Nitrate Pollution of Groundwater Based on GIS in the City of Daloa, West-central Cote d'Ivoire

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Doubt about the quality of tap water, due to its color, taste and unpleasant odors, forces a large part of the population of the city of Daloa (west-central of Cote d'Ivoire) to turn to spring and traditional wells waters whose quality is unknown. This study aims to assess the level of nitrate pollution of these shallow aquifers through 29 points including 9 spring and 20 traditional wells spread all over the city. Nitrate concentrations range from 2.5 mg/L to 301.1 mg/L, with 30% of the wells containing an excess of nitrate, beyond the WHO drinking standard (50 mg/L). The map of levels of nitrate concentrations in the city's wells and springs shows the exposure of the populations of the old downtown neighborhoods to a high health risk due to the high pollution potential of nitrate in the water.

Keywords*: nitrate, pollution, shallow aquifers, spring, traditional wells*

Large African cities are experiencing uncontrolled growth in area and demography leading to anarchic occupation of urban space. The settlement of populations in this urban space is often not followed by a basic sanitation system so that human activities threaten the quality of water resources. The mechanism of pollution of groundwater is an evolutionary process in space and time, difficult to master [1-12]. The impact of these pollutions appears in the deterioration of the quality of the water resources that become unsafe for the population in the majority of cases and even unusable for the other uses in some cases [1-14]. Thus the alteration of the aquifer has gradually become a global concern [15, 16].

The water of the Lobo River treated for the consumption of populations of the municipality of Daloa is burdened in organic matter, pollutants and other toxic substances [17]. The inefficiency of the treatment gives the tap water a colour, odours and unpleasant taste. Doubt about the quality of water, coupled with the weak distribution network [18], forces a large part of the city's population to turn to traditional well water and springs. These resources are superficial aquifers naturally exposed to all forms of pollution [19], some of which come from anthropogenic activities such as agricultural practices, uncontrolled landfills and wild sanitation [20]. On the other hand, traditional wells and domestic wastewater collection systems coexist in households, often at distances of less than 10 m.

According to [21], globally, wastewater is the main source of pollution of groundwater resources. In addition, like cities in developing countries, wild garbage dumps abound in places [22, 23] and especially upstream of the lowlands, areas par excellence of emergence of spring waters of the city. In Daloa, studies of the quality of these resources are very sketchy and even non-existent [24]. Thus, there is a risk of health related to the consumption of traditional wells and springs water. This study aims to enquire about the state of this aquifer through the assessment of nitrate from 29 water points. Geographical Information System (GIS) were used to perform geographic analyses to highlight the spatial distribution map of nitrates in groundwater. Indeed, the map is necessary and unavoidable because it makes it easy to identify areas with potential health risk.

Experimental part
Study area

The city of Daloa is located in west-central Côte d'Ivoire between longitudes 6°24' and 6°29' West and latitudes 6°50' and 6°55' North (fig. 1). This an area par excellence of coffee and cocoa production. In the decades 1960-1980, vast movements of land colonization will lead to a rapid demographic growth in the region [25]. The 2014 General Population and Housing Census estimates the population of Daloa City at around 320,000.

Materials and method

This study required a digital camera for shooting and a GPS for positioning the 29 sampling points as provided by the protocol (table 1).

Traditional wells (fig. 2-a) and springs (fig. 2-b) water samples were collected in polyethylene bottles of 1 L capacity and stored in cooler containing dry ice. Nitrate concentrations were determined by a HACH DR6000 spectrophotometer (fig. 2-c), at the Laboratory of Water Quality of the Faculty of Environment of the Jean Lorougnon Guede University of Daloa (Cote d'Ivoire).

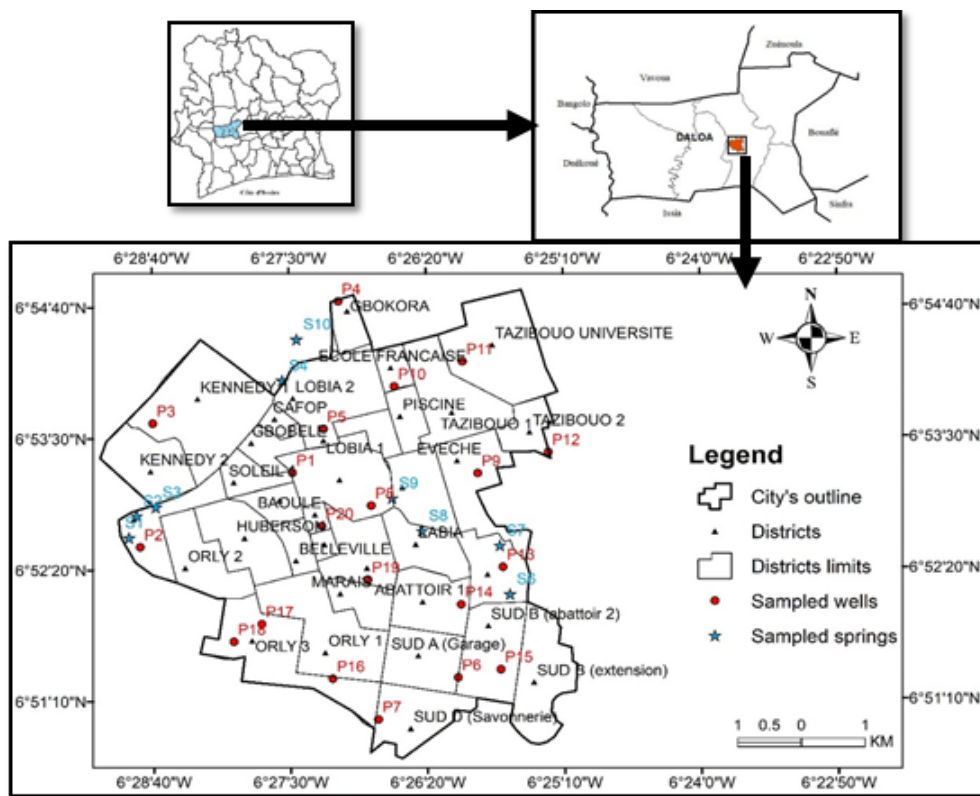*email : vnedeff@ub.ro; Phone: +40723675128; narcis.barsan@ub.ro, Phone: +40742325012

Fig. 1. Daloa City and sampling points

| Sampling points (i) | UTM coordinates | | Concentrations |
	Xi (m)	Yi (m)	Ci (mg/L)
Pi1	Xi1	Yi1	Ci1
Pi2	Xi2	Yi2	Ci2
...	...	...	...
Pi29	Xi29	Yi29	Ci29

Table 1
CHARACTERISTICS OF SAMPLING POINTS

In the ArcGIS 10.2 environment, Spatial Analyst Tools IDW interpolated the resulting nitrate concentrations from sampling points (known x, y coordinates), to elaborate the nitrate map.

Results and discussions

Nitrate concentrations obtained are sometimes very high, with a maximum value of 301.1 mg/L. In spring waters, concentrations are low to moderate; except spring water near the general hospital (49.3 mg/L), which is close to the WHO drinking water guidelines (50 mg/L). On the other hand, in well waters, nitrate concentrations are sometimes very high, well above the WHO standard (table 2).

Table 3 summarizes in 5 classes the results of nitrate concentrations obtained. Moderate concentrations (10 to 30 mg/L) represent more than 34% of the samples; then there are the very high concentrations (over 50 mg/L) that represents about 21% of the samples. High concentrations (30 to 50 mg/L) are the least represented (more than 10% of the samples). Low (5 to 10 mg/L) and very low (0 to 5 mg/L) concentrations are equitably represented.

From classes of nitrate concentrations in the shallow aquifers of the city, a geographical analysis was made to obtain the spatial distribution map of nitrate in the city (fig. 3).

Fig. 2. Collection of water samples and laboratory analyses

Origin of water	Min	Max	Average	Standard deviation
Groundwater	2.5	301\.1	44.1	66.57
Springs	5	49.3	17.71	14.00
Wells	2.5	301.1	55.97	77..27
WHO standard			≤ 50 mg/L	

Table 2
VARIATION OF NITRATE CONCENTRATIONS IN THE SHALLOW AQUIFERS IN THE CITY OF DALOA

Classes of nitrate concentrations (mg/L)	Characteristics of concentrations	Number of samples	Frequency (%)
≤ 5	Very low	5	17.24
]5-10]	Low	5	17.24
]10-30]	Moderate	10	34.48
]30-50]	High	3	10.34
> 50	Very high	6	20.69
TOTAL		29	100

Table 3
CLASSES OF NITRATE CONCENTRATIONS IN THE SHALLOW AQUIFERS IN THE CITY OF DALOA
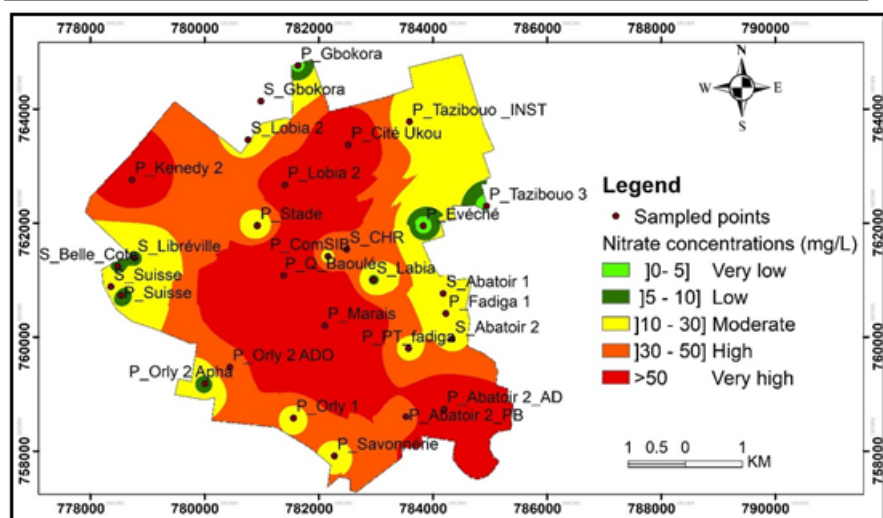

Fig. 3. Spatial distribution of nitrate concentrations in the shallow aquifers in the city of Daloa

This map shows that the shallow aquifer of the city of Daloa is mostly covered by nitrate concentrations beyond the WHO drinking water standard (40% of the total surface area); then come the high concentrations (33% of the study area) and moderate concentrations (25%) (fig. 4). Low and very low nitrate concentrations cover insignificant surfaces and are generally obtained in the peripheries that represent the extension areas of the city (fig. 3).
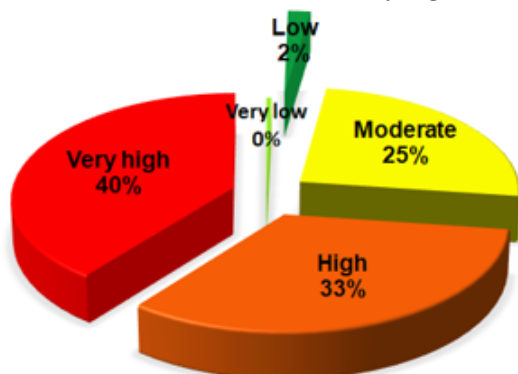

Fig. 4. Spatial division of nitrate concentrations in the shallow aquifers in the city of Daloa

Agriculture is considered to be the main cause of the increase in the concentrations of phytosanitary products in the receiving environment, the first emitter of nitrogen pollution and the second emitter of phosphorus [26]. Therefore the high nitrate concentrations in well water could be justified by intense agricultural activity in the region of Daloa. However, very (17%) to low (17%) nitrate concentrations were observed in some wells. On the other hand, the high standard deviation (77.27 mg/L) between the extreme values shows that this parameter evolves significantly from one well to another. It can thus be said that the impact of agriculture is not considerable on the superficial aquifers of the city. According to [27], maximum nitrate concentrations are not necessarily located under agricultural parcels. In some cases, the contribution of septic tanks can cause nitrate pollution greater than agriculture [28]. Indeed, rapid poorly controlled urbanization contributes to nitrate pollution of groundwater [29].

In Daloa, wells are generally dug in households that lack sanitation. Toilet waters and greywater (sinks, kitchen, washing machine, shower, etc.) are respectively discharged into septic tanks and wells lost. The study shows that contaminated areas are concerned with the town centre and are mostly represented by the old districts where domestic wastewater collection systems would fail. The condition of the old facilities raises some concerns about groundwater, which is a vital resource. These conclusions were drawn following studies carried out in the municipality of Abidjan (Cote d'Ivoire) where the nitrate concentrations obtained are very high in the old districts strongly urbanized [30, 31]. The impact of pit latrines on the quality of groundwater has been subject of several studies [32, 33]. This study reveals sometimes very high nitrate concentrations in well waters (21%) which confirm shallow aquifers pollution in the city of Daloa by domestic wastewater. Highly variable concentrations depend on a

number of factors including the water level in the well and the location of wells in relation to endogenous sources of contamination [19, 34].

For drinking water, the limit value of nitrate concentration is 50 mg/L; beyond that, its poses health risks. In fact, consumption of water that is highly contaminated with nitrates can lead to various health problems [35, 36], such as methemoglobinemia, gastric cancer, goiter, congenital malformations, hypertension, etc. An article published in 2008 by [37] mentions that between 1945 and 1970, nearly 2000 cases of methemoglobinemia were reported in the world literature; most of these cases being associated with the consumption of private well water with a high concentration of nitrates. It is safe to say that the users of these wells are exposed to health risks. A study conducted by [18] at the Orly district of Daloa, to establish a relationship between water supply patterns and population health, showed that 64.03% of waterborne diseases would be associated with the consumption of well water.

Conclusions

Nitrate concentrations in shallow aquifers in the city of Daloa range from 2.5 to 301.1 mg/L with an average of 44.1 ± 66.57 mg/L. In spring waters, they range from 5 to 49.3 mg/L with an average of 17.71 ± 14.00 mg/L. Extreme concentrations are obtained in well water with an average of 55.97 ± 77.27 mg/L. These results show that the high (10%) and very high (21%) nitrate concentrations obtained in the sampled wells are attributable to pollution of the water table by discharges of domestic effluents, especially septic tanks. These wells pose a public health risk because excess nitrates in drinking water can be at the origin of many diseases mentioned in the literature. It is therefore imperative to proceed with their immediate closure.

The resulting map is a decision support tool that can allow authorities to anticipate a health disaster.

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