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Impact of Hydro-Agricultural Developments on the Layer of Quaternary Sands in the Niayes Area

Cheikh Ahmadou Bamba NDIAYE[1*], Moustapha DIENE[2], Astou Dieng FALL[3]
[1*]Agricultural Sciences and Agrobusiness Department at ISEP Abdoulaye Ly of Thies
[2] Department of Geology Faculty of Science and Technology Cheikh Anta Diop University of Dakar, Senegal
[3]Department of Geology Faculty of Science and Technology Cheikh Anta Diop University of Dakar, Senegal
[1*]Contact person : bamba_agro@yahoo.fr

Abstract— *The layer of quaternary sands in the Niayes area contains significant groundwater resources with exploitable reserves estimated at more than 320 000 m3/d (Travi Y., 1988). Nowadays, it is heavily solicited for domestic, agricultural and industrial purposes. As a result, this aquifer is on the one hand threatened by the increase in excessive withdrawals and on the other hand remains vulnerable to the effects of climate change. This study aims to highlight the impact of hydro-agricultural developments on the layer of quaternary sands in the Niayes area. Certainly, hydro-agricultural developments have allowed the development of intensive agriculture to achieve food sovereignty and boost the local economy. However, the study reveals that they have led to increasing pressure on the layer of quaternary sands, manifested by:*

- *the lowering of piezometric levels;*
- *the salination and mineralization of groundwater;*
- *the pollution by pesticides and fertilizers.*

The study showed local salination, particularly in the south of the study area at Notto, Taïba Ndiaye and Darou Khoudoss, but also in the north at Gandon and Thieppe with values between 117 and 12 340 mg/l. The analysis of certain potential indicator ions of agricultural pollution (NO3-, K+, PO4-) also indicated a real impact of agricultural activities on the quality of the groundwater with nitrate levels varying from 15.65 to 405.90 mg/l, the highest concentrations being recorded in the southern part of the Niayes zone. The analysis of water samples reveals high concentrations of pesticides (between 0.1 and 5µg/l), exceeding the admissible standards (0.5µg/l defined by the EU) in the market gardening areas of Thioukougne, Diokoul Diawrigne, Ouest Notto, Keur Sidy Mbengue and Keur Mbir Ndaw. The interpretation of the results on the entire layer of quaternary sands showed that the main affected areas are strongly related to intensive agricultural activities.

Keywords— *Hydro-agricultural developments, layer of quaternary sands, Niayes, impact.*

I. Introduction

During this 21st century, the effects of climate change are being felt on water resources thus causing shortages and difficulties in their management. However, water consumption continues to increase with population growth.

More particularly, in the area of Niayes, nowadays, we witness the recurrent disappearance of surface water reserves and the drying up of Lake Tanma due on one hand to droughts experienced during the years 1970 to 1990 but especially related to the continuous decline in rainfall.

The aquifer system of the quaternary sand sheet of the northern coast is currently severely stressed by anthropogenic action, agricultural and industrial activities. The level of the sheet is in a clear regression favoring, in places, the advancement of the salty bevel. This state of affairs negatively impacts vital environmental resources, agricultural and economic activities as well as the well-being of populations.

The situation remains very worrying and requires urgent solutions based on hydrogeological and hydrochemical investigations in order to ensure rational and sustainable management of the aquifer in the Niayes area.

It is in this broad perspective that this research theme entitled: «Impact of hydro-agricultural developments on the layer of quaternary sands in the Niayes area» is written.

Our research work contributes to the quantitative and qualitative study allowing optimal management of the quaternary sands in the Niayes area.

II. Materials and Method

2.1 Description of the study area

It is located in the western part of Senegal between latitudes 15° and 16°08' North and longitudes 16°13" and 17°17' West. Occupying the free Atlantic of the Senegalese coast, it extends over 180 km long and 5 to 30 km wide from the North Shore of Kayar to Saint-Louis covering an area of 2300 km^2 (PADEN, 2017). Indeed, it is limited to the west by the Atlantic Ocean and to the east by the national road Thies, Saint-Louis. Administratively, the study area covers three administrative regions: Thies, Louga and Saint Louis.

The study area is characterized by the alternation of two main seasons:

- a rainy season of three to five months located between the months of June and October and;
- a dry season for the rest of the year.

Outside the rainy season, sometimes there can be low precipitation known as "Heug". On average, the Niayes area is located between the isohyets 200 mm in the North and 500 mm in the South.

2.2 Water resources of the area

Nowadays, water resources in the Niayes area mainly come from the groundwater table, rainwater supply and some surface waters.

2.2.1 Rainwater

Currently, with climate change and the environmental pressure of the area, we are witnessing an interannual irregularity in precipitation marked by a decrease in precipitated volumes which has resulted in a remarkable shift

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of isohyets towards the south. Indeed, the Niayes area is on horseback with two rainfall regimes:
- the northern Sahelian regime with rainfall less than 300 mm;
- the southern Sahelian regime with rainfall between 300 and 500 mm.

According to table 1, we see that the region of Thiès is the most watered in the area followed by Louga. During the decade 1983-1992, there was a drop in rainfall throughout the area. However, from 2000 onwards, there was an increase in recorded precipitation.

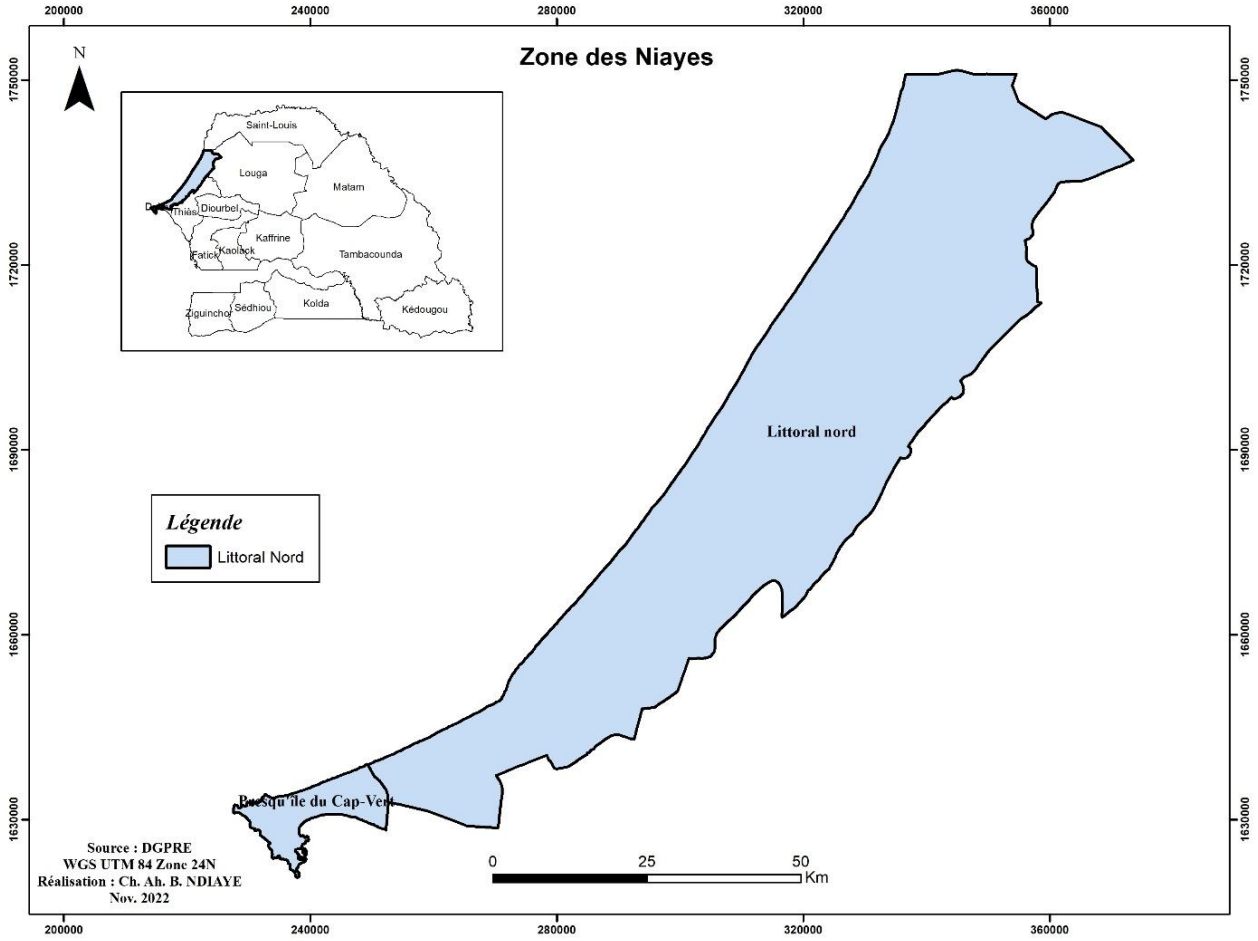

Figure 1: Location of the study area

TABLE 1 : Evolution of rainfall by decade from 1973 to 2022

Rainfall (mm)			
Decades	**Thies**	**Louga**	**Saint louis**
1973-1982	4782.1	2945.7	2349.3
1983-1992	3906.5	2830.1	1942.9
1993-2002	4561.7	2880.7	2617.5
2003-2012	4884.5	3395.4	3185.1
2013-2022	4420.1	3629.2	2737.3

2.2.2 Surface waters

The territory of the NIAYES zone does not present any real river flows. Indeed, it is practically devoid of significant surface water resources. Only the northern part bordering on the delta of the Senegal River contains a larger portion of surface water. However, the invasion of seawater in the delta makes this water unfit for consumption and even affects nearby groundwater. However, the morphology of the area suggests the existence of ancient river valleys perpendicular to the coast. In the south, we observe the presence of many lakes, which were invaded by the sea during the transgression of Nouakchottien.

Despite the various siphonings carried out on surface waters, mainly agricultural and industrial activities, no precise evaluation has been carried out in order to better control the volumes exploited. Yet these data are very important for proper planning and management of water resources. Moreover, climate change and environmental aggression have contributed to the disappearance of certain surface water resources that have become increasingly scarce. Currently, the water resources of the Niayes area mainly come from groundwater.

2.2.3 Groundwater

The layer of quaternary sands on the northern coast, which covers significant exploitable reserves estimated at more than 320 000 m^3/d (Travi Y., 1988) is a free aquifer that presents interesting performances with boreholes capable of providing up to more than 100 m^3/h with less than 10 m drawdown (Dieng, 1987). The vast majority of works in the area have specific flows between 5 and 10 $m^3/h/m$. The largest flows between 10 and 40 $m^3/h/m$ are located on one side to the east of the rural communities of Méouane, Kab Gaye and to the north

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of the rural communities of Ndiokoul Ndiawrigne and Bandeigne.

2.3 Method

The methodology adopted is based on the collection and analysis of existing data from previous work and their updating followed by an analysis allowing to identify the main impacts related to hydro-agricultural developments. The hydrogeological data of the area are obtained at the level of the DGPRE. We have hydroclimatological data from the stations of Thies, Louga, and Saint-Louis taken between 1973 and 2022.

The number of works sampled is equal to 29 consisting of 27 piezometers and 2 boreholes. The samples at the level of these structures were taken in July 2022.

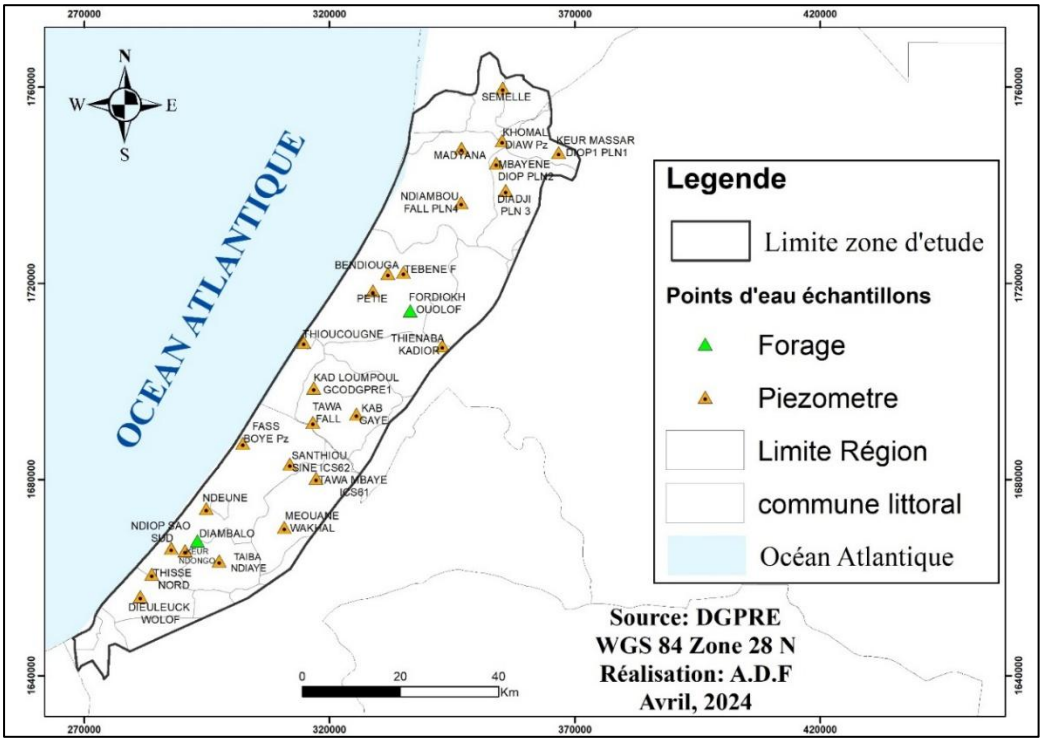

Figure 2: Spatial distribution of monitoring structures

For this study, the evaluation of the impact of agricultural activities on the quality of the superficial aquifer of the Niayes necessarily passes through the analysis of certain specific ions: NO_3^-, K^+ and PO_4^{3-}. Indeed, these ions were selected because of their direct link with agricultural practices, their low content in unpolluted groundwater and their potential influence on the geochemistry of the aquifer. Their analysis thus allows a better understanding of the effects of agricultural activities on groundwater quality. In the same dynamic, we determined the sodium absorption rate (SAR) which represents the amount of sodium ions compared to the amount of calcium and magnesium ions in water. It is influenced by the salinity of the water, the higher the salinity will be, the greater the SAR index. The SAR informs us about the suitability of waters for irrigation and is determined by the following formula:

$$SAR = \frac{Na+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

After processing, data processing and analysis will be carried out using tools:

- Microsoft Excel for calculations and graphic constructions;
- Microsoft Word for word processing.

The study will require the implementation of a database managed by a geographic information system (GIS), including Arcview 3.3 software.

III. Results

3.1 Increasing pressure on the layer

3.1.1 Interannual evolution of the rainfall in the area

From 1973 to 2022, the average annual rainfall in the study area is estimated at about 340mm. However, the region of Thies remains the best watered with an average annual rainfall of 451mm. The northern zone is less humid and has lower than average annual rainfall (340.45mm). Indeed, the regions of Saint Louis and Louga record 256.64mm and 313.62mm respectively.

3.1.2 Agricultural activities

Agriculture is the dominant activity in the NIAYES area and is practiced throughout the year.

a) Evolution of agricultural production

In the region, agriculture is essentially dominated by the horticultural sector which plays a strategic role in meeting the country's consumption needs and accounts for about 80% of Senegal's horticultural exports.

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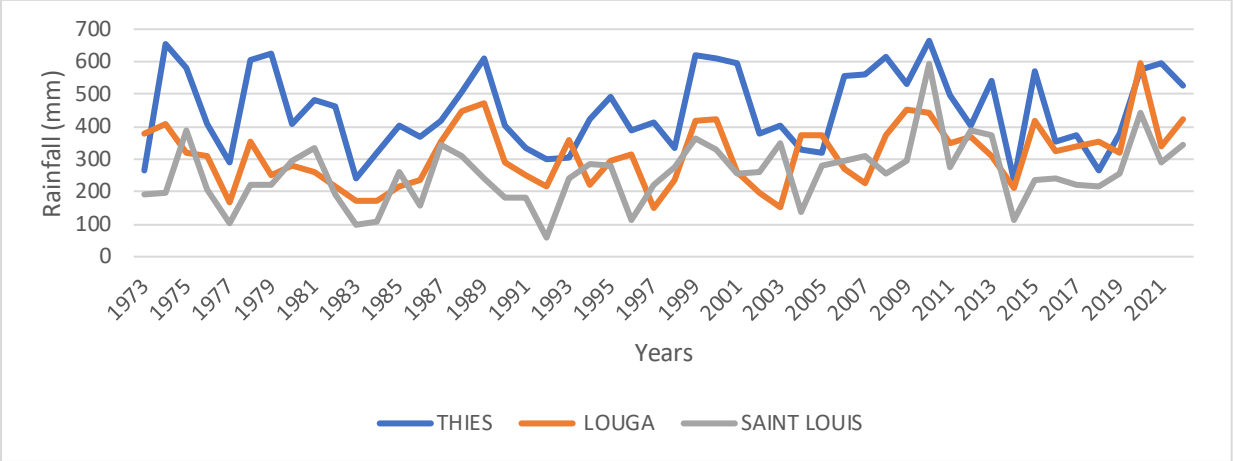

Figure 3: Interannual variations in rainfall at the stations of Thies, Louga and Saint Louis from 1973 to 2022

TABLE 2: Evolution of horticultural productions in Senegal in tons

Crops	Horticultural production 2016/2017	Horticultural production 2017/2018	Horticultural production 2018/2019	Horticultural production 2019/2020	Horticultural production 2020/2021	Horticultural production 2021/2022	Average production from 2017 to 2021
Onion	400 000	434 112	444 871	412 305	435 000	420 000	425 258
Potato	118 783	140 000	158 875	147 985	143 640	140 500	141 857
Industrial tomato	70 000	77 000	73 048	65 850	88 350	84 000	76 375
Cherry tomato	68 000	71 000	78 396	69 560	66 700	67 000	70 109
Melon	28 000	24 532	26 632	24 850	25 308	25 500	25 864
Green bean	18 700	18 815	20 879	19 560	21 122	20 300	19 815
Cabbage	76 116	105 096	105 096	158 412	159 166	155 000	120 777
Gumbo	14 500	14 000	22 115	23 112	21 250	21 500	19 413
Sweet potato	72 000	89 397	72 000	89 730	107 670	110 600	86 159
Carrot	16 000	17 085	17 875	22 300	30 000	28 500	20 652
Bissap	1 300	1 500	1 678	1 510	1 500	1 480	1 498
Other vegetables	200 000	209 751	215 875	208 960	205 000	195 500	207 917
Total/Vegetables	1 083 399	1 202 288	1 229 225	1 244 134	1 304 706	1 269 880	1 212 750
Mango	132 000	128 450	130 000	121 000	122 905	121 500	126 871
Banana	30 000	31 422	33 110	36 500	35 500	36 000	33 306
Citrus fruits	45 000	48 500	52 580	56 800	58 000	58 400	52 176
Other fruit trees	30 000	35 700	59 750	61 350	62 550	61 500	49 870
Total/Fruits	237 000	244 072	275 440	275 650	278 955	277 400	262 223
Total fruit and vegetables	**1 320 399**	**1 446 360**	**1 504 665**	**1 519 784**	**1 583 661**	1 547 280	**1 474 974**

Source : Directorate of Horticulture, 2022

b) Typology of operators

Agriculture is the dominant economic activity of the local populations and is more practiced by the age group 40 to 50 years

Market gardening is the main activity of the area, about 60% of vegetable production in Senegal comes from the Niayes. This production, through the value of its deliveries and the employment it generates, is of paramount importance. Market gardening is practiced in the coastal territory of the Niayes, located largely in the yellow dunes, on about 9 640 hectares (DGPRE, 2014). Mainly, three types of market garden farms exist depending on the size and development mode:

- small farms: characterized by exploitable areas of less than one hectare and are most often individual farms and not family farms;
- the average farms (between 1 and 20 hectares) and;
- modern farms that are very large and can reach or exceed 50 hectares.

The census of horticulture in the Niayes area of 2022 distributed in the administrative regions of Dakar, Louga, Saint Louis and Thiès from the territory of Niayes showed that the horticultural operators of Niayes are mainly located in the region of Thiès with 50.3%, followed by the region of Louga with 25%. The regions of Dakar and Saint Louis have fewer horticultural operators and cover 12.4% and 12.3% respectively.

Anyway, the number of horticultural operators and production sites continues to explode with the strong migration of populations, investors and also given the economic and ecological potential of the Niayes area.

c) Hydro-agricultural developments

According to the DHORT censuses in 2022, four irrigation systems stand out particularly in the Niayes area, of which the most common is the manual system, representing 82% of practices on horticultural farms. It includes irrigation with a watering can and a lance. Then we find the drip system, gravity, sprinkling, and irrigation with the skate, which are less used.

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The laser system is also starting to spread in the region. The spatial distribution map of irrigation systems (figure 5) shows that in Taïba Ndiaye 15% of farmers use the gravity system compared to 49% of other undefined irrigation systems and the manual system also occupies a significant place and in Keur Moussa the drip system is also practiced by 15% of producers. Among these types of irrigation, the manual system seems to be the least economical in terms of water resource use. Indeed, with this irrigation system, water losses are very significant because the producer often makes approximations based on their experience, which can have an impact on the sustainability of the resource. In case of excessive or poorly controlled irrigation, there is a risk of leaching of products. chemicals towards the aquifer and therefore an impact on the quality of the aquifer. Yet it is the most widespread in the Niayes area.

Nowadays, irrigated agriculture continues to intensify in the area and there is an unlimited increase in catchment structures (drilling, mini drilling, wells) characterized by a strong water mobilization capacity. These hydro-agricultural developments have considerably increased the withdrawals from the layer of quaternary sands.

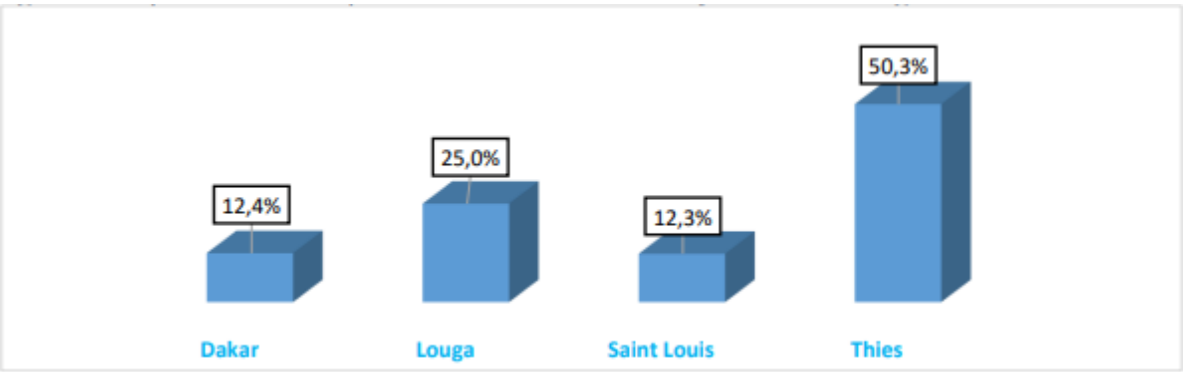

Figure 4: Distribution of horticultural operators by region in the Niayes area

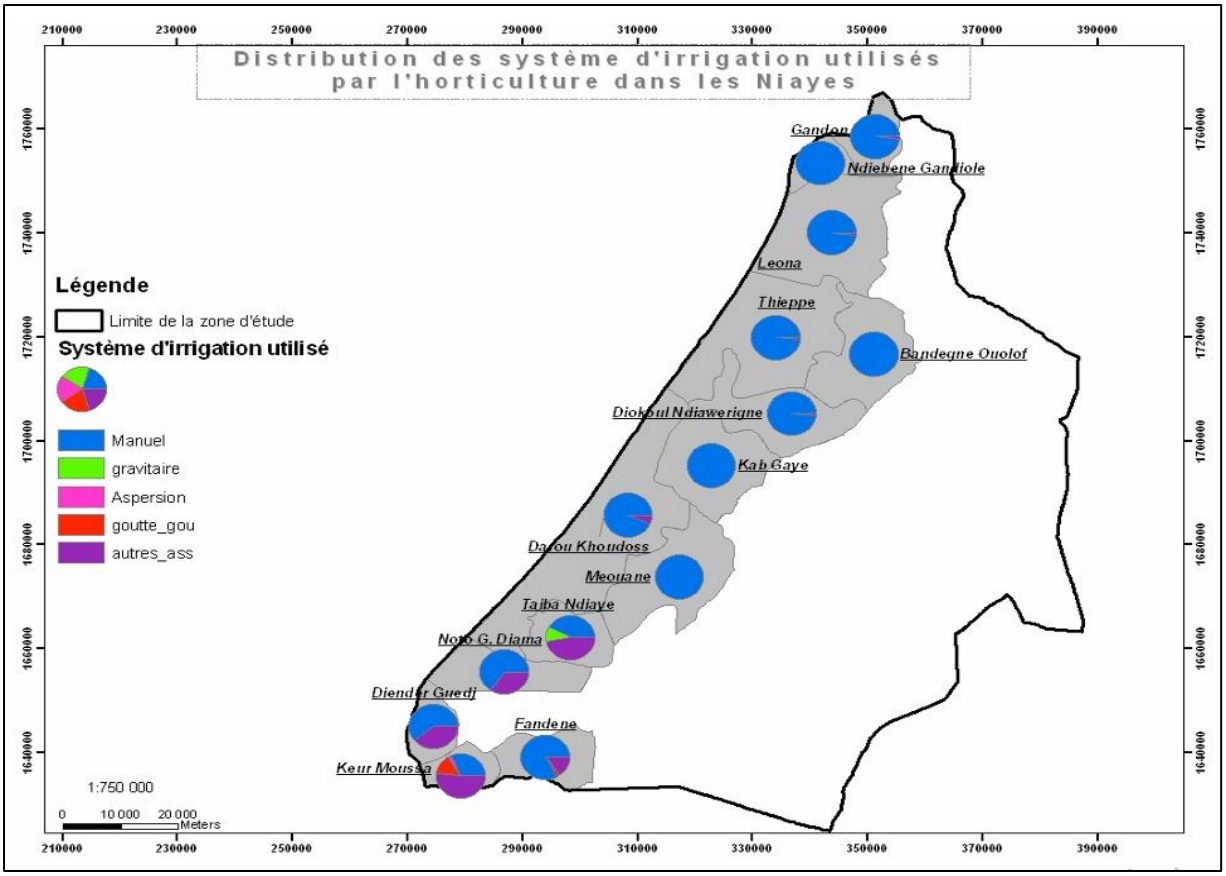

Figure 5: Spatial distribution of irrigation systems used in the Niayes area

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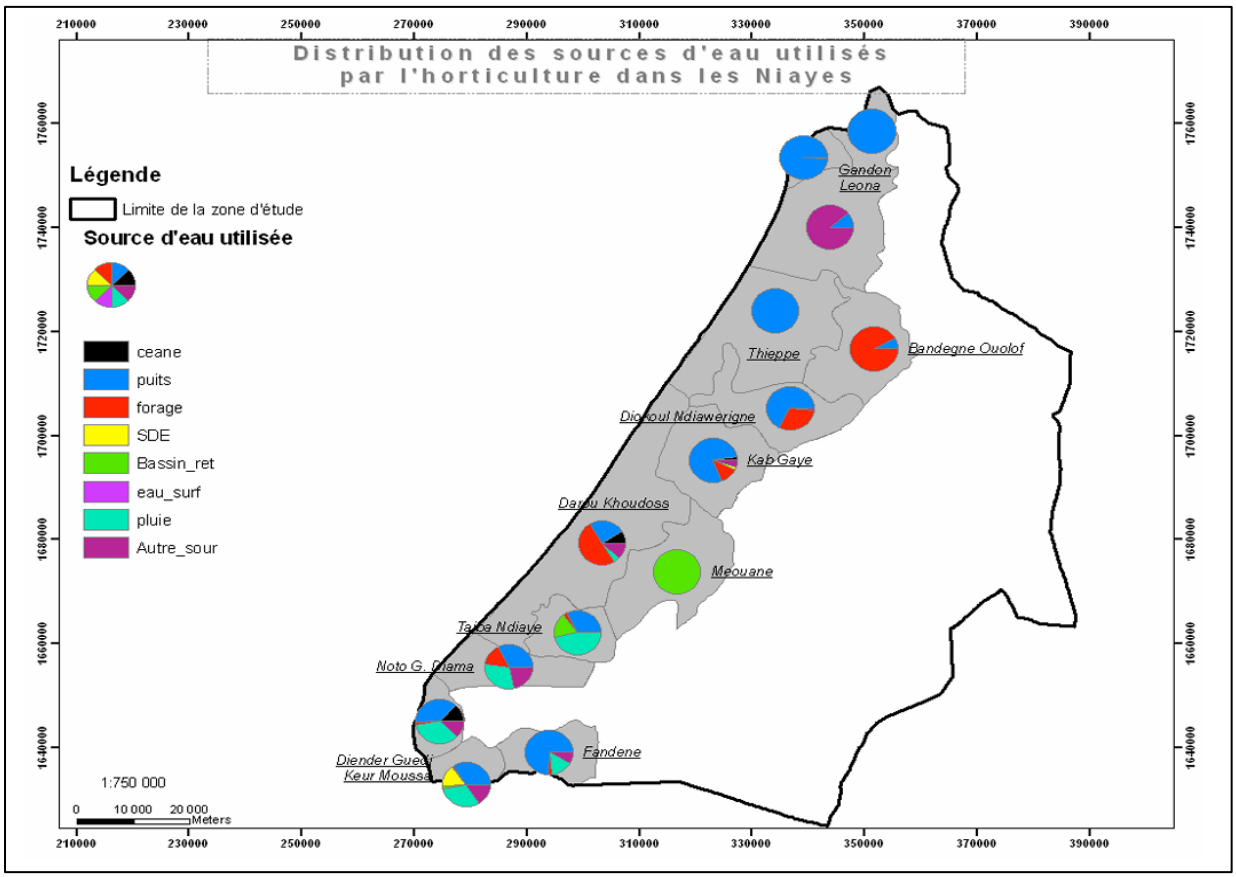

Figure 6: Distribution of water sources used in horticultural production

The agricultural sector remains a major consumer of water from the quaternary sand layer in the Niayes area, approximately 65 282 400 m^3/year, followed by urban supply with 28,056 820 m^3/year (DGPRE, 2014). At this rate of intensive exploitation of the water table, which continues to increase with the population growth of the area endowed with immense potential for hydro-agricultural development, the quaternary sand table runs the risk of saline upwelling in certain places of high demand.

The sustained exploitation of the groundwater, often in the absence of strict regulation and hydrological monitoring mechanisms, tends to promote a gradual decrease in the piezometric level, particularly during dry years. This phenomenon can often be aggravated by a limited recharge of the aquifer, linked to the semi-arid climate and the growing urbanization of the Niayes which reduces the surfaces of natural infiltration.

3.2 Impact on the hydrochemistry of the groundwater

3.2.1 Evolution of electrical conductivity

In the study area, the electrical conductivity of the layer of quaternary sands varies from 117 to 12,340 µS/cm; however, the values recommended by the WHO are less than 900 µS/cm characterizing freshwater. According to figure 7, we note that the lowest values are located in the center and northeast, notably the municipalities of Ngueune Sarr, Badegne Ouolof, Sakal, Léona, Kab Gaye, and Thieppe. On the other hand, the high values of electrical conductivities are located in the south near notably the municipalities of Notto Gouye Diama, Taïba but also in the north at Gandon and Thieppe.

These salt water foci are mainly located in agricultural areas. Indeed, the degradation of the aquifer is largely linked to hydro-agricultural developments. The increase in the degree of mineralization of a aquifer is generally due to saline intrusion or leaching of surface salts. Therefore, this pollution noted at the level of these structures in the agricultural perimeters would be due either to local intensive groundwater operations for agricultural needs in these regions leading to a reversal of flow and thus a saline intrusion, either to a leaching of surface salts from fertilizer products used in agricultural practices.

3.2.2 Distribution of specific ions: NO_3^-, K^+ et PO_4^{3-}

d) Nitrates: NO3-

Nitrates are products of nitrogen oxidation by microorganisms in plants, soil or water. In groundwater, the presence of nitrates is generally due to leaching by precipitation of nitrates naturally produced in the soil or provided in the form of fertilizer. Their concentration in groundwater is less than 10 mg/l (Afssa, 2004).

According to figure 8, nitrate contents vary between 15.65 and 405.90 mg/l. The lowest values and significantly lower than WHO recommendations are noted at works located far from the coast (Ngeuneu Sarr, Kab Gaye, Meouane). On the other hand, the highest values are mainly located in the south (Notto, Mboro) and at the level of a few structures in the north and center.

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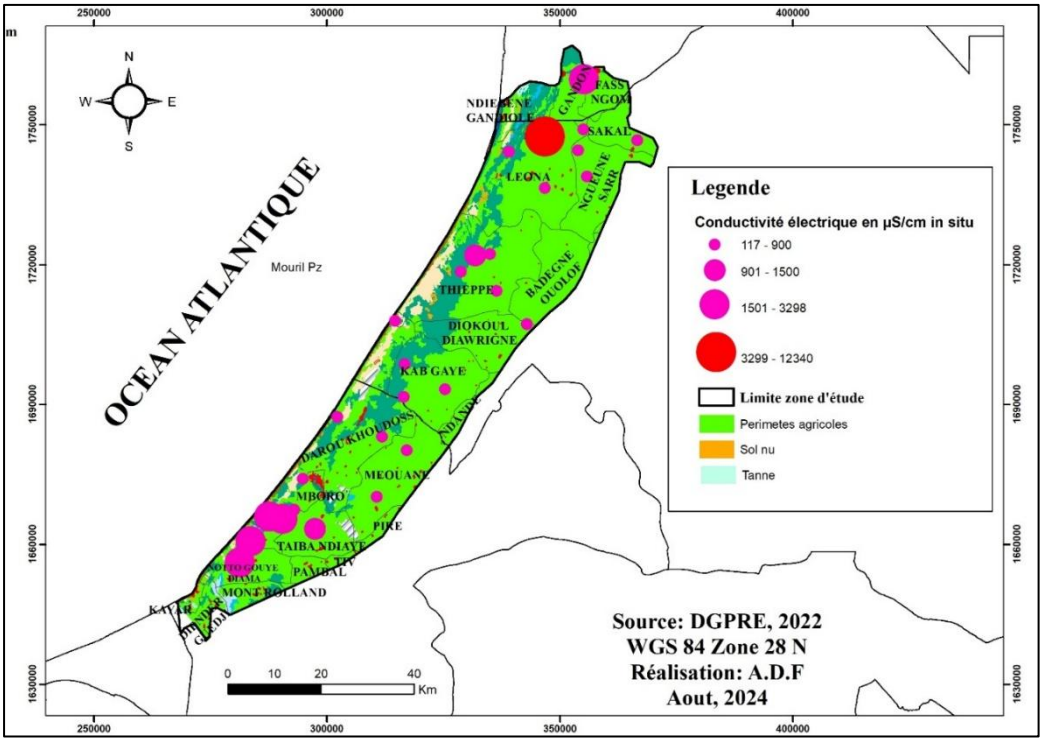

Figure 7: Spatial distribution of follow-up works

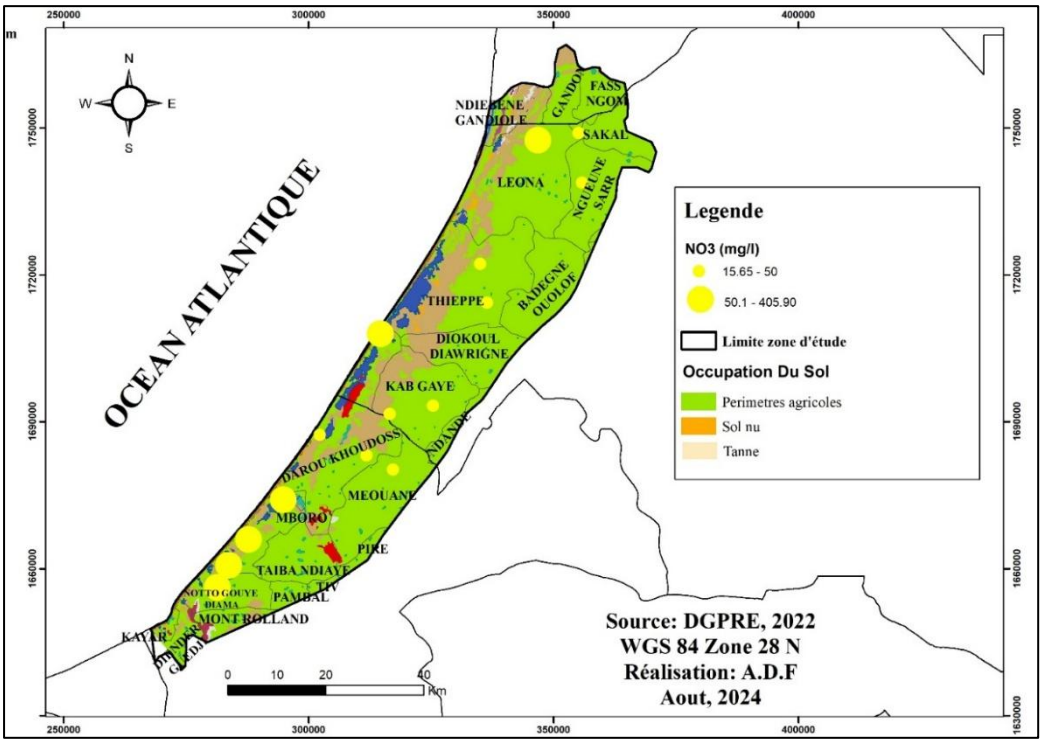

Figure 8: Distribution map of nitrate concentrations in mg/l according to land use

The distribution of these nitrate levels according to land use shows that all structures with NO3- contents higher than WHO recommendations are located in agricultural areas. This indicates local groundwater pollution induced by agricultural practices.

e) *Potassium:* K^+

According to Figure 9, the potassium concentration in the layer of the quaternary sands of the North Coast is relatively low and varies between 0.09 and 6.61 mg/l with the exception of hydro-agricultural development areas located in the municipality of Darou Khoudoss with concentrations that

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exceed 2 mg/l. Indeed, these high concentrations recorded are due to the extensive use of potassium fertilizers.

f) Phosphate : PO_4^{3-}

Figure 10 shows that in the study area, phosphate concentrations are low and range from 0.172 to 0.396 mg/l significantly lower than the allowable concentration for irrigation water (less than 2mg/l). Thus for this phosphate ion (PO_4^{3-}), we do not note a contamination of the water in the layer of the quaternary sands.

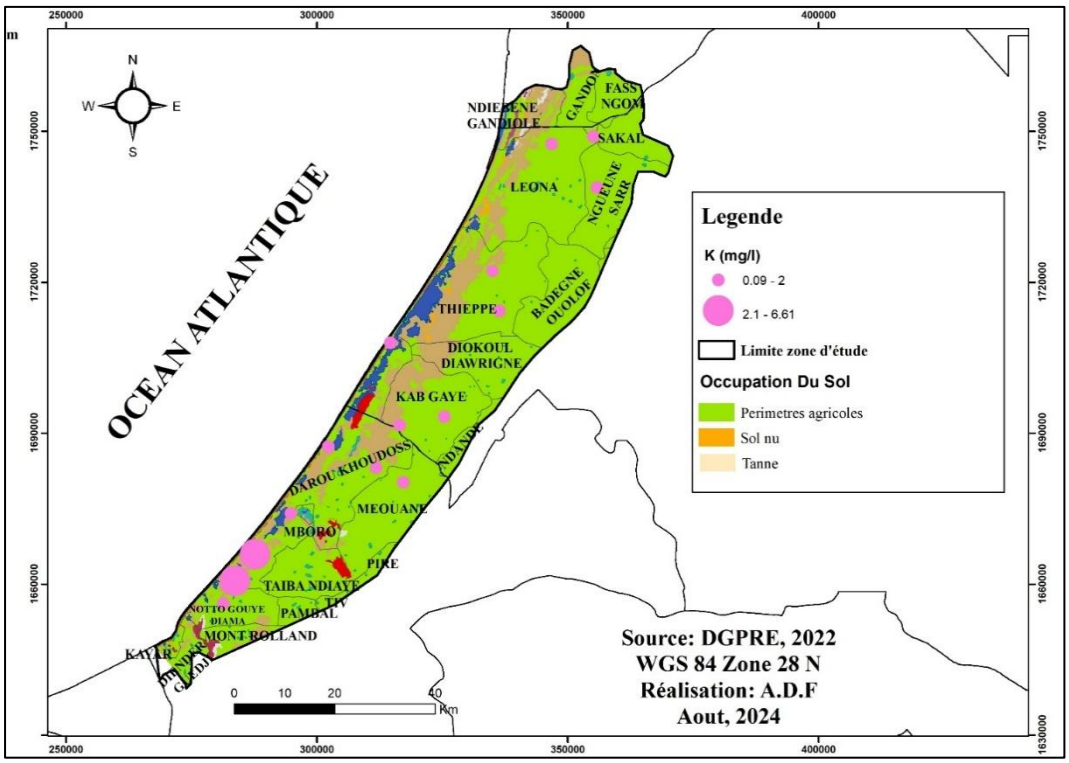

Figure 9: Spatial distribution of potassium concentrations in the groundwater as a function of land use

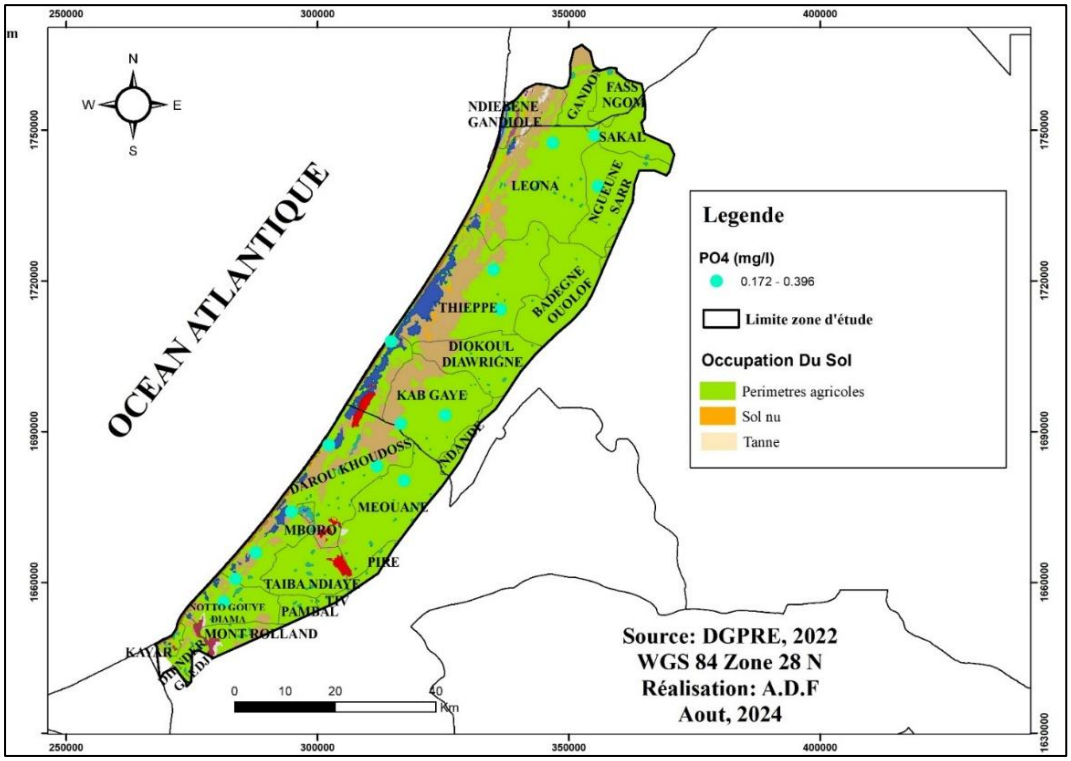

Figure 10 : Spatial distribution of PO43-(mg/l) concentrations as a function of land use

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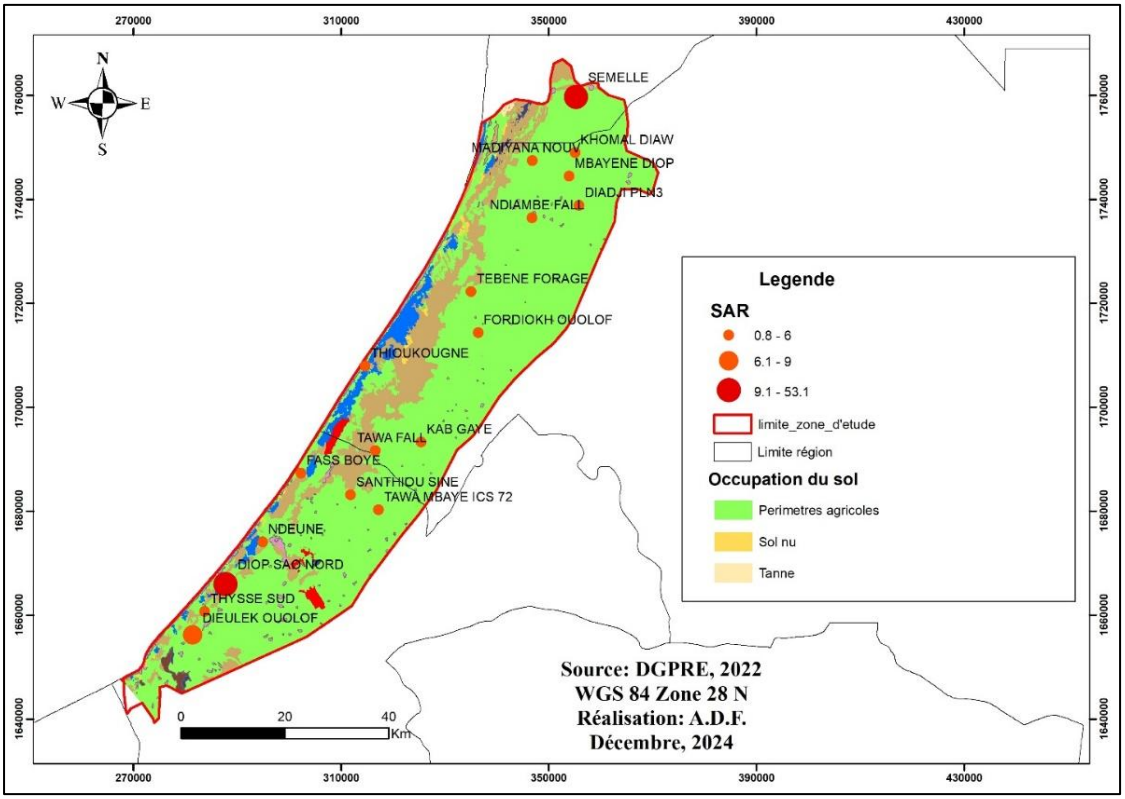

Figure 11 : Spatial distribution of the rate of sodium absorption from the layer of quaternary sands in the Niayes area in July 2022

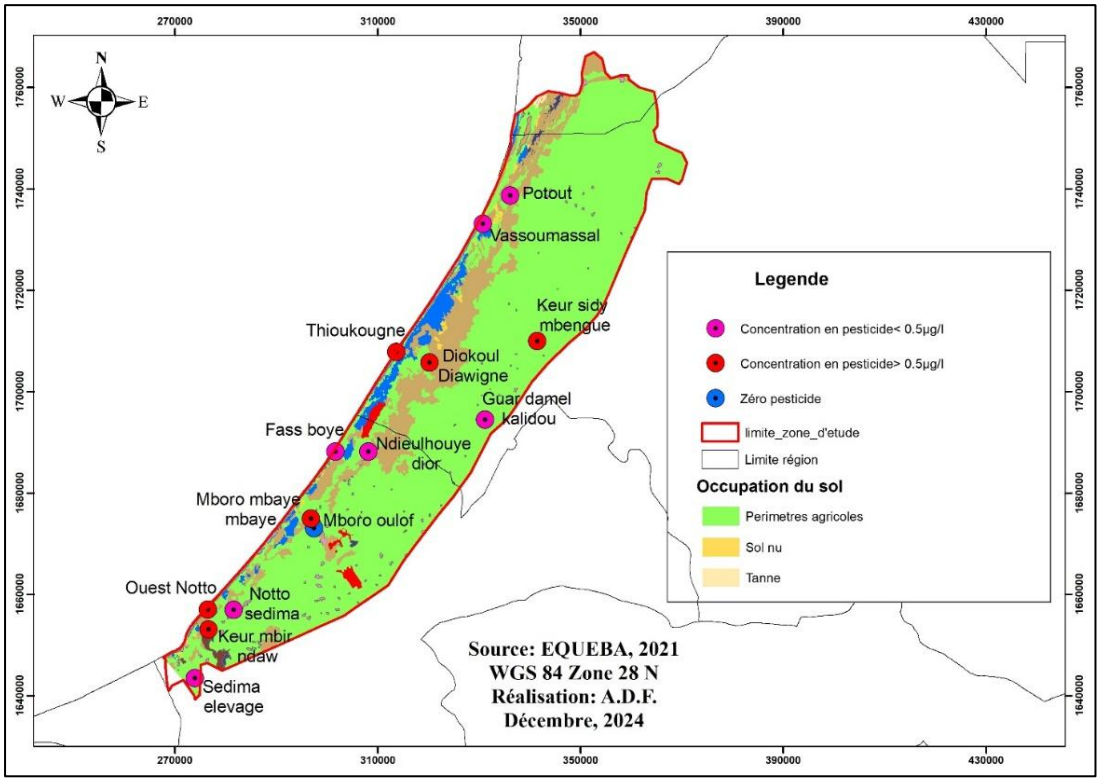

Figure 12 : Spatial distribution of pesticide concentrations based on land use

g) Sodium absorption rate (SAR)

According to Figure 11, the SAR values of the quaternary sand layer are generally low and between 0.8 and 6. Generally, the study area has waters suitable for irrigation (SAR<6). However, we note high values in structures located at Dieuleuck Wolof (SAR between 6.1 and 9), to the north at

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Semelle and at Ndiop Sao located to the south in the Thiès region with SAR greater than 9. For the latter, the waters are not favorable for irrigation of crops sensitive to salinity. We note that all of these high SAR structures are located at the level of hydro-agricultural development areas close to the sea.

3.3 Water contamination related to pesticide use

In the area, agriculture is essentially conventional characterized by the excessive use of mainly chemical inputs, the most used being (10-10-20), (15-15-15), urea, DAP (di-ammonium phosphate 18-46-00) and phosphate. However, producers also use organic fertilizer (especially manure) for bottom dressing. The leaching of these inputs by irrigation and precipitation could increase the concentrations of potassium and nitrates in the aquifer, which can lead to disturbances in its chemical composition.

In addition, pesticides are used to protect crops against the attacks of pests such as insects, weeds and fungi.

According to several studies carried out by CERES Locustox, five categories of pesticides are the most frequently used: organochlorines, organophosphates, dinitroanilines, pyrethroids and uracils.

There are also bio pesticides, exclusively composed of organic products, but little used due to their limited quantity (example, the rapax used against the caterpillar). These many pesticides used can also be a source of degradation of the quality of the surface water when they are washed off by precipitation or excessive irrigation.

Uncontaminated groundwater is normally free of pesticides. According to figure 12, out of the twelve samples taken in the layer of quaternary sands, six have levels of pesticides that exceed the allowable rates in total pesticide concentrations indicated by the EU (0.5 µg/l). These are the localities: Thioukougne, Diokoul Diawrigne, Ouest Notto, Keur Sidy Mbengue and Keur Mbir Ndaw where molecules such as Beta-HCH, Bifenthrin, Lambda-Cyhalothrine, Profenofos, DDT and Endosulfan have been detected in waters.

The presence of pesticides in the waters of the quaternary sands is strongly linked to agricultural activities. Indeed, the contaminated waters are located in market-gardening areas where many pesticides are used for phytosanitary treatment. Obviously the excessive use of these inputs, especially chemical ones, pollutes the waters but also threatens human health.

IV. Conclusion

The Zonde of Niayes contains significant water resources and immense economic and environmental potential marked by the increasing population, the strong presence of farmers and industrialists.

The study shows that hydro-agricultural developments have had significant, direct and indirect effects on the water table of quaternary sands. On the one hand, the implementation of irrigation systems and water reservoirs has allowed an intensification of agricultural production, essential for local food security and job creation. However, this transformation of the hydric landscape has been accompanied by an increase in water withdrawals and increased pressure on the aquifer resource. This situation promotes the decrease of the piezometric level and the risks of saline rise in certain places with high consumption of irrigation water.

Hydrochemical analyses show notable increases in physico-chemical parameters, with high levels of electrical conductivity (117 to 12,340 mg/l), reflecting high salination of the aquifer, particularly in localities near the coast (Notto, Taïba, Mboro...).

Moreover, the intensive use of agricultural inputs and the lack of effective drainage systems create risks of contamination of the aquifer, especially by nitrates and pesticides, compromising the quality of water for domestic and agricultural uses. It is especially noted in certain localities of the southern part of the Niayes zone (Notto, Mboro) where concentrations exceed the potability standards (50mg/l for nitrate and 0.5 µg/l for pesticides).

The vulnerability of the quaternary sands to hydro-agricultural developments imperatively requires the adoption of integrated water resources management strategies, combining:
- regular monitoring of piezometric levels and the quality of the water table;
- water-efficient agricultural practices;
- policies for the regulation of levies;
- artificial recharge measures where relevant.

These actions will make it possible to reconcile agricultural productivity and long-term preservation of the aquifer, ensuring hydric and environmental sustainability in the Niayes area.

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