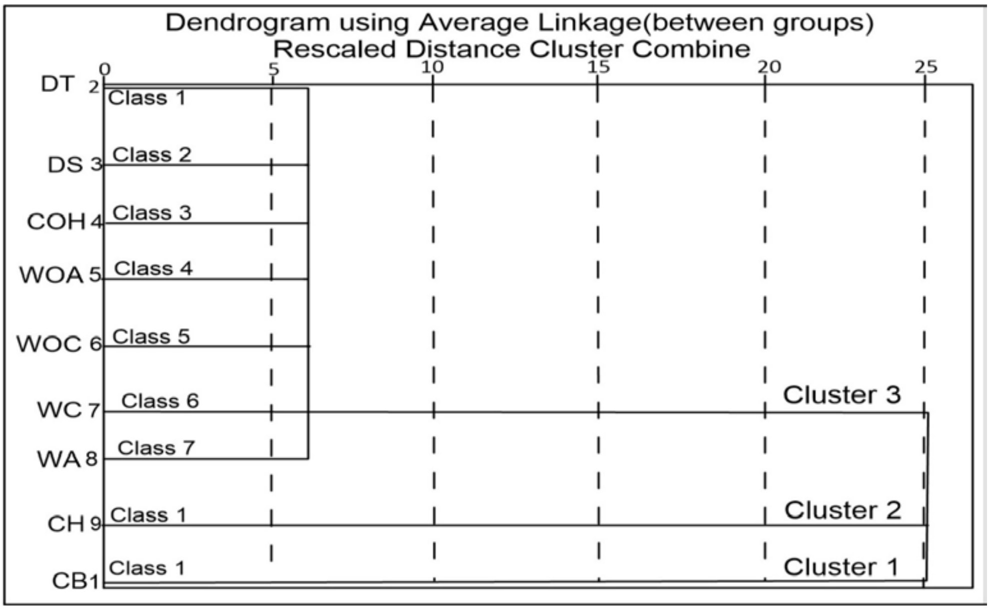

Figure 12. Dendrogram of well placement and well construction parameters contributing to pollution of groundwater in Garoua made up of three clusters: Cluster1; coliform bacteria; and Cluster 2 and Cluster 2 made up of; distance from toilet, distance from dump site, wells without collars, wells without aprons, wells without covers, wells with cover but without aprons and wells with aprons but without cover

4. Discussion

The failure of the average distances of water sources to meet the recommended 30 m agreed with a study conducted by [31] which revealed that a relatively high number of bacterial load were detected from water source near pit latrine. This means the locations of the water sources are either wrongly or poorly located. This gives one of the strong reasons for contamination of the water sources with high total coliform as seen in in Table 5 with relative distance of 1-5 m of the pit latrine and dump site to the water source having total coliforms of 3050 as seen in Table 3. Majority 36 (72%) of the hand dug wells did not have covers whereas 14 (28%) of the wells had covers.

The unavailability of well covers acted as pathways to pollution from external sources. According to Singh et al. 2001 [4] well-constructed hand dug wells protect groundwater from any external contamination. This is consistent with previous studies by (Mendelsohn and Dawson, 2008; Fernandez et al. 2009) [32,33] who suggested that unprotected water sources have high probability of being contaminated by fecal material carried by runoff mainly during rainy season. The poor bacteriological quality of groundwater in Garoua is in line with previous studies carried out in the West Region of Cameroon by Epule et al. 2011; Yongsi, 2010 [31,32,33,34].

Akoachere et al. 2019 [35] cited the abundance of mammal's droppings (Cattle, sheep, goats, dogs and other wild animals that abound) as a means of increasing the potential for non-point pollution.

The construction of toilets and latrines in Garoua is difficult due to the geology (indurated sandstone) and in most parts expensive for poor denizens. Faced with this challenge they squat in the bushes or excrete in poorly constructed latrines which then act as point pollution sources of biological contaminant to these aquifers.

Results from microbial analysis show an increase in bacterial abundances in all seasons. The bacteriological quality of this groundwater varies from one well point to another spatially. These fluctuations were also observed by several authors in the study of groundwater quality in some parts of the city of Yaounde (Nola et al. 2002) [36]. They related these bacterial abundances to differences in human population density, spatial fluctuations in physical properties of the soil of the region, as well as the variability of potential retention by the soil microorganisms. This study found that most of the wells were unprotected and easily liable to contamination by human excreta.

According to the WHO guidelines for drinking water quality, the microbial safety of drinking water includes the prevention of the drinking-water contamination by the microorganisms or the reduction of contamination to levels not injurious to human health [14]. The WHO guideline for drinking-water quality recommends the absence of total coliforms in drinking-water. This study highlights poor quality of the water due to the presence of total coliforms in high concentration. The fecal coliforms present in the groundwater could be associated with high risks of diarrheal diseases outbreaks, such as cholera as suggested by previous studies of [37,38].

Based on WHO classification the MPN in 100ml of well water samples indicate relatively greater MPN counts in the wet, wet-dry and dry seasons than the dry-wet season. This is probably due to: the shallow depth to water levels which in some areas in the wet season dugwell water is at the surface and the increase in surface runoff into wells in the wet season due to badly constructed wells for the wet and wet–dry season.

5. Conclusion

The study determined the anthropogenic factors relating to well placement and well construction factors for biological contamination in Garoua.

The analysis of groundwater contained bacterial contaminants in excess of the recommended limits set by WHO, 2017 The presence of total coliform suggest that there is fecal contamination of the groundwater from the pit latrines, dump site and no well covers due to close proximity.

There is significant association between distances from the nearest toilets, dump sites, wells without cover and the bacteriological loads in the groundwater.

The average distance between the hand dug wells and the nearest latrine doesn't meet up with WHO recommendations (30 m to the nearest latrine), showing groundwater at high risk of contamination by fecal infiltration.

All groundwater sources in Garoua are not safe for human consumption.

It is recommended that communities and local authorities need to train denizens on well construction methods and recommended/regulate dugwell construction and placement distances from contamination sources (Pit latrines and Dumpsites).

In addition, regular assessment of well water quality be undertaken to create awareness amongst local populations to simple and cost effective water treatment techniques for further protection and upgrading of quality in existing dugwells.

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Conflicts of Interest

The authors have no conflicts of interest to declare

Availability of Data and Material

All data submitted were generated from this study and would be available upon reasonable request.

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