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Aptitude of Groundwaters for Irrigation in Katiola Area

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Abstract

The increasing pressures of agricultural development surfaces on water resources availability of Katiola area obliged farmers to the use groundwater for food crops irrigation. However, groundwater used for irrigation makes an impact on soil quality. The aim of this study is to estimate the capability of Katiola area ground waters to irrigate food crops by using an approach based on Sodium Absorption Ratio (SAR) and Permeability Index (PI). The results show that most of the groundwater samples (67%) in the study area are suitable for irrigation, except few points located in south-east.

Keywords: Groundwater, Soil, Irrigation, Cultures, Katiola, Côte d'Ivoire.

Contents

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1. Introduction

The Area of Katiola has been in recent decades a sustained agricultural development attention. Food crops such as yams, rice and maize dominate the area. Citrus fruits production is important in the south-east quarter, and cotton has taken a fairly important place in the whole area under the leadership of a state company called Ivorian company for textile development (CIDT). We note an increase in rice production from 2400 to 3000 tonnes from 1980 to 1984. During the 1988 campaign, the number of rice farmers in the region increased to 1467 individuals for a surface area of 1977 ha [1]. The evolution of cotton production in the region is given by Figure 1. From 2008-2009 to 2010-2011 campaigns, the production decreases with respectively 2970.89 and about 1000 tonnes. After 2010-2011 campaign, the cotton production increases during 2011-2012 and 2012-2013 campaigns. It evolves from 1000 to 5708.22 tonnes.

Therefore, more and more increasing pressures according to development of agricultural production on the water resources availability in the area, obliged farmers to use groundwater for irrigation of crops. In fact, surface water sources dry up often in the dry season and are most vulnerable to climate hazards. Governments and farmers have prepared a lot of irrigable spaces in the areas. However, their use has some consequences on soil quality. Indeed, the irrigation water requirements depend on the type of plant, soil and chemical water quality [2]. If the water used for irrigation has high concentrations of Na^+ and low of Ca^{2+}, the exchangeable ion complex may be supersaturated in Na^+, degrading the structure of the soil, due to the dispersion of clay particles [3]. In addition, salt waters with an electrical conductivity less than 200 $\mu S.cm^{-1}$ have a strong trend to mobilize quickly calcium from the soil, which promotes the dispersion of the particles and the clogging of pore spaces [4]. A study of water suitability for irrigation is therefore important. The aim of this work is to study the ability of groundwater in Katiola area for irrigation.

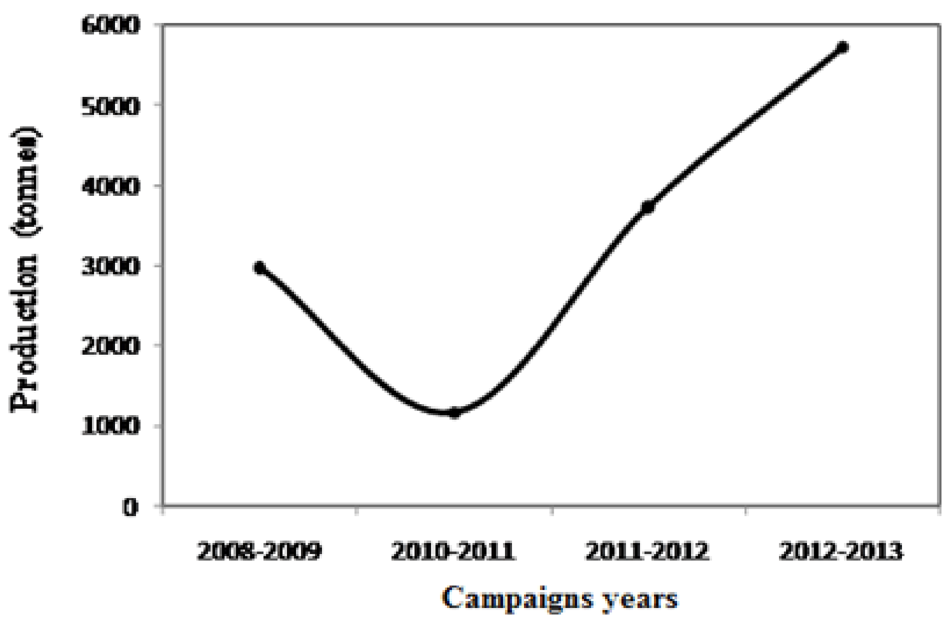

Figure-1. Evolution of cotton production in Katiola department from 2008 to 2013

2. Study Area and Geological Setting

The Katiola area is located at 434 km of Abidjan in the Central-North part of Côte d'Ivoire. It lies between longitudes 4°75 and 5°75 West and latitudes 7°95 and 9°45 North (Fig.2). The study area covers 9452 km^2, with an estimated population of 165 652 inhabitants [5]. The climatic conditions are between Sudanese and Guinean climate. The area is drained by (Bandama and N'Zi) two major rivers and their tributaries, which constitute the natural boundaries of the department, the Bandama at West and N'Zi at East.

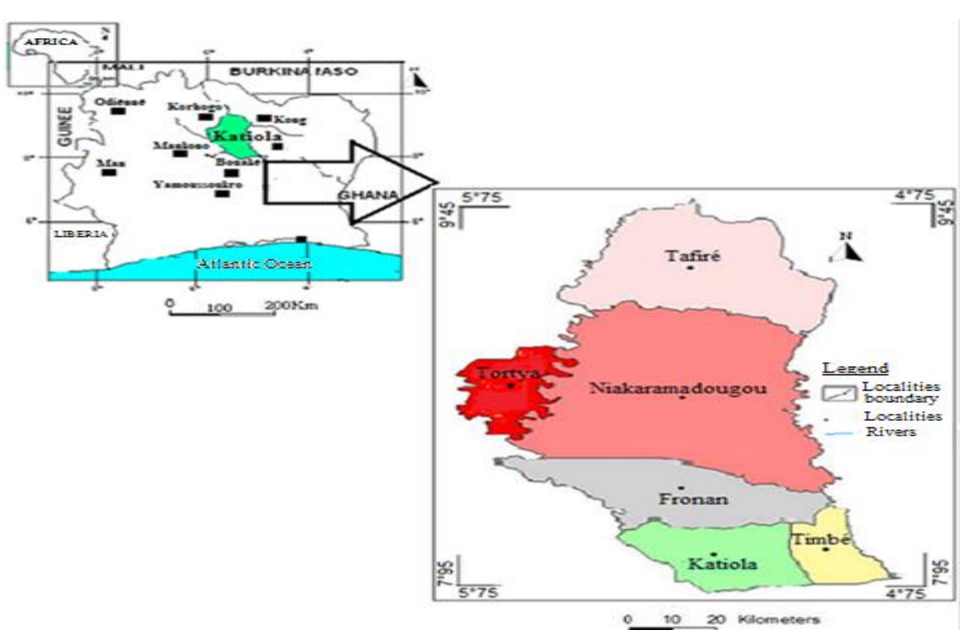

Figure-2. Map Location of the study area

Katiola department lies in the Baoulé-Mossi area with a diversity of birimian rocks, the main ones are: granitoids, metavulcanits, green rocks and metasediments [6]. Crystalline rocks are mainly constituted by migmatites and undifferentiated granites, gneisses and tectonic granites overlapping volcano-sedimentary sequences in most part of the Katiola department (Fig.3).

According to hydrogeological point of view, these rocks have a very low porosity and permeability in sound condition. However, tectonic and physico-chemical phenomena that affect the rock induce secondary porosity and permeability, allowing often these formations to become productivity aquifers. We note the presence of three types of aquifers; regolith aquifers, cracks aquifers and fractures aquifers.

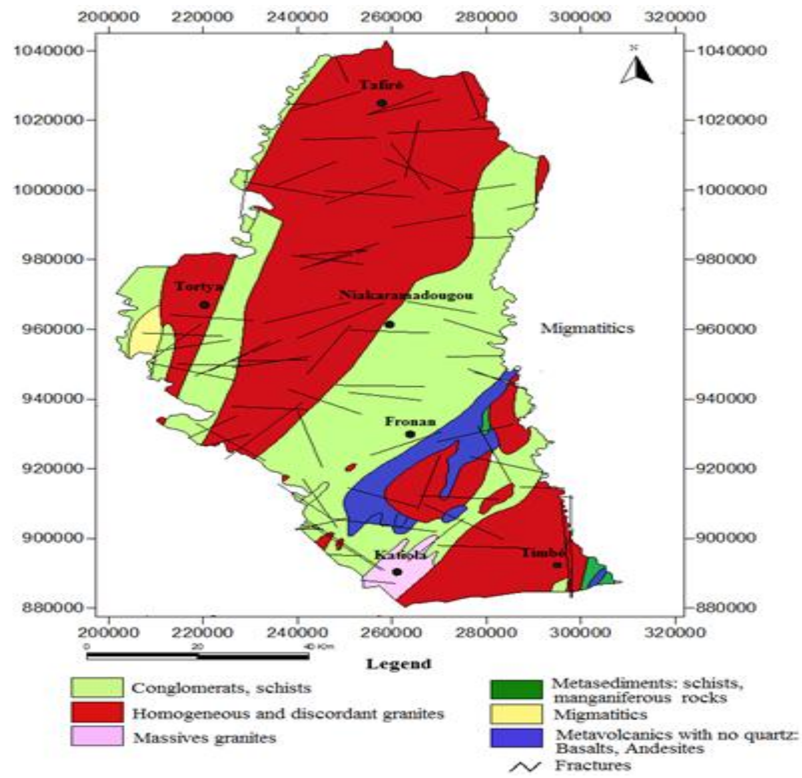

Figure-3. Geological map of the study area

3. Methodology

3.1. Data

For the purposes of this study, 82 water boreholes in the study area have been investigated. These waters have been selected to be the sampling network. These data are from a "post-crisis emergency rehabilitation boreholes" program in the northern regions of Côte d'Ivoire, particularly in Katiola area. This project called "FED 9 ACP IVC 003 / 030/ 000" comes from the European Union (UE) and Regional Center for Water supply and Sanitation-Côte d'Ivoire (CREPA–CI) is its prime contractor. The sampling campaign of water samples took place from 09/02/2005 to 06/04/2006. The chemical characterization focused on, the physico-chemical parameters (temperature, pH, salinity, electrical conductivity) measured in the field and the major components analyzed in the laboratory (dry residue , chloride anions Cl^-, sulphate SO_4^{2-}, bicarbonate HCO_3^-, nitrate NO_3^- and calcium cations Ca^{2+} , magnesium Mg^{2+} , sodium Na^+, potassium K^+.

The quality of groundwater for irrigation may be assess from several parameters [7]. These parameters are sodium adsorption ratio (SAR), total hardness, Mg-hazard (MH), sodium percentage (Na%), salinity hazard, permeability index (PI) and Kelly's ratio [8].

3.2. Water's Parameters of Agricultural Use Calculation

The main factors that can degrade the water quality for irrigation is therefore the concentration of dissolved salts, give as the dry residue or electrical conductivity, potential salinity, the relative concentration of sodium and the amount of toxic elements (boron and chlorine) in water [9]. The total salinity is generally expressed by the total mineralization or electrical conductivity (EC). The latter is related to the dry residue (RS) and the osmotic pressure (π) by formulas 1 and 2:

$$RS\ (mg.L^{-1}) = 0,7EC\ (\mu S.cm^{-1}) \qquad \text{Eq. 1}$$

$$\pi\ (atm.) = 0,00036*EC \qquad \text{Eq. 2}$$

Soil salinity contains all the chlorides of sodium salts and magnesium sulfates. Potential salinity (PS) can be estimated by Doneen [10]:

$$PS = Cl + \frac{1}{2(SO_4^{2-})} \qquad \text{Eq. 3}$$

All terms are expressed in milliequivalent per liter (meq/l).

The presence of Na^+ has harmful effects on soil structure through deflocculation of clay [9]. These effects are interpreted by different authors by calculating several parameters such as the Sodium Adsorption Ratio (SAR), sodium percentage (Na %), sodium exchange percentage (ESP), etc.

The SAR parameter evaluates the sodium hazard in relation to calcium and magnesium concentrations. This parameter is commonly used as an index to evaluate water suitability for irrigation purposes [4, 11]. The SAR was calculated by the following Equation (4):

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \qquad \text{Eq. 4}$$

If the SAR value is less than 10, the water is safe to irrigate with no structural deterioration.

The sodium percentage is an important parameter for studying sodium hazard. It is calculated using the following formula [12] and all concentration are expressed in meq/l:

$$Na(\%) = 100 \times \frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^+ + K^+} \qquad \text{Eq. 5}$$

The sodium exchange percentage is calculated by using Equation 6:

$$ESP = 100 \times \frac{[b(SAR)-a]}{1+[b(SAR)-a]} \qquad \text{Eq. 6}$$

a = 0, 0126 and b = 0, 01475

The first three terms have been combined in a single formula (Equation 7) called the permeability index (PI) defined by Doneen [10]:

$$PI(\%) = 100 \times \frac{Na^+ + \sqrt{HCO3}}{Ca^{2+}+Mg^{2+}+Na^+}. \qquad \text{Eq. 7}$$

Here, like for the others parameters, all the concentrations are in meq/l.

Interpretation from diagrams

Two characteristics diagrams were used to determine the suitability of groundwater for irrigation in Katiola area:

- the sodium adsorption ratio based on the electrical conductivity containing information on the salinity and the risk of soil alkalinization called also sodium hazard (United States Salinity Laboratory's diagram (USSL) [13].
- The Doneen [10] diagram using the potential salinity, soil permeability index and concentrations of toxic substances in water.

4. Results

4.1. Physico-Chemical Parameters Analyzes

The standard method for assessing the water quality for irrigation highlights two characteristics water: overall saltiness estimated by measuring conductivity, and indicator of the risk of secondary salinization and more or less alkalizing of the ground irrigated, expressed by the value of SAR « sodium adsorption ratio » [14]. The results of groundwater samples analysis from Katiola area are presented in Table 1. These results show that groundwater samples are characterized by low salinity. The electrical conductivity (EC) of the water varies from 58.9 (minimum) to 1,098 $\mu S.cm^{-1}$ (maximum) with a mean of 352.76 $\mu S.cm^{-1}$ 67% of water samples have conductivity greater than 200 $\mu S.cm^{-1}$ while 23% have conductivity values less than 200 $\mu S.cm^{-1}$.The values of the sodium adsorption ratio (SAR) range from 0.009 to 0.27, .The permeability index (PI) calculated for the analyzed water is between 49.74 and 225.90 %. The waters with PI values greater than 80% are considered to have a good permeability. Below 25% the waters are considered poor permeability and unsuitable for irrigation.

Table-1. Groundwater chemical composition of Katiola area

Parameters	Units	Average	Minimum	Maximum
pH		6.22	8.4	7.27
EC	$\mu S.cm^{-1}$	352.76	58.9	1,098
Ca^{2+}	$mg.L^{-1}$	29.22	8.02	72.14
Mg^{2+}		5.91	0.49	14.58
K^+		1.88	0.12	6.18
Na^+		3.54	0.22	8.96
Cl^-		13.14	3.55	49.64
HCO_3^-		148.85	18.3	396.5
SO_4^{2-}		7.31	0	160
NO_3^-		4.49	0	33.5
SAR	%	0.14	0.009	0.27
PI	%	84.48	49.74	225.90

4.2. Sodium Adsorption Ratio (SAR)

The United States Salinity Laboratory's diagram [13] relates the SAR with the electrical conductivity (EC) of groundwater and places the samples in irrigation water categories (Fig.4). The analysis of this figure reveals that the most of water samples fall in the section S1, class of low power alkalizing (SAR) and are situated between C1 conductivities (low conductivity) and C2 (mean conductivity).These waters are generally suitable for irrigation of most cultivated species, without the risk of causing effects of permeability resulting from the exchangeable sodium percentage. It is observed in the diagram 4 samples, or 5% of the water falling into the C1S1 field. They are water samples. 33 (Dousoulokaha) , 35 (Folonfokaha), 5 (N'Golodougou) and 11 (Selile). 77 samples or 94 % of the water gather in the C2S1 category. Only one sample (58) 1% of waters falls in the C3S1 field, and its represents the waters of Ourougbankaha. These waters can’t be used generally for irrigation without prior dilution with water of low salinity [7].

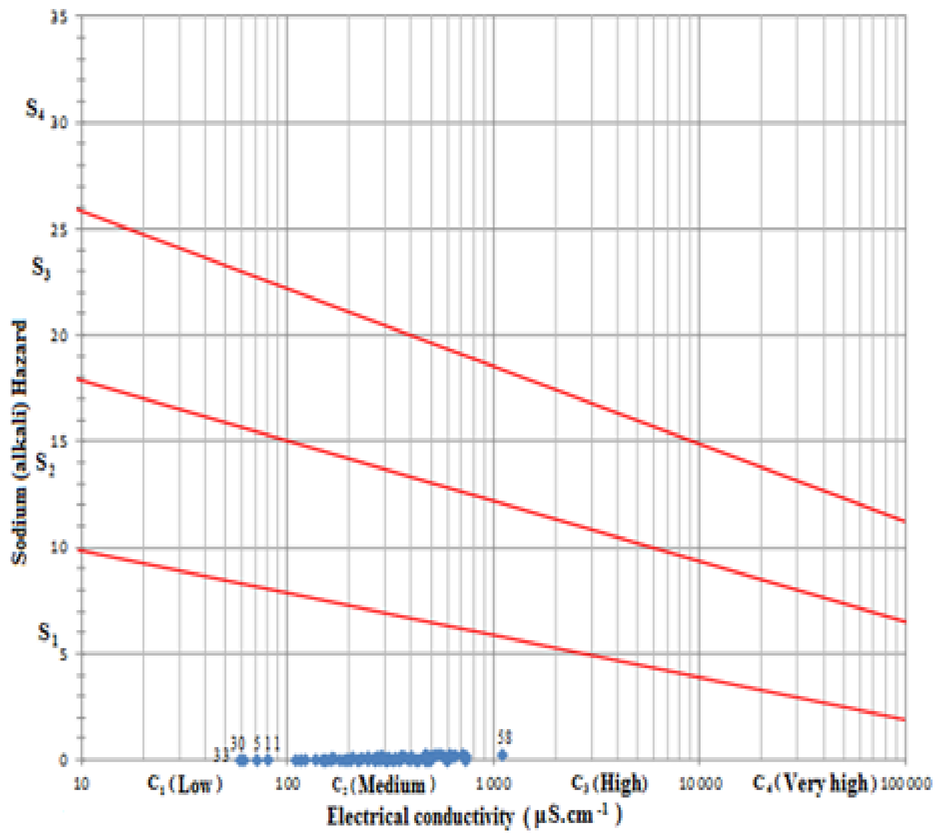

Figure-4. Classification diagram of the Katiola area groundwater for irrigation [15]

4.3. Permeability Index (PI)

Figure 5 is the representation of data on the Doneen [10] diagram. Calculated PI varies between 50 and 116%. In terms of permeability index, Class III represents the best types of water for irrigation. It includes the water samples like (9, 10, 11, 36, 42, 50, 52, 54, 57, 65, 71, 73, 74, 75, and 79). Class II, represents the water of an intermediate class quality and are likely used for irrigation, with certain precautions. It contains the water samples (39, 41, 46, 48, 49, 51, 53, 56, 59, 60, 76, 77, 78, and 80). Class I, represents the water unsuitable for irrigation with samples as (20, 35, 38, 40, 43, 44, 45, 47, 58, 61, 72, 81, 82). Therefore, the analysis reveals that about 29% of water samples are in Class I, 33% in class II and 38% in class III.

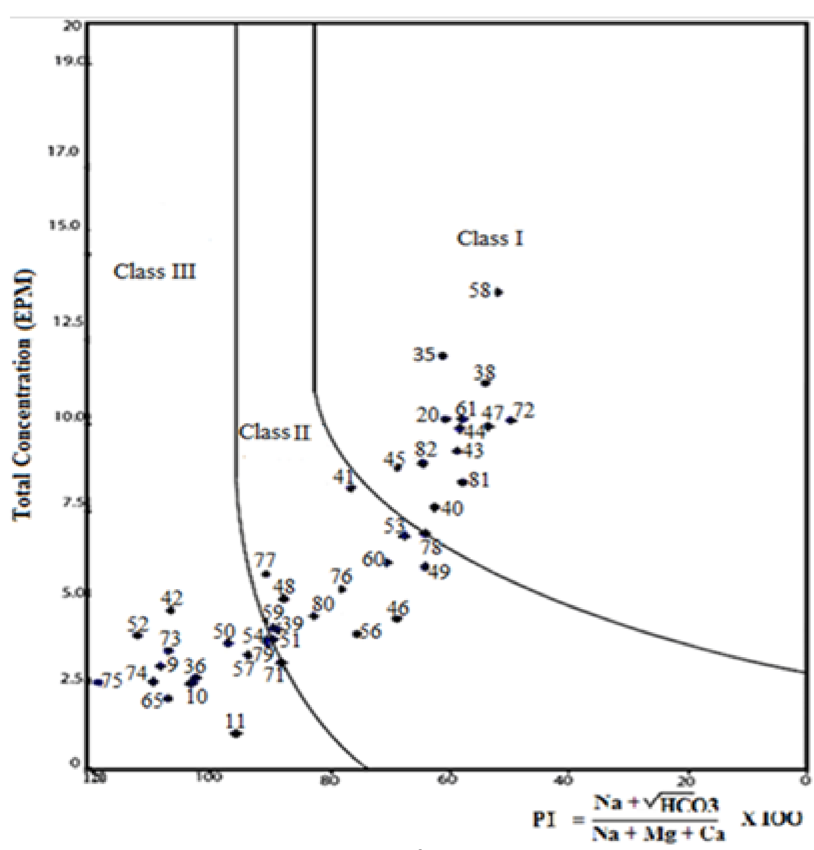

Figure-5. Doneen’s diagram of Katiola groundwater samples

4.4. Mapping of Groundwater's Suitability for Irrigation

To give practical meaning to this study, we mapped the ability of the area water for irrigation, according to the SAR and permeability index (PI) (Fig.6a). The first map (Figure 6a) highlights three areas. The waters of excellent quality for agriculture (C1S1) are located in the south-west of the region. The highly mineralized poor quality waters are located in the extrem south-east (Ourougbankaha). Acceptable waters quality or intermediate (C2S1) take place in the rest of the area. The second map drawn according to the interpretation of Doneen [10] (PI) (Fig.6b) more or less confirms the observations from the first, and shows that the poor water quality for irrigation is located in the south-east of the study area.

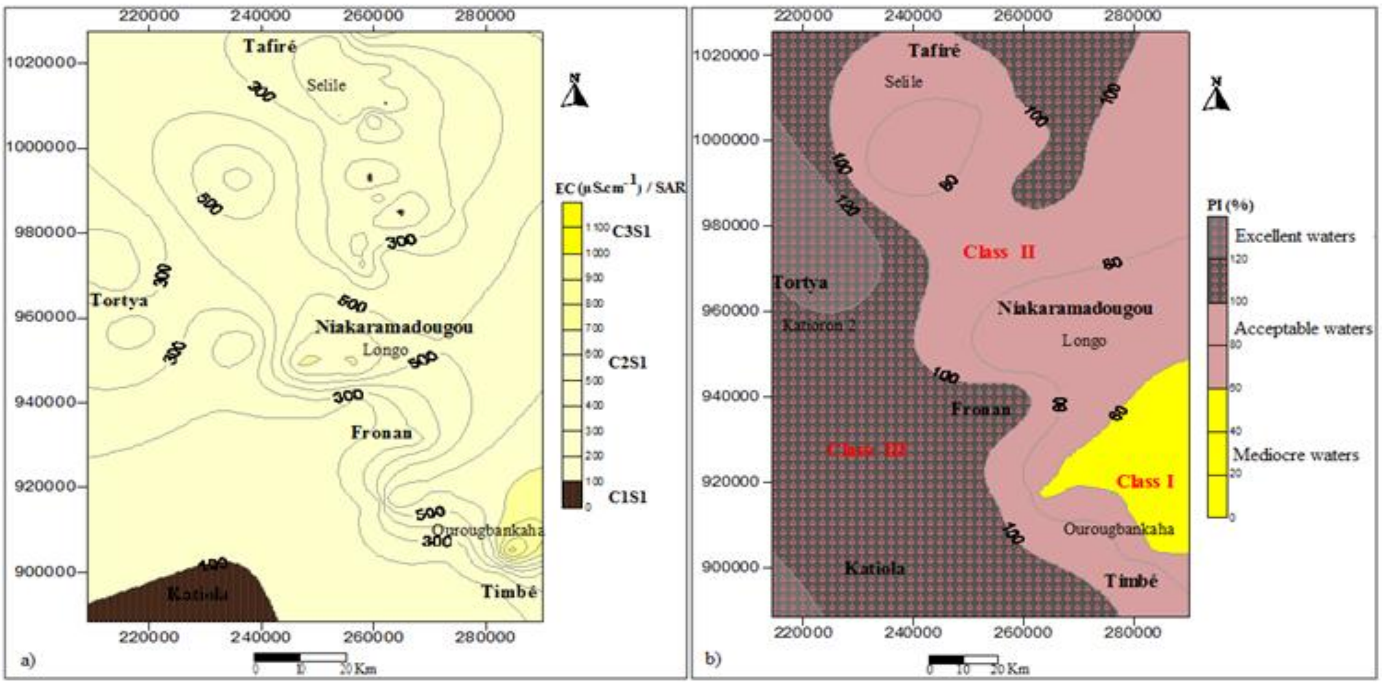

Figure-6. Maps of groundwater for irrigation in Katiola area based on a) SAR and b) Permeability index (PI)

5. Discussion

The irrigation water requirements depend on the type of plant, soil and chemical water quality [2]. Indeed soils containing high levels of sodium are notorious for having a bad soil structure [16]. For example, if the water used for irrigation has high concentrations of Na^+ and low Ca^{2+}, the exchangeable ion complex (complex soil adsorbent) may be supersaturated in Na^+, thus destroying the soil structure, because of the dispersion of clay particles [3]. Such soils can stunt the growth of the plant [17]. In addition, Cheverry [14] shows that in a clay zone, very humus (10% of organic matter) with a biological activity "CO_2 producing " originally waters rich to bicarbonates are in equilibrium with the partial pressures of relatively high CO_2, and can be locally aggressive to the alkaline earth reserves sediments. When the capillary rise phase solutions throughout the profile several factors will contribute to make water "encrusting" and more dangerous for alkalinization. Low salinity water whose electrical conductivity is lower than 200 $\mu S.cm^{-1}$ have a strong trend to mobilize quickly calcium from soil, which promotes the dispersion of the particles and the clogging of pore spaces [4]. This problem could occur in the study area, with 23 % of the analyzed waters with EC values below 200 $\mu S.cm^{-1}$.

Two diagrams were used in this study to determine the quality of agricultural use of groundwater in the area. The sodium adsorption ratio as a function of the conductivity and Doneen [10] pattern. SAR reveals levels Sodicity below 10%. So there is no risk of alkalinization of soils in the study area. This result is consistent with Biémi [18] and Soro [2] results, respectively in the regions of Upper Marahoué and Grand Lahou. The waters mainly fall into the C1S1 and C2S1 classes corresponding respectively to low and medium salinity water, hence low risk of alkalizing. The waters of Class 1 are safe for most crops. Those of class 2 are suitable for plants with low tolerance. On the other hand the stone fruit can accumulate dangerously sodium [2]. A single water sample (Ourougbankaha) is located in the C3S1 class, which represent highly mineralized waters with lows risk of soil salinization. This water class is suitable for irrigation of some species much salt tolerant and well-drained soils and leached [19]. In the absence of an adequate drainage system, any use of this type of resource that does not include most frequent leaching of irrigated soils, leading to a gradual salinization and cause a significant decline in agricultural productivity, or even a loss irreversible fertile soils. This is lost in terms of production, meaning that, when soil salinization increases by improper irrigation with contaminated water, the productivity is lower. We can expect to falls in yields of some crops grown at the study area [4].

Younsi [20] and Debieche [21] reported that the permeability of the soil depends on several other factors such as the total concentration of water, the amount of sodium, the bicarbonate concentration and the nature of the soil. In the second graph based on the measurement of the index of permeability index, the waters are divided according to the three classes. The waters of the class I and II have acceptable qualities intermediaries for irrigation. On the other hand, the waters of Class III are unsuitable quality for irrigation. Their poor permeability may hinder the supply of water for cultivation. It makes it much harder farming practices on agricultural land. It bad for the lifting surface crusting (seal) produced by water logging [22]. These phenomena are associated with a number of disadvantages, including diseases, salinity, weeds and ventilation and nutrition problems [23]. The groundwaters in Katiola area except for a few points are suitable quality (excellent) for agricultural use. However, it should be noted that the irrigation of agricultural areas by groundwater may present the risk of pollution to groundwater [9].

6. Conclusion

This study estimated the suitability of groundwater in the Katiola area (agricultural area) for irrigation. Following this work, we retain the majority of groundwater in the region with the exception of those located in the south-east sector are suitable quality for irrigation of most crops. These waters are generally low mineralized with Sodicity levels well below to 15%, safe alkalizing or sodium binding to the complex soil adsorbent. In terms of permeability index, 71% have an intermediate water permeability index acceptable for irrigation. The highly mineralized waters poor in the south-east with significant risk of soil salinization, are likely suitable for the irrigation of some species much salt tolerant and well-drained soil and leached. In the absence of an adequate drainage system, any use of this type of resource that not include most frequent leaching of irrigated soils, leading to a gradual salinization and cause a significant decline in agricultural productivity, or even a loss irreversible fertile soils.

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