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Research Article

ASSESSMENT THE ROLE OF SOME ABIOTIC FACTORS IN THE ABUNDANCE DYNAMICS OF *PSEUDOMONAS AERUGINOSA* IN WELLS IN SANDY AND CLAYEY-LATERITIC SOILS IN CAMEROON (CENTRAL AFRICA)

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ABSTRACT

The aim of this study was to assess the influence of some abiotic factors monitoring abundances of *Pseudomonas aeruginosa*, in open and closed wells in sandy and clayey-lateritic soils in Cameroon (Central Africa). In closed wells, the abundance of *P. aeruginosa* varied from 1 to 153 CFU/100 ml in sandy soil, and from 1 to 60 CFU/100 ml in clayey-lateritic soil. In open wells, it varied from 1 to 200 CFU/100 ml in sandy soil, and from 1 to 58 CFU/100 ml in clayey-lateritic soil. Abundances of *P. aeruginosa* underwent temporal variations in wells. Meteorological, physicochemical and hydrological factors impacts at different magnitudes the abundance dynamic of cells. Positive correlation ($P<0.05$) between rainfall and *P. aeruginosa* abundances were more observed in wells in clayey-lateritic soil than those of sandy soil. Lower cells abundances observed in some open wells were related to the high insolation periods ($P<0.05$). The hierarchical organization was made by expressing percentage and ranking in descending order of the mean of sum of squares of each MANOVA test factor showed that in open wells, the water electrical conductivity and alkalinity seems to be the main factors controlling the *P. aeruginosa* abundance dynamics in sandy soil whereas the total suspended solids seems the main factors in clayey-lateritic soils. In closed wells, this bacteria abundance dynamics seems to be mainly controlled by the dissolved oxygen and carbon dioxide content in clayey-lateritic soils whereas the main factors in sandy soil are the dissolved oxygen content and the well depth.

INTRODUCTION

The bacterium *Pseudomonas aeruginosa* is an opportunistic pathogen. Although it is generally not pathogenic for a healthy population, it is typically problematic in immunocompromised patients. It has been shown responsible for the deaths of infants drinking contaminated water, although an effect of this severity is not typical (Bitton, 2002). The study of its ecology in shallow aquifers is a useful starting point for understanding the potential of transmission of bacterial diseases via drinking groundwater.

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Many studies carried out on aquatic environment have shown that various abiotic factors may influence the composition of bacterial communities and their growth. In most aquifers, the predominant microorganisms are thought to be aerobic or facultatively-aerobic heterotrophs, mostly in the genus *Pseudomonas* (Kazumi and Capone, 1994). These bacteria may have to experience a range of adverse conditions, including very low nutrient concentrations, and are adapted to grow and survive at extremes of organic carbon availability. Evidence for extreme nutrient limitation of bacteria in aquifers is provided by estimates of inter-related bacterial abundance, nutrient supply, and metabolic activities (Kazumi and Capone, 1994). One of the main stress factors that bacteria face in the environment is solar ultraviolet (UV) radiation, which leads to lethal effects through oxidative damage.

Many bacteria (e.g., *Escherichia coli*) are able to repair DNA damage caused by ultraviolet component (UVC) irradiation via a chromosomally encoded UVC-inducible, mutagenic repair system, which is mediated via a key macromolecule–RecA protein. The common freshwater bacterium *P. aeruginosa* has little resistance to the damaging effects of UVC radiation since it does not contain this system, but it contains RecA protein (Miller *et al*., 2000). The bactericidal effect of solar radiation often evoked in natural aquatic environment is still debated. Rainfall-driven run off, which is closely related to the region's climate and soil, has found to be a major risk factor for water quality (Njitchoua *et al*., 1997). Groundwater contamination from pathogens depends on the soil chemical properties, adsorption capability, the ability of the soil to physically strain the pathogens and pathogen survival (Weiss *et al*., 2008). According to Pitt *et al* (1999), groundwater contamination from pathogens occurs more readily in areas with sandy soils and where the water table is near the land surface. The influx of pathogens in groundwater during infiltration of stormwater runoff also related to the rainfall volume and intensity (Pitt *et al*., 1999). Soil clogging development and soil moisture, which are closely related to the air temperature and relative humidity, has found as affecting the bacterial infiltration rate in soil column (Tyler *et al*., 1993).

Douala and Yaounde are the main cities of the Cameroon with the highest population densities and where the problems of water supply and sanitation are most worrying. These two regions have different types of climate and soils according to their geographical locations. Many people there rely on groundwater as the major source of drinking water, which is subject to contamination of varying sources, including percolation from surface water, septic tanks, latrines and other on-site systems, direct injection of wastewater effluent and surface water through wells (Nola *et al*., 2001; Nougang *et al*., 2011). Studies conducted at Yaounde showed that groundwater harbours diverse bacterial microflora, primarily consisting of faecal bacteria, which are commensal or pathogenic. The abundances of *Aeromonas hydrophila* and *P. aeruginosa* undergoes spatiotemporal changes depending on the variation of several physicochemical and hydrological factors (Nola *et al*., 2001). However, critical information about the influence of changing climate variables on abundances of *P. aeruginosa* remains unknown. Douala town has a sandy soil texture while Yaounde town has a clayey-lateritic one. Comparative studies examining varying effects of meteorological factors on the abundances of *P. aeruginosa* in groundwater according to the soil texture have not yet been carried out in these two towns. Our study aimed at evaluating the impact of soil texture and some meteorological, hydrological and physicochemical factors on the abundance dynamic of *P. aeruginosa*, in well waters of Douala and Yaounde, and their respective importance.

MATERIALS AND METHODS

Study areas and sampling sites

The study was carried out in sandy and clayed-lateritic soils represented respectively at Douala and Yaounde, the biggest and most important towns of Cameroon (Central Africa). Douala metropolis is a coastal area located along the Gulf of Guinea between latitude 4° 04' North and longitude 9° 70' East (Figure 1). Soils present a diversity marked by the dominance of ferralitic soils with sandy texture (Hieng, 2003). Vegetation is relatively poor, made up of mangrove swamps that essentially occupy the edges of the coast (Letouzey, 1979). Yaounde is a forest area between latitude 3° 87' North and longitude 11° 52' East (Figure 1). It has ferro-lateritic acidic soils with clayed texture (Bachelier, 1959). The vegetation is made up of dense forest zone (Letouzey, 1979). In each study area, 8 wells were selected among which 4 open wells (coded OSW1, OSW2, OSW3, OSW4 in sandy soil, and OCLW1, OCLW2, OCLW3, OCLW4 in clayed-lateritic soil) and 4 closed wells (coded CSW1, CSW2, CSW3, CSW4 in sandy soil, and CCLW1, CCLW2, CCLW3, CCLW4 in clayed-lateritic soil). The diameter of selected wells was 1.5 m in order to ensure good exposure of well to the sun and have a good penetration of the solar radiations into the open wells. The closed wells were safe from solar radiation. They have been considered as control for the study of the impact of solar radiation.

Water sampling

Water samplings were done from April 2013 to April 2014. Sampling duration was 13 months. Water samples from the 8 wells of each town were collected and analysed monthly. At each sampling point, two water samples were collected, one in a 500 ml sterile glass bottle for bacteriological analysis and the other in a 1000 ml polyethylene bottle for physico-chemical analysis (APHA, 2012). Water samples were collected in wells at the water surface where bacterial production is strongly affected by UV from sunlight radiation (Sommaruga *et al*., 1997). This zone is sufficiently oxygenated and constitutes the preferential microhabitat of *P. aeruginosa* which metabolism is strictly respiratory.

Bacteriological analysis

Membrane filtration was used to isolate and enumerate *P. aeruginosa* cells according to the standard methods (APHA, 2012). For each well, raw or diluted water sample was filtered through a sterile 47 mm, 0.45µm-pore-diameter, gridded membrane filter, under partial vacuum. Funnel was rinsed with three 30 ml portion of sterile dilution water. Filter was removed with a sterile forceps and placed on agar in 55 × 9 mm Petri dish (Gosselin a Corning Brand, France). The Cetrimide Nalidixic agar culture medium (CN, Difco Laboratories, Detroit, MI, USA) was used. Incubation was done at 37°C for 24h. The typical *P. aeruginosa* colonies on CN agar medium were subsequently identified according to Holt *et al* (2000). The identification of each *P. aeruginosa* colony was confirmed using King B medium.

Physicochemical and hydrological analyses

Physicochemical and hydrological analyses were made according to Rodier (2010). At each sampling site, well depth, water column thickness and water table level were measured using graduated line with weight attached. *In situ* parameters like temperature, pH, electrical conductivity and dissolved oxygen were determined using a multi parameter analyzer kit (HANNA Instruments). Carbon dioxide and alkalinity were determined by titrimetric method. Total suspended solids (TSS) were measured by filtration of water samples, and then weighted, after transit in the steamroom at 105°C.

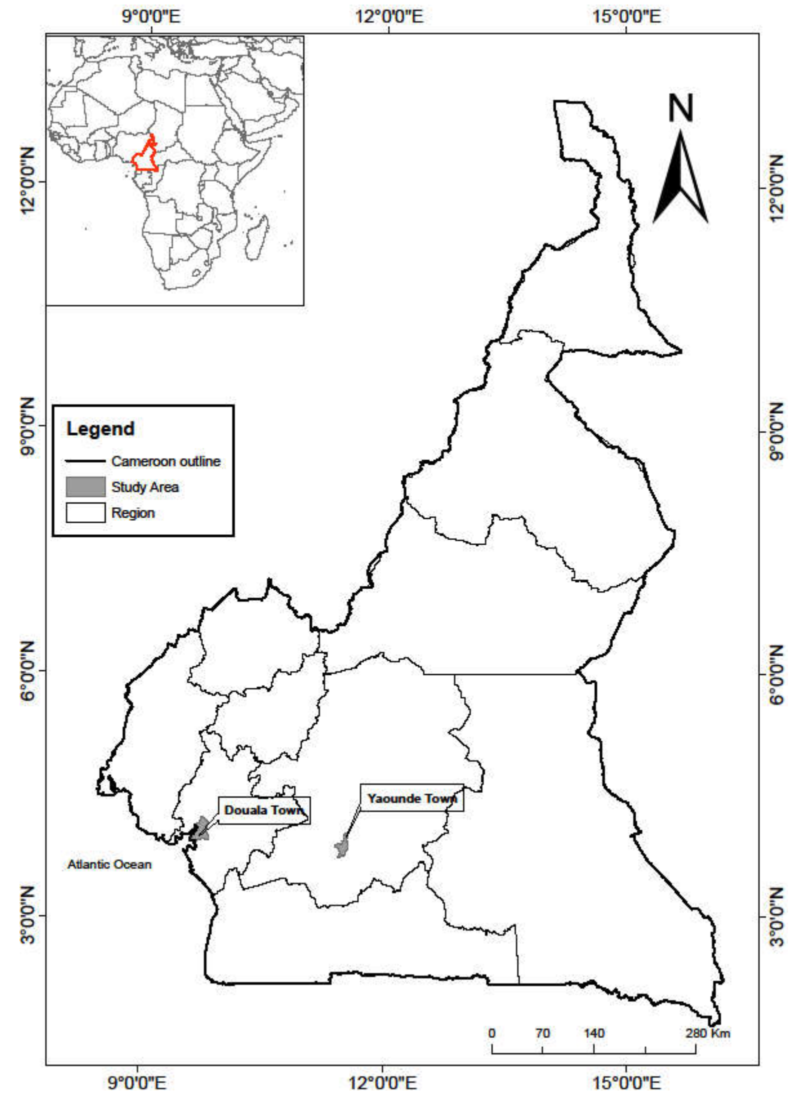

Figure 1. Sampling sites in the towns selected for the study

The chromic acid wet digestion titrimetric method was used to measure organic matters (Chemical oxygen demand) in the samples (Rodier, 2010).

Collection of meteorological data

Meteorological data were collected following the water sampling frequency. Rainfall was measured using automatic rain gauge. The insolation and the daylight duration were measured respectively using automatic LP PYRA pyranometer and MEUDON heliograph. Air temperature and relative humidity was measured respectively using TESTO 925 thermometer and EXTECH M0210 moisture meter. The values of the measured parameters were adjusted from the NASA Surface Meteorology and Solar Energy data set available via the Internet at http://eosweb.larc.nasa.gov/sse/ (on 19th December 2014)

Data analysis

Monthly changes in *P. aeruginosa* densities at the different sampling sites were plotted using the SigmaPlot 10.0 software. Due to their skewed distributions, the bacterial counts (x) were log-transformed [$\ln(x+1)$]. Correlations between different bacterial counts and meteorological, physico-chemical and hydrological parameters were assessed using the Spearman's correlation coefficient [using Statistical Package for Social Sciences software version 20.0 (SPSS, Inc., Chicago, IL, USA)]. To compare the mean abundances of *P. aeruginosa* among wells, Kruskal-Wallis H-test and Mann-Withney U-test were used. A p-value of 0.05 was assumed to be statistical significance level. A hierarchical order of meteorological, physicochemical and hydrological factors monitoring the abundance dynamic of *P. aeruginosa* was performed by the MANOVA test using the R software. This hierarchical organization was made by expressing percentage and ranking in descending order of the sum of squares of each MANOVA test factor to several factors.

RESULTS AND DISCUSSION

Rainfall

The annual rainfall volume recorded in Douala town was 3043 mm. The temporal variation of this parameter identified two different rainfall periods; a long period of about 8 months (March to October) where rainfall volume was high and ranged from 228 to 446 mm, and a short period that lasts four months (November to February) where rainfall volume was relatively low and varied between 19.8 and 89 mm (Figure 2). The weather of Douala is a humid equatorial coastal type influenced by the sea.

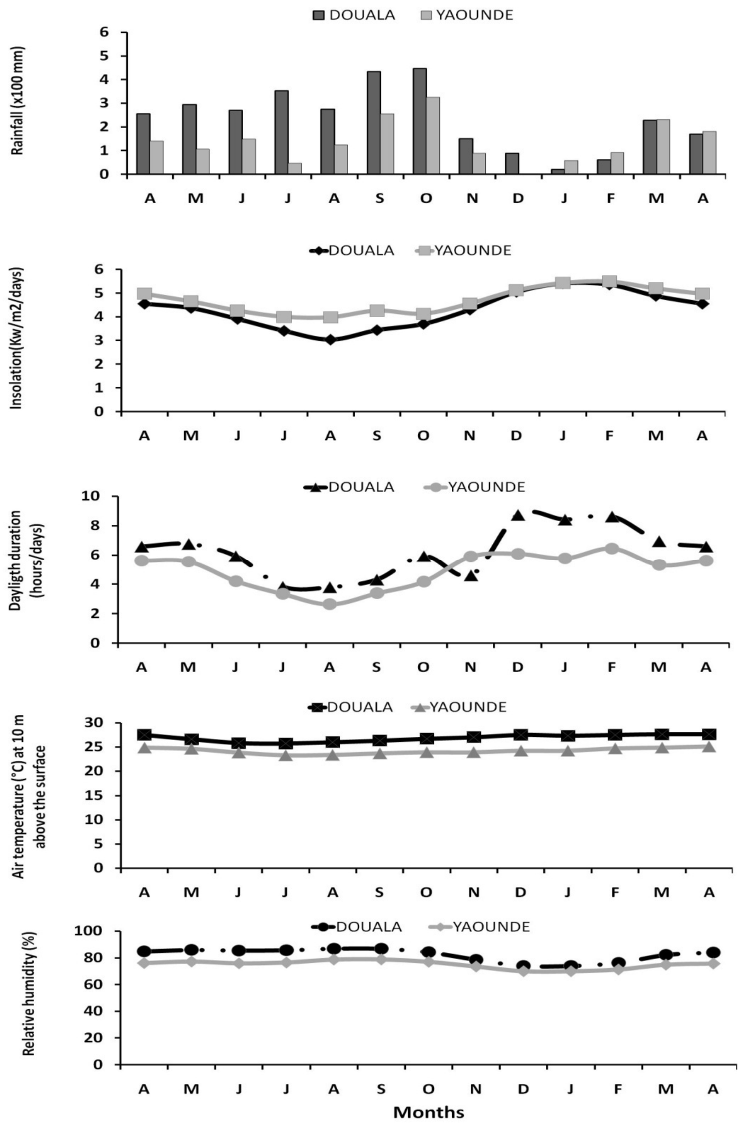

Figure 2. Monthly variations of climatic data of studies sites (A: April 2013, M: May, J: June, J: July, A: August, S: September, O: October N: November, D: December, J: January, F: February, M: March, A: April 2014).

However, the proximity of Mount Cameroon (4100 m height) also influences the climate that becomes very wet (Succhel, 1988). In Yaounde, the annual rainfall volume reaches 1793 mm. The lowest rainfall volumes were obtained in July (46.4 mm). The month of December is characterized by the absence of rains. The precipitation was high in the months of September and October where maximum rainfall volume reached 324.6 mm (Figure 2). The Yaounde region experiences a particular climate termed by Succhel (1988) as "type Yaoundeen". It is a tropical subequatorial climate characterized by four seasons including a long dry season (December to February), a short rainy season (March to June), a short dry season (July to August) and a long rainy season (August to November).

Insolation and daylight duration

The monthly values of insolation fluctuated between 3.04 and 5.41 kWh/m^2/day in Douala with a mean value of 4.31 ± 0.76 kWh/m^2/day. In Yaounde, insolation oscillated between 3.98 and 5.49 kWh/m^2/days with a mean of 4.70 ± 0.54 kWh/m^2/day (Figure 2). In both towns, minimum values of insolation were recorded in the month of August whereas the maximum values were observed in January.

However, the values of daylight duration showed a slight difference between the two study areas. The annual mean daylight duration was 6.24 ± 1.73 hours/day in Douala and 4.93 ± 1.22 hours/day in Yaounde (Figure 2). This difference could be justified by the geographical position or the climate types of the regions.

Air temperature and relative humidity

The monthly values of air temperature at 10 m above the surface of the region earth fluctuated slightly between 25.7 and 27.6°C in Douala town, with an annual mean value of 26.85 ± 0.72°C. In Yaounde town, air temperature ranged from 23.3 to 25.1°C with an annual mean value of 24.2 ± 0.59°C. In both towns, minimum values of air temperature were recorded in July whereas the maximum values were observed in April.

Air temperature recorded in Douala town seems to be relatively high when compared to Yaounde town. Relative humidity was found to be ranged from 73.9 to 86.9% in Douala town, with an annual mean value of 82.2 ± 4.84%. Air humidity was relatively less in Yaounde town and fluctuated between 69.9 and 78.16 ± 2.99% with an annual mean value of 74.95%. In both towns minimum values of air humidity were recorded in

December and January whereas the maximum values were observed in August. However, relative humidity observed in Douala town seems to be relatively high when compared to Yaounde town. This difference would be related to the high values of air temperature recorded in Douala town. The proximity of the sea associated with the high temperature enhances evaporation process which leads to the higher air humidity in Douala town.

Physicochemical characteristics of wells in Yaounde and Douala

Table 1 shows mean values and standard deviations of physico-chemical parameters measured in the open and closed wells in sandy (Douala) and clayey-lateritic soils (Yaounde). In wells of Douala, the temperature value ranged from 26.92±0.65 (CSW3) to 27.5±0.96°C (OSW2). Temperature of waters was higher in open wells compared to closed wells and corresponds to the ambient air temperature. The electrical conductivity values were found to be ranged from 238.69±82.80 µS/cm (OSW1) to 559.69±153.5 µS/cm (OSW2). According to Rodier (2010), the mineralization rate of wells of Douala was average. The concentration of dissolved carbon dioxide ranged from 14.46±6.80 mg/l (OSW1) to 17.63±4.35 mg/l (OSW2). The pH values varied from 5.88±0.55 (OSW2) to 6.65±0.35 (CSW4) which reveals acidic groundwaters. The low pH value (5.88±0.55) recorded at OSW2 would be related to the high concentration of carbon dioxide (17±4.35 mg/l) registered at the same sampling well. Basically, the pH of water is determined by the amount of dissolved carbon dioxide which forms carbonic acid in water. Boughrous (2007) added that, pH of groundwater is also determined by the geological nature of the watershed rocks.

In sandy lands rich in siliceous and silicated minerals, waters are acidic. This could explain the fact that pH values were relatively close (Table 1) at all sampling well with sandy soil. Wells in Douala were poorly oxygenated. Dissolved oxygen was found to be ranged from 2.46±0.98 (CSW4) to 5.53±0.85 mg/l (OSW1). The maximum value of organic matter was found as 7.24±4.83 mg O_2/l at sampling well CSW4 where oxygen was minimal (2.46±0.98 mg/l). Minimum value of organic matter was found as 2.94±1.40 mg O_2 /l at sampling well OSW4 where oxygen was relatively high (5.51 mg/l).

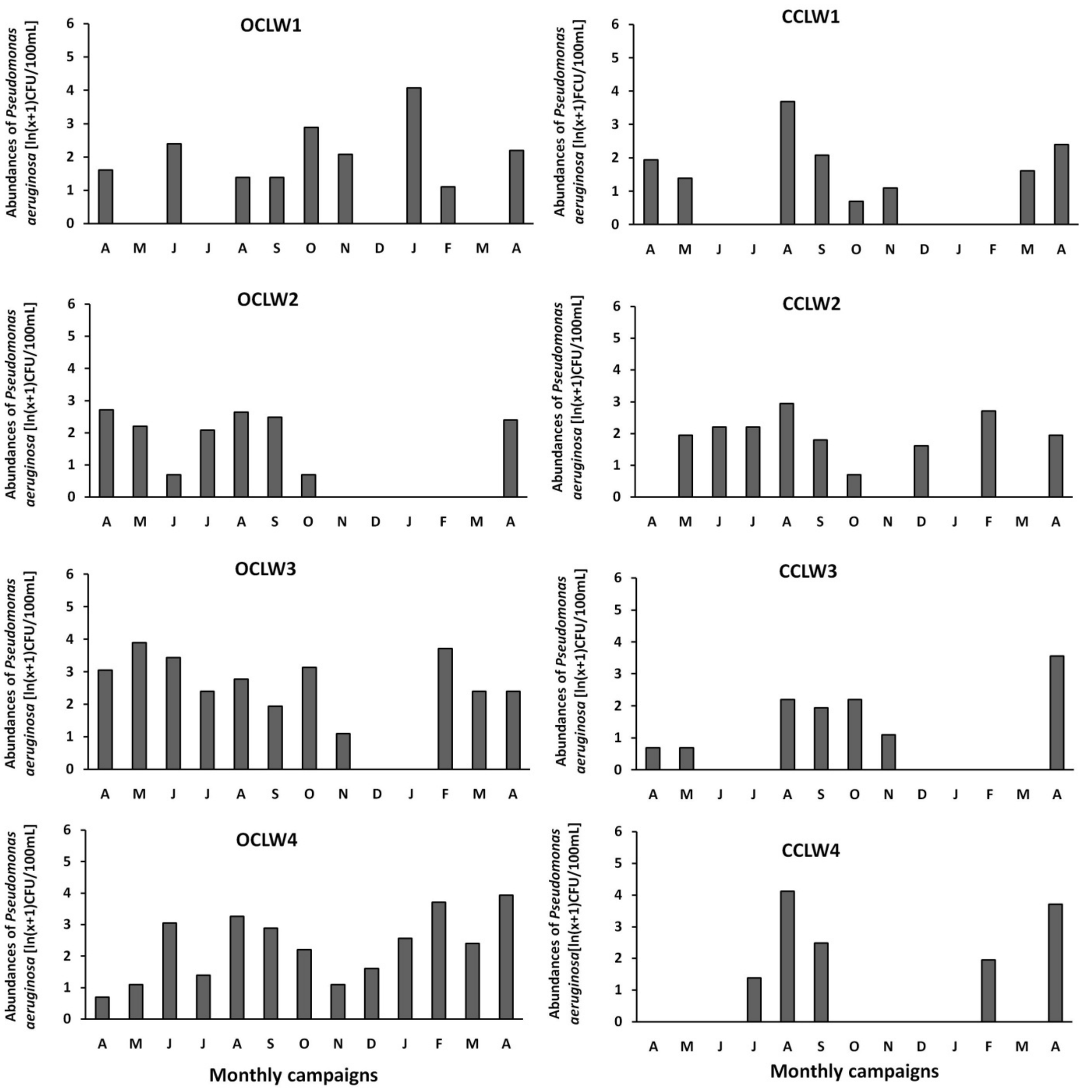

Figure 3. Monthly variations of *Pseudomonas aeruginosa* abundance collected from open sandy soil wells (OSW) and closed sandy soil wells (CSW).

These results suggest that the concentrations of dissolved organic matter (DOM) and dissolved oxygen (DO) in groundwater will be hyperbolically related. It would imply that the DOM is relatively bioavailable (Chapelle *et al*., 2011). According to Findlay *et al* (1993), relative concentrations of DO and DOM in groundwater systems can be affected by microbial metabolism. Water alkalinity ranged from 36.81±5.48 mg $CaCO_3$/l (OSW4) to 135.35±55.60 mg $CaCO_3$/l (CSW4). Water alkalinity is mainly determined by bicarbonates, carbonates and hydroxide ions. This parameter measures the capacity of the water to neutralize acids and it reflects its inherent resistance to pH changes. The groundwaters with sandy soil seemed to be poorly buffered and pH sensitive since their alkalinity values were generally below about 100 mg CaCO3 /l (Muthukumaravel, 2010). In wells of Yaounde, temperature ranged from 24.18±0.61 (OCLW1) to 25.15±0.63°C (CCLW3) (Table 1). The maximum value of electrical conductivity reached 710.23±139.4 µS/cm (OCLW4) and minimum value reached 182.15±32.8 µS/cm (OCLW2). The observed difference in electrical conductivity may be due to the local source of pollution. The wells in Yaounde were slightly acidic with pH ranging from 5.13±0.71 (OCLW3) to 6.97±0.23 (OCLW1). The acidic pH values of groundwaters could be related both to the concentration of carbon dioxide and the crystalline nature of the watershed rocks which characterizes Yaounde region (Boughrous, 2007). The concentration of carbon dioxide in wells oscillated between 12.43±7.50 mg/l (OCLW2) and 16.95±6.13 mg/l (CCLW4).

Dissolved oxygen level in wells varied from 3.87±1.48 mg/l (CCLW4) to 5.02±1.16 mg/l (OCLW4). These low-dissolved oxygen levels could be explained by the presence of the organic matter and heterotrophic bacteria consuming oxygen in the corresponding well water samples (Findlay *et al*., 1993). The concentration of organic matter measured in wells varied from 1.43±0.83 mg O_2 /l (OCLW4) to 3.97±2.26 mg O_2/l (OCLW1). Organic matter can be delivered to groundwater via percolating through the unsaturated zone. Foulquier *et al* (2010) showed that the observed variability of organic matter concentrations could be related to the mixing of recharge waters from land surface with underlying ambient groundwater. Total alkalinity was found to be ranged from 3.40±2.74 mg $CaCO_3$/l (OCLW3) to 179.58±50.78 mg $CaCO_3$/l (OCLW1). The gap between alkalinity values in wells was very important in wells with clayed-lateritic soil.

Hydrological characteristics of wells

Total well's depth ranged from 387.6 (OSW4) to 778.8 cm (OSW2) in Douala and from 163.6 (OCLW3) to 1301.2 cm (CCLW3) in Yaounde. When examining water table level below the surface, the values this hydrological parameter varied from 39.28 ± 5.93 (OSW4) to 301.24 ± 11.70 cm (OSW2) in wells of Douala and from 36.28±5.79 (OCLW3) to 742.66 ± 6.53 cm (CCLW3) in wells of Yaounde. Water table level seems to be more near the land surface in wells of Douala when compared to wells of Yaounde.

Abundances of *P. aeruginosa* in wells

In closed wells with sandy soil, abundances of *P. aeruginosa* often reached 153 CFU/100 ml in December (CSW3) (Figure 3). The lowest abundance, 1 CFU/100 ml, was recorded in March, June and November. In closed wells with clayey-lateritic soil, the cell densities sometimes reached 60 CFU/100 ml in August (CCLW4) (Figure 4). The lowest microbial density, 1 CFU/100 ml, generally appeared in May and October. Temporal variations in cell abundances were observed in closed wells of sandy and clayey-lateritic soils. These results are in agreement with the works of Nola *et al* (2001) that underlined a spatio-temporal change in the abundances of opportunistic bacteria such as *Aeromonas hydrophila* and *P. aeruginosa* in well waters with clayey-lateritic soil.

In open wells with sandy soil exposed to solar radiation, the abundances of *P. aeruginosa* reached 200 CFU/100 ml in July (OSW4) (Figure 3). In most open wells with sandy soil, low bacterial density, 1 CFU/100 ml, was recorded in December, January and February. These low abundances coincided with high sunlight duration recorded at the same period. In open wells with clayey-lateritic soil, the cell abundances reached 58 CFU/100 ml in January (OCLW1) (Figure 4). The lowest bacterial density 1 CFU/100 ml was observed in April, June and October. Generally *P. aeruginosa* cells were rare in open wells.

The mean abundances of *P. aeruginosa* cells were calculated for each series of sandy and clayey-lateritic soil well waters. The mean abundances of cells were compared using H-test of Kruskall-Wallis. It was noted that there was no significant difference (P 0.05) amongst the mean abundance of *P. aeruginosa* cells collected from sandy and clayey-lateritic soil groundwaters. The mean abundances of *P. aeruginosa* were also calculated for open and closed wells for each type of soil. No significant difference (P 0.05) was noted amongst the mean abundance of cells collected from open and closed wells for each type of soil.

Relationship between *P. aeruginosa* abundance and meteorological parameters

Correlations between different bacterial counts and meteorological parameters considered were assessed using the Spearman's correlation coefficient and the results are presented in Table 2. Significant positive correlationships ($P<0.05$) between rainfall volume and *P. aeruginosa* abundances in some wells (CCLW1, CCLW3) of Yaounde have been noted. This relationship between rainfall volume and cell abundances could be explained by the infiltration of stormwater runoff containing *P. aeruginosa* toward groundwater during rainfall (Curriero *et al*., 2001). *Pseudomonas* is reported to be the most abundant bacteria microorganism in urban runoff, and the higher potential groundwater contamination has been indicated (Pitt *et al*., 1994). In wells of Douala, there was no significant correlation (P 0.05) between rainfall and *P. aeruginosa* abundances. This is a surprising result since monthly rainfall volumes were found to be relatively high in Douala region (Figure 2), and the sandy soil texture observed in this town is more permeable to allow stromwater infiltration. Several factors could limit groundwater contamination from *P. aeruginosa* presents in stormwaters runoff. Adsorption of *P. aeruginosa* to the soil particles is an important factor affecting retention of opportunistic pathogen in soil leading to a reduction of groundwater contamination during rainy seasons (Kwon *et al*., 2013).

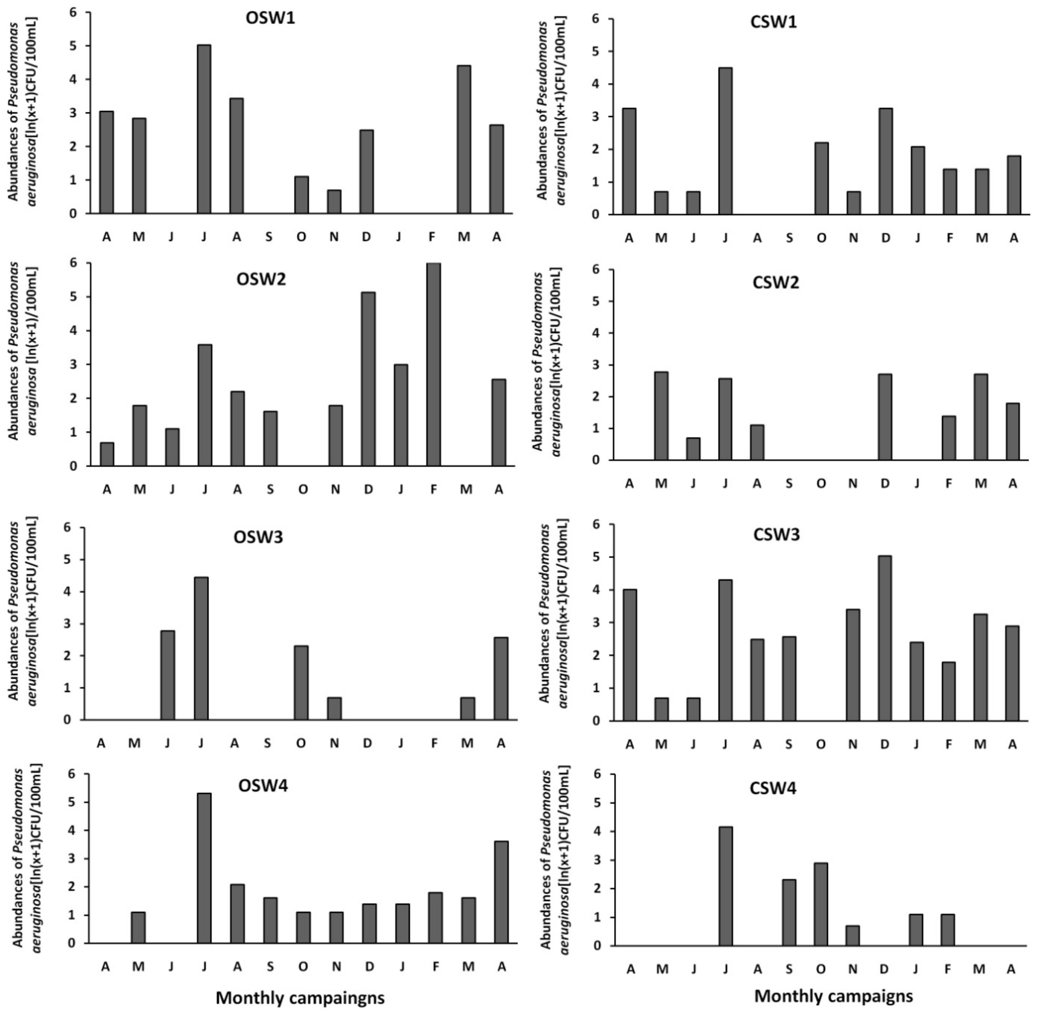

Figure 4. Monthly variations of Pseudomonas *aeruginosa* abundance collected from open clayed-lateritic soil wells (OCLW) and closed clayed-lateritic soil wells (CCLW)

The sandy and clayey-lateritic soils prospected in our study are located in urban regions where soils are generally compacted due to the construction practices and the repeat passage of vehicles. Soil compaction reduces infiltration rate of stromwater runoff since it affects the physical properties of soil by increasing its strength and bulk density, decreasing its porosity (Pitt *et al.*, 2002).

Air temperature was negatively correlated ($P<0.05$) with cell abundances in some wells in Douala (CSW2) and Yaounde (CCLW4). This relationship meant that increasing in air temperature could lead to a reduction in *P. aeruginosa* abundances in groundwaters. Air temperature generates a significant influence on the soil temperature which affects soil clogging development (Tyler *et al.*, 1993). Clogging by the accumulation of suspended solids and organic matter at the infiltrative surface of the soil leads to reduced permeability and reduced bacterial transport in soil column (McCray *et al.*, 2000). Kristiansen (1981) observed a higher degree of clogging at a high temperature. Relative humidity and *P. aeruginosa* abundances were no correlated (P 0.05) in wells with clayey-lateritic soil. However, relative humidity was positively correlated ($P<0.05$) with cell densities in wells in sandy soil (CSW1, CSW2). Significant relationship between relative humidity and *P. aeruginosa* abundances seemed to be related to the soil texture.

Relationship between insolation and *P. aeruginosa* abundances has been evidenced in open wells. In Douala, cell abundances were generally low during high insolation period (Figure 3). It has been noted in Yaounde that increased insolation and daylight duration significantly favors ($P<0.05$) decreasing in *P. aeruginosa* abundances (OCLW2) (Table 2). These results corroborate the works of several authors who suggest that bacteria are particularly vulnerable to UV radiations damage because their small size limits effective cellular shading (Garcia-Pichel, 1994).

Magdalena *et al* (2014) showed that UVA (representing the major fraction of UV radiation reaching the earth's surface) is typically lethal against *P. aeruginosa* cells due to the presence of 2-heptyl-3-hydroxi-4-quinolone in water also known as *Pseudomonas* quinolone signal (PQS). PQS is an intercellular quorum sensing signal which acts as an endogenous photosensitiser. According to Fernandez and Pizarro (1996), this could explain the high sensitivity of *P. aeruginosa* to UVA when compared to enteric bacteria sensitivity such as *Escherichia coli*. Some open wells in Douala (OSW2) have high bacterial densities in December during which insolation is high. It has been noted that correlation between insolation and *P. aeruginosa* abundance was not significant (P 0.05) in some open wells of Douala and Yaounde. The variation of the relationship between abundances of *P. aeruginosa* and solar radiance from open wells to one another may be related to the

Table 1. Means (and standard deviations) of physicochemical and hydrological parameters of well waters in Douala and Yaounde

Parameters considered	Sampled wells in each type of soil															
	Sandy soil (Douala)								Clayed-lateritic soil (Yaounde)							
	OSW1	OSW2	OSW3	OSW4	CSW1	CSW2	CSW3	CSW4	OCLW1	OCLW2	OCLW3	OCLW4	CCLW1	CCLW2	CCLW3	CCLW4
Temp. (°C)	27.06	27.5	27.46	27.23	26.93	27.27	26.92	26.95	24.18	24.27	24.46	24.78	24.42	24.38	25.15	24.23
	(0.58)	(0.96)	(0.72)	(0.78)	(0.44)	(0.73)	(0.67)	(0.65)	(0.61)	(0.67)	(0.56)	(0.72)	(0.45)	(0.79)	(0.63)	(0.48)
EC (µS/cm)	238.69	559.69	273.31	390.23	410.15	493.69	526.12	357.38	434	182.15	228.85	710.23	242.46	221.46	923.54	620.23
	(82.80)	(153.5)	(67.43)	(70.69)	(82.66)	(110.4)	(195.6)	(142.89)	(89.58)	(32.8)	(149.8)	(139.4)	(39.55)	(46.26)	(280.2)	(115.1)
pH	6.42	5.88	6.18	6.18	6.37	6.27	6.63	6.65	6.97	5.69	5.13	5.98	5.19	5.19	6.24	6.1
	(0.35)	(0.55)	(0.58)	(0.52)	(0.37)	(0.5)	(0.33)	(0.35)	(0.23)	(0.83)	(0.71)	(0.44)	(0.70)	(0.87)	(0.49)	(0.43)
DO (mg/l)	5.53	4.83	3.67	5.51	4.22	3.43	4.65	2.46	4.45	4.36	4.73	5.02	4.25	4.97	4.49	3.87
	(0.85)	(0.87)	(1.63)	(0.85)	(1.21)	(0.98)	(1.33)	(0.98)	(1.47)	(0.66)	(0.79)	(1.16)	(1.13)	(0.67)	(0.94)	(1.48)
TSS (mg/l)	10.77	14.31	10.85	10.69	6.62	8.85	5.77	16.31	30.46	3.31	10.46	8.38	9.54	5.77	10.62	4.75
	(11.24)	(14,04)	(7.77)	(6.73)	(5.42)	(8.52)	(7.76)	(16.36)	(28.99)	(3.15)	(10.63)	(8.79)	(9.77)	(7.19)	(11.55)	(6.85)
Alk.(CaCO3)	94.35	45.19	60.73	36.81	67.92	77.77	149	135.35	179.58	3.42	3.40	62.85	6.37	22	137.65	67.69
	(21.26)	(89.13)	(56.60)	(5.48)	(18.70)	(28.07)	(46.02)	(55.60)	(50.78)	(2.38)	(2.74)	(49.21)	(12.06)	(62.73)	(77.69)	(12.71)
CO_2 (mg/l)	14.46	17.63	14.81	15.79	15.30	15.72	17.52	16.40	14.96	12.43	13.23	15.20	14.24	13.73	12.75	16.95
	(6.80)	(4.33)	(7.36)	(5.11)	(6.22)	(6.35)	(4.35)	(5.19)	(7.72)	(7.50)	(8.39)	(7.43)	(6.13)	(7.38)	(8.54)	(6.13)
OM (mg/l)	3.77	4.89	4.55	2.94	4.55	3.62	3.33	7.24	3.97	2.44	2.23	1.43	1.78	1.88	5.16	1.74
	(3.42)	(2.77)	(2.77)	(1.40)	(3.68)	(1.98)	(2.60)	(4.83)	(2.26)	(1.70)	(0.92)	(0.83)	(1.22)	(1.37)	(3.55)	(0.84)
D. well (cm)	745.3	778.8	478.9	387.6	394.7	638	634.9	511.8	522.34	648.7	163.6	504.5	1300.6	650.15	1301.2	605.7
Wat.tab (cm)	137.38	301,24	107.68	39.28	60.96	165.55	174.65	115.28	141.52	303.08	36.28	136.94	742.66	176.05	714.11	59.49
	(15.51)	(11.70)	(10.16)	(5.93)	(8.78)	(15.79)	(19.97)	(12.75)	(12.46)	(13.14)	(5.79)	(4.27)	(6.53)	(9.68)	(1.99)	(5.22)

Temp. = Temperature; EC: electrical conductivity; DO = Disolved Oxygen; TSS: Total Suspended Solids; Akl. = Alkalinity; OM = Organic matter; D. well = Depth well; Wat. Tab = Water table level; OSW: open sandy well; CSW: closed sandy well; OCLW: open clayed-lateritic well; CCLW: close clayed-lateritic well.

Table 2: Spearman correlation "r" coefficients between abundances of *P. aeruginosa* and meteorological and hydrological factors

Factors considered	Sampled wells in each type of soil															
	Sandy soil (Douala)								Clayey-lateritic soil (Yaounde)							
	OSW1	OSW2	OSW3	OSW4	CSW1	CSW2	CSW3	CSW4	OCLW1	OCLW2	OCLW3	OCLW4	CCLW1	CCLW2	CCLW3	CCLW4
Rainfall	0.298	-0.158	0.287	-0.031	-0.39	-0.059	-0.385	0.278	0.31	0.385	0.343	0.292	0.560*	-0.232	0.536*	0.135
Air temp.	-0.024	-0.311	-0.201	0.089	0.151	-0.484*	-0.019	-0.144	0.057	-0.192	-0.189	-0.123	0.235	0.242	0.113	-0.485*
Rel. hum	-0.158	0.811**	0.429	0	0.532*	0.483*	0.432	0.423	0.283	-0.33	0.039	0.05	-0.399	-0.089	-0.405	0.118
Insolation	-0.282	0.329	-0.356	-0.129	0.13	0.162	0.179	-0.243	-0.071	-0.546*	-0.155	0.088	-0.071	-0.546	-0.155	0.088
Daylight.du	-0.24	0.326	-0.368	-0.174	0.111	0.354	0.088	-0.309	0.036	-0.584*	-0.186	-0.083	0.036	-0.484	-0.186	-0.083
Water tab. l	-0.133	0.132	0.281	0.467*	-0.187	-0.179	-0.396	0.609*	-0.043	0.349	0.079	-0.153	-0.138	0.017	0.293	-0.063
Well depth	-0.881**								0.143							

**: P <0.05; **: P <0.01; df = 12; Air temp. = Air temperature; Rel. hum = Relative humidity; Daylight.du = Daylight duration; Water tab. l = Water table level; OSW = open sandy well; CSW= closed sandy well; OCLW= open clayey-lateritic well; CCLW= close clayey-lateritic well.

Table 3. Spearman correlation "r" coefficients between abundances of *P. aeruginosa* and physicochemical factors of well waters

Factors considered	Sampled wells in each type of soil															
	Sandy soil (Douala)								Clayed-lateritic soil (Yaounde)							
	OSW1	OSW2	OSW3	OSW4	CSW1	CSW2	CSW3	CSW4	OCLW1	OCLW2	OCLW3	OCLW4	CCLW1	CCLW2	CCLW3	CCLW4
EC	0.22	0.039	-0.649*	-0.235	-0.214	-0.362	0.25	-0.114	0.025	-0.419	0.014	-0.298	-0.408	-0.389	-0.104	-0.2
pH	-0.018	0.089	0.284	-0.25	0.301	-0.299	-0.124	-0.261	-0.191	-0.071	0.139	-0.237	-0.226	-0.089	-0.125	-0.259
DO	-0.081	0.398	0.275	-0.175	-0.474	-0.215	0.019	-0.159	0.477*	0.072	0.011	0.304	-0.034	-0.193	-0.064	-0.034
Temp.	-0.141	0.011	-0.127	-0.2	0.207	0.369	-0.048	-0.096	-0.147	-0.015	-0.183	0.375	-0.295	0.235	-0.039	-0.043
OM	-0.073	-0.107	0.176	-0.173	0.036	0.053	-0.014	-0.261	0.425	0.573*	-0.049	-0.178	0.557*	0.031	-0.42	0.283
CO_2	-0.29	-0.201	0.286	-0.122	-0.422	0.057	-0.27	-0.012	-0.017	0.226	0.457*	0.087	0.684**	0.434	0.555*	0.449*
Alkalinity	-0.213	-0.403	0.619*	-0.54*	0.19	-0.108	0.017	0.099	0.117	0.381	0.563*	-0.549*	0.213	-0.11	-0.226	-0.197
TSS	0.134	0.18	0.432	0.128	0.225	0.034	-0.001	0.078	0.053	-0.338	0.064	0.403	-0.091	0.083	-0.232	-0.026

*: P <0.05; **: P <0.01; df = 12; EC: electrical conductivity; DO = Disolved Oxygen; Temp. = Temperature; OM= Organic matter; Carbone. diox = Carbone dioxide; TSS: total suspended solids; OSW= open sandy well; CSW= closed sandy well; OCLW= open clayey-lateritic well; CCLW= close clayey-lateritic well.

Table 4. Percentage (%) of the mean of sum of squares of meteorological, hydrological and physicochemical factors impacting the abundance dynamic of *P. aeruginosa*

Parameters considered	Sampled wells in each type of soil			
	Sandy soil		Clayey-lateritic soil	
	OSW	CSW	OCLW	CCLW
Rainfall	0.85	0.01	0.02	2.10
Insolation	6.82	1.09	2.89	0.37
Daylight duration	2.77	0.66	0.86	2.02
Air temperature	1.11	0.34	1.11	5.45
Relative humidity	0.65	2.05	0.65	7.64
Well depth	12.34	11.28	1.34	4.03
Water table level	0.9	0.97	0.9	0.06
EC	32.45	0.76	33.28	0.65
pH	5.04	5.03	2.04	2.61
Oxygen	0.3	48.61	0.27	16.2
Temperature	7.09	3.43	2.09	0.53
Organic matter	0.7	1.19	0.7	0.005
Carbon dioxide	6.38	10.93	6.08	56.09
Alkalinity	13.49	10.11	5.69	0.91
TSS	6.92	1.15	40.26	1.24

EC: electrical conductivity; OSW= open sandy well; CSW= closed sandy well; OCLW= open clayey-lateritic well; CCLW= close clayey-lateritic well characteristics of the native habitat on which exhibition of bacteria to the solar radiance depends on. According to Kevin *et al* (2012), suspended solids could limit light penetration in water column and protect miroorganisms from solar radiation. Impact of solar radiance can also be compromised by interference of hydrological and physicochemical factors that are able to modulate microbial abundances (Nola *et al.*, 2001).

Relationship between *P. aeruginosa* abundance and hydrological parameters

In Douala, total well depth was negatively correlated ($P<0.05$) with *P. aeruginosa* abundances. Variation of the water table level significantly favors ($P<0.05$) the increase in *P. aeruginosa* abundances (OSW4 and CSW4) (Table 2). In wells of Yaounde, there was not significant correlation between hydrological parameters and *P. aeruginosa* abundances. Significant relationship between hydrological factors and cell abundances has been marked in wells in sandy soil (Douala). According to Weiss *et al* (2008), the potential of groundwater contamination is a complex function of soil and contaminant properties and the depth to the water table. When water table level is near the land surface, the duration of infiltration is short and groundwater contamination from pathogen occurs more readily.

Relationship between *P. aeruginosa* abundances and physicochemical parameters

In wells of Douala, abundances of *P. aeruginosa* were negatively correlated ($P<0.05$) with electrical conductivity at OSW3 well (Table 3). Variation of external osmolarity is one of the main stress factors that bacteria face in the environment (Morbach and Krämer, 2002). Domenech *et al* (1992) added that enzymatic activity of *P. aeruginosa* is altered by cationic composition of water. This could explain why a direct effect between *P. aeruginosa* survival and the level of mineralization water was observed by Serrano *et al* (2012). In wells of Yaounde, cell abundances were positively correlated ($P<0.05$) to organic matter, alkalinity, oxygen, and dissolved carbon dioxide contents. The presence of the biodegradable organic matters in well waters stimulates metabolism and enhance the bacterial abundances (Goldscheider *et al*., 2006). *P. aeruginosa* is a heterotrophic bacterium that uses organic nutrients as carbon and energy provider. This bacterium decomposes organic matters via respiratory process, and this can induce the production of in water.

Hierarchical order of abiotic factors impacting the abundances of *P. aeruginosa* in wells

Table 4 summarizes the hierarchical order of meteorological, physicochemical and hydrological factors impacting the abundance of *P. aeruginosa* in open and closed wells of sandy and clayey-lateritic soils. This hierarchical organization was made by expressing percentage and ranking in descending order of the mean of sum of squares of each MANOVA test factor to several factors.

The dissolved oxygen and carbon dioxide are the mains factors impacting the abundance dynamics of *P. aeruginosa* in closed wells of sandy and clayey-lateritic soils. In open wells, abundance of *P. aeruginosa* was mainly controlled by TSS and electrical conductivity respectively in clayey-lateritic soil and sandy soil. These results show that abundances of *P. aeruginosa* were mainly controlled by physicochemical factors. Meteorological factors have a relative less impact on the cell abundances dynamic when compared to other factors.

Conclusion

Abiotic parameters and *P. aeruginosa* abundance in wells from sandy and clayey-lateritic soils seems relatively different, in open wells as well as in closed. Meteorological, physicochemical and hydrological factors impacts at different magnitudes the abundance dynamic of cells. In open wells, the water electrical conductivity and alkalinity seems to be the main factors controlling the *P. aeruginosa* abundance dynamics in sandy soil whereas the total suspended solids seems the main factors in clayey-lateritic soils. In closed wells, this bacteria abundance dynamics seems to be mainly controlled by the dissolved oxygen and carbon dioxide content in clayey-lateritic soils whereas the main factors in sandy soil are the dissolved oxygen content and the well depth.

REFERENCES

Bachelier, G. 1959. Pedological survey of soils in Yaounde, Contribution for the study of ferralitics soils genesis. *Tropical Agronomy*. 19, 279–305.

Bitton, G. 2002. Encyclopedia of Environmental Microbiology. John Wiley & sons, inc., publication. p.3527.

Boughrous Ali Aït, 2007. Biodiversity, ecology and groundwaters quality of two arid regions of Morocco: the Tafilalet and the region of Marrakech. PhD thesis, Grounwater Hydrobiology Group, University of Cadi Ayyad, Marrakech, Morocco.

Chapelle, F. H., Bradley, P. M., McMahon, P. B., Kaiser, K. & Ron Benne, 2011. Dissolved Oxygen as an Indicator of Bioavailable Dissolved Organic Carbon in Groundwater. *Ground Water*. U.S Government work, p.12.

Curriero, F.C., J.A. Patz, J.B., Rose & Lele S. 2001. The association Between Extreme Precipitation and Waterborn Outbreaks in the United States, 1948-1994. *Am. J. Public Health*. 91, 1194-1199.

Domenech, C.E., Lisa, TA., Salvano, M.A., Garrido, M.N. 1992. *Pseudomonas aeruginosa* acid phosphatase, Activation by divalent cations and inhibition by aluminum ion. *FEBS letters*. 299, 96-8.

Entry, J.A. & Farmer, N. 2001. Movement of Coliform Bacteria and Nutrients in Ground Water Flowing Through Basalt and Sand Aquifers. *J. Environ. Qual.* 30, 1533-1539.

Fernandez, R.O., Pizarro, R.A. 1996. Ultraviolet-A lethal effect on *Pseudomonas aeruginosa*, *Photochem. Photobiol*. 64, 334–339.

Findlay, S., Strayer, D., Goumbala, C. & Gould, K. 1993. Metabolism of streamwater dissolved organic carbon in the shallow hyporheic zone. *Limnol. Oceanogr*. 38, 1493–1499.

Foulquier, A., Malard, F., Mermillod-Blondin, F., Datry, T., Simon, L., Montuelle, B. & Gilbert J. 2010. Vertical change in dissolved organic carbon and oxygen at the water table region of an aquifer recharged with stormwater: biological uptake or mixing? *Biogeochemistry*. 99, 31–47.

Garcia-Pichel, F. 1994. A model for internal self-shading in planktonic organisms and its implications for the usefulness of ultraviolet sunscreen. *Limn. Oceanogr.* 39, 1704–1717.

Goldscheider, N., Hunkeler, D., Rossi P. 2006 Review: Microbial biocenosis in pristine aquifers and an assessment of investigation methods. *Hydrogeol. J.* 14, 926-941.

Hieng, IO. 2003. Study of Geotechnical Parameters of the Soils in Cameroon. CLE (ed.), Yaounde, Cameroon.

Holt, J.G., Krieg, N.R., Sneath, P.H.A., Staley, J.T. & Williams S.T. 2000. Bergey's manual of determinative bacteriology, Lippincott Williams and Wilkins, edn. Philadelphia, p. 524.

Kazumi, J. & Capone, D. 1994. Heterotrophic microbial activity in shallow aquifer sediments of Long Island, New York. *Microb. Ecol*. 28, 19–37.

Kevin, G.M., Ronán, M.C., Hans-Joachim, M., Martella du Preez, Eunice, U., Pilar, F. 2012. Solar water disinfection (SODIS): A review from bench-top to roof-top. *J. Hazar. Mater. 14450*.

Kristiansen R. 1981. Sand-filter trenches for purification of septic tank effluent: The clogging mechanism and soil physical environment. *Journal of Environment Quality*. 10: 353-357.

Letouzey, R. 1979. Phytogeographic map of Cameroon at 1/32 500 000. In : Atlas Jeune Afrique du Cameroun, Jeune Afrique, Paris, p. 45.

Magdalena, P., Meichtry. M., Pizarro, R. A., Costa, C. S. 2014. Role of the Pseudomonas quinolone signal (PQS) in sensitizing *Pseudomonas aeruginosa* to UVA radiation. *J. Photochem Photobiol*. 142, 129–140.

McCray J.E., Huntzinger D.H., Van Cuyk S. and Siegrist R. 2000. Mathematical modeling of unsaturated flow and transport in soil-based wastewater treatment systems. Proc. WEFTEC 2000. Water Environment Federation, Washinton D.C. Pp. 20.

Miller, R. V. 2000. *recA*: the gene and its protein product. In: Encyclopedia of microbiology, Luria S (ed.), 2nd edn, San Diego, Pp. 43–54.

Morbach, S. & Krämer, R. 2002. Body shaping under water stress: osmosensing and osmoregulation of solute transport in bacteria. *Chembiochem*. 3, 384–397.

Muthukumaravel K. 2010. Evaluation of Ground Water Quality in Perambalur. *Ind. J. Environ. Sciences*. 14, 47-49.

Njitchoua, R., Dever, L., Fontes, J.C. & Naah, E. 1997. Geochemistry, origin and recharge mechanisms of groundwaters from the Garoua Sandstone aquifer, northern Cameroon. *J. Hydrol.* 190, 123–140.

Nola, M., Njine, T., Sikati, V. F. et Djuikom, E. 2001. Distribution of *Pseudomonas aeruginosa* and *Aeromonas hydrophila* in grounwaters in equatorial region of Cameroon and relationships with some chemical parameters of water. *Rev. Sci. Eau*. 14, 35-53.

Nougang, M. E., Nola, M., Djuikom, E., Noah, E.O.V., Moungang, L. M. & Ateba, B. H. 2011. Abundance of Faecal Coliforms and Pathogenic *E. coli* Strains in Groundwater in the Coastal Zone of Cameroon (Central Africa), and Relationships with Some Abiotic Parameters**.** *Cur. Res. J. Biol. Sc*. 3, 622-632.

Pitt R., Chen S-E., Clark S. 2002. Compacted urban soil effects on infiltration and bioretention stormwater control designs. Global Solutions for Drainage Proceeding of the Ninth International Conference on Urban Drainage, Portland, Oregon.

Pitt R., Clark S., and Field R. 1999. Groundwater contamination potential from stormwater infiltration practices. *Urban Water*. 1: 217-236.

Pitt R., Clark S., and Parmer K. 1994. Potential groundwater contamination from intentional and nonintentional stormwater infiltration. Research project, Cooperative Agreement N°. CR819573 EPA/600/SR-94/051 United States Environmental Protection Agency, Cincinnati, OH.

Rodier, J., Bernard, L., Merlet, N. 2010. Water Analysis. Dunod (ed.), 9th edn, Paris, Pp. 3-715.

Serrano, C., Romero, M., Alou, L., Sevillano, D., Corvillo, I., Armijo, F. & Maraver, F. 2012. Survival of human pathogenic bacteria in different types of natural mineral water. *J. Water Health.* 10, 400-405.

Sommaruga, R., Obernosterer, I., Herndl, G.J. & Psenner, R. 1997. Inhibitory effect of solar radiation on thymidine and leucine incorporation by freshwater and marine bacterioplankton. *Appl. Environ. Microbiol*. 63, 4178-4184.

Standard Methods for the Examination of Water and Wastewater, 2012. 20th edn, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Succhel, B. 1988. Climat types in Cameroon. Thesis, University of Bordeaux III, France.

Tyler E.J., Milner M., and Converse J.C. 1993. Soil acceptance of wastewaters from chamber and gravel infiltration systems. University of Wisconsin-Madison, SSWMP Publication. p. 12.

Van Wesemael, B. 2006. Contents in organic matters in soil in Walloon Region. Report of Catholic University of Louvain/Department of Geography. Statement on the Walloon environment, Belgium.

Weiss P.T., LeFevre G. and Gulliver J. S. 2008. Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices, A Literature Review. Project Report No.515. Stormwater Assessment Project, University of Minnesota.

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