

# Assessment of environmental impacts due to reuse of untreated wastewater in periurban agriculture of Dakar, Senegal

*Final report for the grant “Young Scientists” 2003*

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## Abstract

Urban agriculture (UA) occurs in most developing countries and contributes not only to food security and poverty alleviation, but also to public health and sustainable resource management. It produces cheaper and more diverse food, more green space in cities, improves sanitation by recycling wastewaters and creates additional income for households. However, urban agriculture can have both positive and negative impacts on public health and environment:

- Health risks: abuse of pesticides and chemical fertilisers, use of contaminated waters or wastes (for market gardeners in contact with pesticides and untreated waste water, and for population eating fresh vegetables and drinking ground water).
- Environmental risks: impacts on soil quality and on surface and ground waters.

In Senegal, as in many other semi-arid countries of West Africa, municipal waste waters are often used for irrigation in suburban areas. This practice has the advantage of solving the problem of scarcity of water and resulting in accelerated growth of crops, but, on the other hand, bears considerable risks for microbial and chemical contamination for farmers, consumers, soils and ground waters.

Several UA sites have been investigated in the suburbs of Dakar: Pikine, Patte d'Oie, Ouakam, Thiaroye, Mbao and Mbeubeuss. They are all located in the *Niayes* ecosystem, a 10km wide coastal zone of dunes and wetlands. The dunes are dominated by permeable sandy ferruginous soils with maximum 4% organic matter in their top layer. In the lower zones, hydromorphic organic soils and acidic-sulphate soils are found. The ground water, slightly saline (up to 6 permil), shows shallow levels between 1 and 5 m. Natural biodiversity was important, but is decreasing due to human activities.

Irrigation is applied twice a day by traditional hand-sprinkling, either with only waste water or waste water mixed with local groundwater. The wastewaters are typically slightly reducing and contain high amounts of suspended solid matter (1600 mg/l), carbon (1500 mg/l DOC), nitrogen (200 mg/l  $\text{NH}_4^+$ ) and phosphorus (50 mg/l  $\text{PO}_4^{3-}$ ). Their heavy metal content is astonishingly low (most elements are below 10 microg/l, except Zn and Cu (max. 100 resp. 70 microg/l)). This shows that they are mainly domestic wastewaters. Their microbiology is dominated by enterobacteria (*E.coli*, *Shigella*, *Salmonella*) which is also found on the grown vegetables. FISH-results also indicate the presence of enterobacteria-DNA at up to 60 cm soil depth (Ndiaye, 2005). The decreasing Zn values point to the same average depth to which components of the waste water apparently typically migrate before they are either consumed by plants or evaporate.

The Thiaroye shallow ground water is contaminated by nitrates, chlorides and ammonium (resp. 370mg/l, 470mg/l and 18 mg/l, n=20) due to inadequate household sanitation equipment and intrusion of saline water. Cissé (2000) reports that pesticides reach a considerable level in this ground water, leading to risks for public health. Up to 160 microg/l has been found in wells, which is 300x the WHO guideline for drinking water.

A network of piezometers in suburbs and recently installed free flow lysimeters and piezometers on periurban agricultural sites will allow more precise quantification of pesticide in groundwater and its accumulation in the soils. All data, including physical characteristics of sites, socioeconomic data provided by enquiries and all results from agronomical, epidemiological and microbiological analysis done by partners in Senegal will be included in a Geographic Information System (GIS). This GIS will constitute a useful tool for city planners to consider the specificities of the *Niayes* in the master plan of Dakar urban development.

# 1 Introduction

## 1.1 Urban agriculture practices

In numerous developing countries, the urban population is exploding, from 20% in 1970 to more than 50% nowadays (OECD, 1997). Therefore, urban poverty is also growing and leads destitute populations to launch new income-generating activities, such as urban or periurban agriculture. Specialists estimate that 200 million of people in the developing countries survive today thanks to urban agriculture. According to Milstone and Lang (2003), 60% of the need in vegetables in Dakar is produced in urban zones; 36% of the families of Ouagadougou, Burkina Faso are employed in UA; in Shangaï, China, 100% of milk, 90% of eggs and 60% of vegetables are produced in urban zones, thus employing 20% of inhabitants; 37% of the families of Dar Es Salam, Tanzania, produce 90% of the leafy vegetables consumed on 23% of the city land. Irrigation is often provided with waste water coming from sewage, as in Mexico, where 80% of the irrigation in urban zones is furnished by sewage.

It has been established by many scientists that this ancient and worldwide practice of re-using untreated waste water has many effects, both positive and negative ones.

Positive effects:

- Owing to the lack of water in several Sahelian countries and to the considerable need for water for agriculture (70% of water use), it is a precious source of water for irrigation.
- Because of the high price of water in Sahelian countries, market gardeners can save a great deal of money by using waste water diverted from domestic sewage.
- As waste water contains a high level of organic matter, nitrogen, phosphorous and potassium, its reuse can reduce the need for manure in poor sandy tropical soils.
- Owing to the lack of treatment plants, a high proportion of wastewater re-use in urban agriculture, as in Mexico, could lead to sustainable recycling of waste.
- The cycle of vegetative production is shortened, so agronomic efficiency is presumably doubled.

Negative effects:

- One consequence for market gardeners irrigating with waste water is the direct contact with microbiologically contaminated water which can cause health problems (skin irritation, asthma, ankylostoma, schistosoma).
- It has been recognised by many authors (Cissé, 1997; Baumgartner et Belevi, 2000 ; Gaye et Niang, 2002) that also crops irrigated with waste water are bacteriologically and parasitologically contaminated. Uncooked vegetables are often badly rinsed in deprived households. As a consequence, oral contamination can occur and even increase poverty when health costs rise.
- There is a likelihood of micro organism reaching the ground water
- Urban agriculture contributes to critical contamination of the groundwater by nitrate and microcontaminants (pesticides such as DDT, aldrin, chlordane, dieldrin, hexachlorohexane, prohibited but still in use in developing countries).

Consequently, public health is involved, since neighbouring wells are still used for drinking water.

- An excess of waste water brought into some categories of soils can produce warping and an ensuing loss of fertility.
- If effluents from industries or craftsmen's activities are mixed with domestic sewage, which can occur illegally in developing cities, the subsequent daily irrigation might accumulate poisonous trace metals (such as Cd, Cr, Zn, Ni, Cu, Co, Pb, As, Hg ) in soil, ground water or, even worse, in crops.
- It is presumed that hormone and medicine residues from sewage could affect not only the soil biosphere, thus provoking a loss of fertility, but also could reach the groundwater.

There is clear evidence that UA has a considerable development potential but it is important to determine under which conditions UA can be a sustainable activity.

## 1.2 *Aim of this study*

This work is a **preliminary study** of a research project which will be submitted to Swiss NSF and which will include two PhD and several Master theses, focusing on different aspects, such as microcontaminant pathways through soils and groundwater; microbiological assessment and appropriate water treatment; parasitological studies; soil and groundwater salinization evaluation; and socioeconomical impacts of reusing wastewater. The global aim of the overall project is to contribute to a more sustainable urban agriculture, by improving environmental and health impacts with an effective north-south partnership. In parallel to this preliminary study, a master thesis is on progress (Ndiaye, 2005), focusing on the transfer of pathogenic bacteria to the cultivated soil and local groundwater.

This preliminary study pursues the following goals:

- To characterise main urban agriculture (UA) sites which are concerned by little sustainable practises;
- To investigate UA soil types and the subsurface groundwater chemistry;
- To assess different waste waters from Dakar area, such as suburban domestic sewage, city centre open-air sewage, industrial waste waters, road run-off water and waste water at the Cambérène treatment plant;
- To initiate the set up of a database which will include soil and water analysis, socio-economic data from interviews and geographical data of the different UA sites in Dakar. This database integrated in a Geographic Information System (GIS), will be a tool for researchers as well as for decision makers.
- To quantify trace metal (Cr, Cd, Pb, Ni, Zn, Cu, Co, As, etc.) content in waste water used for irrigation, in ground water, in soils and in organic manure and to evaluate risks and accumulation rate in the future.
- To quantify several types of pesticide contents (organochlorides, carbamates, organophosphate) in a few ground water samples and to evaluate the risks and accumulation rates in the future.

### 1.3 Institutional framework

The following institutions have been implicated in this preliminary study:

- **University of Lausanne, Faculty of Geosciences and Environment, Centre d'Analyse Minérale (CAM):** heavy metal analysis with FRX; major elements analysis in wastewater, groundwater, surface water and soil percolation water with ionic chromatography; trace elements in wastewater, groundwater, surface waters and soil percolation waters with ICP-MS;. *Contact: Hans-Rudolf Pfeifer*
- **Swiss Federal Institute of Technology, Lausanne (EPFL), School of Architecture, Civil and Environmental Engineering (ENAC), Laboratory of Soil Sciences:** soil analyses. *Contact: Fabienne Favre Boivin*
- **University of Dakar, Institut Fondamental d'Afrique Noire (IFAN), Laboratoire de Traitement des Eaux Usées:** physicochemical analysis of irrigation waters (wastewater and natural groundwater) with TSS, BDO5, DOC; pathogenic bacteriological analysis by cell cultivation; parasitological analysis; Heavy metals in waters with voltametry-polarography. *Contact: Seydou Niang*
- **Institut de Recherche pour le Développement (IRD):** carbon and nitrate content in soil and irrigation water; microbiological community impacts on nitrogen content; impacts of wastewater on productivity. *On Pikine site only. Contact: Aliou Guissé, Yacine N'Dour.*
- **Service National de l'Hygiène (SNH)** from Ministère de la santé et de la Prévention: coordination of CRDI-Patte d'Oie research program. *Contact : Temba Baldé*
- **Institut Sénégalais de Recherche Agronomique (ISRA):** analysis of organic manure and inquiries about manure practises. *Contact : Youga Niang*
- **Mairie de la Patte d'Oie :** *Contact : Modou Alpha Thiam, president of environment commission.*
- **Enda RUP:** socio-economical inquiries, member of commission in PACN and PASDUNE. *Contact: Mohamed Diagne*
- **Swiss Federal Institute for Environmental Sciences and Technology, Department of Water and Sanitation in Developing Countries (SANDEC):** scientific collaboration. *Contact: Dionys Forster, Doulaye Koné.*

## 2 Methodology

### 2.1 Environmental approach

We consider that urban agriculture can be represented as an *agro-ecosystem*. Fig 2 shows the different inputs and outputs of this agro-ecosystem. In order to quantify

concentrations of contaminants<sup>1</sup> in soils and ground water, it is necessary to evaluate the fluxes of inputs and outputs. Moreover, this will enable to predict the possible accumulation rate of contaminants in soils, water and plants. This chemical element transfer point of view will help us to investigate the fate of the contaminants; therefore, it is important to go beyond the size of cultivated plots and to investigate on a regional scale. The dynamic processes of contaminant transfer, such as sorption/solubilisation, oxidation/reduction, leaching, etc. will be investigated with sampling of waste water, soil, soil solution (with free flow lysimeters) and ground water (with piezometers).

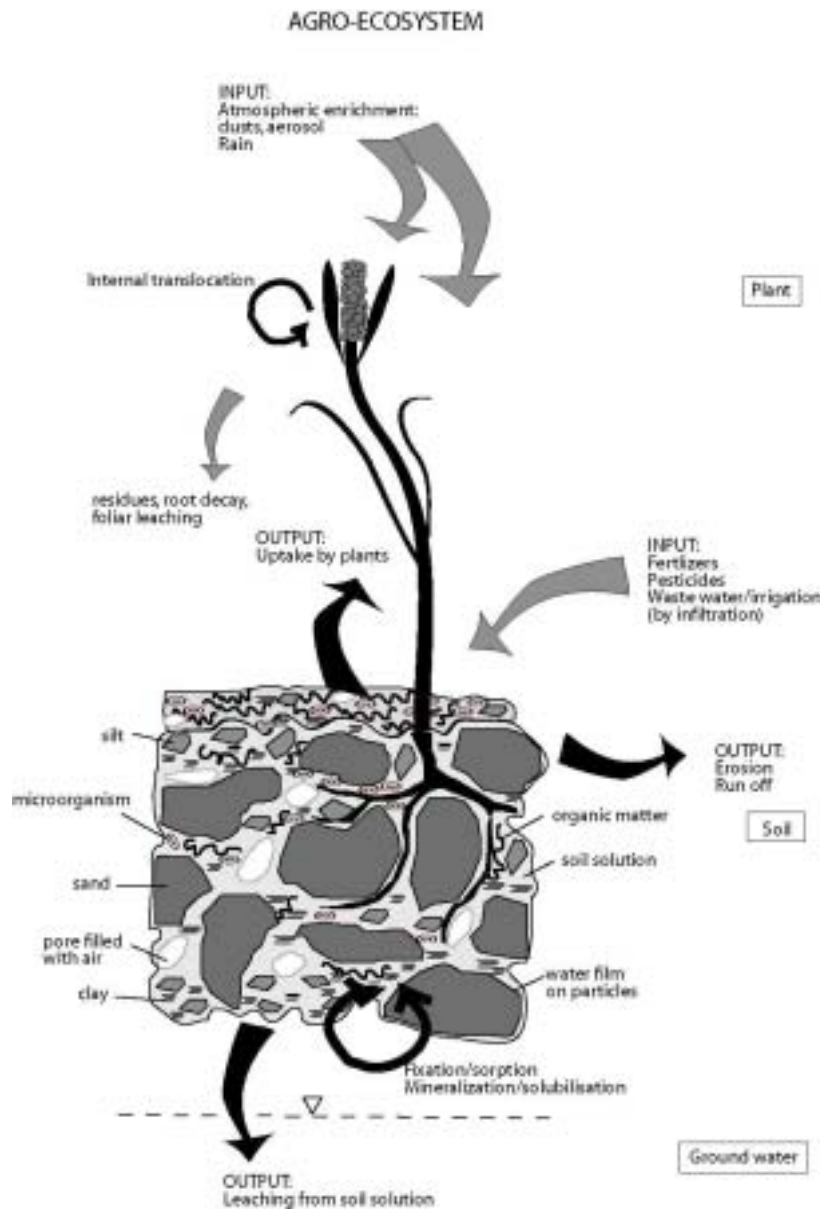


Fig. 1: agro-ecosystem, modified after Adriano, 1986

<sup>1</sup> By contaminants, we denote trace elements (such as heavy metals or metalloids), persistent organic pollutants (such as pesticides, PCBs) and pathogenic micro-organisms (such as faecal bacteria and parasites).

## 2.2 Sampling method

### Soil:

In order to characterise the soil types of the Niayes, four pedological pits (one per soil type) have been dugged, described and each horizon has been sampled separately. Two “reference” soils have also been chosen, one is not cultivated, the other is outside the city of Dakar. All other soil samples have been taken with a hand-drill, as a function of depth and soil horizon. The choice of soil sampling sites has been established by the following criterion: representativity of soil type, situation in the slope, irrigation water type, proximity of roads of high density of traffic. In total, 38 soil profiles have been investigated, representing 141 horizons. These samples of approximately 200g have been stored in plastic bags until they have been dried at IFAN in air-dry oven at 30°C.



Fig2: soil sampling. A) with hand drill; B) in pedological pit.

### Water:

In order to characterise not only waste water, but also ground water and drinking water, numerous samples have been taken in different suburbs of Dakar: the two local ground waters, the shallow Thiaroye ground water and the deep Cretaceous aquifer (cf Fig. ) have been sampled at several localities (n=15) in piezometers. Samples of shallow wells (*céanes*) and deeper pumped wells from cultivated areas were selected based on statistical arbitrary choice, respecting the total proportion between irrigation with natural and waste water, and between *céanes* and pumped wells (n=36). Besides, waste waters were sampled directly from sewers in UA sites, at the unique Cambérène treatment plant and in open-air drain (n=9). Finally, drinking water from the suburbs around the Pikine UA site was sampled (n=1) as well as rain in pluviometers (n=2).



Fig3: water sampling. A) in piezometer (here under installation); B) in cèane; C) in lysimeter.

Water samples were directly prefiltered with a Nalgene manual pump using 1.2  $\mu\text{m}$  cellulose filters and then filtered through a 0.45  $\mu\text{m}$  glass-fibre syringe filter. 1.2  $\mu\text{m}$  filters were kept for TSS quantification. Afterwards, water samples and filters were refrigerated and stored in a cool box in 15 and 30 ml PE bottles; one of them has been acidified with  $\text{HNO}_3$ . Samples for pesticide analysis were collected in 1L PE bottles without been filtered and rapidly stored in a deep freezer. Physicochemical parameters, such as pH, temperature, Eh, conductivity, dissolved oxygen and alkalinity were measured in the field.

### 2.3 Laboratory techniques

All analyses, except Total Suspended Solids (TSS), BDO5 and COD (provided by IFAN, Dakar) were conducted in Switzerland:

- XRF for major and trace elements in soils and sediments
- Ion chromatography for major cations and anions in waters
- C-analyzer for organic carbon in waters
- Coulometric analysis for organic carbon in soils
- Laser particle sizer for soils and sediments
- XRD spectra for soils and sediments mineralogy, in particular clays
- ICP-MS for trace elements in waters

## 3 Investigation sites

### 3.1 Urban zone of Dakar

The city of Dakar has more than 2.3 millions inhabitants and its urban growth is around 4%. The urbanisation rate has quickly increased, from 13% in 1960 until nearly 60% (estimation for 2020). Therefore, its population density is close to 4000 inhab/ $\text{km}^2$  and this process of densification will continue as the Atlantic Ocean limits its spatial extension (Fig.4). Even the Niayes zone, invaded by near-surface ground water during the rainy season, has been required for habitations. This phenomenon leads to conflicts with market gardeners of the Niayes, as they loose more and more fields every year and yet produce around 60% of the total vegetables to feed Dakar (Seck et al, 1997).

## 3.2 The Niayes zone

### 3.2.1 General aspects

Urban and periurban agriculture is mainly located in the Niayes zone, a unique and vulnerable ecosystem composed of sandy dunes and depressions invaded by the shallow ground water. Tropical vegetation was diverse but has been considerably reduced since urban pressure has increased (Fig 5). The Niayes is a 10km wide coastal zone from Dakar until St-Louis close to the Mauritanian frontier (Fig 4). Because non-salted water and a close access to cities were easily disposable, it has become the biggest zone for vegetable and fruit production. Collect of medicinal herbs, fishery and production of ornamental plants are other activities encountered in the Niayes. Niang and Gaye (2002) have reported that 60% of the Niayes gardeners are ancient rural farmers while the other 40% are urban citizens affected by economical crisis. Diverse ethnics are established as market gardeners, but all cultivate in a traditional and familiar way on extremely small plots (0.01- 0.1 ha, Fall & Fall, 2001).

The ecological and economic functions of this unique greenbelt of Dakar are obvious, but they have never been considered by urban planners. Recently, the **PACN (Programme d'appui à l'Aménagement et à la gestion Concertée et durable des Niayes)** has been founded by the Ministry of Urbanism together with the NGO "Enda Tiers-Monde" to support political decisions. Its objectives are to establish discussions between every actor implicated in the Niayes and to denote financial systems existing in the Niayes. In addition, **PASDUNE (Programme d'Action pour la Sauvegarde et le Développement Urbain des Niayes et zones vertes de Dakar)** has been launched to consider the specificities of the Niayes in the master plan of Dakar urban development. This is a two-year pilot experiment involving research teams and NGOs to take into consideration the preoccupations of the population and to propose adequate land planning.

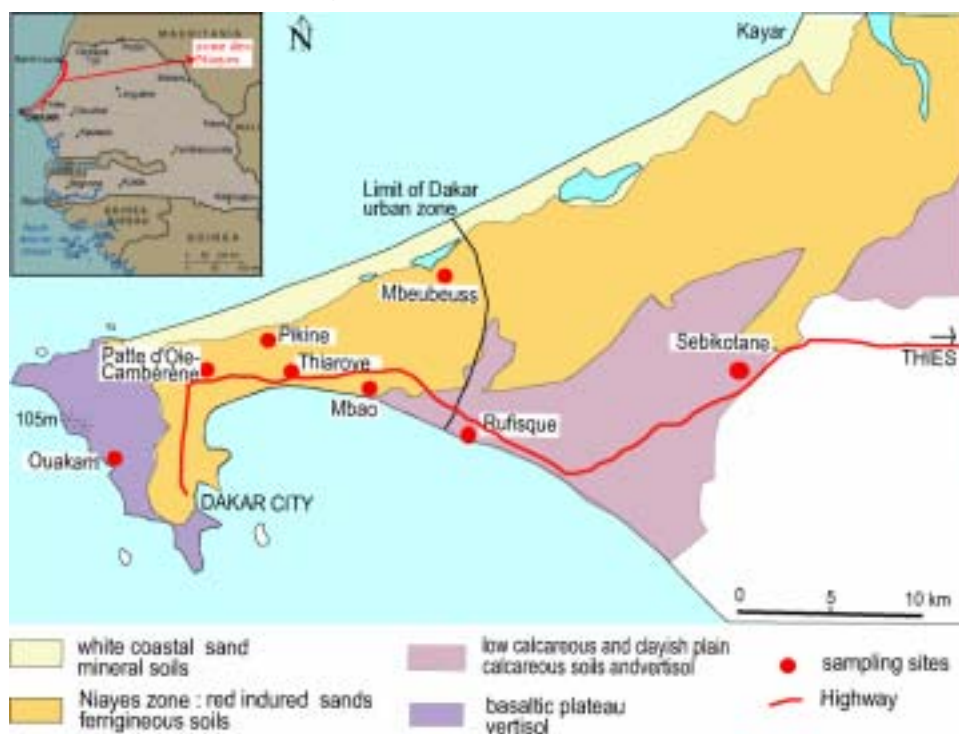


Fig4 : The Niayes zone in the Dakar area, its main soil types and sampling sites

### 3.2.2 The site of Patte d'Oie-Cambérène

#### *Physical characteristics:*

The urban agricultural site of Patte d'Oie is located in the Niayes zone, along the Dakar-Rufisque highway, surrounded by suburbs (Fig 4 and 5).

More than 200 market-gardeners cultivate principally lettuce, tomatoes, bissap, onions, sweet peppers, aubergines and mint and breed pigs and poultry. Floriculture, production of seedbeds, collection of medicinal herbs are other activities in this site.

#### *Practices:*

Gardeners irrigate crops with natural ground water in wells or in traditional shallow wells called "céanes", which are rather holes in the lower zones. Women come to buy vegetables in large quantities to sell in city markets. Cultivators were working individually until 2004, when they formed an association to become stronger stakeholders in front of local authorities. Ground water has varying salinities in each field, and a few gardeners use untreated wastewaters coming from the suburb of Patte d'Oie to irrigate crops. In this way, salinity is reduced. Pesticides and organic manure – composed of peanut or fish residues, poultry or sheep excreta- are regularly deposited. Moreover, water from wells is daily drunk by workmen.

#### *Difficulties:*

This zone endures numerous pressures such as growing of suburbs, embanking, solid municipal wastes from suburbs, lowering of groundwater levels and the consequent increase of salinity, as well as land insecurity for the cultivators.

### 3.2.3 Pikine

#### *Physical characteristics:*

This UA site of 60ha and around 600 plots is located north of Patte d'Oie site, further away from the highway (Fig 4,5 and 6). Four sandy dunes are intensively cultivated and a lake delimits the fields. At the other side of the lake, still on the Niayes, one golf field has recently been implanted as well as a technopole. These new activities seem to preserve the ecosystem; furthermore they are public recreational zones.

#### *Practices:*

Pikine UA site has been cultivated since 1975 with domestic waste water coming from the sewage of HLM Las Palmas and Golf suburbs. More and more cultivators use waste water for economical reasons cited above. Today, 60 plots are daily irrigated with waste water, which represents 8'200 plots of 2-3 m<sup>2</sup>, each receiving 40 litres per day, making a total of 328'000 litres of waste water per day (Fig. 7). Due to waste water re-use, Pikine is the principal site where lettuce is cultivated, especially during the hot season. Other minor production is onion, aubergine, tomatoes and pepper. Farmers are well organised and regrouped in a GIE (group of economical interest). They cultivate collectively an important field with a motor-pump in addition to their individual plots.

#### *Difficulties:*

Those who are not furnished with waste water have problems with ground water becoming saltier every year. Pikine has the highest salinity level of all UA sites. One handcraft of tannery is located in the UA perimeter and also contributes to increasing salinity, but it has not been proved that this tannery contaminates with Cr.

### 3.2.4 Mbao

#### *Physical characteristics:*

This UA site is established both side of the principal highway Dakar-Rufisque (Fig 4). Much smaller than Pikine and Patte d'Oie-Cambérène, it is also less organised. Farmers work individually extremely small plots. Further away from the highway, but next to the chemical industries of Senegal, a few irrigated plots are also found.

#### *Practices:*

Irrigation is exclusively done with natural ground water, which is somewhat less saline than in Pikine and Patte d'Oie-Cambérène.

#### *Difficulties:*

The groundwater used for irrigation close to the chemical industries seems to prevent from a good crop development.

### 3.2.5 Thiaroye

#### *Physical characteristics and practices:*

The situation is close to the one of Mbao, along the highway and fairly small.

### 3.2.6 Meubeuss

#### *Physical characteristics:*

This relatively small UA site is located at the bottom of the enormous landfill of Mbeubeuss (Fig 4). This landfill, which is the only one collecting solid wastes from Dakar, receives absolutely all kinds of wastes without any control. Industrial, chemical, sanitary wastes are mixed with domestic wastes. Onsite, a "village" of recyclers has informally been implanted. Glass, metal, even compost is recycled and resold.

#### *Practices:*

Ground water from *céanes* is used for irrigation.

#### *Difficulties:*

Numerous solid wastes are found on the fields.

### 3.2.7 Ouakam

#### *Physical characteristics:*

This UA site is located on the 20m thick basaltic plateau close to Dakar city centre and constitutes a site limited in width, but with a considerable longitudinal extension along the coast. Irrigation water is exclusively waste water from military camp. Soil is heavy to harvest, because of its high clay content. This strongly contrasts from others sites from the Niayes zone.

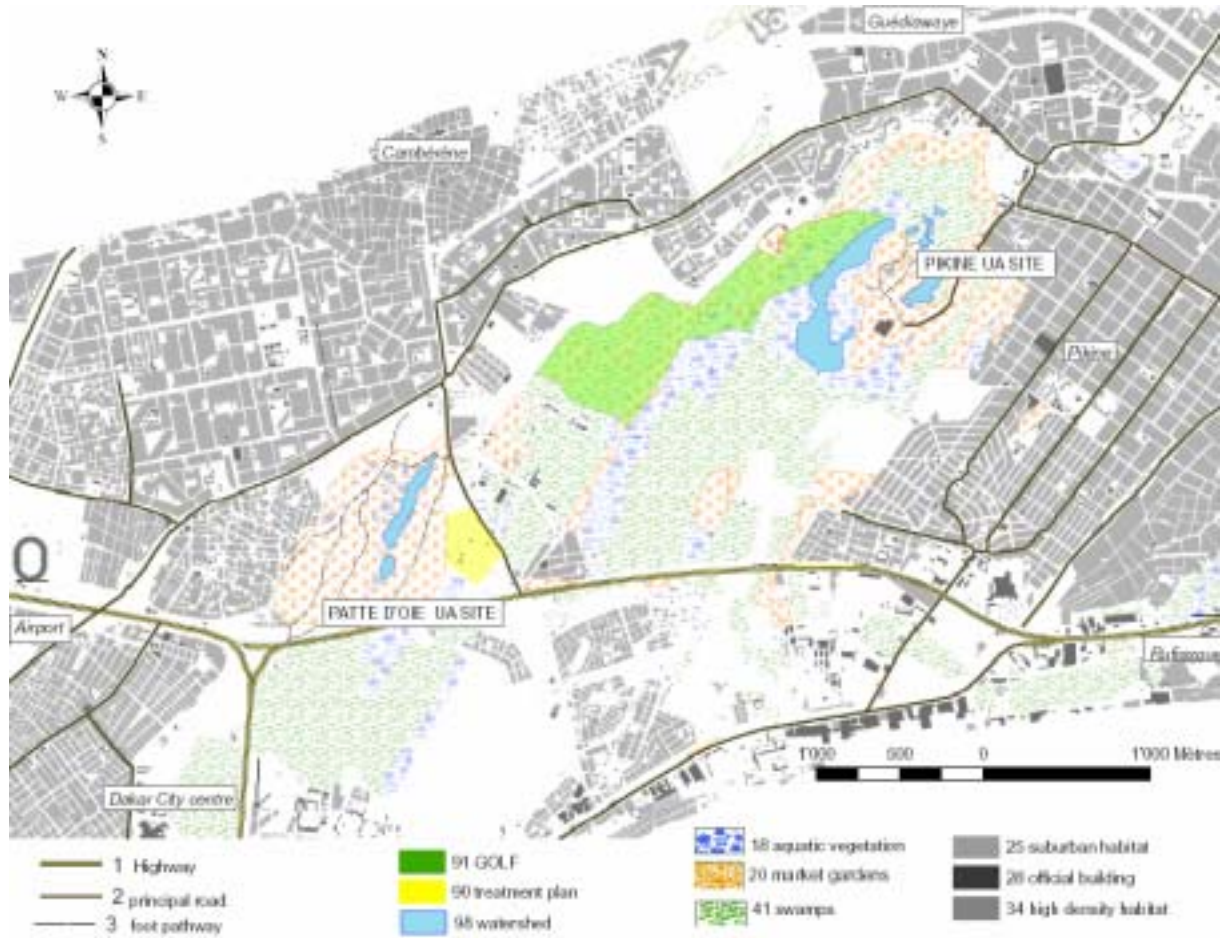


Fig 5A: map of the two main urban agriculture sites of Dakar (Pikine and Patte d'Oie), drawn with ArcGIS based on data obtained at CSE, Dakar.

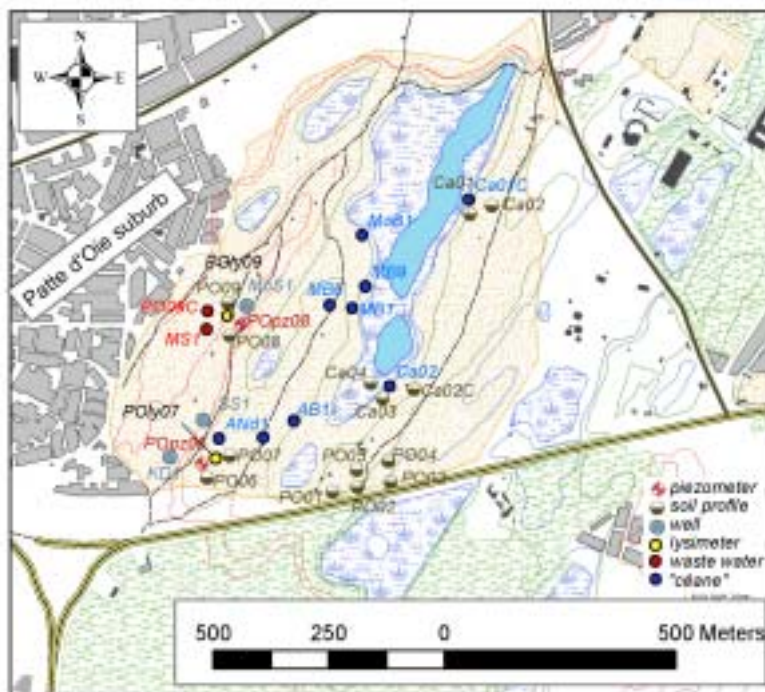


Fig 5B: detailed map of Patte d'Oie UA site, with samples localisation.

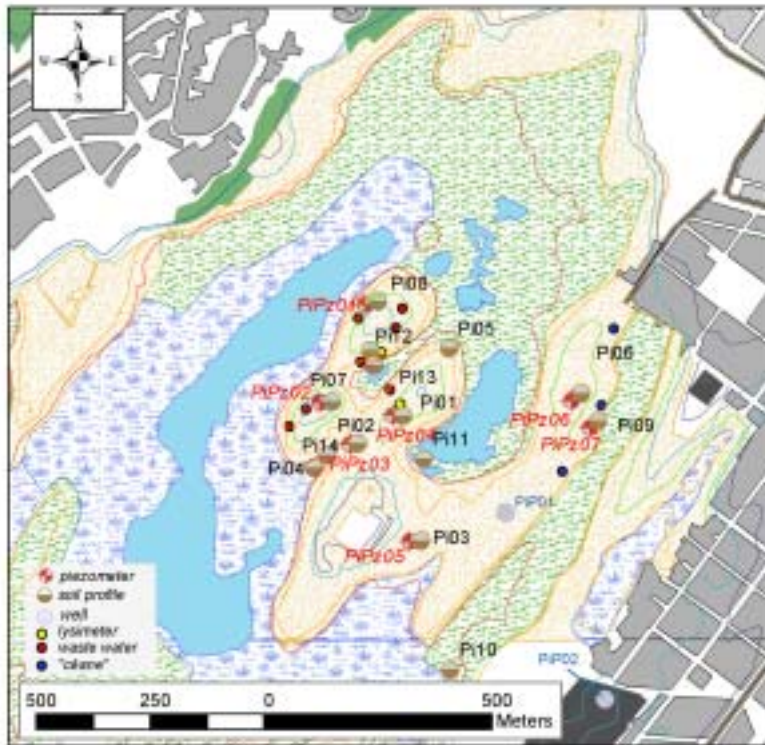


Fig 5C: detailed map of Pikine UA site, with sample localisation.

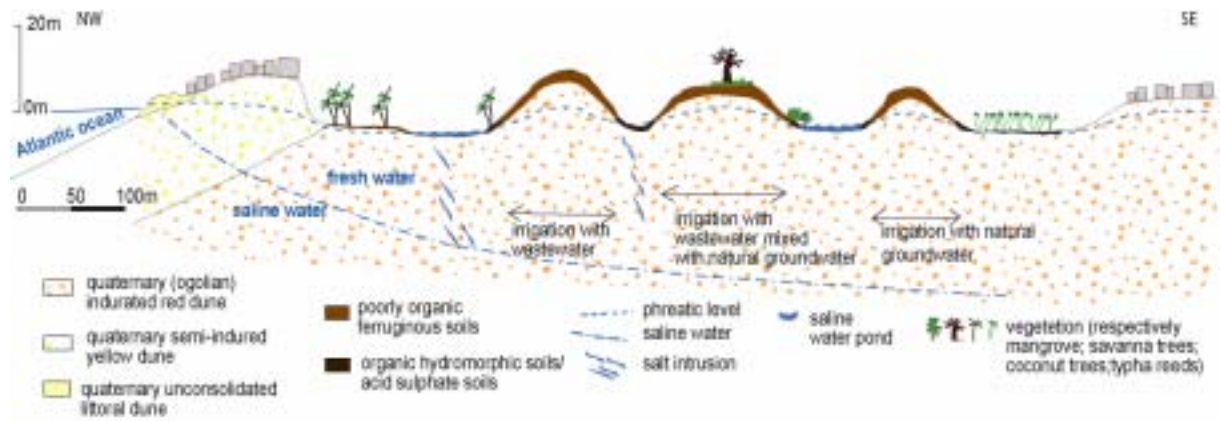


Fig6 : cross section through the Niayes zone at Pikine.



Fig 7: irrigation modes at Pikine

### 3.3 Climate

The climate in Senegal is varying from north to south with increasing rainfall (Fig 8). The sahelian zone in north gets little rain, 200mm/year while the south-soudanese zone in Casamance receives nearly 1200mm/year. Dakar is located in the middle and gets 450mm/year rainfall, concentrated during one single period between July and October. The culmination occurs in August with strong storms. In Dakar, the climate is influenced by Atlantic Ocean, consequently its microclimate is composed of four seasons: hot and rainy from July to October, cool and dry from October to December, cool and humid from December to March, and hot and dry from April to June.

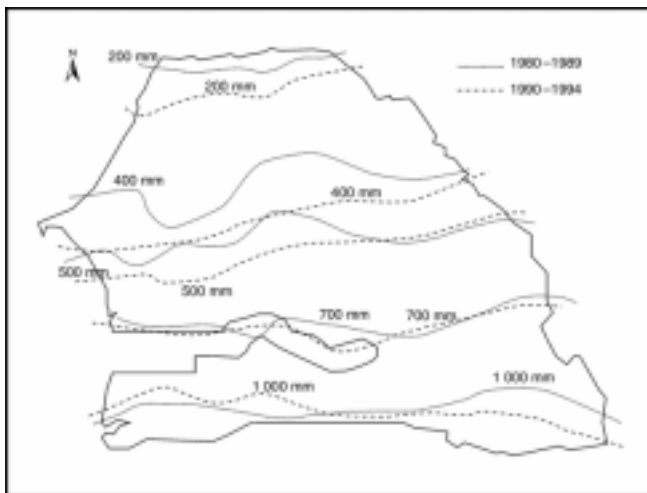


Fig 8 : climate in Senegal (Fall and al., 2000).

### 3.4 Hydrogeology

In Dakar area, ground water pumped for drinking water is contained in several different aquifers (Tandia and Deme, 2003):

- **Quaternary sands aquifer:** it contains two ground waters: the confined infrabasaltic groundwater at the head of Dakar peninsula (A) and free Thiaroye groundwater from Cambérène to the East of Dakar peninsula (B) (Fig. 9).

**A) The infrabasaltic aquifer** is composed of marine quaternary sands, overlain by impermeable basaltic rock on the west coast.

**B) The Thiaroye phreatic aquifer:** include the Niayes dune system. As it is recharged by rainfall, its level fluctuates with seasons.

- **Paleocene aquifer:** consist of karstic limestones and calcareous marlstones, pumped at Sébikhotane.
- **Maastrician aquifer:** consist of sands and calcareous sandstones, pumped at Pout.

80% of Dakar drinking water supply (162'000 m<sup>3</sup>/day) provides from these three ground waters and the remaining 20% (39'000 m<sup>3</sup>/day) from the Guiers Lake, 250km north of Dakar trough channels. The situation is critical, as rainfall has declined and demand has raised.

Not only quantity is problematic, but also quality: firstly, ground water is vulnerable as sandy mineral soils do not filtrate potential contaminants. That is why nitrates from old and permeable septic tanks contaminate the shallow ground water. Secondly, because of overpumping, there is intrusion of the saline water lying below, which is degrading both ground water and irrigated soils.

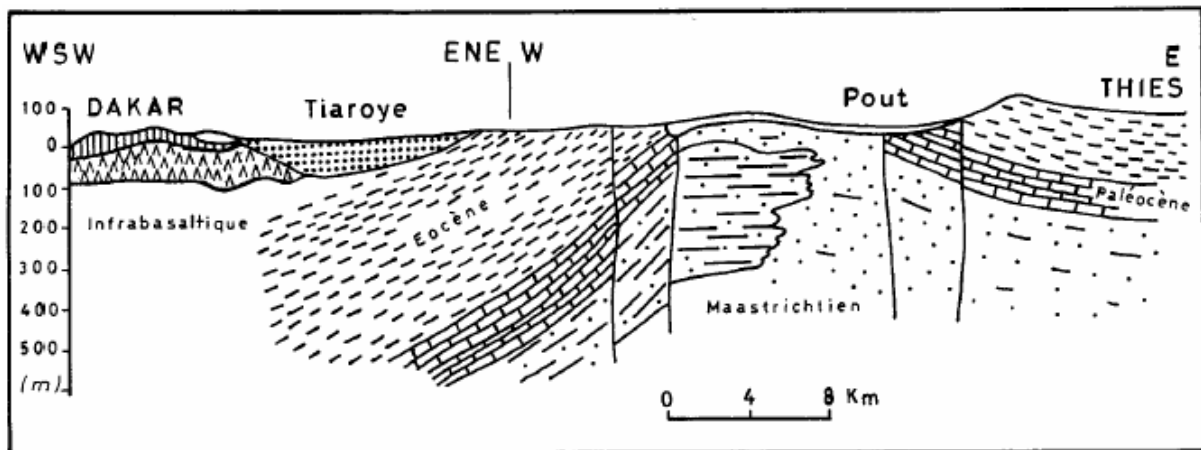


Fig 9 : Hydrogeology of the Dakar area (from Mudry and Travi, 1992)

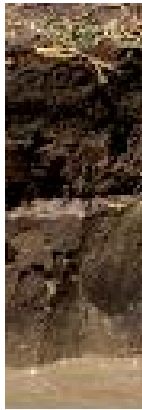
## 4 Results

### 4.1 Soil characterisation in the urban zone of the Niayes

#### 4.1.1 General aspects

This study has shown that soils vary not only from one UA site to another, but also within a UA site, as a function of topography and hydrological situation. In Pikine, as figured on Fig.6, four different soil types have been observed: sandy ferruginous soils (Fig 10b) are the dominant soil type and are found on tops and on slopes of dunes, while organic or mineral hydromorphic soils (Fig 10a) or sulphate-rich soils are found in the depressions

(for detailed description, see § 4.1.1 to 4.1.6). The last ones are degraded soils, which are extremely acid and saline and therefore inadequate to cultivate. As a function of salinity degree, halophyte vegetation is supported until absence of vegetation. Very often, an anthropogenic origin (irrigation, effluent water, intrusion of saline water) causes the irreversible degradation of these soils (Loyer, 1991). Fortunately, they do not seem to represent an important surface in Pikine, but it will be important to evaluate their expansion and to establish the cause of degradation. This aspect will be an important part of the Swiss NSF research project.



**Fig 10A : hydromorphic organic soil (peaty):**  
Horizon A1 is deep and rich in organic matter (Corg max 6%). Horizon Ag is grey (due to reduced Fe) with red spots and black concretions.



**Fig 10B : sandy ferruginous soils:**  
Very low content in organic matter (C org < 1%). Deep, ochre color, sandy (> 80% sand, 1- 3% clay), permeable. Acidic pH, extremely poor (SiO<sub>2</sub> >90%).

Patte d'Oie soils are similar to the ones in Pikine, but salted sulphate soils have not been observed.

Ouakam UA soils clearly differ from others, as they lie on the basaltic plateau (dolerite) and are constituted of 25% clays and 72.5% fine loam. They are called brown eutric soils ("sols bruns eutrophes"). Due to the geological background, we would expect increased concentrations of natural trace elements, such as Ni and Cr. We effectively found relatively high levels, respectively 350 and 300 mg/kg. Zn is also present with 100 mg/kg. As exclusively waste waters are used for irrigation on this site, it is necessary to investigate this site in more details.

In the Niayes outside Dakar, a few km north of Sebothotane (Fig. 4), cultivated soils are more clayish in the deep horizons (15% clay, 45% fine loam at 90-100cm), so Fe and Al content is much higher than in ferruginous or hydromorphic soils (Fig.11 below).

Based on 37 soil profiles, representing 140 samples, it has been shown that the organic and clay content vary respectively from <0.3% to 6% Corg (Fig.13 below) and from 1% to 25% particles <2µm (particule size, see Fig12). These variations in key parameters indicate that micro-pollutants could have a totally contrasting behaviour in these different soil types. It is expected that sandy ferruginous soils do not retain micro-pollutants, thus mobilizing them to flow to the groundwater or to the downhill soils by run-off or percolation, while hydromorphic organic soils and sulfate-rich and clayish soils adsorb them on organic matter, clay or Fe-oxy/hydroxide surfaces, thus involving an accumulation process on the long term. These hypotheses will be described in § 4.2 below.

Fig. 11 shows that ferruginous, hydromorphic mineral and hydromorphic organic soils have similar concentrations in  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$ . Fig. 12 and 13 denote that organic carbon and particle size are slightly increased in hydromorphic soils, as well as with topography. Further investigation of Fe-forms (free-Fe, crystallised-Fe and amorphous-Fe) and clay mineralogy will give us more information about chemical differences in these soils.

In contrast, sulphate salted soils, brown eutric soils and clayish soils have higher contents in  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$ , mostly because of aluminium-rich clays. Kaolinite is supposed to be the main mineralogical clay, but XRD analyses are in progress to verify it.

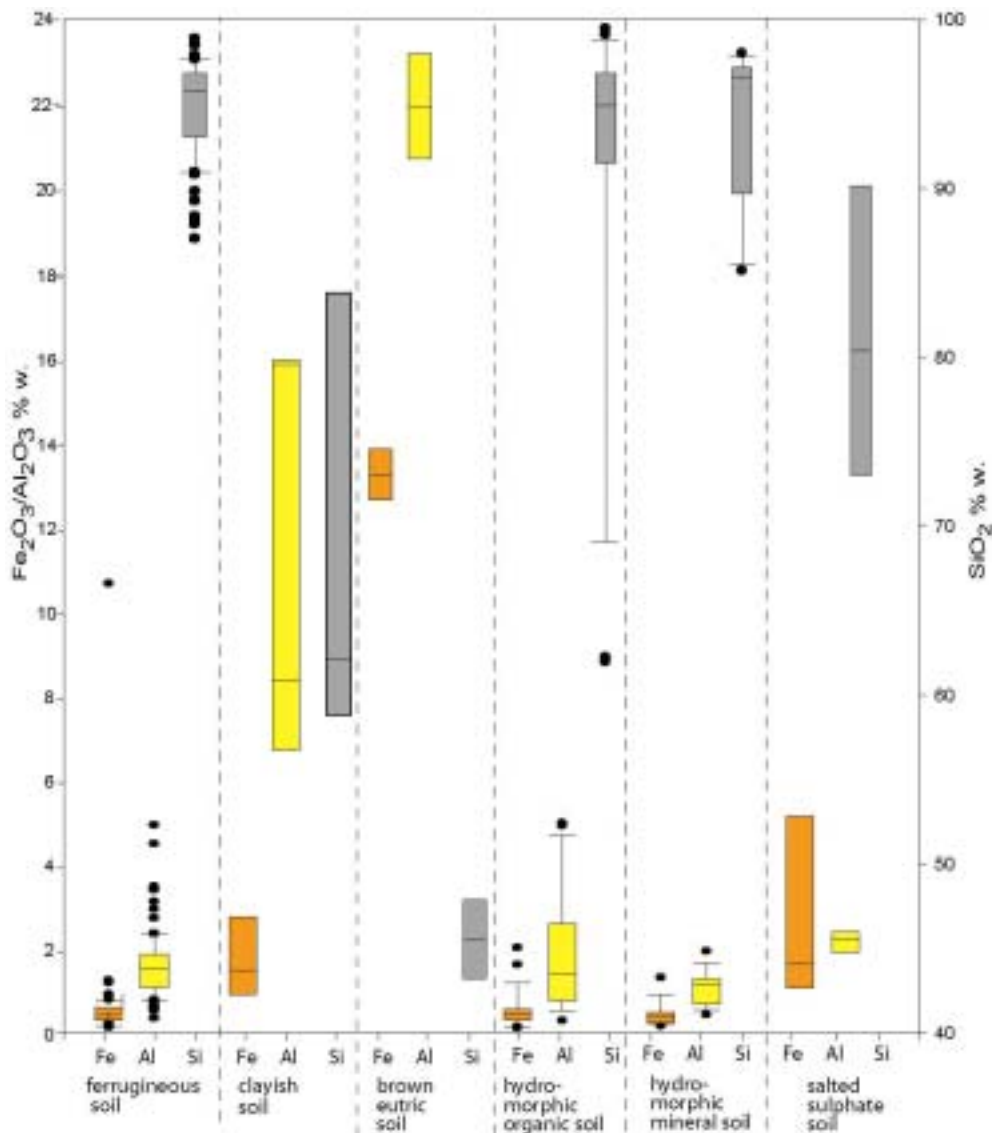


Fig.11: major elements as a function of soil type

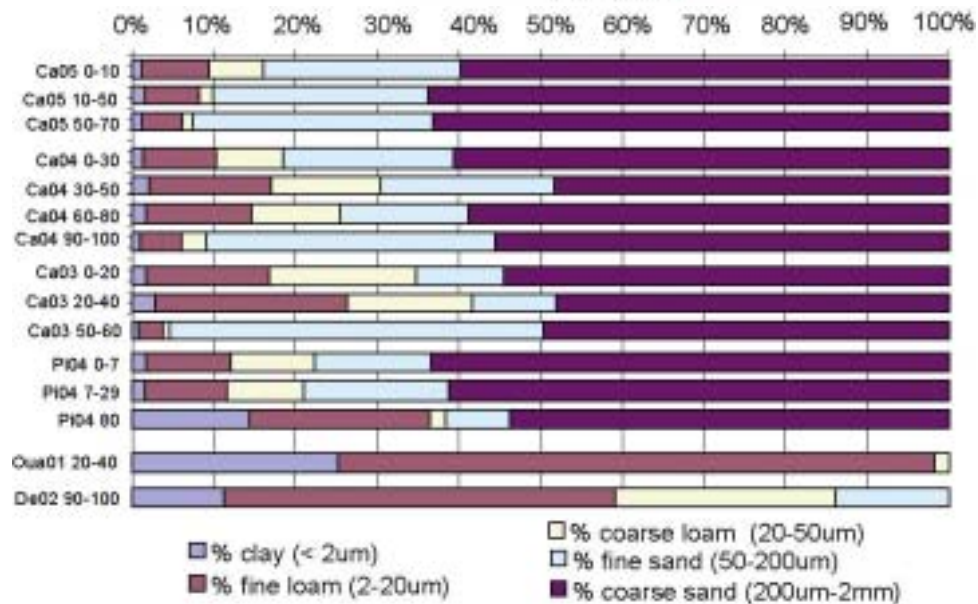


Fig12 : particle size of typical soils. Ca05: ferruginous soil, top of dune; Ca04: hydromorphic mineral soil, end of slope; Ca03: hydromorphic organic soil, depression; Pi04: salted sulphate soil, depression; Oua01: brown eutric soil; De02: clayish soil, depression.

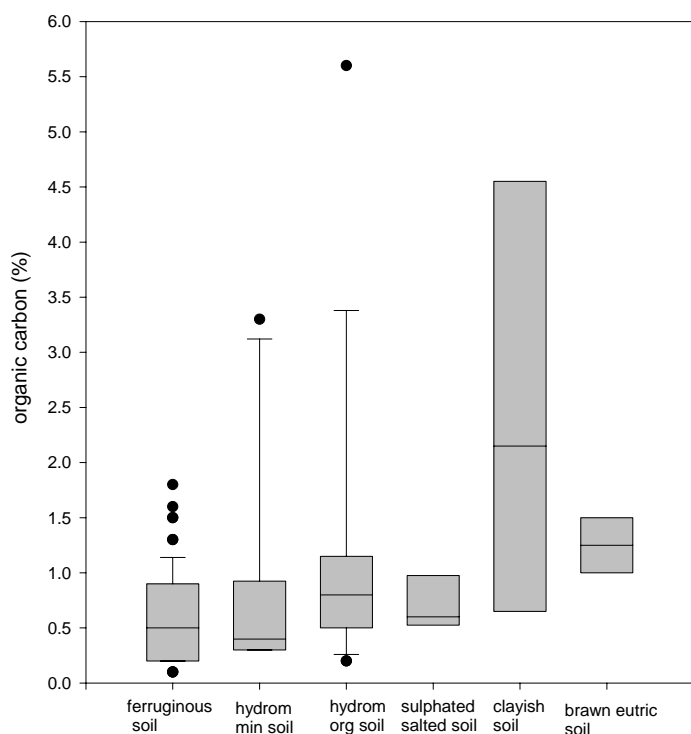


Fig.13: organic carbon content in function of soil type

#### 4.1.2 Detailed soil description

In the Niayes, the dominant soils are **tropical poorly washed ferruginous soils** (Fig. 14). Their  $Fe_2O_3$  content varies from 0.3 – 1.3% weight,  $Al_2O_3$  from 0.7 – 5.0 %w and  $SiO_2$  is 87.0 – 98.9%w (Fig. 11). pH is between 6 and 7, but manure input,

waste water and salinisation tend to increase their pH until 8. Particle size distribution includes 85-90% sand, 10% loam and a few % clay (Fig 12). Organic carbon content is low, but organic manure allows to reach 1-2% C org. Khouma (2000) describes a similar soil in Bambey (100km west of Dakar).

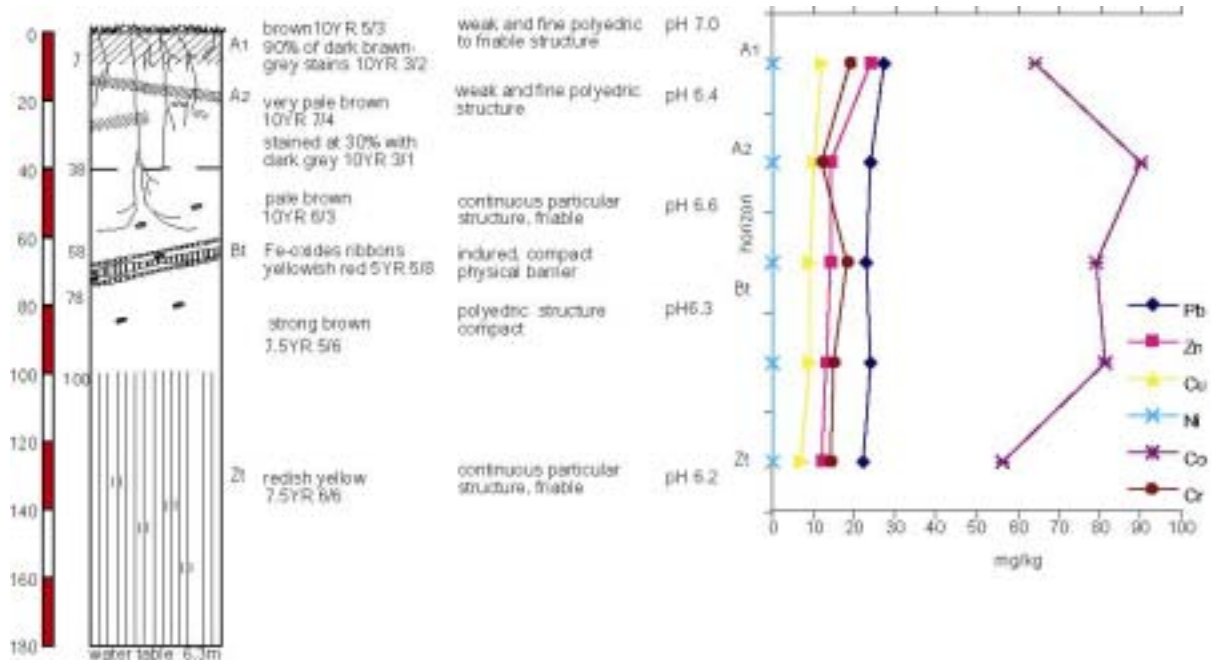


Fig 14: typical deep ferruginous soil. Profile PI03, non cultivated soil, Pikine (left: description, right: trace element content).

**Hydromorphic organic soils** (Fig. 15) typically have four horizons and often higher trace element contents. Clay and organic carbon content are higher.

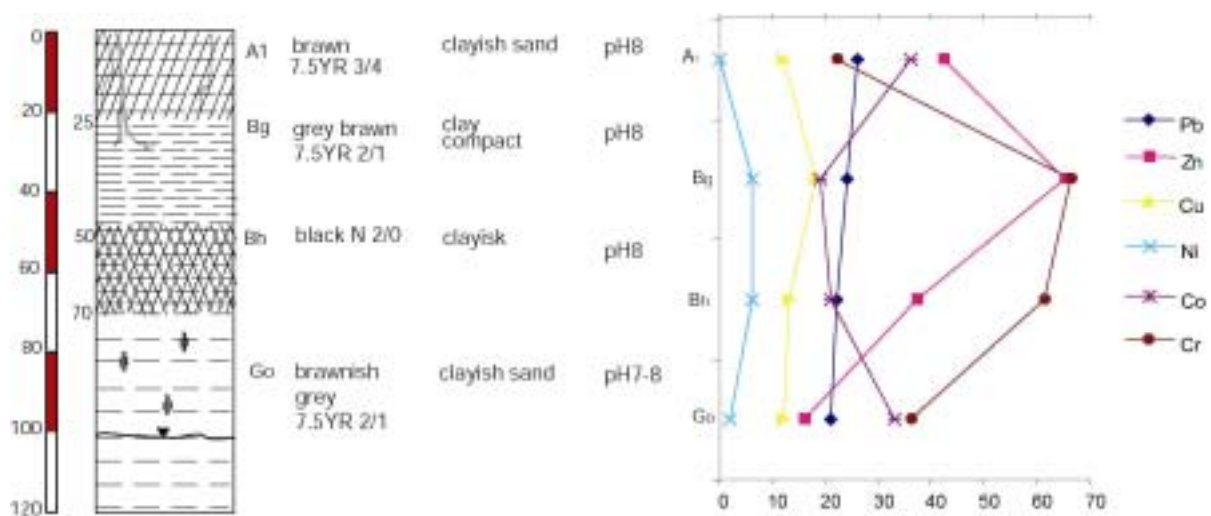


Fig15: hydromorphic organic soil. Profile PI09, cultivated, Pikine (left: description, right: trace element content).

**Hydromorphic mineral soils** (Fig. 16) are shallow soils influenced by shallow ground water. They lie on sandy substrate and have low organic carbon content.

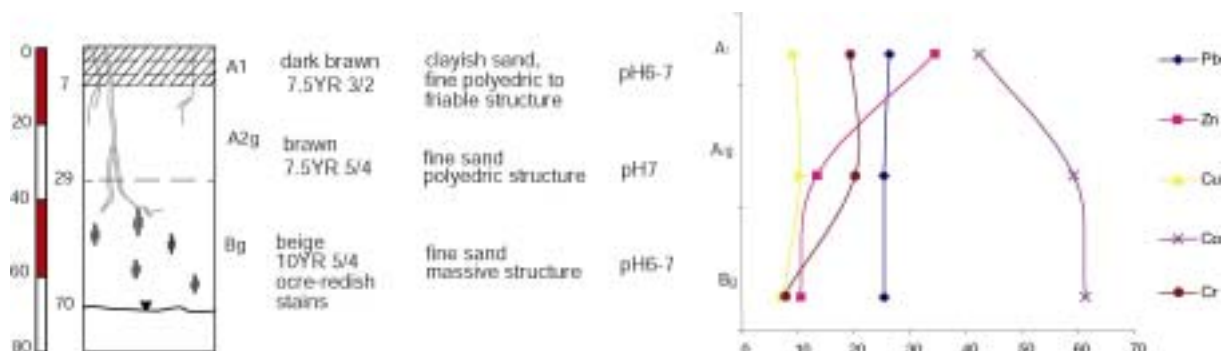


Fig16: hydromorphic mineral soil. Profile Pi05, cultivated, Pikine (left: description, right:trace element content).

**Salted sulphate acidic soils** (Fig. 17) are found where salinisation process is important and cultivation is not possible. Salts precipitate in surface. In the deep horizon, under oxygen-reducing conditions, Fe-sulphur, such as pyrite is found.

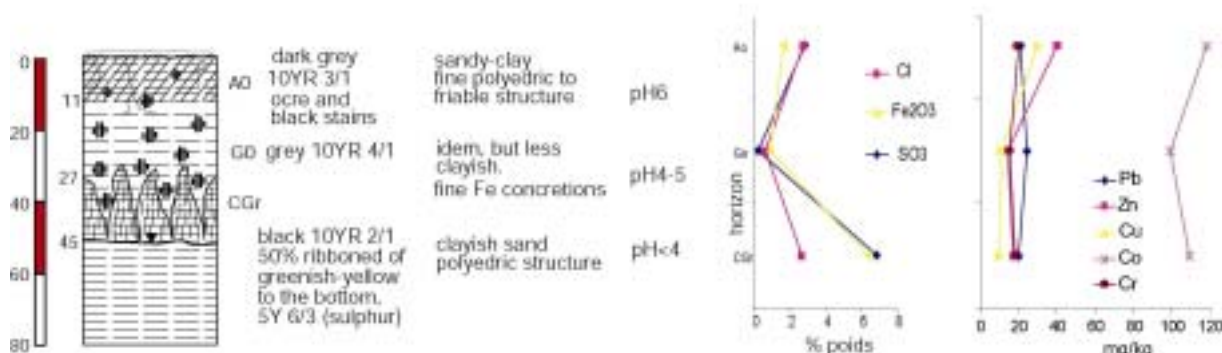


Fig17: salted sulphate soil. Profile Pi04, uncultivated, Pikine (left: description, right:trace element content).

Brown eutric soils and clayish soils have not yet been described in details.

#### 4.2 Trace element contamination in the UA soils

Chemical analyses show that the hypothesis cited above -that trace element behaviour would be different as a function of soil type- is only partially verified. The two clayish soils have indeed higher contents of Zn, Ni and Cr (Fig 18). Although the brown eutric soil might retain trace elements on its clay particles and clay/Fe-oxides colloids, the trace elements do not come only from waste water, but also from the geological substrate, i.e. dolerite rocks usually containing high level of Ni, Zn and Cr. Rock sample should be sampled during the next field work period. The clayish soil analysed in this work comes from outside Dakar and is not irrigated with waste water, thus being a doubtful comparison. More samples of clayish soils will give more information about the influence of soil type.

Fig. 18 shows that in UA sites, a regional background of 20 mg/kg Pb, Zn and Cr, and of 10 mg/kg Cu are typical.

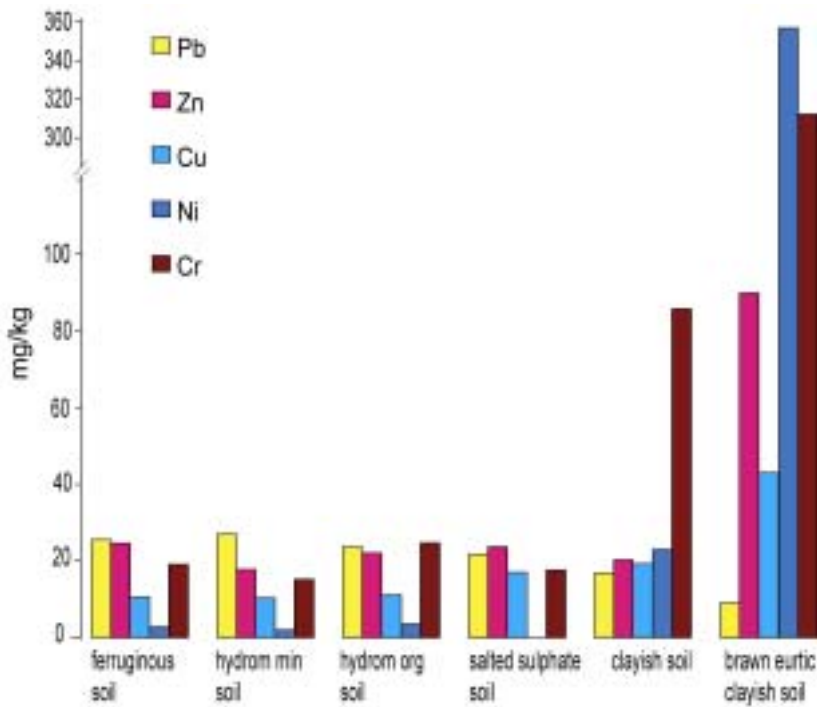


Fig 18: trace elements as a function of soil type (mg/kg element, mean content)

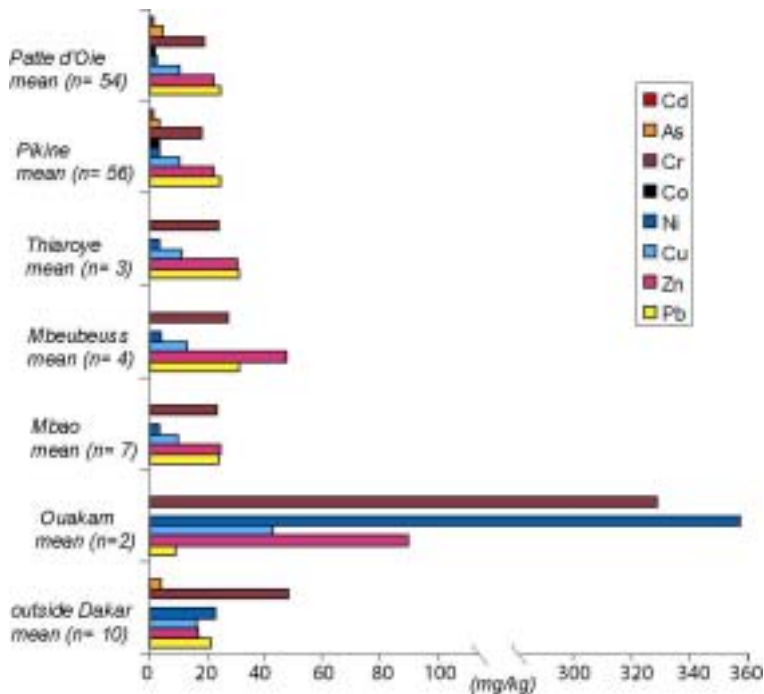


Fig 19: trace elements as a function of localisation

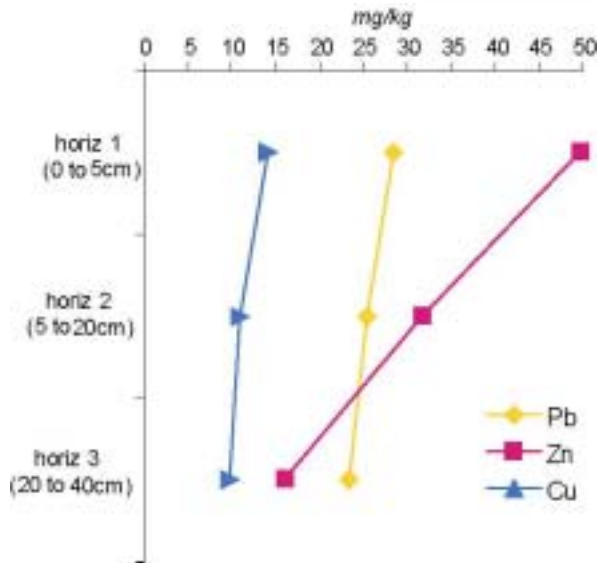


Fig. 20: Pb, Zn and Cu content from 5 soil profiles along highway in Patte d'Oie

Fig. 20 shows that atmospheric contamination occurs along the Dakar-Rufisque highway. Trace elements in these soils do not stem from UA activity (pesticides and waste water aspersion), but from atmospheric city pollution (transport and industries next to Dakar harbour). "Bergerhof" aerosol samplers have recently been installed and will allow to quantify and analyse atmospheric dusts.

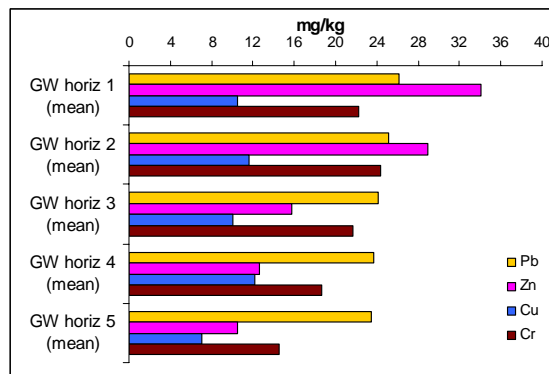
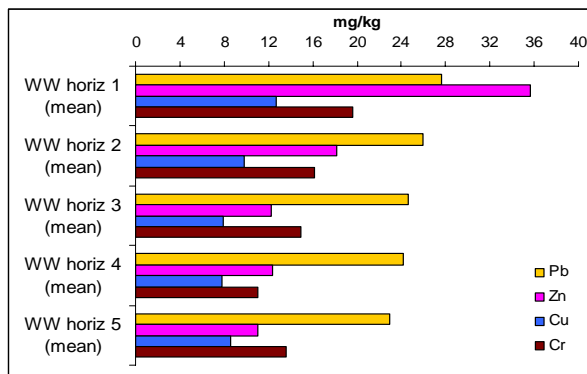


Fig. 21: trace elements as a function of soil depth in Pikine and Patte d'Oie. A): 9 soil profiles irrigated with waste water; B): 9 soil profiles irrigated with ground water.

### 4.3 Soil discussion (first results)

Only a slight increase of lead, copper, and chromium is detectable in the two first soil horizons (0-50cm) irrigated with waste water, while a significant increase of zinc is denoted (Fig. 21 A). In soils irrigated with ground water, no accumulation of lead, copper nor chromium in the soil surface horizons can be observed, while zinc is accumulated (Fig. 21 B). This could signify a Zn input from fertilizers or pesticides. The comparison of trace element contents between waste water-irrigated soils and ground water-irrigated soils also demonstrates that the concentrations of 10 to 40 mg/kg of each element are a regional background in the Dakar periurban zone. These concentrations are below the Swiss guide value. In Pikine and Patte d'Oie, the slight accumulation of trace elements in waste water irrigated soils until 50cm can be correlated with results from Ndiaye (2005), who found enteriobacteria until 60m depth in the same soils. So it can be supposed that waste water influence soils down to 50-60cm. Today, these contaminations are not significant and do not endanger urban agriculture.

## 4.4 Waste water characterisation

### 4.4.1 Composition

The domestic waste water content from suburban zones of Dakar is varying significantly during a day, a week or a season, as a function of water use (shower time, laundry day, prayer day, climate, presence of handcraft effluents, etc.). The characteristics shown in Tab. 1 represent two sampling seasons for Pikine, comprising daily variation, but only one season for Patte d'Oie and Ouakam. Waste waters are much more concentrated than in northern countries because water is scarcely available (40-70L/inhab/day) and expensive, so less dilution occurs. As a comparison, TSS in waste waters from Switzerland is around 120 (mg/L), COD is around 280, NH<sub>4</sub> around 20 and total P around 6 (Gujer, 2002). In Switzerland, around 160 litres/inhab/day are consumed, without industrial and agriculture use (total : 400L/inhab/day).

Tab.1: physicochemical and microbial characterisation of waste water used for irrigation in UA

	<b>Pikine (n=10)</b>	<b>Patte d'Oie (n=2)</b>	<b>Ouakam (n=1)</b>
Conductivity (μS/cm)	3200 to 4200	1500 to 2200	2000
pH	7.3 to 8.2	7.3 to 7.6	7.6
TSS (mg/L)	400 to 1600		
Chemical oxygen demand (mg/L)	600 to 1500		
Dissolved org C (mg/L)	50 to 100		
Eh (mV)	-400 to -200	20 to 30	
O <sub>2</sub> (mg/L)	0 to 1	4 to 7	
NH <sub>4</sub> <sup>+</sup> (mg/L)	160 to 250	115 to 125	40
NO <sub>3</sub> <sup>-</sup> (mg/L)	0	9 to 35	0.5
Cl <sup>-</sup> (mg/L)	300 to 530	100	100
PO <sub>4</sub> <sup>3-</sup>	30 to 70	0 to 30	10
K <sup>+</sup>	55 to 70		
Cr	4 to 20	2 to 2.5	2
Zn	60 to 220	30 to 40	80
Cu	6 to 110	4 to 16	15
Faecal coliform (CFU/100ml) Faruqui & al,2004)	17 × 10 <sup>3</sup> to 11 × 10 <sup>6</sup>	-	47 × 10 <sup>4</sup> to 47 × 10 <sup>5</sup>
Parasite prevalence (%) (Faruqui & al,2004)	41	-	60

In terms of parasites in Pikine waste water, Gaye and Niang (2002) report 1.8x10<sup>7</sup> N/100ml of streptobacillus, 6 larvae /10ml of anguillule, 25 cysts/10ml of entamoeba and 3 eggs /10ml of Ascaris.

#### 4.4.2 Quantification

In Pikine, the main UA site where waste water is reused, it is around **330 m<sup>3</sup>** of waste water that is daily used to cultivating 60 vegetable plots constituted of 8200 beds, each irrigated with 40 litres per day. However, this amount is permanently increasing due to the availability of waste water.

This is a small part of the 180'000 m<sup>3</sup> of waste water daily produced in Dakar, of which only about 40% is collected and only 6% of the collected waste water (4'000 m<sup>3</sup>) is treated. The remaining is discharged without treatment to the sea.

#### 4.5 Ground water characterisation

Fig22 shows that the local ground water is strongly contaminated by chloride and nitrate and that the amount is strongly varying with small distances. The impact of waste water is partly responsible of high NO<sub>3</sub> levels in Pikine and Patte d'Oie, together with organic manure. However, the inadequate sanitation disposals in the suburbs of Dakar, mostly old unconsolidated septic tanks which are directly in contact with the subsurface groundwater, are also responsible for the regional contamination. The saline intrusion due to overexploitation of ground water is responsible for high level of chloride in Pikine and Patte d'Oie, and this phenomena is gaining a regional scale. WHO guideline for drinking water of 50mg/L nitrate are exceeded in the whole periurban zone of Dakar.

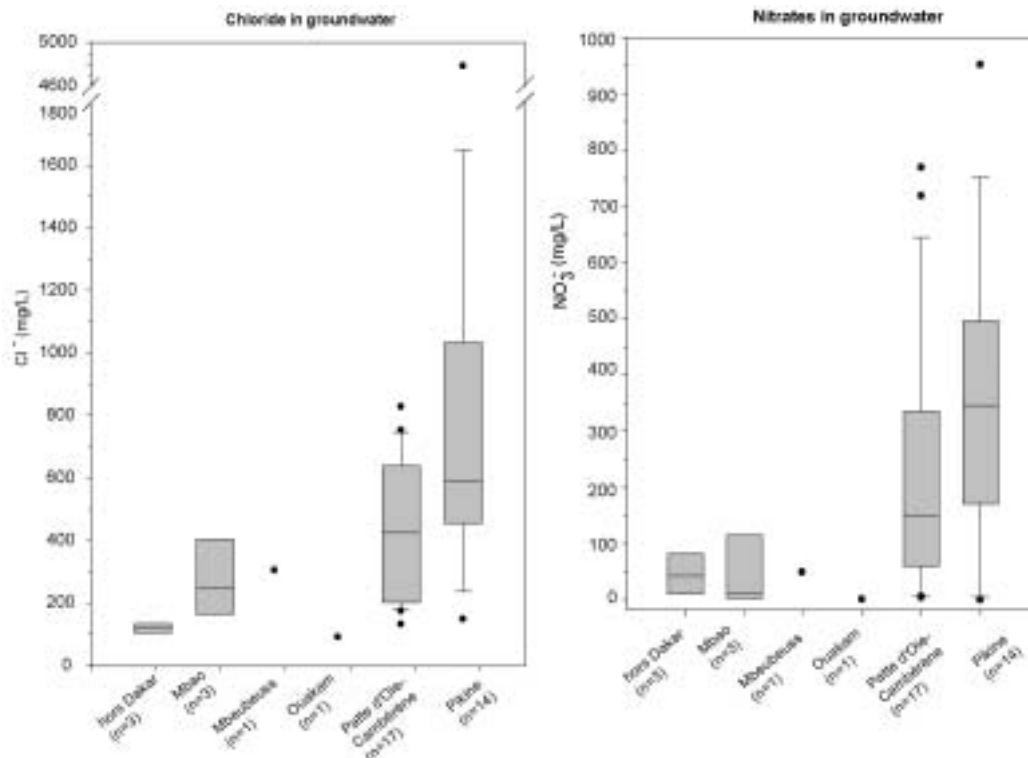


Fig22: nitrate and chloride in local ground water, in function of localisation in the periurban zone of Dakar.

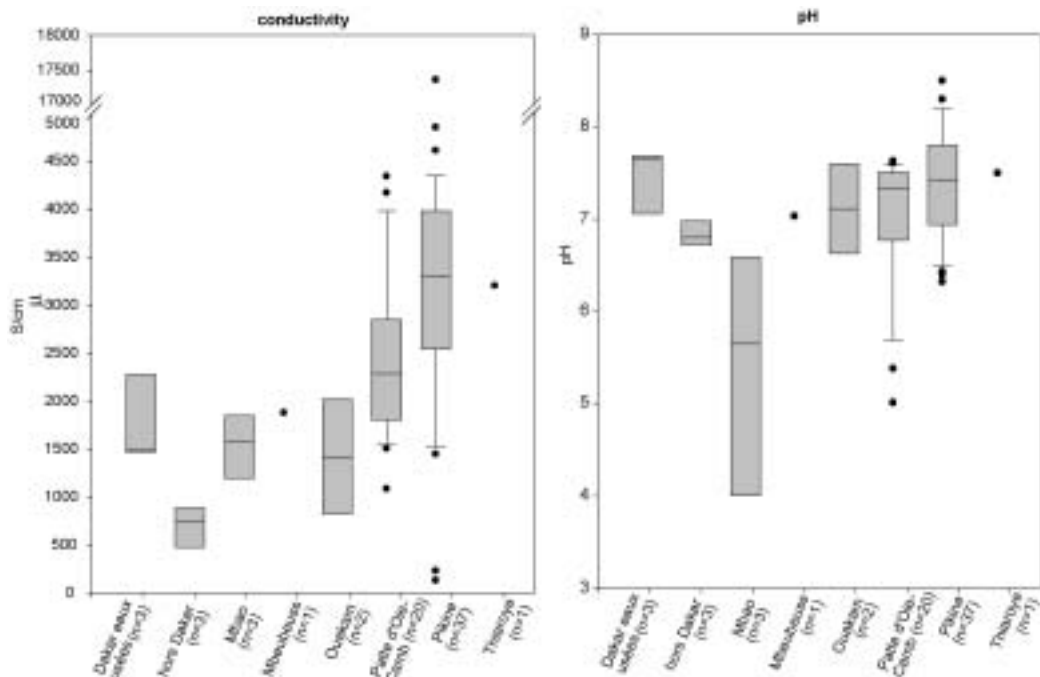


Fig23 : conductivity and pH in function of localisation in the periurban zone of Dakar

Mineralization outside Dakar is low, denoting the important urban impact of the city. pH is globally close to 7 and both waste water and saline ground water seem to increase it. pH of the ground water in Mbao (sampled in a *céane*) is extremely low (3.9), probably due to the national chemical industries (ICS).

Outside the city of Dakar, trace elements in the Thiaroye aquifer are low (below 10µg/L per element), as shown in Fig 25 (see *Dène* samples, located next to Sebifhotane, Fig 4). The concentrations reaching 80-120 µg/L of Co, Ni and Zn in Mbao UA *céane* are probably the consequence of chemical industries standing behind. The Zn concentration in Mbeubeuss *céane*, exceeding 250 µg/L, is due to the enormous landfill situated above UA site. According to this landfill, the content in other trace elements is surprisingly low.

In Pikine and Patte d'Oie UA site, the ground water is clearly contaminated, exceeding drinking water WHO guidelines for Pb. This is important to mention as ground water is daily drunk by market gardeners from Patte d'Oie. The source of Pb, however, does not come from waste water (content below 10µg/L), but seem to provide from atmospheric input; rain samples contain 60µg/L Pb. Atmospheric dusts have not yet been analysed.

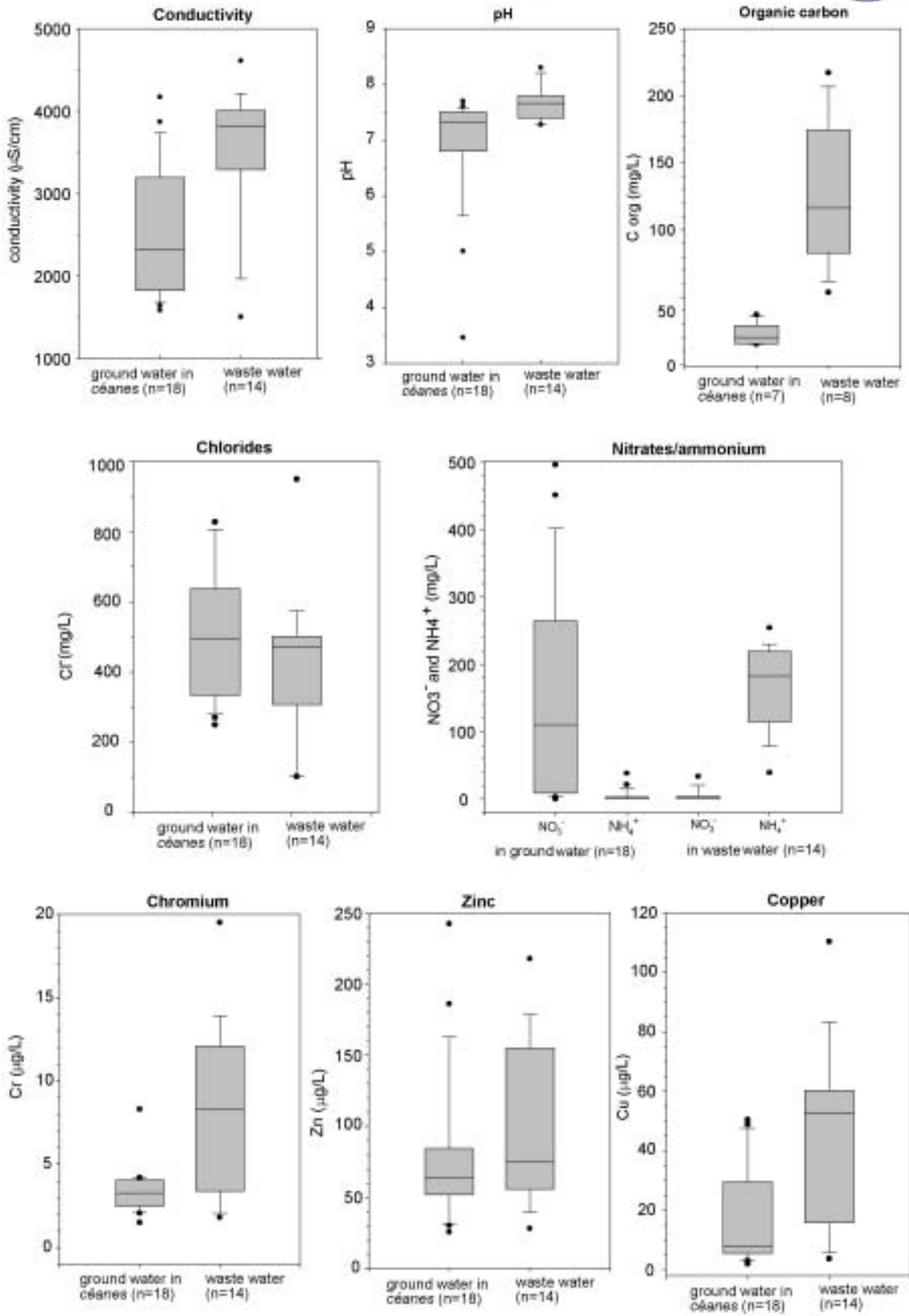


Fig 24: comparison of physicochemical parameters from groundwater and wastewater.

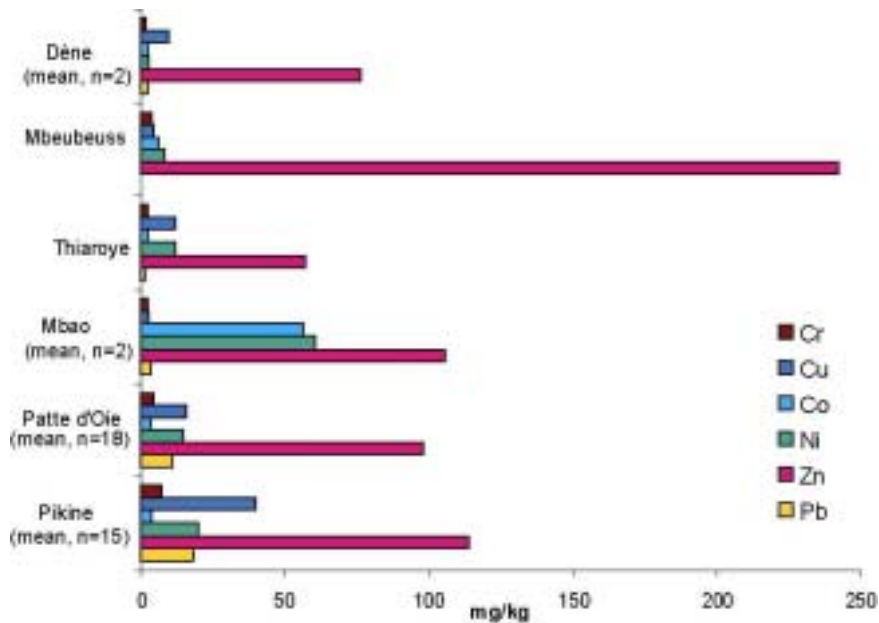


Fig25: trace element content in ground water, in function of UA site.

#### 4.6 Water discussion (first results)

The UA activity in Pikine and Patte d'Oie have a marked impact on ground water signature, especially for chlorides and nitrates. Overpumping of the ground water and irrigation with waste water are the direct causes. A steadily increasing amount of waste water is applied on the highly permeable soils of Pikine, and as a consequence, the strongest impact is found there. Not only urban agriculture, but also handicraft tannery inside this UA site is concerned: Tab 2 shows the water composition in the *céane* just downhill of the tannery.

Tab.2: *céane* characteristics next to tannery.

Conductivity (uS/cm)	17'360	SO4 (mg/L)	329
Salinity (‰)	8.7	Fe (ug/L)	2224
Cl (mg/L)	4785	Cr (ug/L)	16
Na (mg/L)	2627	Zn (ug/L)	90

In terms of inorganic trace elements, we found surprisingly low concentrations in waste waters, meaning a strict domestic source. However, the concentrations are clearly higher in the ground water from UA site than from rural market gardens. However, the link between waste water and ground water contamination has not been clearly demonstrated.

## 4.7 Conclusion

Today, irrigation with waste water is still marginalised and the generalisation of this practice could provoke a more severe contamination of inorganic elements in soils and groundwater. Moreover, a possible change in waste water composition could affect all predictions, especially if industrial effluents are present. The organic contamination (pathogenic bacteria and parasites, pesticides, pharmaceuticals) has not been considered in this study and conclusions about danger of reusing waste water could therefore not be established.

## 5 Perspectives

### 5.1 Work to be done in the near future

- Soil parameters such as cationic exchange capacity, saturation rate, iron extractions and further particle size will be done in order to detail the soil characterisation.
- Mineralogical analyses by XRD will be provided to establish the type of clay present in the different soil types.
- 5 pesticide analyses will be soon provided by a cantonal laboratory to have a first idea of groundwater contamination by organochlorine and organophosphorous.

The investigations of these key-parameters will allow establishing a precise soil characterisation which will give precious information about micro-contaminant behaviour. Key parameters influencing micro-contaminant behaviour, an important issue to understand and predict sustainability.

### 5.2 Long term questions

- Correlation with pesticides and microbiological analyses will be essential to understand this agroecosystem.
- A more detailed study in the field of sulphate soils, clayish soils outside Dakar and brown eutric soils in Ouakam will be necessary.
- Assessment of soil salinity will be done by geophysical survey and laboratory experiments.
- Impact of salinisation on micro-contaminant pathways.
- Study of mineralogical processes along the slope.
- Impact of organic matter on micro-contaminant pathways.
- Evaluation of pesticides in soils, groundwater and crop.

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## 8 Appendix

- A1: soil parameters
- A2: water parameters
- B : soil analyses results
- C : water analyses results
- D : particle size

## Appendix A1

Profile	dept	locality	soil type	irrigated with	W coord	N coord
De02	0-10	outside Dakar	clayish soil	ground water	265319	1642528
De02	40-80	outside Dakar	clayish soil	ground water		
De02	80-90	outside Dakar	clayish soil	ground water		
De 02	90-100	outside Dakar	clayish soil	ground water		
Oua01	0-20	Ouakam	brown eutric clayish soil	waste water	232016	1628040
Oua01	20-40	Ouakam	brown eutric clayish soil	waste water		
De01	0-20	outside Dakar	ferruginous soil	ground water	265319	16642528
De01	30-50	outside Dakar	ferruginous soil	ground water		
De01	60-80	outside Dakar	ferruginous soil	ground water		
De03	0-30	outside Dakar	ferruginous soil	ground water	258000	1635000
De03	40-60	outside Dakar	ferruginous soil	ground water		
De03	80-100	outside Dakar	ferruginous soil	ground water		
Mb-01	0-10	Mbao	ferruginous soil	ground water	240758	1634648
Mb-01	10-20	Mbao	ferruginous soil	ground water		
Mb-01	30-40	Mbao	ferruginous soil	ground water		
Mb-02	0-10	Mbao	ferruginous soil	ground water	247986	1631604
Mb-02	10-20	Mbao	ferruginous soil	ground water		
Mb-02	30-40	Mbao	ferruginous soil	ground water		
Mb-02	50-60	Mbao	ferruginous soil	ground water		
Mbb-01	0-10	Mbeubeuss	ferruginous soil	ground water	242750	1631258
Mbb-01	10-20	Mbeubeuss	ferruginous soil	ground water		
Mbb-01	30-40	Mbeubeuss	ferruginous soil	ground water		
Mbb-01	50-60	Mbeubeuss	ferruginous soil	ground water		
Ca05	0-10	Patte d'oie-Camb	ferruginous soil	ground water	238165	1631494
Ca05	10-50	Patte d'oie-Camb	ferruginous soil	ground water		
Ca05	50-70	Patte d'oie-Camb	ferruginous soil	ground water		
Ca02	0-7	Patte d'oie-Camb	ferruginous soil	ground water	238364	1631972
Ca02	7-15	Patte d'oie-Camb	ferruginous soil	ground water		
Ca02	15-50	Patte d'oie-Camb	ferruginous soil	ground water		
Ca02	70-80	Patte d'oie-Camb	ferruginous soil	ground water		
PO-01	0-5	Patte d'oie-Camb	ferruginous soil	ground water	240752	1631147
PO-01	5-20	Patte d'oie-Camb	ferruginous soil	ground water		
PO-01	30-40	Patte d'oie-Camb	ferruginous soil	ground water		
PO-01	50-60	Patte d'oie-Camb	ferruginous soil	ground water		
PO-02	0-5	Patte d'oie-Camb	ferruginous soil	ground water	237770	1631298
PO-02	5-20	Patte d'oie-Camb	ferruginous soil	ground water		
PO-02	30-40	Patte d'oie-Camb	ferruginous soil	ground water		
PO-03	0-5	Patte d'oie-Camb	ferruginous soil	ground water	237833	1631354
PO-03	10-20	Patte d'oie-Camb	ferruginous soil	ground water		
PO-03	30-40	Patte d'oie-Camb	ferruginous soil	ground water		
PO-04	0-5	Patte d'oie-Camb	ferruginous soil	ground water	237726	1631292
PO-04	10-20	Patte d'oie-Camb	ferruginous soil	ground water		
PO-04	30-40	Patte d'oie-Camb	ferruginous soil	ground water		
PO-05	0-5	Patte d'oie-Camb	ferruginous soil	ground water	237709	1631393
PO-05	10-20	Patte d'oie-Camb	ferruginous soil	ground water		
PO-05	30-40	Patte d'oie-Camb	ferruginous soil	ground water		
PO-06	0-10	Patte d'oie-Camb	ferruginous soil	ground water	237673	1631343

Profile	depht	locality	soil type	irrigated with	W coord	N coord
PO-06	10-20	Patte d'oie-Camb	ferruginous soil	ground water		
PO-06	30-40	Patte d'oie-Camb	ferruginous soil	ground water		
PO-06	80-100	Patte d'oie-Camb	ferruginous soil	ground water		
PO-06	150-180	Patte d'oie-Camb	ferruginous soil	ground water		
PO-06	250-280	Patte d'oie-Camb	ferruginous soil	ground water		
PO-07	0-10	Patte d'oie-Camb	ferruginous soil	ground water	237689	1631358
PO-07	15-30	Patte d'oie-Camb	ferruginous soil	ground water		
PO-07	50-60	Patte d'oie-Camb	ferruginous soil	ground water		
PO-08	0-10	Patte d'oie-Camb	ferruginous soil	waste water	237751	1631678
PO-08	10-20	Patte d'oie-Camb	ferruginous soil	waste water		
PO-08	30-40	Patte d'oie-Camb	ferruginous soil	waste water		
PO-08	60-70	Patte d'oie-Camb	ferruginous soil	waste water		
PO-08	100-120	Patte d'oie-Camb	ferruginous soil	waste water		
PO-08	250-280	Patte d'oie-Camb	ferruginous soil	waste water		
PO-08	650	Patte d'oie-Camb	ferruginous soil	waste water		
PO-09	0-10	Patte d'oie-Camb	ferruginous soil	waste water	237694	1631703
PO-09	10-20	Patte d'oie-Camb	ferruginous soil	waste water		
PO-09	20-30	Patte d'oie-Camb	ferruginous soil	waste water		
PO-09	40-50	Patte d'oie-Camb	ferruginous soil	waste water		
PO-09	80-90	Patte d'oie-Camb	ferruginous soil	waste water		
Pi07	10-15	Pikine	ferruginous soil	waste water	241028	1633401
Pi07	20-30	Pikine	ferruginous soil	waste water		
Pi07	60-80	Pikine	ferruginous soil	waste water		
Pi07	500	Pikine	ferruginous soil	waste water		
Pi07	600	Pikine	ferruginous soil	waste water		
Pi07	700	Pikine	ferruginous soil	waste water		
Pi01	0-7	Pikine	ferruginous soil	waste water	241214	1633364
Pi01	0-30	Pikine	ferruginous soil	waste water		
Pi01	30-85	Pikine	ferruginous soil	waste water		
Pi01	85-130	Pikine	ferruginous soil	waste water		
Pi01	130-190	Pikine	ferruginous soil	waste water		
Pi01	300	Pikine	ferruginous soil	waste water		
Pi01	400	Pikine	ferruginous soil	waste water		
Pi01	500	Pikine	ferruginous soil	waste water		
Pi03	0-7	Pikine	ferruginous soil	non irrigated	241216	1633052
Pi03	7-38	Pikine	ferruginous soil	non irrigated		
Pi03	38-58	Pikine	ferruginous soil	non irrigated		
Pi03	58-70	Pikine	ferruginous soil	non irrigated		
Pi03	58-100	Pikine	ferruginous soil	non irrigated		
Pi03	100-180	Pikine	ferruginous soil	non irrigated		
Pi06	0-10b	Pikine	ferruginous soil	ground water	241498	1633237
Pi06	10-30	Pikine	ferruginous soil	ground water		
Pi06	30-50	Pikine	ferruginous soil	ground water		
Pi06	100	Pikine	ferruginous soil	ground water		
Pi06	200	Pikine	ferruginous soil	ground water		
Pi08	0-7	Pikine	ferruginous soil	waste water	241210	1633660
Pi08	20-30	Pikine	ferruginous soil	waste water		
Pi08	180-200	Pikine	ferruginous soil	waste water		
Pi12	0-10	Pikine	ferruginous soil	waste water	241119	1633469
Pi12	10-20	Pikine	ferruginous soil	waste water		

Profile	depht	locality	soil type	irrigated with	W coord	N coord
Pi12	30-40	Pikine	ferruginous soil	waste water		
TH-01	0-10	Thiaroye	ferruginous soil	ground water		
TH-01	10-20	Thiaroye	ferruginous soil	ground water		
TH-01	30-50	Thiaroye	ferruginous soil	ground water		
Pi02	10-20	Pikine	hydrom min soil	waste water	241125	1633376
Pi02	40-60	Pikine	hydrom min soil	waste water		
Pi02	80-90	Pikine	hydrom min soil	waste water		
Pi02	100-120	Pikine	hydrom min soil	waste water		
Pi02	150-160	Pikine	hydrom min soil	waste water		
Pi05	0-7	Pikine	hydrom min soil	waste water	241292	1633474
Pi05	7-29	Pikine	hydrom min soil	waste water		
Pi05	29-70	Pikine	hydrom min soil	waste water		
Pi10	0-20	Pikine	hydrom min soil	non irrigated		
Pi10	30-50	Pikine	hydrom min soil	non irrigated	241292	1633012
Pi10	50-70	Pikine	hydrom min soil	non irrigated		
Ca03	0-20	Patte d'oie-Camb	hydrom org soil	ground water	238063	1631546
Ca03	20-40	Patte d'oie-Camb	hydrom org soil	ground water		
Ca03	50-60	Patte d'oie-Camb	hydrom org soil	ground water		
Ca01	0-10	Patte d'oie-Camb	hydrom org soil	ground water	238310	1631979
Ca01	10-30	Patte d'oie-Camb	hydrom org soil	ground water		
Ca01	30-40	Patte d'oie-Camb	hydrom org soil	ground water		
Ca01	50-70	Patte d'oie-Camb	hydrom org soil	ground water		
Ca04	0-30	Patte d'oie-Camb	hydrom org soil	ground water	238096	1631508
Ca04	30-50	Patte d'oie-Camb	hydrom org soil	ground water		
Ca04	60-80	Patte d'oie-Camb	hydrom org soil	ground water		
Ca04	90-100	Patte d'oie-Camb	hydrom org soil	ground water		
Pi09	0-20	Pikine	hydrom org soil	ground water	241555	1633192
Pi09	20-50	Pikine	hydrom org soil	ground water		
Pi09	50-70	Pikine	hydrom org soil	ground water		
Pi09	80-100	Pikine	hydrom org soil	ground water		
Pi11	0-20	Pikine	hydrom org soil	non irrigated	241237	1633232
Pi11	30-50	Pikine	hydrom org soil	non irrigated		
Pi13	0-20	Pikine	hydrom org soil	waste water	241128	1633436
Pi13	30-40	Pikine	hydrom org soil	waste water		
Pi14	0-20	Pikine	hydrom org soil	non irrigated	240994	1633212
Pi14	20-40	Pikine	hydrom org soil	non irrigated		
Pi04	0-11	Pikine	sulphate salted soil	non irrigated	241025	1633239
Pi04	11-27	Pikine	sulphate salted soil	non irrigated		
Pi04	27-45	Pikine	sulphate salted soil	non irrigated		
Mbb-comp	<2mm	Mbeubeuss	compost			
Mbb-comp	>2mm	Mbeubeuss	compost			

## Appendix A2

water type	name	W coord	N coord	water type	name	W coord	N coord
waste water	canal uni			soil water	Pi-12ALys1	241119	1633469
waste water	EBCamb				Pi-		
waste water	canal 6			soil water	12BhLys1	241119	1633469
céane	DeC01	265319	1642528		Pi-		
piezometer	P2-6	247799	1633714	soil water	12FeLys1	241119	1633469
well	DeP01	265319	1642528	drinking water	HLMep		
céane	Mb-01	240758	1634648	surface water	PiMa02		
céane	Mb-02	247986	1631604	surface water	PiMa01		
piezometer	PAQPUD-3	246505	1630766	surface water	PiNa10		
céane	Mbb-01			surface water	PiNa13		
waste water	Oua01	232016	1628040	waste water	PiEUS0		
piezometer	VDN	233877	1629537	waste water	PiM2		
céane	CaC02	238063	1631546	waste water	PiEU1		
céane	CaC01	238310	1631979	waste water	PiEU2		
céane	ANd1	237698	1631405	waste water	PiEU3		
céane	AMb1			waste water	PiM3		
céane	MoB1	238042	1631896	waste water	PiEUS3		
céane	AB1	237804	1631408	waste water	PiEUS2		
céane	MB9	238050	1631772	waste water	PiEUS1		
céane	MB6	237964	1631727	waste water	PiM1		
céane	MB1	238019	1631719	waste water	Pi-EUB		
céane	NdF1	237878	1631448	piezometer	Pi-02	241210	1633660
céane	IMB2			piezometer	PiPz01	241108	1633570
waste water	MS1	237693	1631683	piezometer	PiPz06	241498	1633237
waste water	PO-09C	237695	1631712	piezometer	PiPz07	241555	1633192
piezometer	PO-08a	237751	1631678	piezometer	PiPz03	241075	1633263
piezometer	PO-06a	237673	1631343	piezometer	Pi-03	241075	1633263
piezometer	PO-06b	237673	1631343	piezometer	Pi-01	241108	1633570
piezometer	PO-08b	237751	1631678	piezometer	Pi-07	241555	1633192
well	KD1	237578	1631364	piezometer	Pi-04	241214	1633364
well	SS1	237680	1631452	rain	Pi-Pluv1	241214	1633364
well	MoS1	237764	1631711	rain	Pi-Pluv2	241214	1633364
céane	PiC3			well	PiP01		
céane	PiC2	241510	1633151	well	PiP02cim	241764	1632790
céane	PiC1			céane	Th-01		
céane	Pi-tannerie			soil water	PiSol14	240994	1633212