UTILITY OF GIS APPLICATIONS IN THE STUDY OF THE USE AND WATER QUALITY ON THE PETITE COTE OF SENEGAL

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Abstract: Groundwater is a vital resource for humanity. Nowadays, the climatic deterioration causes depletion by high evaporation of surface water. Thus, most water needs are met by groundwater. This fact is verified in Senegal, which is a Sahelian country. The situation is alarming in the Petite Côte of Senegal. The groundwater resources are subject to a plethora of uses because the presence of surface water in the area is only temporary (during winter). The plurality of uses, most of the time wasteful, leads to an overexploitation of groundwater resources. In addition, certain human activities generate pollution of water from aquifers that are already affected by the natural fluorine pollution and salinisation.

Keywords: fresh water, hydrogeology, sustainable development

1. INTRODUCTION

In Senegal, the main freshwater resources are divided in surface water and groundwater. Groundwaters occupy an important place. They constitute the most exploited fresh water resource. In the region of Petite Cote of Senegal, many aquifers are exploited, like Continental Terminal, Eocene and Paleocene, which are karstic aquifers and Maastrichtian. Maastrichtian aquifer is the most exploited. It is picked up approximately 180 m of depth. Superficial groundwater is being exploited using traditional wells and pumps. Its depth varies between less than 20 m in the continental zone and 10 m to the beach zone.

In this zone, the drinking water is provided by the Senegalese Des Eaux (SDE). SDE is a private company that has signed a leasing contract with the Senegalese State. In 1995, the Water Sector Project (Projet Sectoriel Eau - PSE) has led the reform of the water sector, one result being the dismemberment of National Water Company of Senegal (Societe Nationale des Eaux du Senegal – SONES) in three branches: the SDE, that operates the drinking water utility for major urban centers of Senegal based on a 10-year lease contract which was extended for 5 years from April 2006, the National Office for Sanitation of Senegal (Office National de l'Assainissement du Senegal - ONAS) and SONES, responsible among other missions to manage the patrimony.

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The water passes through several stages. The water is pumped from wells with a pumping system. Intakes are done at the level of Paleocene and Maastrichtian aquifers. The water is subsequently conveyed by a transport network (consisting of underground pipes) and then stored in water towers where is processed. Finally, a distribution system brings water to end users or to distribution points, such as pumps and fountains. SDE has in the Petite Cote zone a Regional Directorate, which is divided into several centers, including those of Mbour, Joal Fadiouth and Thiadiaye.

Additionally, the water from aquifers is also collected by other users. The groundwater resources are used by farmers and gardeners, producers of mineral water and other private companies. It is used by households that combine the use of tap water with the well's water or who lack access to drinking water. Some hotel and hostel owners use it, also, to sprinkle their lawns or gardens.
However, this water is of questionable quality due to the sanitation lack and the development of peri - urban agriculture with use of pesticides. In fact, our zone of study does not have a sanitation system and the absence of the sewerage network causes pollution of groundwater. In addition to the contamination, we note a salinisation of the surface groundwater which would slow down the rise of activities such as agriculture.

Our study is based on an in-depth analysis of major users of water, activities and practices, and relationships that exist between those and water quality. This study aims to:

- Show the contribution of water to the development of business activities on the Petite Cote;
- Show the level of access to water;
- Conduct an inventory of freshwater resources;
- Provide a set of indicators to characterize, monitor, assessing freshwater resources;
- Develop a tool for decision support.

2. PRESENTATION OF THE STUDY AREA AND RESEARCH METHODOLOGY

The Petite Cote is a natural region of Senegal. She is also a coastal region located to the west of the country, on the south coast. This region is located some 70 km from the capital, Dakar. Its uniqueness is its attractiveness due to tourism development and the large number of activities which it abounds. The map of the studied zone is presented in Figure 1.

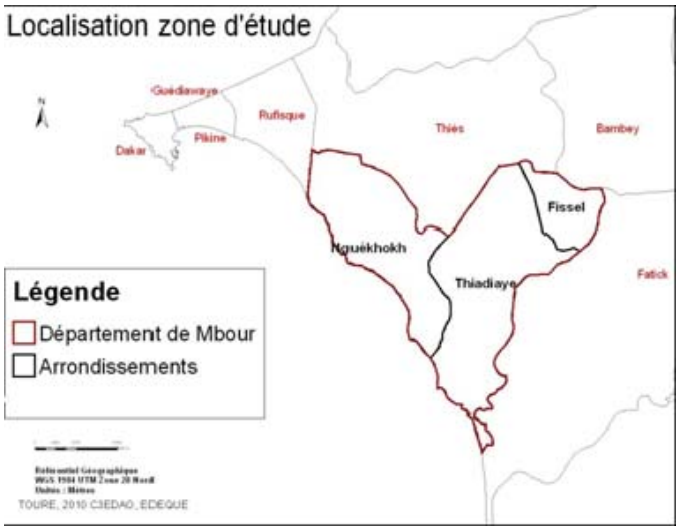

Fig. 1. Map of the investigated zone.

The study of the use and water quality on the Petite Cote requires, first, a discernment of the question of supply (fresh water resources available) and demand (and main use users) for better understanding of the problem. So we will proceed, initially with an identification of the indicators which make it possible to characterize the fresh

water resources. This operation will be followed by a collection of available data and creation of database. In this last phase the use of GIS will be very helpful.

2.1. Identification of fresh water indicators

These indicators are used to characterize, monitor and evaluate water resources. The indicators to be analyzed are: the nature of the aquifers exploited, the availability of water, the types of water supply, the types of uses and users of water.

2.1.1. The nature of the aquifers exploited

The aquifers are geological structures likely to fill with water. The groundwater represents the water level which occupies the aquifer. The groundwaters which are exploited on the Small Coast are the Paleocene one, the Eocene and Maastrichtian. It will be a question of saying to which type they belong: captive, free, fissured, fractured or karstic. The captive groundwaters are overhung by an impermeable geological layer. As for the free groundwaters, they have a permeable roof. The free groundwaters are exposed to pollution and evaporation. It will be a question, also, of analyzing the flow in the aquifers.

The parameters of the flow are as follows:

- The permeability, which is given by the measurement of the interconnection between the pores;
- The transmissivity which represents the sensitivity of the aquifer to transmit a decompression from one point to another. The pumping rate must be compensated by the groundwater. Transmissivity is the parameter that determines the flow rate of water flowing per width unit of the saturated zone of a continuously aquifer measured in an orthogonal direction to that of the flow, and per hydraulic gradient unit. The transmissivity is equal to the product between the average permeability of the saturated section of the aquifer and its thickness. It is expressed in m2/s. The transmissivity is an essential characteristic which makes it possible to envisage the flows that one can collect in a drilling [1].
- The diffusivity which is the capacity of the aquifer to diffuse water.

At this point, the observation of the piezometric network (or network of well, drillings) is necessary.

2.1.2. The availability of water

The availability remains unpredictable because of the dryness, floods and other weather events. As for the data on the uses of aquifer's water, they were collected during household surveys and interviews at the SONES and Direction of Planning and Management of Water Resources (Direction de Gestion et de Planification des Resources en Eau – DGPRE).

2.1.3. The types of water supply

On the Petite Cote, we distinguish three modes to supply water:

• SDE connections provide a water "which can be drunk without health risk".
• the standpipes;
• the water of the groundwater: it is polluted more and more because of lack of sanitation.

2.1.4. The types of uses and users of water

The water has several uses, whatever its quality, drinkable or not. The "safe" water is produced by the SDE which carries out pumping on the level of the deep groundwaters of the Petite Cote (Maastrichtian, Paleocene, Eocene). However, the unequal distribution of the water of the SDE leads to use inadequate water for some type of uses. It is the case of households, which use the water from wells for drink, cooking or bath. Thus, the contamination of the water makes the population that uses it vulnerable to water-related diseases. Moreover, other people combine the use of drinking water with that of the groundwater to reduce the cost of the water bill.

On our questionnaire, we ask questions relating to the different types of use and the corresponding resource type. Among users, we find also, farmers, ranchers and gardeners who use water from groundwater, and mineral water producers. The data about these users are collected using questionnaires and interviews that there are addressed.

2.2. Data acquisition

Data collection consists in interviews, surveys and direct observations. The interviews have led us to the SDE Mbour center, hygiene service, DGPRE, the General Directorate of SONES.

The interview to SDE was focused on water availability, service, age of pipes, source of supply, limit of the network, other main problems facing the distribution. The hygiene department has informed us about the quality of safe water and helped us to make our quality measurements. The DGPRE informed us about the sources of freshwater in the studied area, providing a list of water bodies, which are there and the various exploitations which are carried out.

Always, for establishing indicators, collection of all available data (statistical and spatial) that can be used in the construction of indicators on freshwater resources we have been very useful.

2.3. Identification and creation of the GIS database

• Space data: Identification and creation of the information layers and the variables necessary to the database constitution. The data come from the statistics, charts, images at our disposal and from taken measurements. The data resulting from the charts are vectorized in order to store the information under numerical format.
• The data assignees: it is about the information of the cartographic database. That implied a joint of the statistical tables to the cartographic table being behind the space data.
• Spatial analysis: identification queries and spatial analysis operations needed to determine the spatial interactions and relationships between the various activities carried out, and the water quality. The analysis result shows the unique zoning that can characterize these relationships.

3. RESULTS AND DISCUSSION

3.1. Mapping of the primary resource used: groundwater

Jurassic and tertiary deposits yield major aquifers containing water resources.

(a) The superficial groundwater

It is located in the Continental Terminal (CT) sandstones and in limestone formations from Paleogene (Eocene, Paleocene). The Continental Terminal is constituted by Quaternary, Miocene and Oligo Miocene formations. The CT aquifers are characterized by a low depth. The precipitations are the main filling source because of the permeable and porous character of the deposits which constitutes it. It is collected using village wells. These groundwaters are exploited because of the many advantages and are the victim of an important pollution. The water can be reached in less than ten meters and depth can exceed the 100 meters. A distribution of wells which use the superficial groundwaters is presented in Figure 2.

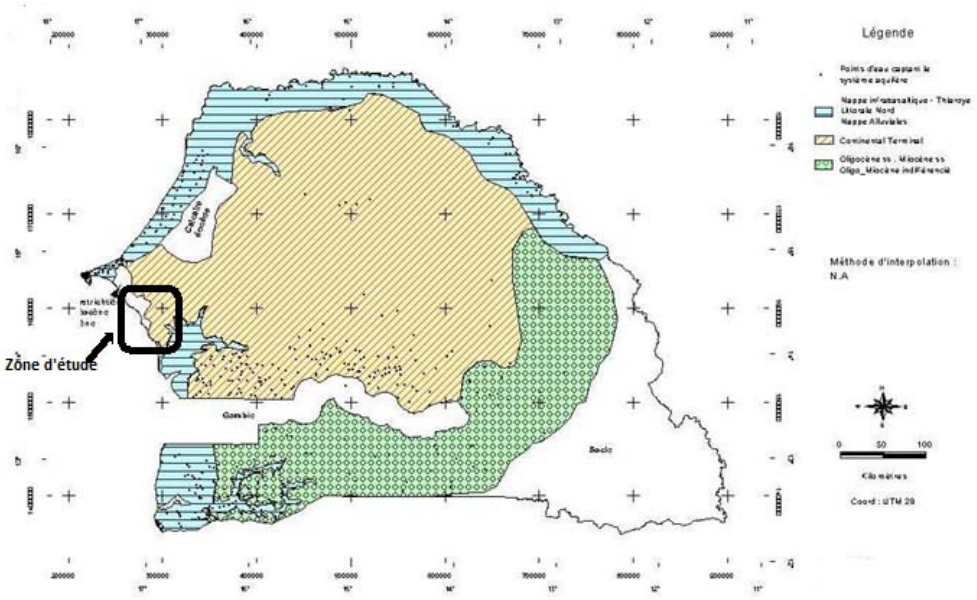

Fig. 2. Map of wells using superficial groundwaters.

(b) The Paleocene formations

They are composed of marlstones, calcareous marl or limestone. Formations are part of the aquifers of the tertiary and are present along the Petite Cote. In these aquifers the water is very salty and the depth decreases from West to East. The water is localized in karstic limestone Paleocene channels. A distribution of wells which use these groundwaters is presented in Figure 3.

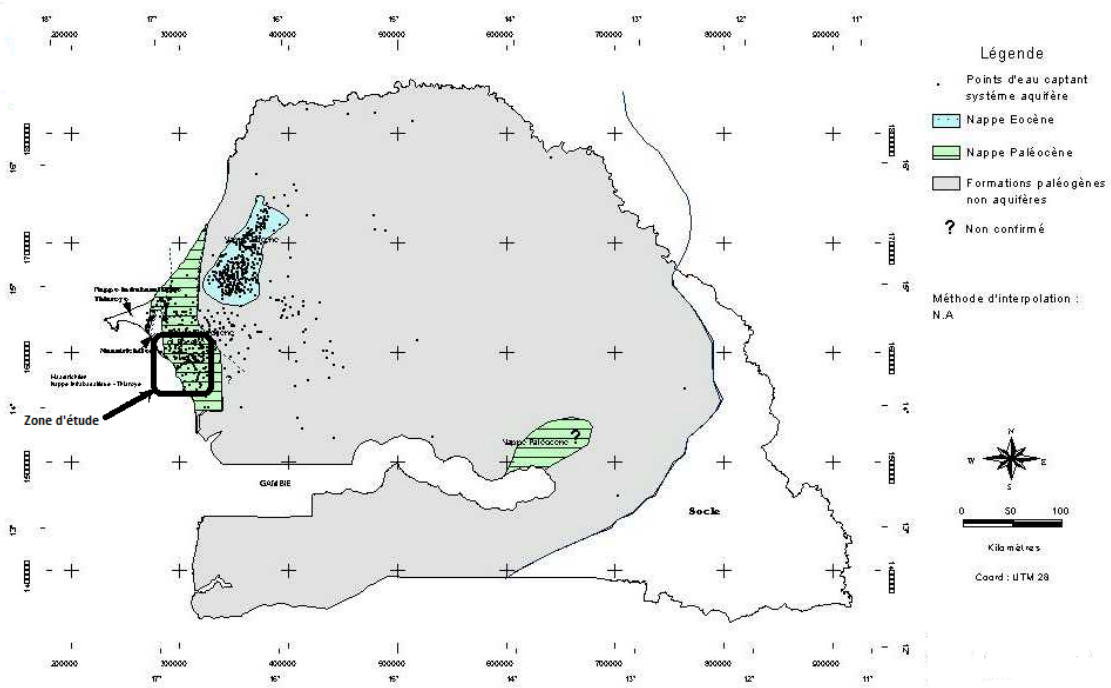

Fig. 3. Map of wells using water from Paleocene formations.

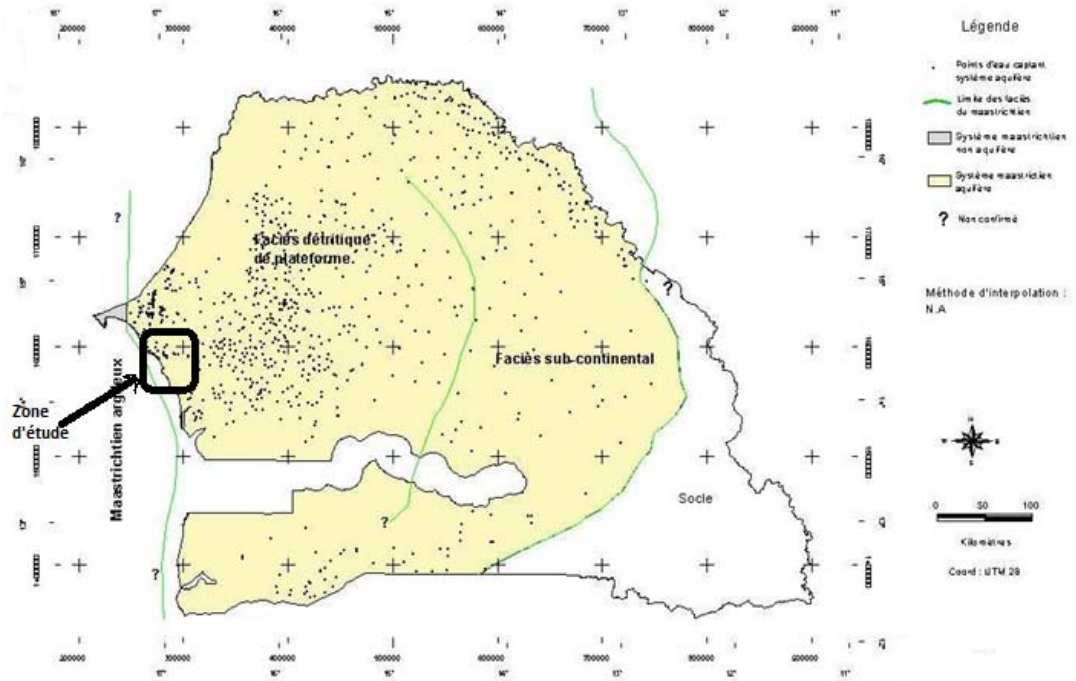

Fig. 4. Map of wells using water from Maastrichtian formations at the level of year 2001.

(c) The Maastrichtian formations

These groundwaters are contained in the Maastrichtian limestone and sand and are the largest in quantity and depth. These formations are found throughout the basin Senegalo Mauritania (up to Aleg, Mauritania). However, in the Thies region, is flush only to west, between Thies and Sebikhotane. The waters of Maastrichtian can rise up to a few meters from the surface. These aquifers are driven primarily by runoff from the Precambrian basement. On the Petite Cote, we note also the possibility of charging from Ndiass Horst. To fill its losses, the Maastrichtian waters also try to aspire the water overlying the Paleocene formations. However, the layers between these two groundwaters are not sufficiently permeable.

The water is generally captured between 100 and 400 meters by drilling. Its potential is 300 to 400 billion cubic meters [2]. The distribution of wells which use these groundwaters at the level of year 2001 is presented in Figure 4. From 2001 until now, other water points have emerged.

3.2. Groundwater exploitation and spatial distribution of different users and uses of water on the Petite Cote

3.2.1. Groundwater exploitation

The main aquifers exploited in the Petite Cote are Maastrichtian, Paleocene and Continental Terminal. Contrary to the Continental Terminal, which is a free groundwater, the Maastrichtian and Paleocene are captive. The Ndiass Horst is the recharge zone for Eocene, Paleocene and Maastrichtian formations. These last two aquifers are overexploited today. Indeed, "the history of a captive aquifer has generally two episodes. First episode may be characterized as permanent or quasi permanent, in which the filling and drain processes are natural and therefore, relatively constant over time throughout a year or several years. This is the original situation. After that, occurs the operating period with episodes corresponding to different pumping schemes (opening of new drilling operation, closure of some other, variation of flow pumped)." [3].

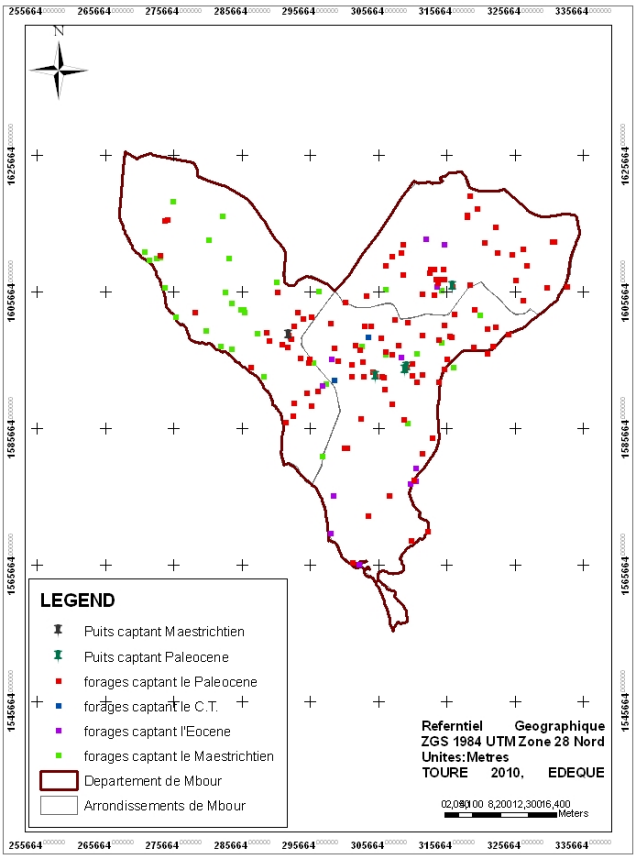

Fig. 5. Map of water extraction points in Mbor region.

The main purposes of this resource are: drinking water supply, production of table water, agriculture, tourism, domestic activities, consumption etc. SONES Company operates the Maastrichtian and the Paleocene groundwaters for drinking water supply. It has set up 9 boreholes which are used to supply water in the Petite Cote zone. The distribution of the water exploitation points in Mbor region is presented in Figure 5, in function of the geological source.

Town of Mbour has two water towers. One distinguishes R1 or tower water from Mbour Escale and R2 which is that of the district ONCAD on the road of Kaolack. The capacities are 1000 m³ for R1 and 3200 m³ for R2. The R1tank is used exclusively to cover the needs of Mbour. The R2 water tower of ONCAD, with a capacity of 3200 m³, remains the largest of West Africa, used mainly to assure the water stock. It makes it possible to feed the entire zone located between Mbour and Joal. The Mbour center takes care of the drinking water supply of the localities being along the road until Joal, on close to 30 km, passing by Nianing, Mbodiène, Ngazobil. Moreover, there is a connection between Mbour and Somone passing by Saly's reservoir. Saly has, also, the own water tank, R3 with a capacity of 2000 m³. This water undergoes another treatment only disinfection [4]. Figure 6 presents a model of the water distribution system in Petite Cote area.

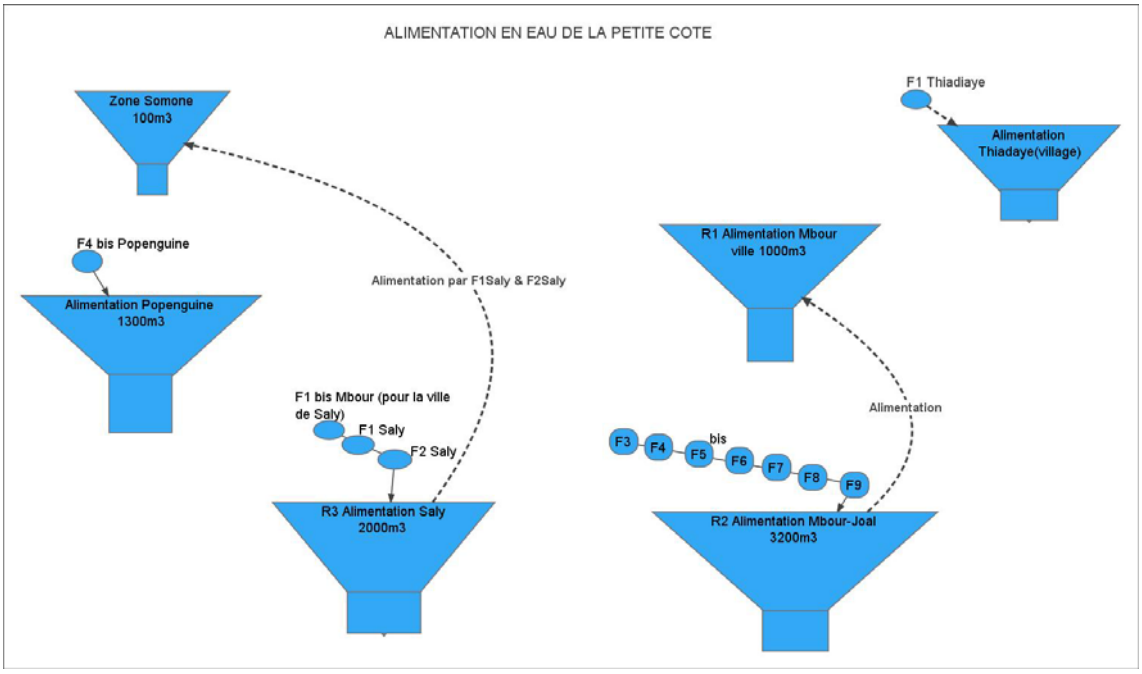

Fig. 6. Model of water distribution system.

3.2.2. Water users

The main identified users are:

- Households that use water for the following purposes: consumption, hygiene, household, trade (selling ice cold water);
- Businesses and professionals including ice-makers, producers of marketed mineral water and hoteliers. The tourism sector is the most important user for consuming large quantities of water, especially during the touristic seasons. In the touristic resorts, the water is used to fill swimming pools, for bathing, cooking, laundry, dishes. To Kirene (on the plateau Diass), water is pumped from aquifers to produce the mineral water with the same name. This type of operation is founded also in Soune Thiambokh in the rural community of Keur Moussa. The exploited resource in this locality has used to produce the Safi mineral water;
- Farmers;
- Services: schools, health stations etc.

3.2.3. Spatial distribution of uses and users of water

The network of the SDE does not cover the entire Petite Cote. It is present in the urban centers such that the town of Mbour. However, it does not cover all the city considering its spectacular extension. The city increases at a vertiginous rate and in parallel, the services like accesses to drinking water do not follow. As a result, an unequal access to water occurs. The network is present in the old urban centre (first district) and on the level of certain habitats planned of the new center (towards Saly). It is non-existent on the level of the limits (blurs) and the irregular districts (example of Baye Deuk, irregular district in Mbour). In these sectors, the use of the ground water prevails. This use is also noted in the rural areas.

We find, also, clean water on the level of the drillings managed by the village committees (which evolved to Associations of the Users of Drilling - ASUFOR), for example in the village of Diass.

The exploitation of mineral water is done in the Northern part of Petite Cote. However, bottled water is used through all the country for drink, by considerable inhabitants, especially in the urban zones.

3.3. The cost of water

The price of water varies according to its different sources:

- Well water: the use is free. However, it is an estimated cost according to the amortization of the initial expenditure (investment) of digging on his lifetime;
- SDE water. The average price per cubic meter rises to 446 Francs CFA [5], but varies in function of consumption:
    1. TS (social rate) for the first 20 cubic meters consumed (191.32 CFA Francs / m^3)
    2. TP (normal rate) which is between 21m^3 and 40m^3 consumed (629.88 CFA Francs / m^3)
    3. TD (deterrent rate) which corresponds to consumption exceeding 40m^3 (788.67 CFA francs per cubic meter).
- Water fountains terminals and resellers: more expensive than the water from SDE. On Petite Cote, this water is used by the poor (who have no means to obtain the connection, or those whose connection to the network has been suspended) and those who are not covered by the network;
- Mineral water produced by local or foreign operators; the local operators pay the cost of pumping. The water is sold in bottles, and it remains the most expensive water.

The drinking water has an economic value, including the cost of maintenance, the exploitation, the distribution, but also of the quality of the service.

3.4. Quality of the resource

The groundwater resources are affected by pollution. They are exposed to the bacteriological pollution, salinisation, Fluor, chlorides and nitrates pollution. We will present the results about the last three forms of pollution.

3.4.1. Fluor pollution

The origin of this pollution is linked to natural levels of phosphate from Eocene in which water circulates. However, fluorine is also present in extracted water in the case of most wells from Paleocene structures. The rate of fluoride allowed in drinking water is 1.5 mg / l, according to WHO (World Health Organization). Beyond this rate, the consumer is exposed to fluorosis. A rate higher than 1.7 mg / l promotes dental fluorosis, which is manifested by a change in the dents email. It changes his color to yellow or brown. The consumer is exposed to the bone fluorosis when the rate of Fluor exceeds 5 mg / l. The high concentration of Fluor also promotes tooth loss and prolonged exposure to a concentration exceeding 10 times the standard causes intoxication. In Figure 7 is presented the distribution of wells with an increased risk of Fluor pollution.

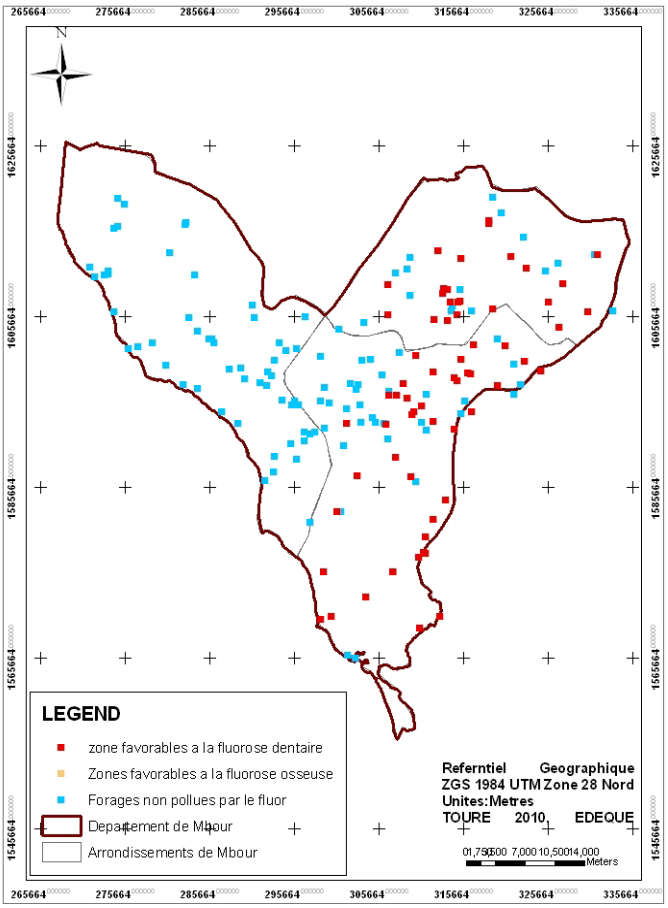

Fig. 7. Map of water extraction points in Mbor region as a function of Fluor content.

3.4.2. Pollution with chlorides

It is favored by contamination of water wells by chlorides and by salinisation of groundwater caused by seawater intrusion or by fossil saline deposits. A chloride concentration above 250 mg / l affects the organoleptic quality of consumed water. It is also an obstacle to the development of activities such as agriculture. According to Mc Neely [6], we should not find more than 150 mg / l in irrigation water. The data about the pollution with chlorides are summarized in Figure 8.

3.4.3. Pollution with nitrates

It is caused by the use of pesticides in agricultural areas. Contamination of water by nitrates is observed at some wells. The agriculture and gardening, practiced in the area, use significant amounts of pesticides. The watering of cultivated surfaces generates, through the infiltration of water, a contamination of the groundwater. The high concentration of pesticides in water leads to an increase in the nitrate proportion. The nitrate contamination of waters of the Maastrichtian is especially noticeable in the areas, where the aquifer is at a low depth and in the seashore, where the groundwater level is low.

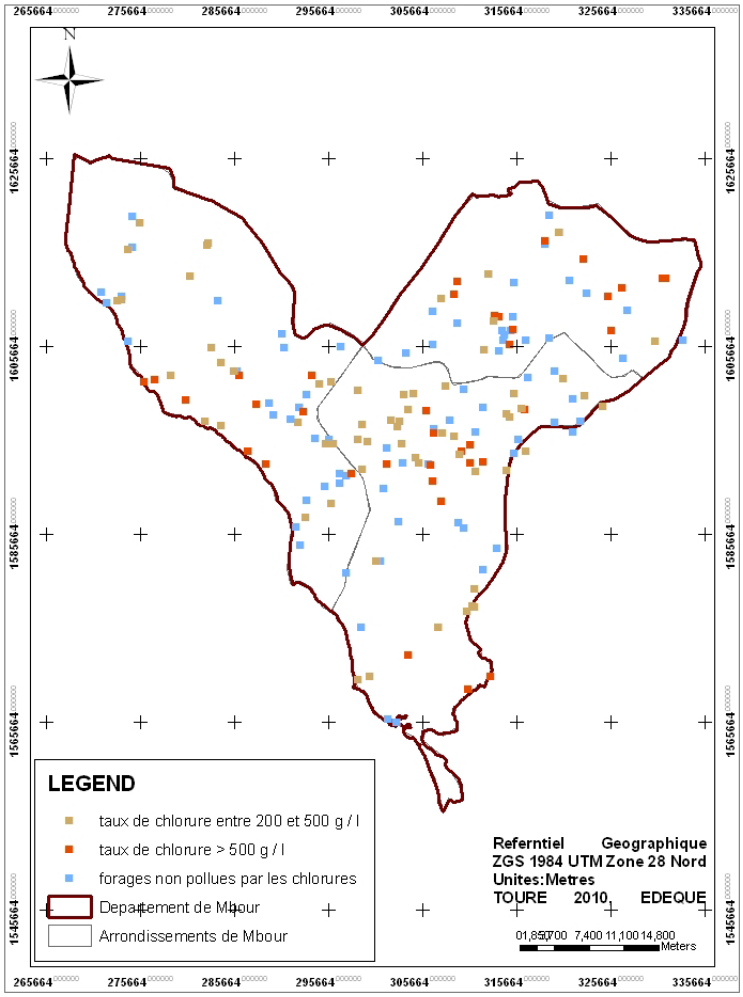

Fig. 8. Map of water extraction points in Mbor region as a function of cloride content.

4. CONCLUSIONS

Our study shows a strong exploitation of subsoil waters of our zone of study. This exploitation involves a fall of the level of the groundwater and a salinisation of fresh waters. Moreover, the absence of the sanitation systems and certain activities such as farming pollute the water. To the entropic pollution must be added the natural pollution of waters with high concentrations of fluoride and salinisation.

It is clear that in the Petite Cote, the rational management of water takes part in the economic and social development of the zone. The major part of the activities turns around water:

- Tourism remains a major consumer of water, especially with the filling of swimming pools and meeting other water needs of tourists;
- Agriculture and horticulture suffering nowadays from water scarcity and salinisation of groundwater caused by over-exploitation of groundwater, lower level, the advance of salty sea water, the climatic deterioration;
- The request of the populations which either do not have access to water and use an unsuitable water being a vector of diseases, or do not have enough water.

REFERENCES

[1] Guide d'application de l'arrêté interministériel du 11 septembre 2003 relatif à la rubrique 1.1.0 de la nomenclature eau, Ministère de L'Écologie et du Développement Durable, France, 2004.
[2] Kane, A., Fall, A.N., Hydrologie, in Atlas du Sénégal, Ed. Jaguar, Paris, 2007.
[3] Danis, M., Quintard, M., Simulation numérique du comportement d'une nappe aquifère captive: estimation directe des processus transitoires, Hydrological Sciences Journal, 32, 1987, p. 105-111.
[4] Cabinet MERLIN, Ingénieurs Conseils, Etude d'identification et de faisabilité d'un programme d'investissement eau potable, Rapport définitif du PEPAM, 2015, financement Agence Française de Développement, 2007.
[5] Blanc, A., Ghesquieres, C., «Secteur de l'eau au Sénégal : un partenariat équilibré entre acteurs publics et privés pour servir les plus démunis», Document de Travail n° 24, Département de la Recherche de l'Agence Francaise de Developpement, 2006.
[6] McNeeley, R. N., Neimanis, V. P., Dwyer, L., Water Quality Source Book. A Guide to Water Quality Parameters. Inland Waters Directorate, Water Quality Branch, Environment Canada, 1979.