Czech University of Life Sciences Prague

Faculty of Tropical AgriSciences

Proposal of technology treatment of fluoridated waters, Senegal

MASTER'S THESIS

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Abstract

In Senegal, a large number of boreholes in the western part of the country, the most populated, are salted. Unsalted water points are often polluted (wells), and nearly a third of them have very high fluorine concentrations (up to 10mg per liter). It is estimated that more than 500 000 rural people are thus subject to a major health risk. Fluoride is one of the most abundant elements in the earth's crust. It is found in the form of fluorite (CaF_2), biotite ($(Mg, Fe)_2Al_2(K, H)(SiO_4)_2$), cryolite ($Na_3(AlF_6)$) and fluorapatite ($Ca_{10}F_2(PO_4)_6$). The presence of excess fluoride ions in drinking water is, therefore, the cause of serious poisoning. In Senegal, as in many other countries globally, studies show that from 2 mg/L, all children are affected and that 60% of them have severe fluorosis for levels close to 4 mg/L. The challenge of removing excess fluoride ions from water meant for human consumption is a complicated scientific subject requiring a multidisciplinary approach due to the various treatment operations undertaken. This research provides an up-to-date review of the available defluorination techniques and a proposition of appropriate methods for drinking water in rural Senegal. Activated alumina, bone char, and aluminum salt were shown to be effective in developing coutries in defluorination of household water. The affordability being always the driving element to the process selection.

Keywords: defluorination, nanofiltration, reverse osmosis, sustainable development, Senegal, NDP (Notto-Dismon-Palmarin), water purification technologies, flouridated water, dental@bone fluorosis

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

DIPLOMA THESIS ASSIGNMENT

Bc. Ba Doudou

Tropical Agriculture
Sustainable Rural Development in the Tropics and Subtropics

Thesis title

Proposal of technology treatment of fluoridated waters, Senegal

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Objectives of thesis

Main objective:
The main objective of this thesis is the mitigation of amount of fluorine contained in the wells and boreholes in rural Senegal: NDP case, by proposing a purification technology.

Specific objectives:
•Find the source of NDP water pollution,
•Evaluate the level of fluoride contamination in NDP waters,
•Evaluate the impact of fluoride to the population,
•Propose the proper water purification technologies for mitigation of amount of fluoride in NDP water network

Methodology

•Collect water samples from the NDP water distribution network,

•Perform laboratory analyses of our samples thus obtained,

•Use monthly, semi-annual, annual reports and lab analysis reports from NDP network managers,

•Interpret the results using physico-chemical aspects software modelling (PHRREQC),

•Use relevant and published scientific articles, periodical papers available in French and English, internet databases as Web of Science, Science Direct, Google Scholar…etc

•Propose a technology to attenuate the amount of fluorine contained in NDP waters

The proposed extent of the thesis

40-60

Keywords

Senegal, NDP (Notto-Dismon-Palmarin), water purification technologies, flouridated water, dental@bone fluorosis

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Recommended information sources

Alley E. 2017.Water quality control handbook. Alexandria: WEF Press. Various pages. Available at http://accessengineeringlibrary.com/browse/water-quality-control-handbook-second-edition

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Karia, G.L., Christian, R.A (2013) Wastewater Treatment: Concepts and Design Approach, ISBN-13: 978-8120347359, 448 p.

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Dean

Prague on 26. 12. 2020

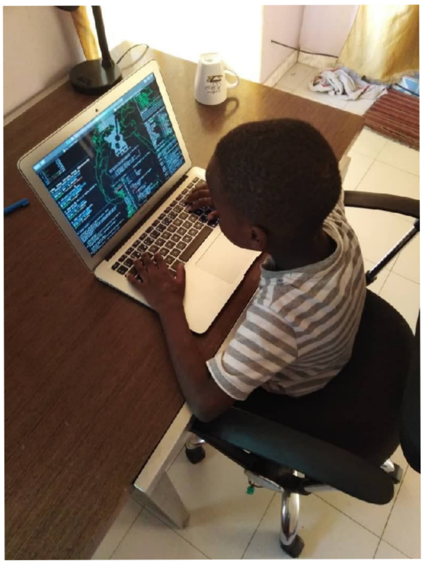
Dedication

To the rural population, in Senegal, living in extremely difficult conditions, without access of water, electricity, proper food and education, most of the time forgotten in the public policies... Fouta Tampi

To the Talibes...

To Baye Cheikh Diop...

To the victims of Coronavirus...



To Assane, my nephew, who I believe will be the next Einstein...

I still believe in the United States of Africa!

Declarations

I hereby declare that I have done this thesis entitled **Proposal of technology treatment of fluoridated waters, Senegal** independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

Prague 2021
Doudou BA

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I would like to thank my family and my friends that are always supporting me and inspiring me, my Dad, my Mum, ...
I come back to thank once more my supervisor Dr. Vladimir Krepl, for all his efforts towards the research and his management that is challenging me every day to give the best of myself.

List of Abbreviations

ANSD Agence Nationale de la Statistique et de la Demographies. 10, 12

Br- Bromide. 60

Cl− Chloride. 59

CO3 2− Carbonates. 47

DGPRE Direction de Gestion et de Planification des Ressources en Eau. 16

EPT Ecole Polytechnique de Thiès. 67

ESP Ecole Supérieure Polytechnique de Dakar. 67

F2 Borehole number 2. 55

F4 Borehole number 4. 56

F− Fluoride. 59

HCO3 − Bicarbonates. 47

ICS Industries Chimiques du Senegal. 11

meq/l Milliequivalents per liter. 47

mg/L Milligram per liter. 14

NO2- Nitrites. 59

NO3- Nitrates. 59

NTU Nephelometric Turbidity Unit. 56

OFOR Office des Forages Ruraux. 39

pH Pothential of hydrogen. 55

PO43- Phosphates. 60

SO_4^{2-} Sulfates. 59

UCAD Université Cheikh Anta Diop de Dakar. 67

USEPA United States Environmental Protection Agency. 65

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Chapter 1

Introduction

1.1 Introduction

In Senegal, a large number of boreholes in the western part of the country, the most populated, are salted. Unsalted water points are often polluted (wells) and nearly a third of them have very high fluorine concentrations (up to 10mg per liter).

The fluoridated water seems 'good' (when not salted) to those who consume it because it has no taste, it is after a decade of consumption that the effects of fluoride on the organism are felt, and the impact of the consumption of these waters is variable from a village to another.

It can be estimated that more than 500 000 rural people are thus subject to a major health risk. Quality standards have been established (they stipulate in particular that any drilling where fluorine concentrations are higher than 3 mg/L should be closed, without any possible derogation), but they are not applied.

Fluoride is one of the most abundant elements in the earth's crust. It is found in the form of fluorite (CaF_2), biotite ($(Mg, Fe)_2Al_2 (K, H) (SiO_4)_2$), cryolite ($Na_3 (AlF_6)$) and fluoroapatite ($Ca_{10}F_2 (PO_4)_6$).

Since these minerals are poorly soluble in water, the concentration of fluoride ions in surface water is generally low. However, the physicochemical characteristics of certain salts and water tables (high temperatures for example) in contact with these rocks promote the dissolution of minerals containing fluorine. (Pontié et al. 2006)

The presence of excess fluoride ions in drinking water is therefore the cause of serious poisoning. Like any trace element, fluoride is necessary and beneficial to the human body at low concentrations, but toxic at higher doses. Indeed, from 0.5 mg/L in fluoride ions, water plays a prophylactic role, but from 0.8 mg/L, the risk of fluorosis begins and becomes strong above 1.5 mg/L . The accepted standard varies in a concentration range of 0.7 to 1.5 mg/L for temperatures of 12 to 25 ° C.

In Senegal, as in many other countries in the world, studies show that from 2 mg/L, all children are affected and that 60% of them have severe fluorosis for levels close to 4 mg/L.

Even more serious damage to the bones and joints (bone fluorosis) is observed when the water contains more than 7 mg/L.

The mapping of the fluorine content in the waters of the Senegal basin indicates that the high values are located in areas where the presence of phosphate deposits is observed and in areas of recognized deposits. The physicochemical characteristics close to phosphate soils and fluoridated soils explain the existence of fluorine where there are phosphates. Since calcium fluoride has properties similar to calcium phosphate, they are generally found associated in nature in the form of fluoroapatite.

This is why in phosphate-producing countries (Tunisia, Morocco, Algeria, and Senegal)Pontié et al. 2006, fluorosis problems are often observed, mainly due to drinking water. The waters richest in fluoride are often slightly salty; it is not necessary to defluorinate all domestic water, but only drinking water.

The Mbour-Thiès-Diourbel-Fatick zone in Senegal is a good illustration of this connection.

Water loaded with fluoride ions circulates in a paleokarst located under an almost continuous layer of phosphate sediments; the fluoride ion concentration drops as soon as this coverage is interrupted to fall below 0.1 mg/L beyond that. In phosphate regions, water from confined aquifers can commonly have concentrations that vary from 5 to 15 mg/L depending on the season. Exceptionally, it may encounter maximum peaks of up to 20 mg/L.

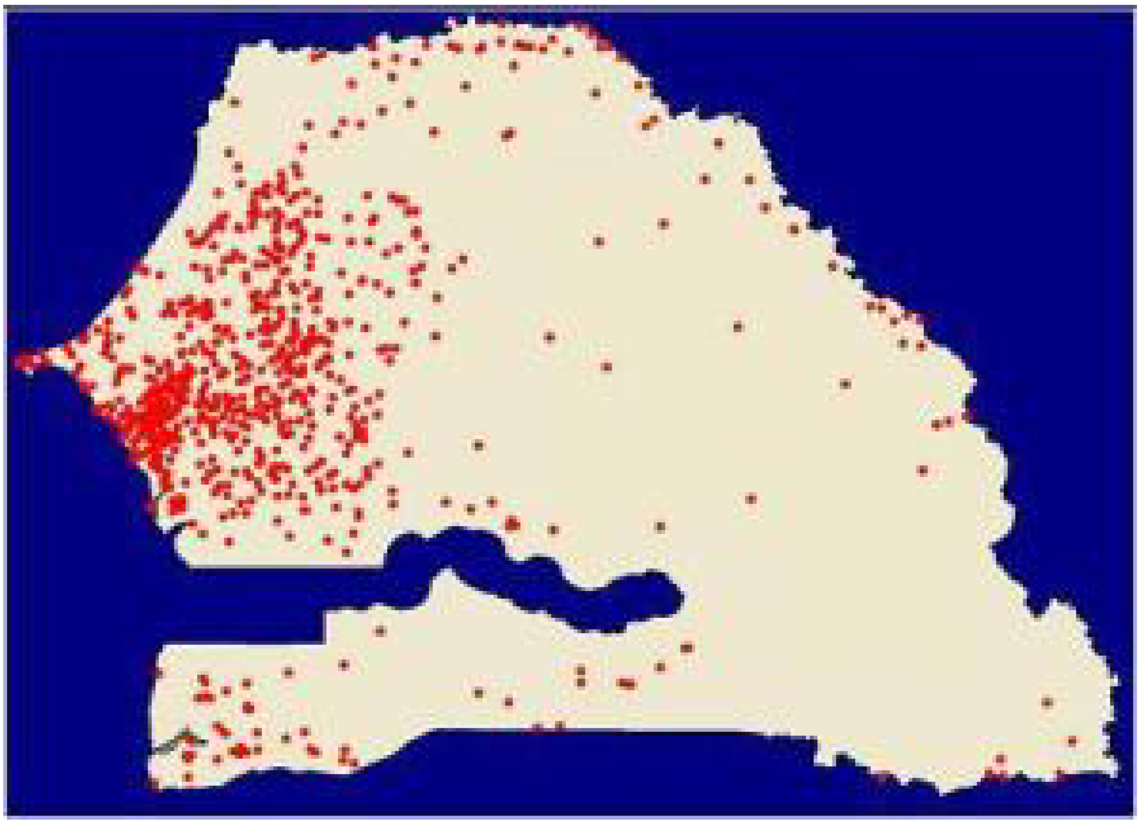


Figure 1.1: Over 800 boreholes exceeding the fluorine standard, Senegal
Source: SGPRE 2001

1.2 Arguments against fluorine

Fluoride is a cumulative poison. On average, only 50 percent of the fluoride ingested each day is excreted by the kidneys. The rest accumulates in our bones, in the pineal gland, in the other tissues. If the kidneys are damaged, the accumulation of fluorine increases, as well as the danger (Connett 2000).

At the biological level, fluoride is very active, even at low concentrations. It interferes with hydrogen bonds (Emsley 1981) and inhibits many enzymes (Waldbott, Burgstahler, et al. 1978).

In several studies, fluoride has been shown to be a mutagen chromosomes and it interferes with the enzymes needed for DNA repair (Tsutsui et al. 1984, Caspary et al. 1987, Kishi et al. 1984 and Mihashi et al. 1996). Recent studies have also found correlation between fluoride exposure and chromosomal damage in human (Sheth et al. 1994, Wu 1995, Meng et al. 1997 and Joseph et al. 2000).

Rats, fed for one year with fluoridated water at 1 ppm sodium fluoride or aluminium fluoride, have suffered from morphological changes in the kidneys and brain, increased accumulation of aluminium in the brain and formation of beta-amyloid deposits, which are features associated with Alzheimer's disease Varner et al. 1998.

Five Chinese studies link the lowering of intelligence quotients among exposure to fluoride. One of these studies Fa-Fu 1991 indicates that even moderate levels exposure to fluoride (eg 0.9 ppm in water) may aggravate neurological disorders caused by a deficiency of iodine. Sodium fluoride is an extremely toxic substance just 200 mg of fluoride ions are enough to kill a young child, 3-5 grams (a teaspoon) are enough to kill an adult.

Studies by Jennifer Luke 2001 have shown that fluoride accumulates in the pineal gland of humans, to potentially very high levels. In his doctoral thesis, Luke also demonstrated, using animal studies, that fluoride inhibits melatonin production and triggers precocious puberty Luke 1997.

During the first half of the 20th century, fluoride was prescribed by European doctors to reduce the activity of the thyroid gland in people with hyperthyroidism (overactive thyroid) (Stecher 1960; Waldbott and Lee 1978). (Fluoridated water acts as) a thyroid-depressant drug, which may promote a higher incidence of hypothyroidism (under active thyroid) in the population, with all the problems associated with this disorder. Such problems include depression, fatigue, weight gain, muscle and joint pain, increased cholesterol levels, and heart disease.

In Russia, Bachinskii et al. 1985, found decreased thyroid function in ”healthy” people drinking fluoridated water at 2.3 ppm.

Some of the early symptoms of skeletal fluorosis (a disease of the bones and joints, caused by fluoride, which affects millions of people in India, China, and Africa) are analogous to the symptoms of arthritis. According to a review of the fluoridation performed by Chemical and Engineering News: ”Since some clinical symptoms are analogous to arthritis, the first two clinical stages of skeletal fluorosis could easily be misdiagnosed” Bachinskii et al. 1985.

According to the Agency for Toxic Substances and Disease Registry (ATSDR 1993) and according to several researchers (Juncos et al. 1972; Marier et al. 1977 and Johnson 1979), the elderly, diabetics and the elderly are particularly vulnerable to the toxic effects of fluoride. people with kidney failure.

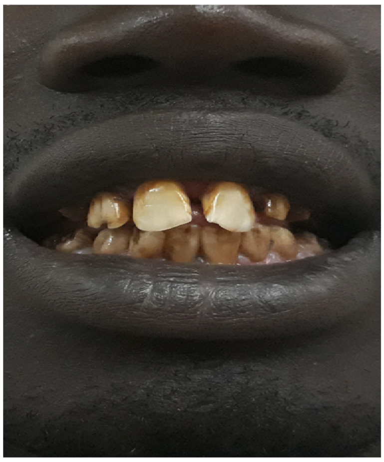
Also vulnerable are those who suffer from malnutrition (eg calcium, magnesium, vitamin C, vitamin D, iodide and low protein diets) (Massler et al. 1952; Marier et al. 1977; Fa-Fu 1991; Chen 1991; Teotia et al. 1998).

Sodium fluoride is extremely toxic - just 200 mg of fluoride ions are enough to kill a young child, 3-5 grams (one teaspoon) is enough to kill an adult.

Figure 1.2: Dental Fluorisis

source: BBC

Figure 1.3: Dental Fluorisis : ”Kaolack Teeth”, referring to Kaolack, a region in Senegal where the residents have dental fluorisis due to consumption of fluorinated waters



source: webself.net

Figure 1.4: Dental Fluorisis

source: google images

Figure 1.5: Children in rural village who suffer from dental fluorosis due to alcohol from the high levels of fluoride in their groundwater system. India, Bihar

alamy bank of images : https://www.alamyimages.fr

Figure 1.6: Child - boy suffering from skeletal fluorosis, India, Bihar

alamy bank of images : https://www.alamyimages.fr

Figure 1.7: Child - girl suffering from skeletal fluorosis, India, Bihar

alamy bank of images : https://www.alamyimages.fr

1.3 Description of the study area

Located 70 km from Dakar, the Thiès region is one of the 14 administrative regions of Senegal. It is located in the West of the country, in a ring around the Cape Verde peninsula. It covers an area of 6,601 km2 or 3.4% of the national territory. It is limited to the north by the region of Louga, to the south by the region of Fatick, to the east by the regions of Diourbel and Fatick, and to the West by the area of Dakar and the Atlantic Ocean.

1.3.1 Physical data

The region presents a relatively flat relief except for the plateau of Thiès, which culminates at 105 m of altitude, the massif of Diass, which rises to 90 m of altitude and the basin of Thiès, which extends over an area of 65 km² and measures 128 m above sea level. These geological forms contain a lot of wealth (limestone, basalt, phosphate attapulgite, etc.).

The main types of soil there are:

- Leached tropical ferruginous soils with a sandy texture called ”Dior soils.” which constitute 70% of cultivable areas;
- tropical ferruginous soils with a sandy-clay texture called ”deckdior” which represent 15% of cultivable areas;
- leached tropical ferruginous soils with a clay-humus texture known as ”deck.” representing 10% of cultivable areas;

- and hydro-morphic soils with a hummus texture called lowland soils which represent 5% of cultivable areas.

The vegetation is composed of:

- the degraded shrub savannah dotted with mono-specific stands of Acacia seyal, Baobabs, a park in Kad and palm trees,
- the filao strip in the Niayes and the PARFOB plantations in the forest classified from Bandia (Eucalyptus and Prosopis juliflora),
- thirteen (13) classified forests with an area of 94,473.6 ha, ie a classification rate of 14.3

Fauna, on the other hand, can be subdivided into two classes:

- furry fauna made up of small ruminants and rodents,
- Palaearctic migratory birds represent avian fauna near water points.

The region has significant groundwater (terminal continental water table, Paleocene water table, Eocene water table, the Maastrichtian, the coastal sand table) and surface water (Lake Tanma, the Somone lagoon, and two retention basins). The water from the wells is of relatively good quality (salinity less than 0.3 g / l) but in some places contains an excess of iron and fluorine (Fissel area, Ndiaganiao).

Eco-geographic zones:

In the Thiès region, four ecogeographic zones have been identified; it is :

- the large coast is known as the northern coastal zone or the Niayes coastal zone: It contains a significant hydro-agricultural potential, which makes it an area of intense market gardening activities. The large coast is also home to mining and chemical industries, fishing (Cayar, Fass Boye), livestock,
- the small coast: It's opening to the sea, its mild temperatures have given it a tourist vocation. It is also an important fishing area with important landing points such as Mbour, Joal, Ndayane,
- the groundnut basin: it mainly occupies the eastern part of a route which passes through the localities of Méckhé, Tivaouane, Thiés, Nguékokh, and Mbour. The soils are degraded by the practice of a long groundnut monoculture,
- the so-called massifs zone: is enclosed within a space between the localities of Thiés, Mont Rolland, Pout, Sébikotane, Diass, Sindia, and Diobass. It is characterized by rugged relief; this area is home to the highest points in the region (Diass massif and the Thiès plateau etc.) and several classified forests (Thiès, Pout, Bandia, Diass). The richness of the subsoil has encouraged the establishment of mining companies.

1.3.2 Climate

Sea currents influence the region's climate. Indeed, the area is located in a transition zone subject to the maritime trade winds and the Harmattan influence. It has a Sudano-Sahelian environment (South, South-East) and more Sahelian in the North and North-East. The West zone, for its part, has a Sub-Canary climate. Average annual precipitation is in the order of 400 to 600 mm of water per year.

After Dakar, the Thiès region is positioned as the region of Senegal with the most significant economic potential. It holds this favorable financial position from the dynamism of the agriculture, livestock, fishing, tourism, crafts, trade, and mining sectors.

1.3.3 Agriculture

The region, according to the agricultural sector, can be subdivided into three specific rural zones, which are:

- the coastal zone of Niayes for market gardening and fruit production;
- the central location for groundnuts, arboriculture, and also cassava;
- the southern area for market gardening and food crops.

The region has significant assets in the fruit field related to existence:

- favorable soil and climatic conditions for arboriculture;
- forestry projects and plant nurseries;
- a forestry training and retraining center.

Most of the vegetables so prized by the Senegalese come from the Niayes area (Cayar, Notto, M'boro); without forgetting the tubers of Taïba N'Diaye, N'Domaure, Kerr N'Diomba; mangoes, melons, and oranges from Pout, Tivaouane, etc.

Table 1.1: Matrix of sectors to be promoted in the Thiès region (ANSD)

Global sector potential	Strategic product / zone potential (Activities to be initiated)
Fruit arboriculture and traditional market gardening	Arboriculture, cassava (potential cash crop but no significant comparative advantage), millet and sorghum Local products (fruits and cereals for processing)
Export and tropical vegetable crops	Intensification of high value-added crops due to land and water limitations; Production potential under management and contractualization with small producers (eg green beans)
Livestock, groundnuts, millet, sorghum: Traditional food crops	Maintenance of traditional cultures but the potential for growth for crops with very high added value limited Local products (milk and cereals for processing) Potential for the development of crops such as bissap, sesame and jatropha Availability of milk for processing
Fishery products	Important raw materials (even if sometimes there is competition between sales to fishmongers and processors), product quality
Mining activities	Mining production sites already identified; Highly developed industrialization potential for mineral extraction ; Potential for infrastructure development

1.3.4 Artisanal fishing

The region of Thiès occupies the first place in terms of artisanal fishing. These performances are the result of an almost permanent fishing activity due to the assets it has:

- 200 km of coastline, comprising two (2) maritime facades: a north facade, approximately 120 km long,
- from Cayar to Diogo and a south front, commonly called Petite Côte 75 km long (from Ndayane to Joal),
- the width of its continental shelf gives it an overabundance and diversity of coastal pelagic species,
- favorable hydrological conditions with upwelling, a phenomenon of deep upwelling waters rich in nutrients for fish.

1.3.5 Art and culture

Handicrafts are characterized by the dynamism and creativity of local artisans, especially in the Mékhé area, which benefits from the proximity of a significant tourist market and the increasing promotion of the use of local products. The acquisition of a specific technical skill and, above all, the development of local creativity are real assets of regional craftsmanship. The craftsmen of the region are among the best in Africa: the shoe, the belt, the Mekhé basket; pottery from Pire or Celko; sculpture or plastic art from the Thiès craft center or the Manufacture des Arts; gold necklaces or sets of jewelry are examples of interest to the world of collectors. Who knows, the region cannot ignore its culture and the talent of its artists. Thiès is known as the city of theatrical and artistic works of Senegal. The craft center of Thiès is full of artisans who try to organize themselves according to their means and limits. About fifteen trades can be identified in the region: Leather goods; Painter; Sculpture; Basketry; Jewelry store; Shoe repair; Sewing; Metalwork; Weaving; Carpentry cabinetmaking; Calabash sculpture; Sheet metal; Auto mechanics; Hairdressing; Electricity building. Already with an excellent recovery in the sector around a chamber of commerce, industrial, craft, and trade promotion, real economic advantages and job promises can emerge.

1.3.6 Tourism

The region has a significant tourist potential with many hotels and beaches that can accommodate a large number of tourists. It has two maritime facades, one to the north with the Grande Côte housing the market garden and fruit area of Niayes. In the south, the Petite Côte is the most frequented tourist area in Senegal. M'Bour, Toubab Dialaw, and Saly are visited by millions of tourists worldwide; large hotels line the beaches. Religious tourism occupies a very important place in the region with Maouloud and Gamous thanks to the establishment of the Tidiane brotherhood around Tivaouane, Thiénaba, Ndiassane, and Pire but also with the pilgrimage of Poponguine.

1.3.7 Hydraulic

The region has significant groundwater tables, both shallow and deep.

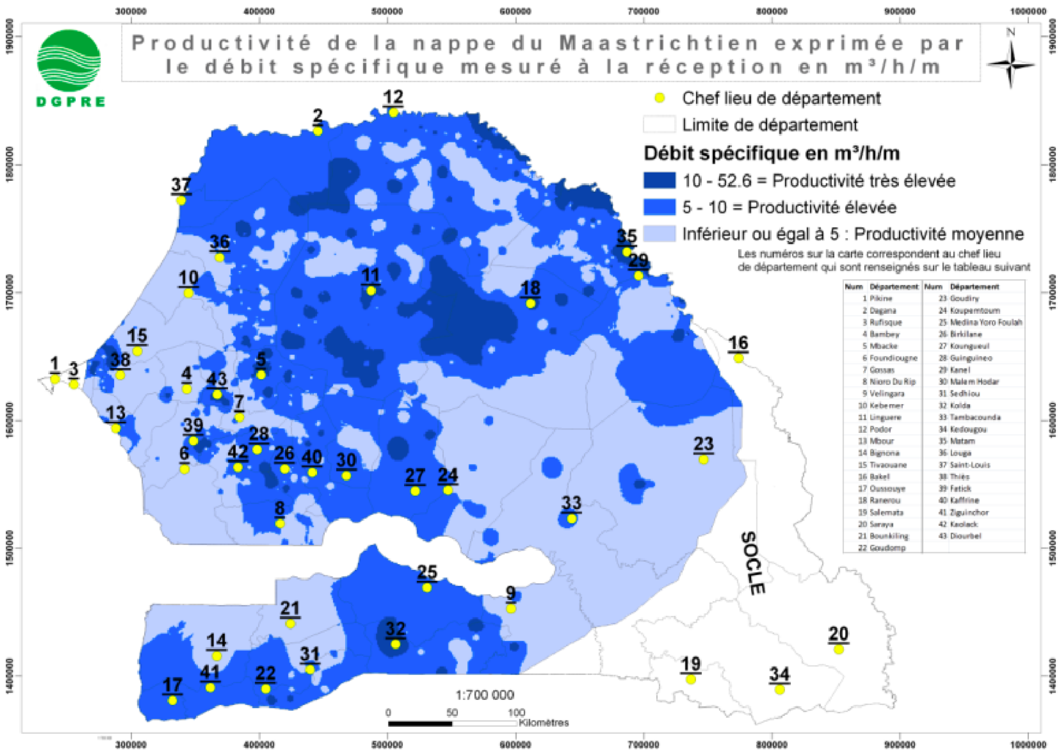
- The sand table of the north coast: located between the sea and the National II from Cayar. The water level varies between 1 to 10 meters in the Niayes and 10 to 35 meters elsewhere. Farmers and ICS boreholes heavily use this table cloth;

- The Paleocene: found everywhere in the region at an average depth of 150 meters. It is heavily exploited in Mbour and at Pout, where the static level is relatively low (30 to 80 m / soil). This tablecloth shows a decrease of 0.5 to 1 m per year due to heavy exploitation. The water quality is very variable depending on the area. This is how in places like Ndiaganiao the water is unfit for consumption because of its high fluorine content (about 12 mg/L).

Table 1.2: Distribution of boreholes in the Thies region

INDICATORS	*THIES*	*MBOUR*	*TIVAOOUANE*	*REGION*
Number of functional boreholes	27	22	44	93
Number of functional boreholes	00	00	02	02
Number of standpipes	138	210	422	770
Number of management committees drilling	22	21	32	75
Number of villages connected	128	1340	288	1756
Total water production (m3)	24 740	26 040	42 080	92 860
Number of standstill drilling	01	03	00	04

Figure 1.8: Productivity of the Maastrichtian aquifer expressed by the specific flow rate measured at the reception in m3 / h / m



Source: DGPRE

Figure 1.8 shows the productivity of the Maastrichtian aquifer (Senegal) expressed by the specific flow rate measured at the reception in m3 / h / m. The yellow dots indicate the county's (district's or region's) head, with a number on top of each dot indicating the county name.

It is determined by a blue color descent gradient, from the mean productivity (light blue) 5 m3/h/m, high productivity 5 and 10 m3/h/m to very high productivity (dark blue), between 10 and 52.5 m3/h/m.

In rural areas, most of the water consumed comes from boreholes and wells. The region has 93 functional boreholes carried out by the State with a 92,860 m3. Despite this critical device in terms of hydraulic equipment, there is a problem covering needs and judicious spatial distribution (29% of boreholes are located in Thiès, against 28% in Mbour and

43% in Tivaouane). This capacity covers only 39% of the drinking water supply needs populations, livestock, and various agricultural production activities.

The difficulties are, above all technical and natural, closely linked to the persistent drought. They relate to:

- the generalized drop in the level of water tables;
- the intrusion of the salty wedge from the sea into the sand sheets of the coastline and terminal continent;
- over-exploitation of aquifers;
- the lack of consultation between the actors (NGOs, private promoters, State structures) stakeholders in the sector;
- insufficient upkeep and maintenance of works and hydraulic equipment;
- the ineffectiveness of certain hydraulic works management committees.

The development of inland valleys within the national hydrographic network and retention basins framework is likely to strengthen the potential of agricultural hydraulics in the region. The reform of the boreholes management policy (installation and functionality of management committees) should also contribute to the proper maintenance of hydraulic structures.

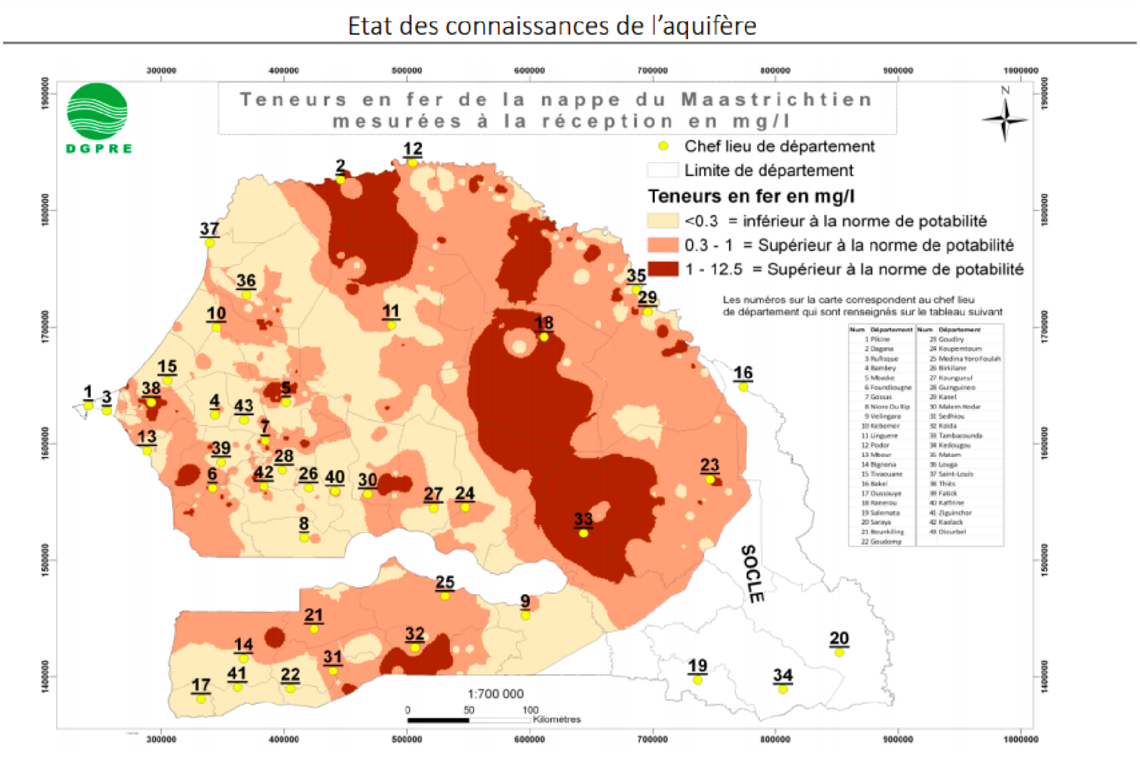
1.3.8 Industries and Mines

The Thiès region has indisputable mining potential, a source of wealth that could develop all of Senegal; the subsoil offers a great diversity of mineral substances, including industrial minerals (phosphates, industrial limestones, barite, etc.), heavy minerals (zircon, titanium), ornamental stones and construction materials (cement works, etc.) which are mainly found in the reserves of AllouKagne, Diogo and Taïba. We also note the existence of significant reserves of alumino-calcium phosphates at Lam Lam (around 80 million tonnes), which can be recovered by calcination in the fertilizer and animal feed sectors. In Pallo, As in Taiba, phosphate was formed during the Tertiary, the source rocks being phosphate of lime and clay rich in alumina.

The presence of deposits, the railway, and the facilities granted by the Code of investments give the Thiès region an advantageous status, although still insufficiently exploited. In 2006, the area had 18 industrial units spread over the three departments.

As can be noted, despite a diversified agricultural production, the region of Thiès has very few agro-food industries. For mines, the production of phosphates and attapulgite is mainly intended for abroad.

Figure 1.9: Iron content of the Maastrichian water table measured at reception in mg/L



Source:DGPRE

Figure 1.9 shows the distribution of iron concentrations in the Maastrichian water table (Senegal), as measured at the site of receipt in milligrams per liter of water. The yellow dots indicate the county's (district's or region's) head, with a number on top of each dot indicating the county name. It is determined by a color gradient, with yellow areas representing iron concentrations lower than 0.3 mg/L and thus below the World Health Organization (WHO) limits, light red areas representing iron content exceeding the WHO limits but in a range between 0.3 and 1 mg/L, and dark red areas representing iron content exceeding the WHO limits but in a range between 1 and 12.5 mg/L. An examination of the map reveals that the western half of the country is more exposed to high fluorine concentrations. In contrast, the center and western parts of the country have fluorine concentrations safe for drinking water use. Our research region is in the western portion of the nation, where the soil is between blue and light brown, leading us to believe that the water collected and distributed in this area may have iron concentrations that exceed the permitted limit.

It is worth highlighting the concentration of industries in the departments of Thiès and Tivaouane, as well as the predominance of the chemical and extracting.

Many quarrying sites contain laterite, sandstone, limestone, clay, attapulgite, phosphate, and basalt. In addition, the region benefits from a peat deposit potential of over 40 million m3 in the Niayes area, titaniferous sands, and natural gas.

Essentially, the difficulties are related to:

- the crisis in the world market for phosphates and fertilizers;
- the high cost of energy and other production factors;
- insufficient rural electrification;
- the weak diversification of the regional industrial fabric;
- difficulties in accessing credit;
- the many difficulties encountered by the textile industries in the region.

1.4 Geology and Hydrogeology

Geological characteristics, chemical qualities of rocks, and the climate of an area determine the fluoride content in groundwater (Atia et al. 2015).

Travi 1993 established the first schematic hydro-geological map of Senegal in 1988. The different hydro-geological units identified are:

- aquifers of fissures and alteration of Precambrian crystal formations of eastern Senegal which limit the sedimentary basin to the east;
- and the aquifers of the sedimentary basin grouped into two groups (lower and upper) which correspond to the main geological formations.

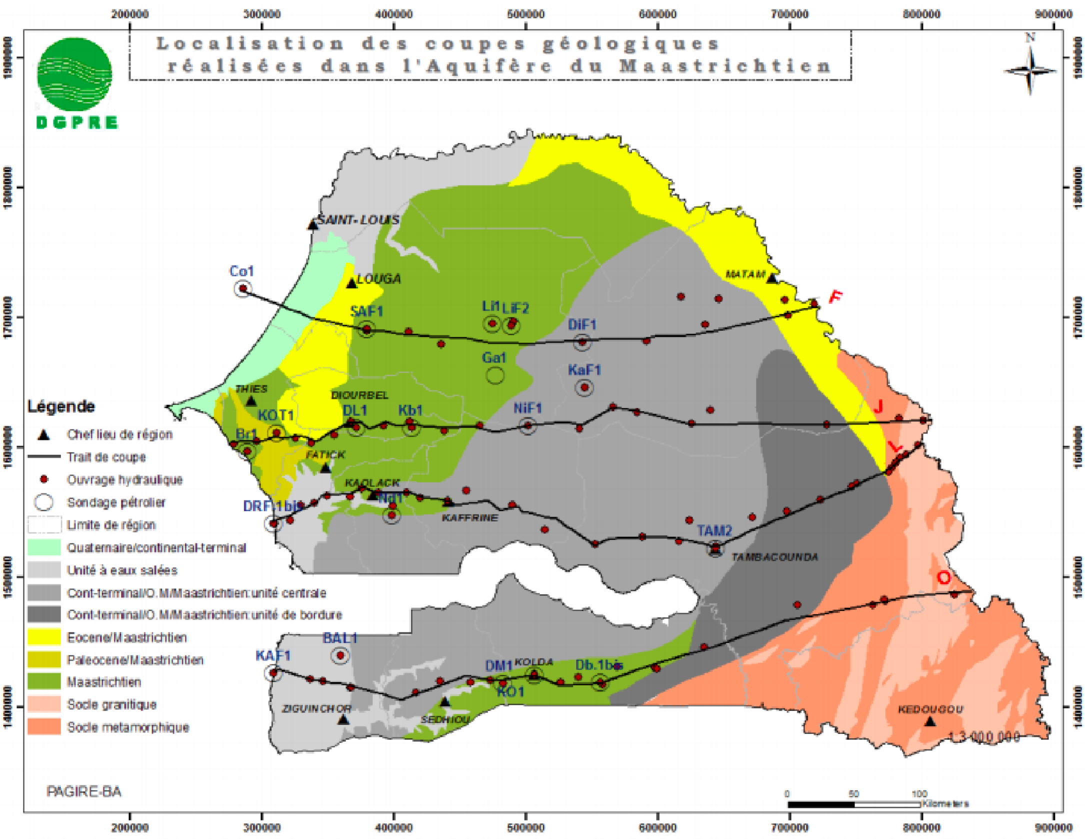
Senegal's hydro-geological units are grouped into four central aquifer systems:

The heterogeneous superficial aquifer system brings together recent predominantly sandy, sandy clay, and sandstone formations between Dakar and Saint-Louis and the alluvial formations of the Senegal River valley. It includes the: sub-basaltic aquifers of Dakar, Thiaroye (between Patte d'oie and Kayar), the North Coast (from Kayar to Saint Louis), the Oligo-Miocene (Tamba Kaffrine, Casamance), the Continental Terminal Ferlo (regions of Saint Louis, Matam, Louga), Sine Gambia (Fatick, Kaolack, Kaffrine) and Casamance.

The semi-deep aquifer system groups together the limestone to marl-limestone formations of the Eocene (between Khombole and Louga going towards Diourbel and the valley of the Senegal river) and of the Paleocene (areas of Sébikoane, Pout, Mbour).

The deep Maastrichtian aquifer system covers 2/3 of the territory except for the basement. The aquifer system of the basement corresponds to the granite and metamorphic formations located in the country's South-East (regions of Tambacounda and Kédougou).

Figure 1.10: Location of the geological sections made in the Maastrichtian aquifer. (DGPRE)



The table cloth presents the network currently monitored by the DGPRE. It has 498 structures, 454 of which are functional. There are 290 piezometers, 127 boreholes, 16 boreholes, and 65 wells.

For a good grid of the network, Senegal is divided into eight zones. During the year, measurements are taken during low water (dry season) and after the rainy season. In the Dakar region, where the water tables are coastal and in high demand for the city's drinking water supply, measurements are carried out monthly.

The data collected relate to the depths and quality of the water, in particular the physicochemical (temperature, pH, conductivity, and dry residue, which are measured in the field) and chemical parameters. These are obtained after laboratory analysis of a water sample and concern the following ions: Sodium (Na +), Calcium (Ca2 +), Magnesium (Mg2 +), Potassium (K +), Iron (Fe), Carbonates (CO3 2-), Bicarbonates (HCO3-), Chloride (Cl-), Sulphates (SO42-), Nitrates (NO3 -), Fluorine (F-), Phosphorus (PO4) and certain heavy metals in the Kédougou area.

1.5 Guidelines for drinking-water quality

A certain number of general parameters are used to characterize water intended for human consumption or industrial uses, particularly hardness, alkalinity, salinity, fluoride, turbidity, etc. Drinking water must also comply with the regulations in force in the country.

Regarding water quality, several parameters can be distinguished at the same time, grouped into five (5) categories:

- Organoleptic parameters
- Physico-chemical parameters
- Parameters concerning unwanted substances
- Parameters concerning toxic substances
- Microbiological parameters (fecal coliforms)

All of the elements that characterize water necessarily belong to one of the categories below.

Table 1.3: WHO standards for drinking water

Sr. No:	Parameter	WHO standards	Remarks
1	Colour (TCU)	15	It may be extended up to 50 if toxic substances are suspected
2	Turbidity (NTU)	5	It may be relaxed up to 25 in the absence of alternate
3	pH	6.5 to 8.5	It may be relaxed up to 9.2 in the absence
4	Total Hardness (as CaCO3), mg/L, max.)	300	It may be extended up to 600
5	Calcium as Ca (mg/L)	75	It may be extended up to 200
6	Magnesium as (mg/L)	30	It may be extended up to 100
7	Copper as Cu (mg/L)	0.05	It may be relaxed up to 1.5
8	Iron (mg/L)	0.3	It may be extended up to 1
9	Manganese (mg/L)	0.1	It may be extended up to 0.5
10	Chlorides (mg/L)	250	It may be extended up to 1000
11	Sulphates (mg/L)	150	It may be extended up to 400
12	Nitrates (mg/L)	45	No relaxation
13	Fluoride (mg/L)	< 1.5	If the limit is below 0.6 water should be rejected, Max. The limit is extended to 1.5
14	Phenols (mg/L)	0.001	It may be relaxed up to 0.002
15	Mercury (mg/L)	0.001	No relaxation
16	Cadmium (mg/L)	0.01	No relaxation
17	Selenium (mg/L)	0.01	No relaxation
18	Arsenic (mg/L)	0.7	No relaxation
19	Cyanide (mg/L)	0.05	No relaxation
20	Lead (mg/L)	0.1	No relaxation
21	Zinc (mg/L)	5	It may be extended up to 10.0
22	Chromium as Cr+6 (mg/L)	0.05	No relaxation
23	Mineral Oil (mg/L)	0.01	It may be relaxed up to 0.03
24	Residual free Chlorine (mg/L)	0.2	Applicable only when the water is chlorinated

Chapter 2

Aim

2.1 Aim of the thesis

The thesis aims to provide an up-to-date review of the available treatments at the home level and the industrial grade and propose a proper technology to remove the excess fluorine in the wells and boreholes in rural Senegal: NDP case.

It involves the following steps:

- Finding the source of NDP water pollution,
- Evaluate the excess fluoride contained in NDP waters
- Evaluate the impact of fluoride to the population,
- Review and propose a proper purification technology to mitigate the amount of excess fluorine

2.2 Structure of the thesis

The thesis has the following structure:

- Materials and methods
- Results
- Discussion
- Conclusion

Chapter 3

Fluoride Treatment Methods

There are specific fluoridation techniques based on the principles of precipitation and adsorption/ion exchange. Unfortunately, these techniques have little or no effect on salt processing (Amath 2017).

There are also so-called membrane treatment technologies (nanofiltration, reverse osmosis, electrodialysis) that significantly reduce the salt and fluorine content. At the same time, there are alternative sources (Water transmission, Impluvium, Mini hand drilling in shallower water tables) that are easy to build permanently and give the simultaneous solution for the wage problem.

3.1 Chemical Precipitation

- Principle:

  There are several techniques for the partial removal of fluorides from drinking water, which nevertheless guarantee a fluoride intake that meets standards.

  Precipitation can be defined as the deposition in a liquid of an insoluble substance which then settles by decanting at the bottom of the vessel in which the reaction has taken place. Fluoride ion precipitation processes are based on the formation of insoluble compounds from these ions and require decanting and filtration after coagulation.

  However, it is necessary to consider the excess precipitation reagents in the treated water, which can alter its quality; which require additional processing steps. Fluoride ions can be precipitated in CaF2 (Fluorite) by adding calcium salts, Ca(OH)2, CaSO4 or CaCl2.

  However, due to the low solubility of most fluorides, it is challenging to perform treatments by precipitation of insoluble fluorides to treat drinking water.

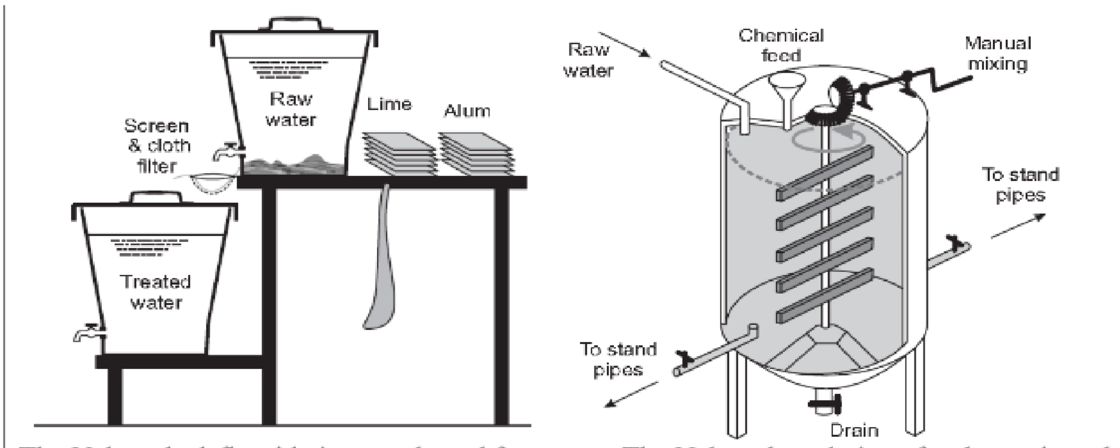
- Removal of fluoride ions:

  When an aluminum salt is added to a solution containing fluorides, hydrolysis of the aluminum first occurs. This caused acidification of the solution and increased sulfate content. Co-precipitation of the hydroxide formed with the aluminum fluoride, with the formation of an aluminum oxyfluoride of the AlOF type. This technique uses high concentrations of reagents to make the water drinkable, which increases the cost of treatment.

- Aluminum sulphate and lime (Nalgonda technique):
  Nalgonda (Figure 3.1) is a combination of several unit operations, and the process involves rapid mixing chemical interaction, flocculation, sedimentation, filtration, disinfection, and sludge concentration to recover water and aluminum salts. Hydrated aluminum salts, a coagulant commonly used in water treatment, are used to flocculate water fluoride ions.

  The aluminum salt can be added as aluminum sulfate or aluminum chloride, or a combination of these two. Since the process is preferably carried out under alkaline conditions, lime is added. If the raw water has adequate alkalinity, lime may not be used. For disinfection, bleach powder is added. After careful stirring, the chemical elements coagulate into flocs and settle to the bottom.

Figure 3.1: Nalgonda defluoration adopted for community domestic use in Tanzania, Jansen et al. 2007

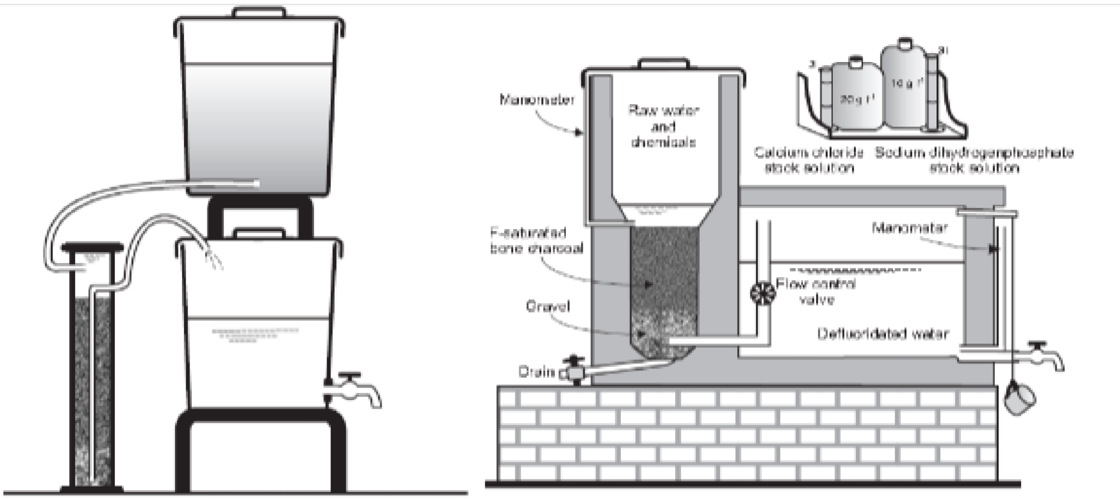


The Nalgonda defluoridation as adopted for community
domestic use in the United Republic of Tanzania.

The Nalgonda technique for domestic and defluoridation

- The main characteristics of the Nalgonda technique involves:
  - No media regeneration
  - No handling of caustic acids and alkalis
  - Easily available chemicals used in municipal water treatment
  - Conventional are not necessary
  - Adaptable for home use
  - Flexible up to several thousand m3/d
  - Applicable in batch, as well as in continuous operation to meet the needs for simplicity of design, construction, operation and maintenance
  - Local skills could be easily used
  - Extremely efficient removal of fluorides from 1.5 to 20 mg/l at desirable levels
  - Simultaneous removal of color, odor, turbidity, bacteria and organic contaminants
  - Normally associated alkalinity ensures fluoride removal efficiency
  - The sludge generated is convertible into alum for use elsewhere
  - Small waste of water and less disposal problems
  - Minimum requirements for mechanical and electrical equipment
  - No energy except muscle power for home equipment
  - Provides defluorinated water of uniform acceptable quality

Figure 3.2: Contact precipitation for house hold use (left) and contact precipitation invented in Ngurdoto Jansen et al. 2007



Contact precipitation for household use

Contact precipitation of fluoride as invented in Ngurdoto

- Experiments carried out in Senegal: An experiment was carried out in 1988 in Senegal on the borehole waters of Fatick.

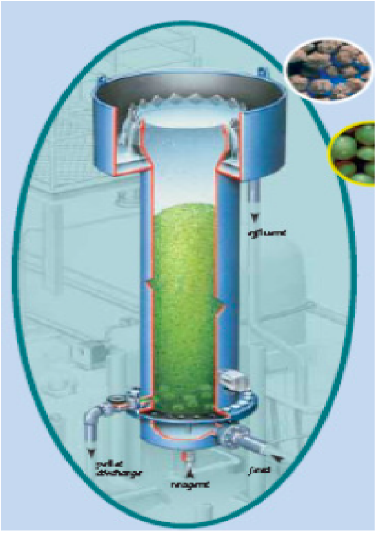
- At the domestic scale: The device consists of plastic buckets with a capacity of 60 liters and sieves. The buckets have a lid and a tap placed in their lower part 5 cm above. The aluminum salt and the lime are added simultaneously to the raw water, stirring slowly for 1 minute and then rapidly for 5 minutes. The water decanted and then filtered through the sieve is thus suitable for use.

- At the community level: For small communities (populations of 200 people on average), the device includes a cylindrical tank with a depth of 2 m equipped with a manual stirring mechanism. On the other hand, if it is a whole sizeable village, the device comprises reactors, a raised tank, an electrical room, and a chemical storage room. The method has several advantages. Indeed, it does not require regeneration and therefore no handling of dangerous products such as acid and soda. The chemicals are available in the market, and the device is simple to design. In addition, color, turbidity, and bacteria are eliminated at the same time.

  It also has certain limitations. Indeed, it can only be used for certain types of water. - These are waters of which: - The dry residue is below 1500 mg/l; otherwise, desalination may be necessary; - The total hardness is below 600 mg/l; otherwise, desalination is required; - the alkalinity of the water must be sufficient to ensure complete hydrolysis of the aluminum added and retain minimum alkalinity between 1 and 2 mg/l in the treated water to obtain a pH between 6.5 and 8.5. - fluorides in raw water must be between 1.5 and 20 mg/l Despite efforts in this area, this has not been pursued, mainly due to difficulties in supplying reagents, and the cost of treatment.

Figure 3.3 depicts a Crystalcor, contact precipitator type developed in Netherlands. In the reactor, fluoride is removed from the water while calcium fluoride pellets with a diameter of 1 mm are produced. The significant advantages of the Crytalactor® are that (1) the installation is compact, (2) calcium fluoride pellets with a high-purity are produced, (3) the produced pellets have a shallow water content 95% to 10% moisture) and (4) the pellets can be reused. Costs comparisons show that the total treatment costs are typically approximately 25% of the costs for conventional precipitation. However, the Crystalactor® is more suitable for wastewaters with high fluoride concentrations (> 10 mg/l). For treating drinking water, the Crystalactor® is only advisable in high fluoride concentrations (> 10 or 20 mg/l). For reaching a concentration below 1 mg/l fluoride, a second technique must be used afterward.

Figure 3.3: In the Netherlands a new type of contact precipitator, named the Crystalactor®, is developed by DHV (Giesen 1998). The Crystalactor® is a fluidized-bed type crystallizer also called a pellet reactor (source: HDV)



3.2 Adsorption method

The adsorption of a substance by a solid is the more or less irreversible fixation of the solute molecules in contact with the surface of this solid without any chemical reaction between them. This is a rapid phenomenon that results in an equilibrium between the adsorbed substance and the remaining solution. The balance depends on the concentration of the solute and the surface area of the adsorbent body. Remember that two types of adsorption are entirely different by the energies involved and their nature.

- Physical adsorption, or Van Der Waals adsorption (Svarovsky 2001), is a reversible phenomenon that results from the inter-molecular forces of attraction between the molecules of the solid and those of the adsorbed substance. It does not change the chemical identity of molecules adsorbed.

This process is well suited to the specific removal of fluorides but requires controlling the pH of the medium. The adsorption capacity depends on the particular surface of the material (Rezaei-Aghdam et al. 2021), the nature of the adsorbent-adsorbate bond, the contact time, the pH, and the initial fluoride concentration. Water defluorination studies using several adsorbents, such as aluminum hydroxide, activated carbon, apatite, and activated alumina, have been carried out and have given encouraging results.

Adsorption isotherm

For this study, we assume that the adsorbent surface is homogeneous and proportional to the mass of the solute. Several models have been used to describe the adsorption phenomenon; the most used are Langmuir and Freundlich.

- Langmuir isotherm: The establishment of this law is made from certain assumptions called Langmuir assumptions: - The number of adsorption sites on the surface of the solid is fixed, and the recovery of the the surface of the solid occurs in a mono-molecular layer. - The enthalpy of adsorption is the same for each adsorption site. - There is no steric hindrance from molecules adsorbed on two neighboring sites. - At equilibrium, the rate of adsorption is equal to the speed of desorption.

  The Langmuir adsorption isotherm can be written as:

  $$q = \frac{Q * b * c}{(1 + b * c)}$$

  C (mg/l) is the equilibrium concentration; q is the amount adsorbed at equilibrium, Q and b are the Langmuir constants relating to the adsorption capacity and energy respectively

  The Langmuir equation can be put in the form:

  $$\frac{C}{q} = \frac{1}{(Q * b)} + \frac{C}{Q}$$

Freundlich isotherm

Unlike Langmuir, who assumes that the enthalpy of absorption of fluids on solids is a constant concerning the rate of recovery of the surface of the solid, Freundlich takes a logarithmic variation of this enthalpy as a function of the rate of recovery. Since the recovery rate is proportional to the quantity of substance adsorbed per unit mass of the product adsorbed, we have the Freundlich relationship:

$$q = K * C^n$$

K and n are constants depending on the system and the temperature. We can write the following relation:

$$log(q) = log(K) + nlog(C)$$

Application to the removal of fluoride ions

- Activated alumina (Al2O3 or aluminum oxide)

  It is obtained by calcination at a temperature below 500 ° C of hydrated alumina Al2O3, 3H2O, brought by the alkaline attack on bauxite. The technique used implements the percolation of water loaded with fluoride ions on a bed of activated alumina, allowing these ions' retention.

Activated alumina is one of the materials with the most remarkable defluorination capacity. It reliably ensures specific elimination of the fluoride ion (> 80%) with, in addition, almost total elimination of the iron present in the solution. It is practically insoluble in water. Its affinity for fluorine is excellent.

Both pH and alkalinity are factors that affect adsorption capacity. Saturated in fluorides, activated alumina can be subjected to regeneration by alumina sulfate, soda, and sulfuric acid.

- Activated carbon

  Activated carbon is very absorbent; it has the property of having thousands of extremely fine cavities in which these particles will be fixed. To split the molecules into finer particles, one can also proceed by Ozonation; This consists of sending gaseous ozone (in the opposite direction), which will break the size of the particles even into more minor elements, then the grains of activated carbon will retain the excess ozone and the small molecules. At the outlet of this water, a small amount of disinfectant can be added to guarantee its quality to the consumer. This same process is used at the Geneva processing plant.

  This material generally leads to good results; regeneration takes place with soda and carbon dioxide. However, it has limits because it cannot be applied in a basic environment and therefore requires very high acidity, which means that it is used very little. With a pH of 3, fluorine can be reduced from 8 to 1 mg/l. However, the method can be expensive since there is a need first to lower the pH and then increase it to a value of 7 for consumption purposes.

  Bauxite showed good defluorination capacity. A study has shown that more than 90% of the fluorine was retained for a contact time of 4 hours, a pH of 7, and an adsorbent dose of 25 g / L.

  However, it should be noted that several other materials have been used as an absorbent for the removal of fluorine. By analyzing the retention rates presented, it can be concluded that adsorption represents an effective method for the defluorination of water.

- Charred bones

  For defluorination, either product obtained from the bones of cattle is used in practice. The use of bone powder is more widespread and is one of the earliest methods of defluorination. Regeneration can be done indefinitely with soda. We can thus use:

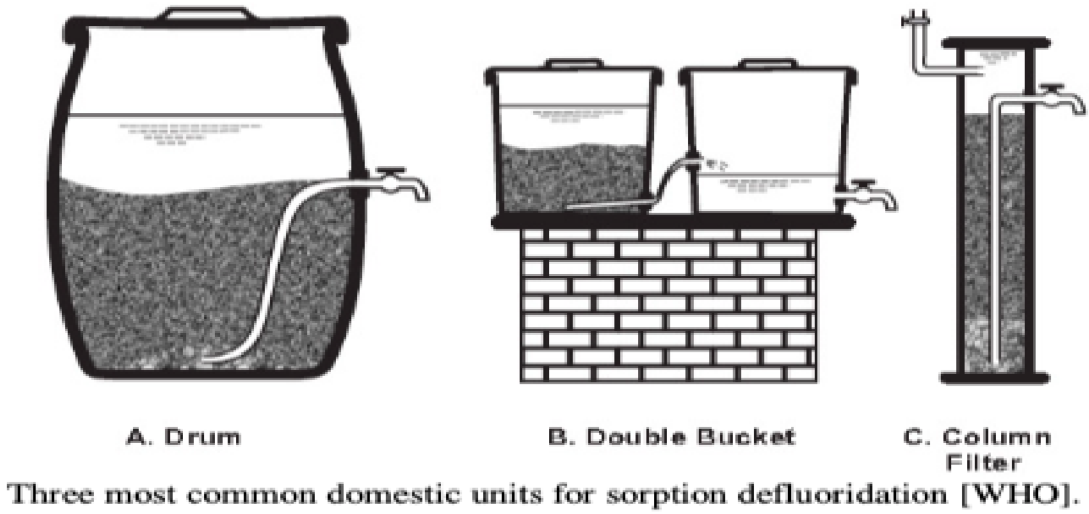
  Natural bones: Dried and crushed bones have a significant defluorination capacity. However, bacteriological and organoleptic problems make this technique less attractive than bone charcoal or synthetic charcoal.

Animal black: It is a black granular solid obtained by calcining cattle bones. It is beneficial for the removal of heavy metals such as aluminum, arsenic, cadmium, chromium, iron, lead, and zinc from wastewater. It is also effective for the extraction of fluorine. The use of animal black is one of the first methods proposed for defluorination. Indeed, it was recognized that animal black charred at 1100-1600 ° C had superior qualities to other untreated bones.

Synthetic bone: Synthetic bone is a mixture of tricalcium phosphate and hydroxyapatite produced by reacting phosphoric acid and lime.

The use of calcined bone poses a real problem because it is difficult to do on a large scale. Not addressing the issue of salinity, the regular supply of bone also poses difficulties. Following the same logic, this method will not satisfy us in solving the double problem (salt and fluorine) of the study area.

Figure 3.4: Bone Charcoal: Three most common domestc units for sorption defluoration [WHO]



3.3 Membrane processes

- Reverse osmosis

  If on one side of an osmosis membrane, we have a concentrated solution and on the other, pure water (or a dilute solution) to equal the chemical potentials due to the difference in concentration, water which alone can cross the membrane, will pass to the concentrated side to dilute this solution. Therefore, the water level will rise on the focused side until the chemical potential due to the pressure difference exactly equals the chemical potential. On the other hand, if a hydrostatic pressure equal to the osmotic pressure is applied on the side of the full compartment, the phenomenon of osmosis is thus prevented from occurring. By definition, this pressure is the osmotic pressure of the system can be written:

$$\pi = \Delta C * R * T$$

Where $\pi$is the osmotic pressure in Pa
ΔC: difference in concentrations in moles / m3
R: ideal gas constant (8.314)
T: temperature in Kelvin (K)

If this pressure is more significant, the phenomenon of osmosis is reversed, and pure water is passed from the concentrated medium to the diluted medium; it is reverse osmosis. Therefore, to obtain pure water from a saline solution, it is necessary to exert a back pressure greater than the osmotic pressure. Experience shows that you have to work at least 2 bars if you want to obtain flow rates economically.

A phenomenon called concentration polarization of the membrane disrupts the smooth running of operations; it is linked to the accumulation of ions along the membrane, which in fact leads to a higher local concentration and therefore requires more backpressure.

This process is very effective in removing almost all of the mineral salts present in the solution. (no selectivity between salts).

This technique is used for:

- Desalination of seawater;
- Desalination of brackish water;
- The production of ultra-pure water;

The production of process water (water used in industrial installations for operation of a process or the manufacture of a product) Reverse Osmosis membranes are also applicable to contaminant removal following:

- Pesticides;
- Radionuclides
- Arsenic;
- Boron;
- Nitrates alone;
- Nitrites-nitrates.

The osmotic pressure P is more important as the concentration is high and the molar mass is low. Note: Since Reverse Osmosis membranes retain most salts, post-treatment must be provided to achieve calco-carbonic balance while respecting the pH limits. The treated water has good microbial quality.

Figure 3.5: WaterPyramid® (WaterSystems 2007) with a total area of 600 m2 and situated under favourable tropical conditions, can produce up to 1250 litres of fresh water a day. The production rate is dependant on site specific factors such as climate and temperature, cloudiness and wind activity. Desalination is driven by the sun and the energy needed for pressuring the WaterPyramid® is obtained using solar cells in combination with a battery back-up system. Intermittent peak demands in electricity, related to e.g. (borehole) pumpingand maintenance, are covered using a small generator system.

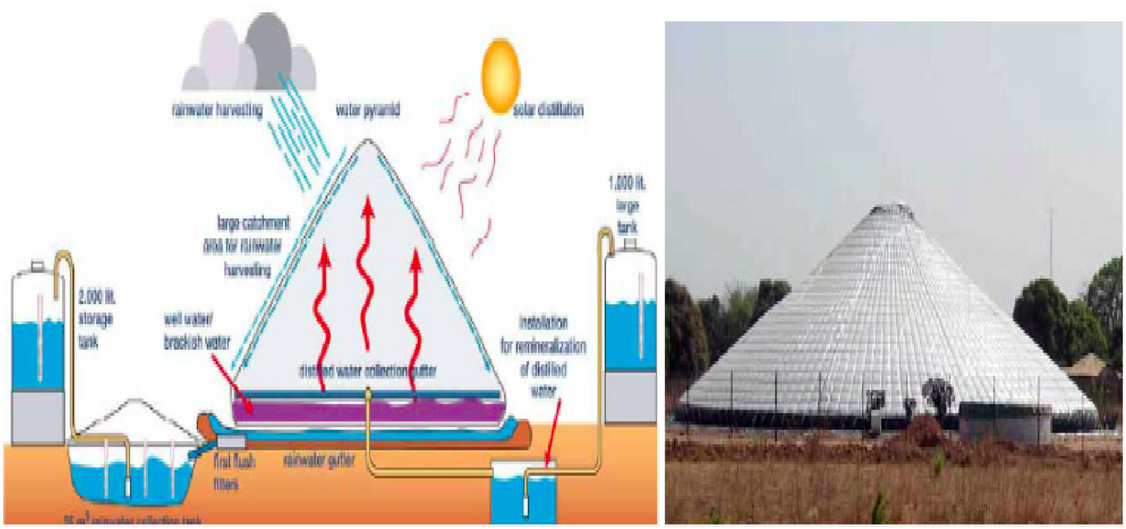


Figure 3.6: The Solar Dew Collector systemSolar Dew (Solar Dew, 2007) developed a new porous membrane to purify water using solar energy. The technique is similar to the WaterPyramid®. Water sweats through the membrane, evaporates on the membrane's surface and increases the air humidity in the evaporation chamber.

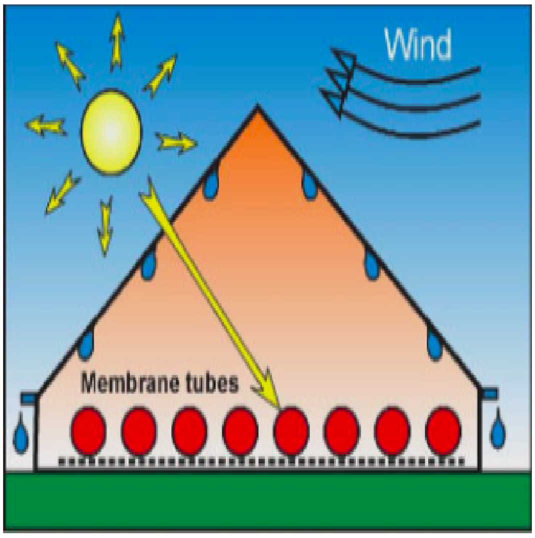
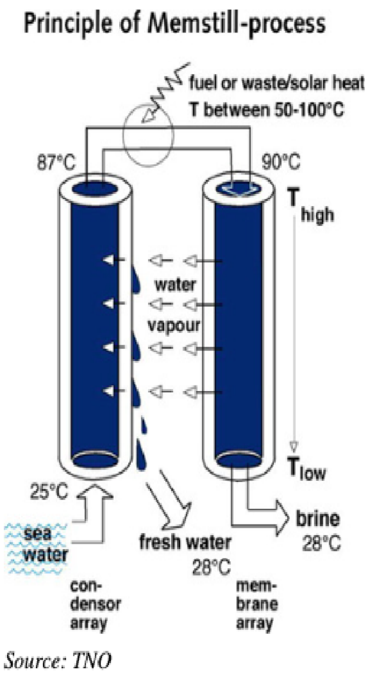


Figure 3.7: Memstill® technology The Netherlands Organisation of Applied Scientific Research (Jansen et al. 2007, TNO) has developed a membrane-based distillation concept which radically improves the economy and ecology of existing desalination technology for seawater and brackish water. This so-called "Memstill® technology" combines multi- stage flash and multi-effect distillation modes into one membrane module (Hanemaaijer et al. 2006).



3.3.1 Electrodialysis

It is a separation technique that allows the selective transfer of ions through membranes with selective permeability under the action of an electric field. The operation aims to extract the salts from a solvent. The salts contained in the water to be treated transferred, UNDER the action of the electric field, from the deconcentration compartments to the concentration compartments. One then obtains on one side and over-concentrated brine and the other purified water. This membrane technique was the first used (in the 1960s); it is especially interesting for brackish water treatment: in fact, the energy cost of electrodialysis is a direct function of the quantity of salt to be eliminated. The application of electrodialysis to remove fluorides in water allows the levels to be lowered to the standards set. Still, the disadvantage is that the treated water must be utterly demineralized before the fluorides can be removed. In particular, new generations of membranes, particularly anionic and bipolar, have appeared on the market with improved chemical resistance. There are now three electro-membrane techniques:

- so-called conventional electrodialysis (ED);
- bipolar membrane electrodialysis (EDMB);
- membrane electrodialysis (EM).
  The common point of these techniques is ion-exchange membranes, making it possible to transfer ions selectively under the effect of an electric field.
- Bipolar membrane electrodialysis:

  Bipolar membranes consist of a side permeable to anions and a side permeable to cations. Under the effect of an electric field, the water present at the heart of the membrane is dissociated into H+, and OH- ions generated respectively by the cationic and anionic faces.
- Membrane electrolysis

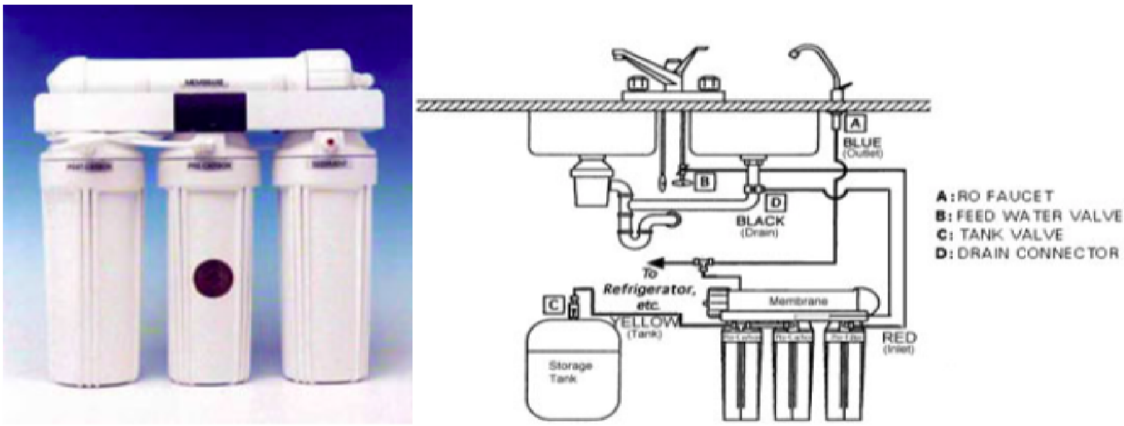
  Membrane electrolysis is the electro-membrane technique in which the effects of an electrodialysis (migration of ions through a semi-permeable membrane) are coupled to those of electrolysis (reactions at the electrodes)

Nano filtration (Reverse Osmose at low pressure

Nanofiltration (NF) is a membrane technology (at low pressure) that is very similar to reverse osmosis by its mode of operation and construction. It is mature technology today.

A nanofiltration membrane mainly retains divalent ions and large molecules. Unlike reverse osmosis, nanofiltration applies lower pressure, generally less than 7 bars, which reduces energy consumption compared to a reverse osmosis plant with the same productivity. It is also necessary to choose nanofiltration rather than reverse osmosis if a certain hardness is maintained, as demineralization would make the water aggressive and lead to corrosion problems in the supply network. Nanofiltration is recommended for brackish water. It has been proven to be undoubtedly capable of effectively solving the water quality problem we face. The challenge today is to adapt it to the drinking water supply in rural areas.

Figure 3.8: Reverse osmosis



RO water filter for household Reverse Osmosis Water Filter Diagram

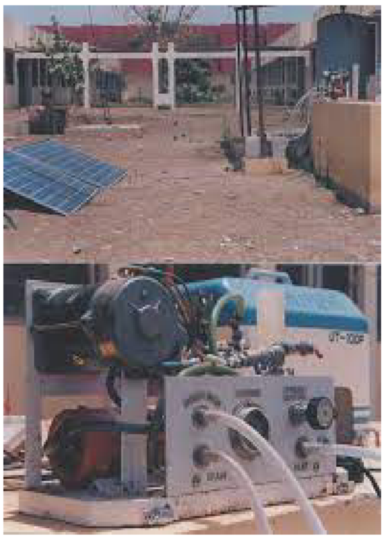


Figure 3.9: First mobile reverse osmosis unit established in Senegal in 1994, village camp of Palmarin, region of Mbour (preliminary studies carried out as part of a Senegalese-Japanese project, University of Dakar, EPT, 1993).

Pontié et al. 2006

3.4 The distillation methods

3.4.1 Solar distillation

A solar still is a passive technique, requiring limited means to distill salty, brackish, or contaminated water (e.g., contained in the ground or coming from a stream) using the heat of the Sun. It requires energy, such as heat; solar radiation can be the source of energy. This process removes impurities such as salt, heavy metals, and microorganisms. Solar distillation is mainly used to obtain small quantities of freshwater. This method makes it possible to supply families, villages, and, exceptionally, small towns. A solar evaporator consists of: a tank designed to contain the saltwater to be evaporated and to absorb solar energy; a glass or plastic roof; channels intended to receive the freshwater produced.

The main operating characteristics are the same for all solar stills. Solar radiation is transmitted through the protective glass and is absorbed in heat by a black surface in contact with the water to be distilled. The water is thus heated and releases water vapor. The vapor condenses on the glass cover (Gaikwad et al. 2012), which has a lower temperature because it is in contact with ambient air and flows into a gutter from where it is sent to a storage tank.

The radiant energy of low wavelength passes through the glass roof and is mainly absorbed by the water and by the bottom of the tank, to be converted into thermal energy. On the other hand, the long-wavelength radiation emitted by the water and by the bottom of the tank cannot pass through the glass roof. The water thus heated produces water vapor; the glass roof, cooled by air and wind, acts as a condenser. In such a still, the water temperature rarely exceeds 70 ° C.

3.5 Alternative sources: Water transfer

Water supply brings together the techniques for getting water from its source through a network of pipes or architectural works to places of consumption. This system is called water transfer.

3.6 Impluvium

An impluvium is a system for capturing and transporting rainwater to a storage location. The possibilities and potential for rainwater collection and treatment to meet drinking water needs can be assessed from annual rainfall amounts. Effect of the volumes of water that can be collected (V in m3/year) are a function of this yearly rainfall (Pan in mm) and the developed collection area (S in m2) according to the following expression:

$$V = Pan * S * 0,8$$

The reduction coefficient of 0.8 is usually adopted to take into account possible water losses. This volume of water thus collected must be used to meet the needs for drinking water and possibly to cook water throughout the dry season, which can last 8 to months. The primary constraints that can be experienced in the construction of rainwater collection and treatment systems are the collection area, the size of the impluviums, and the size of the population that can be served. The following table gives simulation results of the volume of water collected and the size of the people that can be served depending on rainfall and collection area.

3.7 Mini hand drilling in shallower water tables

Manual drilling is not very well developed or popularized in Senegal. These drilling techniques only began to be developed in French-speaking Africa at the end of the 1980s, and they have never been promoted on a large scale. In Senegal, the manual drilling technique is rudimentary and is only practiced in sandy areas (lithology devoid of clay and hard rocks). It is done with an auger by sinking with a single diameter, and the depth of investigation does not exceed 20 meters. The tubing used is made of PVC, and the slits of the filters are made manually and wrapped in a fabric (holes with a diameter of about 2 cm on the PVC). Furthermore, the strainer area is not graveled, and the structures are not generally developed. It should also be noted that these works are not often the subject of chemical analyzes before their surrender. Regarding manual drilling, which could be called mini drilling here, they are only found in Niayes, Casamance, and exceptionally in Tambacounda (sedimentary zone at the level of the alluvial site, in the lowlands). Although the water table is not deep in some areas, the water table is only reached after having passed through layers of clays, laterites, limestones, or marls. These shallow boreholes and not exceeding 20 meters capture the water table. It should be noted that no lithostratigraphic data is available for these works, most often carried out without authorization, and consequently, no datasheet is available at the level of the Water Resources Management and Planning Department (DGPRE).

Figure 3.10: Stratified column of brick chips, pebbles and coconut shells as used in Sri Lanka.

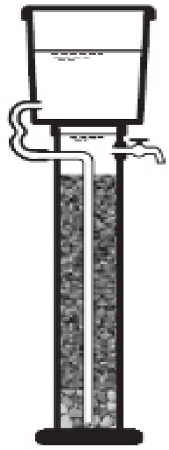
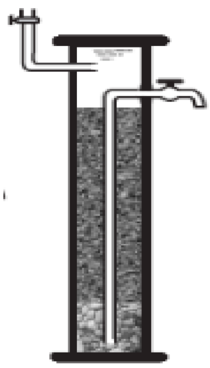


Figure 3.11: Activated alumina

column filter household filter

Figure 3.12: Ion exchange



column filter

3.8 The simpler and more recent methods or devices for small installations

Intended above all to try to solve the problems of sites or regions where it is impossible, nor financially feasible, to build large installations, small innovative companies are currently developing these techniques. They are expected to create and open up exciting prospects, especially in parts of developing countries.

Thus, the recent and ingenious company TMW (Water and Heat Technologies, Paris) has just developed a simpler and less expensive process for the desalination of seawater or brackish water, ”the Aquastill, mobile unit of one piece and all-terrain for isolated sites whose principle is based neither on reverse osmosis nor on distillation, but on the condensation of water vapor, which requires much less energy than distillation.

Chapter 4

Materials and Methods

In the previous chapter, a review of up-to-date existing defluorination technologies were discussed. This chapter is subdivided into two parts: The data acquisition and the data processing.

4.1 Data collection

The data acquisition include the choice of the study area, the field work and the water samples collection.

4.1.1 Choice of the study area

Senegal residents were asked in a recent study about the quality of their drinking water. Seven (7) various Physico-chemical tests were carried out on water drawn from 178 households in Thies (a region in Senegal including our study area). Measured elements included the pH, conductivity, temperature, turbidity, free residual chlorine, nitrates, and fluorine. Of the 178 surveyed, there are approximately 101 households in rural areas: 31 in the department of Tivaouane, 78 in the department of Thiès, and 69 in the department of Mbour.

Data obtained in this region at 101 households surveyed in rural areas was as follows:

- pH: There was found to be almost complete conformity with WHO guidelines with 95% of the water checked, with the average pH value being 7.0 and the WHO goal being (6.5 - 8.5).

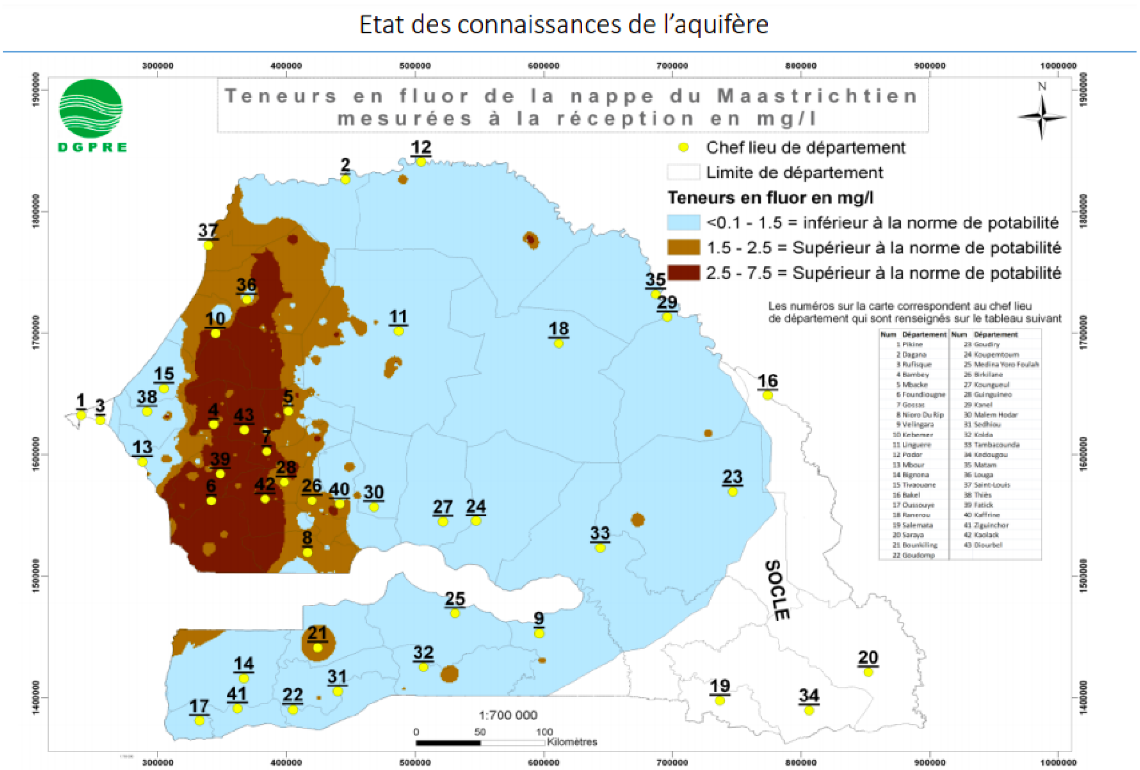
- Conductivity: Around 99% of the water is mineralized, and one home uses highly water-charged water, with a conductivity of 2,194 μS/cm

- Temperature: 90% of drinking water from households examined has a temperature above 25 ° C.

- Turbidity: The turbidity of the water consumed is less than 5NTU equivalent to clear water for 91%; the source is often the supply network from rural boreholes.
- Residual chlorine: 77.23% of households either don't get their water filtered or use water with a residual chlorine amount over the WHO limit of 2 mg/L.
- Nitrates: Drinking water contains nitrates varying from 0.5 to 10 mg/L for 53.46% of households and nitrates are missing for 46.53% of households.
- Fluorine: Fluoride is found in the household water drunk by 64.35%, but with amounts higher than or comparable to WHO 1.5 mg/L at 12.87%.

The drinking water analyzed in the Thiès region revealed the presence of fluorine at concentrations exceeding (figure 4.1) the WHO standard in part of the Mbour department in the households surveyed; however, the disinfection device must be reinforced; nitrates are present in the water of the households surveyed, but at levels not exceeding the WHO standard.

Figure 4.1: Fluoride content of the Maastrichian water table measured at reception in mg/L.



Source: DGPRE

Figure 4.1 shows the distribution of fluoride concentrations in the Maastrichian water table (Senegal), as measured at the site of receipt in milligrams per liter of water. The yellow dots indicate the county's (district's or region's) head, with a number on top of each dot indicating the county name. It is determined by a color gradient, with light blue areas representing fluor concentrations between 0.1 and 1.5 mg/L and thus below the World Health Organization (WHO) limits, light brown areas representing fluor content exceeding the WHO limits but in a range between 1.5 and 2.5 mg/L, and dark brown areas representing fluor content exceeding the WHO limits but in a range between 2.5 and 7.5 mg/L. An examination of the map reveals that the western half of the country is more exposed to high fluorine concentrations. In contrast, the center and western parts of the country have fluorine concentrations safe for drinking water use. Our research region is in the western portion of the nation, where the soil is between blue and light brown, leading us to believe that the water collected and distributed in this area may have fluorine concentrations that exceed the permitted limit.

4.2 Identification of the source of pollution

The mapping of the fluorine content of the waters of the Senegal basin indicates that the high values are located in the areas where the presence of phosphate deposits is observed and in the areas of recognized deposits. The physicochemical characteristics close to phosphate soils and fluorinated soils explain the existence of fluorine where there is phosphate. Since calcium fluoride has properties similar to calcium phosphate, they are generally found associated in nature in the form of fluoroapatite.

Fluorosis problems are often observed in phosphate-producing countries (Tunisia, Morocco, Algeria, Senegal), mainly due to drinking water. The waters richest in fluoride are often slightly salty; it is not necessary to defluorinate all domestic water, but only drinking water.

4.2.1 Field work

The Fieldwork includes the practical training that consisted of spending a month at OFOR, the dedicated National office in Dakar, to manage water resources in the rural area and collect the water sample.

Practical training

This choice of the thesis topic was motivated by a previous personal experience when working at the office as an agent controlling the water operations performed by the delegated companies. I was charged with reviewing the monthly semestrial. Annual reports presented to the office by the DSP (Delegated Public Service, checking the water production (amount of water drilled), the amount distributed (that arrived at the final customer's home), the water loss (amount of water lost during the water transfer from the source to the household) and above all but all the quality of the water the arrive at home.

The question of water quality was in the debates during all the periods I worked for the company. Thus, it was a natural reflex after choosing the topic to return to my home company to collect data such as (reports, monthly, yearly, labs analyses, and several programs reports and water samples that would allow me to do my research.

First, compare laboratory analysis from reports and those that I intended to perform in Prague from water samples thus collected.

The result from that comparative study would confirm or infirm the potential chemical contamination of the water, particularly the Fluor.

- The General objective of the Practical Training was:
  - Collect data from reports and collect water samples
- The Specific objectives was:
  - To review all reports (monthly, yearly, and laboratory analysis) from NDP network managers,
  - To discuss, learn from the Office des Forages Ruraux managers,
  - Collect as much as possible data related to the research question
  - Perform a mission order to the source and collect water samples

The result from that comparative study would confirm or infirm the potential chemical contamination of the water particularly the Fluor.

- Results: At the end of the internship:
  - All reports (monthly, annually, laboratory analysis,) were reviewed,
  - The discussion with OFOR managers were possible,
  - Data from reports and other sources linked to the research question were collected,
  - The mission and water samples collection were realized.

Figure 4.2: Student, Ing.Doudou BA, visiting the office of OFOR and presenting his research study about Mesh optimization using single ring infiltration to the chief officer of OFOR, Mr. Seyni Ndao

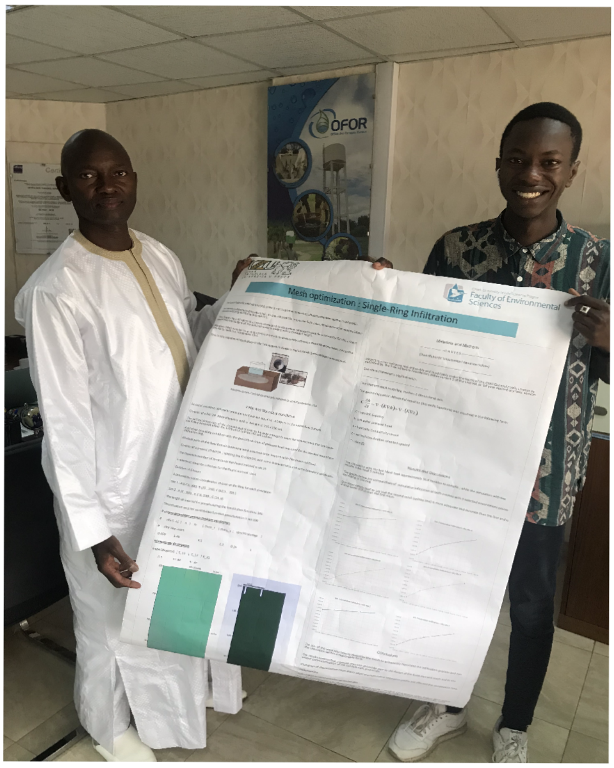


Figure 4.3: Model of water supply of OFOR to the rural area.

4.3 Mission order: Collection of Water Samples

A crucial part of our internship was collecting water samples for counter expertise analysis after reviewing all available resources of the Offices des Forages Ruraux (OFOR), such as documentation, monthly reports, and laboratory analyses... The water sample collection was authorized by the Chief Officer of OFOR, mister Seyni Ndao through a mission order to tassette where the boreholes are being operated. The mission confirmed, a company car, a company driver, the technician operating in the sites were put at my disposal accompanied by an official mission order letter that we presented to the authority of the locality. The Dakar - Tassette trip took around 2 hours and a half, including the stop by we did at the managing office of the Tassette waters, a company named SEOH, to meet the Managing Directing and some technicians and former colleagues. When we finally arrived at Tassette, the operating technician was already waiting for us; we then went to each borehole (forage) to collect the water directly from the source. The drilling (boreholes) were located in distant places. We were able to collect water from F2, F3, F4 **??** drilling and from a reservoir. The borehole F1 is eliminated and out of order.

Figure 4.4: Dakar - Tassette - Dakar trip

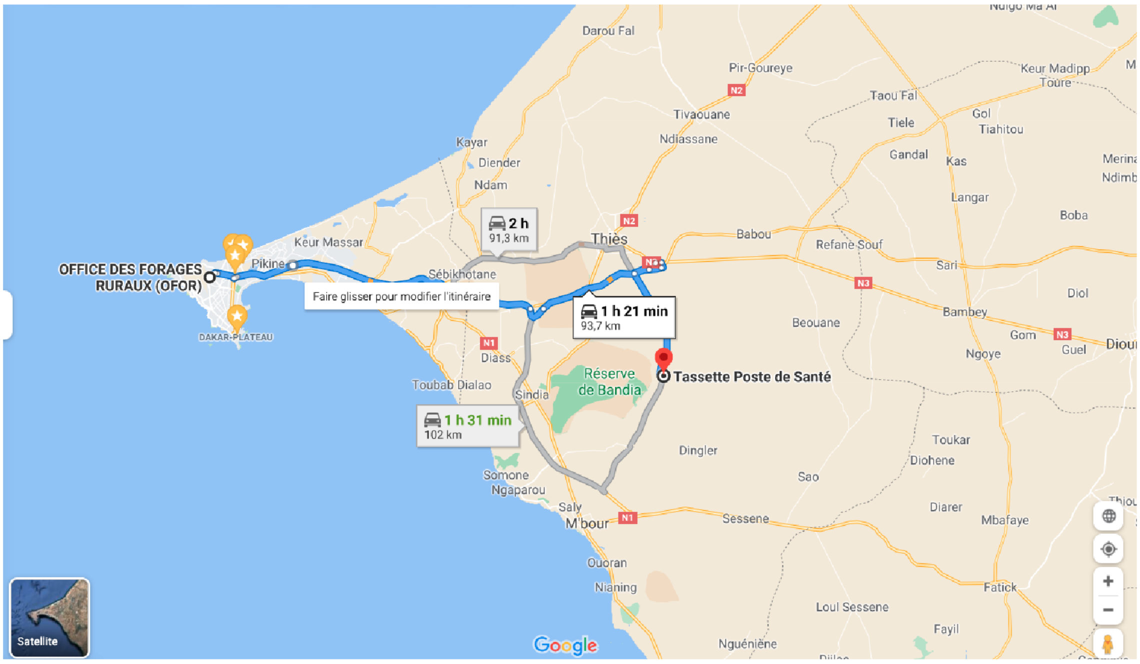


Figure 4.5: Geographic coordinates and technical characteristics of boreholes

Figure 4.6: Tassette, a village in Thies where water samples are collected

4.4 Laboratory Analysis performed at Bambey University

A certain number of general parameters are used to characterize water intended for human consumption or industrial uses, particularly hardness, alkalinity, salinity, fluoride, turbidity, etc. The drinking water must also comply with the regulations in force in the country.
In the quality of the water, several parameters can be distinguished at the same time, grouped into five (5) categories:

- Organoleptic parameters
- Physicochemical parameters
- Parameters for unwanted substances
- Parameters for toxic substances
- Microbiological parameters (fecal coliforms)

All of the elements that characterize water necessarily belong to one of the categories below.

The water samples are collected on June 06 2018, between 07h05 am and 11h25 mn, and the laboratory analyses were performed the next day. Water samples were collected from different sites of the NDP, including from directly the source, the boreholes (Forages F2, F3, F4), and the two reservoirs and some particular points of the NDP network Tassette, Sandara Serere, Ndiosmone center, Ndiadiene, and Tataguine.
.

PH determination

The pH measures the concentration of H + ions. Pure natural water is neutral, that is to say, at a pH equal to 7. The pH of water represents its acidity or its alkalinity; it varies between 0 - 14 and is an essential indicator of the quality of water. This parameter conditions many physicochemical balances between water, dissolved carbon dioxide, carbonates, and bicarbonates, which constitute buffered solutions that confer favorable development on aquatic life. It depends on multiple factors, including the origin of the water, the soil's geological nature, and the watershed. Living organisms are susceptible to even limited abrupt variations. It is a physicochemical parameter that influences the ionic balance of other elements by increasing or decreasing their toxicity. PH below seven can cause severe corrosion of metal piping. High concentrations of certain chemicals, such as lead, can result from the corrosion of certain types of pipes, and corrosion increases with decreasing pH. When the pH is above 8.0, the efficiency of the chloride disinfection process decreases.

Determination of Conductivity

Electrical conductivity reflects the ability of an aqueous solution to conduct electric current. The electrical conductivity indicates the overall mineralization of this water. Salt molecules dissociate into ion pairs when they come into solution in water. These pairs of ions carry electrical charges and therefore allow current to flow through water. The more mineralized the water, the more ions there are, and consequently, the higher the conductivity will be. This measurement does not determine the ions responsible for the conductivity but rather the overall constituents dissolved in the water. Generally, calcium and magnesium contribute the most to conductivity. This is a property that increases with temperature hence the importance of doing tests at fixed times and in the field. The commonly used unit of measurement is Siemens (S / cm) often expressed in micro siemens / cm (μs / cm) or millisiemens (mS / cm).

The colour

The coloring of drinking water can be due to colored organic matter (especially humic substances), metals such as iron or manganese, or very colored industrial waste. Users may be tempted to turn to other, perhaps unsanitary, sources when provided with water so colored as aesthetically unpleasant. It is therefore desirable that the drinking water be colorless. Their colors vary from barely noticeable straw yellow to reddish-brown, depending on the nature and concentration of coloring matter. These materials are most often of natural origin or come from the degradation of plant materials: wood, lignin, bark, tannin. The degree of the color of water depends not only on the concentration of coloring matters but also on the pH and the conductivity. Coloring substances often have a weak acidic character, and at higher pH, their dissociation is accompanied by color variations (the color unit 1mg/L of platinum or even platino-cobalt or actual uCV color unit.

Turbidity

The two most important properties of natural waters are color and turbidity. Turbidity is an even more subjective notion than color; it is defined as the reverse of clarity or transparency. Turbid water is, therefore, more or less cloudy. High turbidity can protect microorganisms from the effects of disinfection and stimulate the growth of bacteria. In deep water, turbidity prevents the propagation of light, the decrease in intensity limiting and even eliminating plants. In all cases where the water is subjected to disinfection, the turbidity must therefore be below (preferably 1 NTU) for this disinfection to be effective. Determining the turbidity is to measure an optical property of the water resulting from the dispersion and the absorption of light by the particles present.

Ammonium

Ammonium in water usually reflects an incomplete degradation process of organic matter. Ammonium comes from the reaction of iron-containing minerals with nitrates. It is, therefore, an excellent indicator of water pollution by organic discharges of agricultural, domestic, or industrial origin. Ammonium is most commonly found in the form of ammonium chloride. This substance is not dangerous for health. Nevertheless, its inhalation may cause coughing, contact with the skin or the eyes, redness, ingestion, nausea, sore throat, vomiting. Regarding the environment, ammonium itself is not very toxic. Still, it can cause several problems such as corrosion of pipes, bacterial reviviscence inside them, a decrease in the efficiency of the treatment with chlorine, and the development of microorganisms responsible for unpleasant flavors and odors. In the natural environment, on plants, this leads to an imbalance in their diet and increases their fragility vis-à-vis other secondary stress factors. Depending on the physicochemical characteristics of the soil and water, this can lead either to nitrogen enrichment or to acidification with the disappearance of fauna and flora in extreme cases.

Nitrates

They are found in natural waters since they are the typical result of the oxidation of organic nitrogen. All forms of nitrogen (organic nitrogen, ammonia, nitrites, etc.) can cause nitrates through a biological oxidation process. Some healthy water contains significant amounts of nitrates. Their reduction in nitrites NO2methemoglobinemia may lead to severe poisoning of newborns by asphyxiation.

Total Suspended Solids (TSS)

Total Suspended Solids (TSS) is defined as a dry-weight of suspended particles that do not dissolve in a sample of water that can be analyzed by a filter trapped by a filter.

The determination of residues makes it possible to estimate the content of dissolved and suspended matter in water. Determining the residue on unfiltered water makes it possible to assess the dissolved and suspended matter content of water; this is the total residue. If the water is filtered before the measurement, the residue then corresponds to dissolved matter. The result obtained is influenced by the temperature (Hall 1956) and the duration of the drying process.

Total Dissolved solids (TDS)

Total Dissolved solids (TDS) are a measure of the dissolved combined content of all inorganic and organic materials present in a liquid in molecular, ionized, or micro-granular (colloidal sol) suspended form.

TDS concentrations are often reported in parts per million (ppm). TDS concentrations of water can be determined using a digital meter.

Hardness

With particular exceptions, the hardness has a natural character linked to the leaching of the soils crossed and corresponds to the calcium and magnesium content. Natural waters always contain mineral salts, and a large part of chemical analysis consists of determining the most abundant cations and anions. In natural waters, these cations are calcium and magnesium, then sodium Na^+, and finally potassium K^+. It is essentially the Ca^{2+} and Mg^{2+} ions that are responsible for the hardness and act with the soap. The dissolution of limestone and magnesium mainly results from the infiltration of surface water through limestone and dolomitic rock formations. Calcium carbonate dissolved in water has a natural tendency to precipitate; that is to say, it returns to its solid form under certain conditions. Of these, the temperature will have the most critical influence. Indeed, when hard water is heated above 60 °C, an insoluble precipitate is formed called scale or limestone. This lime will thus be deposited on the resistances of devices such as kettles, water heaters, washing machines, dishwashers. When the heating resistances of these devices are scaled, the energy consumption sometimes rises very strongly, damaging the quality of operation and the lifespan of the devices. The effectiveness of detergents also decreases with the hardness of the water. We must therefore use more, which increases water pollution and costs.

Calcium hardness is due to Ca^{2+} ions and magnesian hardness to Mg^{2+} ions. Carbonate hardness is associated with HCO_3^- and CO_3^{2-} and non-carbonate hardness is associated with other anions, for example, Cl^- and SO_4^{2-}. The carbonate hardness is ”temporary,” and the non-carbonate hardness is ”permanent.”

Water with high hardness (TH) (> 20 °f) is called ’hard.’ For TH < 5 °f (1 meq/l), water is considered ’Sweet’.

Calcium

Calcium is an alkaline earth metal prevalent in nature and in particular in limestone rocks in the form of carbonates. A significant component of water hardness, calcium is generally the dominant element in drinking water (Dib et al. 2021). It exists mainly in the form of hydrogen carbonates and smaller quantities, in the form of sulfates, chlorides, etc., the rainwater contains only traces of it.

Magnesium

Magnesium is one of the most common elements in nature; it constitutes about 2.1% of the earth’s crust. Most of its salts are very soluble in water; the carbonate can be dissolved up to 300 mg/L, at 20 ° C. Its geological abundance, its high solubility, its wide industrial use (alloys, pyrotechnics, dry batteries, chemical reducing agent, etc.) mean that the levels in water can be significant, ranging from a few milligrams to several hundred milligrams per liter. Magnesium is a substantial element in the hardness of water; its content, which depends on the terrain crossed.

Potassium

Although in igneous rocks, potassium content is almost as important as that of sodium, its almost constant presence in natural waters does not usually exceed 10 to 15 mg/L. the threshold of taste perception of potassium chloride is approximately 20 times this value. Certain industrial discharges, in particular from potash mines and fertilizer factories, can carry relatively high amounts of potassium into the water. The body's needs are 3 to 4 g/d; they are easily provided by food intake, which is essential (green vegetables and fruits contain 3-4g/ kg).

Bicarbonates and Carbonates

Bicarbonate and carbonate are determined from alkalinity. Weak bases are much more numerous; in the same way, weak acids are much more numerous than the few rare "strong" acids, wholly dissociated. In the field of water, these alkaline substances are mainly carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), ammonia, ... Carbonate and bicarbonate ions combined with calcium or magnesium will precipitate calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) under drought conditions.

Fluorine

Fluorine, the most electronegative and therefore the most potent oxidizing element in chemistry, is not found in the free state in nature due to its high reactivity. It is abundant in the earth's crust (750 to 800 g / t), mainly in fluorite, apatites, micas, etc.

Fluorite or fluorspar (CaF_2), which contains up to 49% fluorine, is the most common; cryolite or sodium aluminofluoride ($Na_3(AlF_6)$) is the most used ore. Due to ionic exchange, water from confined aquifers can have significant fluorine contents and must therefore be carefully controlled. Fluoride and its derivatives are part of the typical human environment because they are widely distributed in nature and present in varying concentrations in almost all foods. According to the authors, food intake ranges from 0.5 to 2 mg/day. The use of fluorides in cariopro-phylaxis shows that 90% of the fluorides administered are metabolized in the body. Excretion occurs mainly through urine, sweat, and trim through feces. The accumulation in the body takes place primarily in the tissues subject to calcification and in the kidneys. Substantially half of the fluoride ingested is deposited in the skeleton; the other half is excreted in the urine.

Chlorides

Water almost always contains chlorides but in very variable proportions. The chloride content generally increases with the degree of mineralization of water. These contents are highly varied and mainly linked to the nature of the terrain crossed. The water in the groundwater adjacent to saline surface water, especially if there is excessive pumping from this groundwater, is brackish. Pollution brings appreciable quantities of chlorides to surface water. This is why an increase in the Cl^- content in a drinking water network can sometimes signify sewage infiltration. Certain industrial discharges also have very high concentrations of chlorides.

Alkalinity

Water can neutralize acids. Alkalinity can be defined as the number of protons (H^+) required to convert carbonates into carbonic acid (H_2CO_3).

In almost all natural waters, alkalinity is due to the presence of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and the ion (OH^-).

Until the acid controls the ions responsible for the alkalinity, the pH hardly changes. Once the acidification process has started, the reaction then produces water (H_2O), carbon dioxide (CO_2), which is released into the air, as well as the accompanying cation (either calcium or magnesium). The alkalinity of water is generally expressed in ppm (mg/L) of calcium carbonate ($CaCO_3$). When we add acid to neutralize the alkalinity, the calcium and magnesium are thereby freed, which, if not, remain trapped by the carbonate, hence the advantage of ”breaking” this alkalinity which prevents calcium and magnesium from being available to the plant (Year-RoundHealth 2019).

If this is not done, as it dries, all carbonates automatically turn into calcium and dolomitic lime. This leaves lime deposits that can clog sprinkler or drip systems or even whitish marks on the leaves if you sprinkle water.

4.5 Laboratory Analysis performed at the Czech Univeristy of Life Sciences

The analysis of anions was performed using an ionic chromatograph 883 Basic IC Plus Metrohm with a column Metrosep A Supp 5, 15 cm x 4 mm I.D., 5 µm particles (Metrohm 6.1006.520). The mobile phase was composed of 3.2 mM sodium carbonate and 1.0 mM sodium bicarbonate. The flow rate was 0.7 mL/min, and the injection volume was 20 µL.

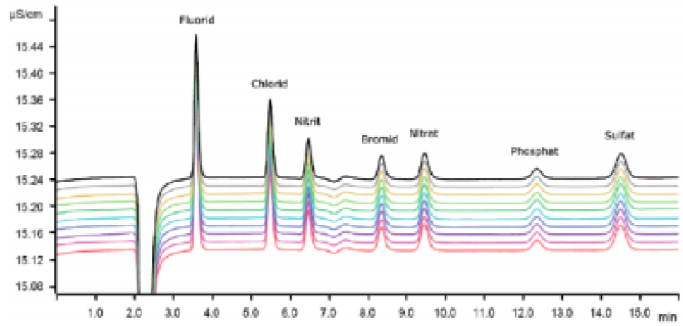
The 883 Basic IC plus allows anions, cations, and polar substances to be determined in different matrices. The concentrations may be up to four orders of magnitude apart. The analysis is always reliable and precise. The 883 Basic IC plus is designed for training in universities and schools. For this reason, it is supplied with a practical textbook, which provides an introduction to the theoretical and practical aspects of ion chromatography.

However, the 883 Basic IC plus is also excellent for routine applications in water analysis, the food sector, or the chemical industry. Wherever high performance at low cost is called for, the 883 Basic IC plus proves to be the ideal solution.

The high detection sensitivity of the 883 Basic IC plus allows analyses to be performed in the µg/L, mg/L, and g/L ranges. This excellent sensitivity is based both on the minimal baseline noise of the chromatogram and on the performance of the intelligent conductivity detector. Both with and without suppression, the 883 Basic IC plus will satisfy your requirements.

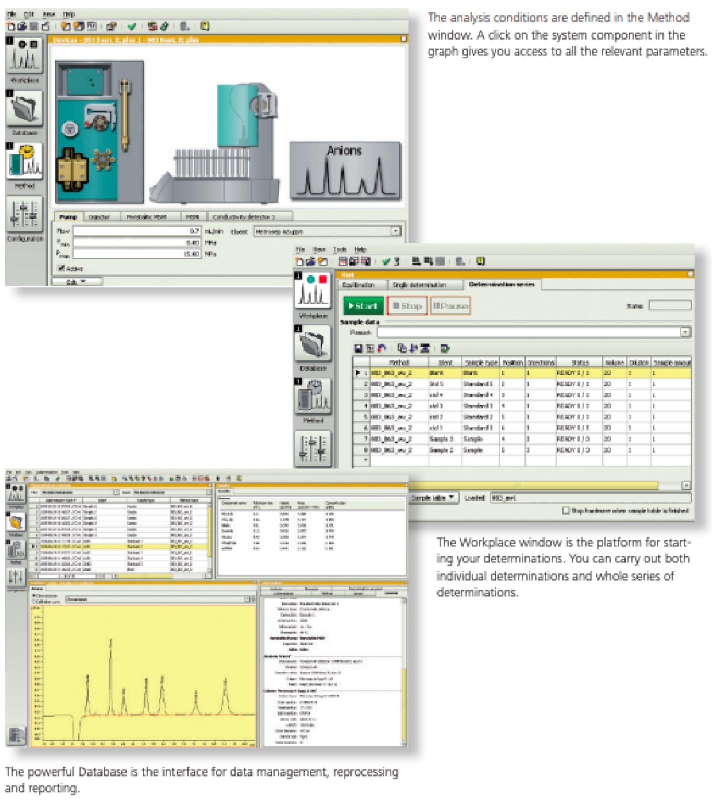
Figure 4.7: Schema of the chromatograph

Figure 4.8: 10 chromatogram



The 10 chromatograms of an analysis of 100 µg/L of various anions (on the Metrosep A Supp 5 - 150/4.0) demonstrate the high precision and outstanding reproducibility that is achieved with the 883 Basic IC plus.

Figure 4.9: Graphical Interface



The water collected from Tassette (Senegal) in normal temperature conditions was stored in small bottles of pure drinking water sold in the supermarket after emptying them. Then the water samples were transported to Dakar for three days before the flight to Prague, where they were stored and frozen before being analyzed in the laboratory in CZU at standard conditions.

Figure 4.10: Laboratory of the Faculty of Environmental Sciences, CZU, with the test set and the water samples

Figure 4.11: In the laboratory of Professor Vymazal (left) and PhD Student Ing. Adam (right)

Figure 4.12: Student Ing. Doudou BA, performing ionic chromatograph analysis at the laboratory of Prof.Vymazal of the Faculty of Environmental Sciences, CZU, Prague 2021

Chapter 5

Results

5.1 Results

In the previous chapter, a discussion on the material and methods were provided. Water samples were collected and analyzed at the University of Bambey (Senegal) and the Czech University of Life Sciences at Prague. This chapter describes the results of the laboratory analyses.

5.1.1 Laboratory analysis performed at Bambey University

The tables 4,3,1,2 in the appendices display the results of the laboratory analysis performed at Bambey University. A summary of the results is provided in the following paragraphs.

Microbiological analysis

Table 5.1 depicts the microbiological analysis. We notice the absence 37 °C in 100ml of Coliform bacteria, Enterococci and Escherichia Coli in all the water samples. That is a great news but not surprising for water destined for human consumption.

Table 5.1: Microbiological analysis

Parameters	Methods	F2	F3	F4	WHO Standards
Coliform bacteria at 37 ° C in 100ml	NPP Kit Colilert	0	0	0	0
Enterococci at 37 ° C in 100ml	NP EN ISO 7899-2	0	0	0	0
Escherichia Coli at 37 ° C in 100ml	NPP Kit Colilert	0	0	0	0

pH

Table 5.2 shows we have neutral pH.The pH values determined in the different zones are between 7 and 8.05. The pH is an essential element in defining the aggressive or encrusting nature of water. It is involved in these complexes with other parameters such as hardness, carbon dioxide, alkalinity, and temperature. This drilling water requires pH within the range of the standard because pH less than 7 can lead to the corrosion of cement or metals in pipes with lead entrainment. If the pH is high, it can lead to encrusting deposits in the distribution circuits. The higher the pH level (the water is more alkaline), the less effective the chlorination is. It is considered that it is not possible to determine whether there is a direct relationship between pH and human health. The WHO recommends for water intended for human consumption a pH of between 6.5 and 8.5 with a maximum permissible value of 9.5.

Table 5.2: pH

Parameter	F2	F3	F4	Unit	WHO Standards
pH	7,6	7,3	7,3	-	6 - 9

Temperature

The temperature 5.3 turns around 33°C. There is no restriction in terms of temperature in drinking water but only ideal values.

Table 5.3: Temperature

Parameter	F2	F3	F4	Unit	WHO Standards
Temperature	33,3	33,4	32,1	°C	-

Conductivity

The study carried out at the various localities, namely F2, F3, F4, shows us that the targeted areas have conductivities that are not exceeding the WHO standards. Concerning water intended for human consumption, conductivity has no direct consequences on health. For water intended for irrigation, it is important to control this parameter because its excess increases the osmotic pressure of the soil water and causes conditions that prevent the roots from absorbing water. These conditions cause physiological drought because although the soil seems to have a lot of moisture, the plants wither. After all, the roots do not absorb enough water to replace that lost through evapotranspiration. The WHO guideline for the quality of water intended for human consumption indicates a guide level for the conductivity of 400 µs/cm at 20 °C. The borehole F2 has the highest conductivity that is below the limit value table 5.4.

Table 5.4: Conductivity

Parameter	F2	F3	F4	Unit	WHO Standards
Conductivity	871	712	660	µs/cm	<1300

Turbidity

In almost all of the areas where samples were taken, the values obtained are less than 5 NTU; only the borehole F4 shows a value of 45,6 NTU, imensely exceeding the WHO standard 5.5. This value should not surprise us because most surface water has high turbidity, and its direct consumption is impossible. Residual turbidity is a hindrance to the effectiveness of microbial decontamination treatments. If we have values above 5 NTU, this will limit the destruction of coliforms even if free residual chlorine is kept for one hour. Even if the chemical and bacteriological qualities are satisfactory and the water is troubled, the user will prefer much clearer water even if he has no information on the physicochemical and bacteriological qualities.

Table 5.5: Turbidity

Parameter	F2	F3	F4	Unit	WHO Standards
Turbidity	3,46	0,58	45,6	NTU	<5

Total hardness

Mainly due to the magnesium and calcium ions present in the water. Hardness has no impact on human health, nor is it considered harmful. However, when the hardness is high, it isn't easy to use. According to the results, all boreholes have hardness on average 32° F. Remember that the ions that makeup hardness provide some of the mineral salts necessary for the body. On the other hand, they present domestic inconveniences through the formation of tartar, especially when they are too high: scaling of machines, washing lines of DWS, traces on the dishes, etc. Conversely, water that is too soft reduces the supply of minerals to the body. Also, when it comes to softened water, the treatment increases sodium in the water and can make it aggressive. Too much sodium is the cause of diseases of the cardiovascular system.

Table 5.6: Total Hardness

Parameter	F2	F3	F4	Unit	WHO Standards
Total hardness	36	32	28	°f	-

Total Alkalinity

Alkalinity is a measure of the water's ability to resist changes in pH, which would tend to make the water more acidic. The alkalinity level is very often examined together with the pH level to get a good idea of the water quality.

Table 5.7: Total Alkalinity

Parameter	F2	F3	F4	Unit	WHO Standards
Total Alkalinity (TA)	0	0	0	°f	-

Table 5.8: Complete Alkalimetric Titre

Parameter	F2	F3	F4	Unit	WHO Standards
Complete Alkalimetric Titre (TAC)	16	32	28	°f	-

Chlorides

The WHO has set a value of ≤ 250 mg/L for chloride concentration in drinking water. Chloride impairs water and beverages prepared from water with a bad taste and may also erode the distribution system at higher concentrations. This value compared with those obtained us being able to say our values exceeded the WHO standards. This is explained by the strong salinization of these waters as well as the soil. Chlorides are widely distributed in nature, usually in sodium (NaCl) and potassium (KCL) salts; they represent about 0.05% of the lithosphere. The oceans contain by far the most significant amount of chlorides in the environment. The presence of chlorides in drinking water sources can be attributed to the dissolution of salt deposits, the spreading of salt on roads to melt ice and snow, effluents from chemical plants, exploitation of oil wells, sewage, irrigation water flow, waste leaching water, volcanic fumes, sea spray and seawater intrusion into coastal areas. Each of these sources can lead to local contamination of surface water and groundwater. The chloride ion is very mobile and ends up being transported in closed basins or to the oceans. Estimating the daily intake of Chloride from food is complicated by the widespread use of salt as a condiment. A salt-free diet provides about 600 mg of Chloride per day. However, due to the addition of salt to food, the daily intake of Chloride averages 6 g, but it can go up to 12 g. Assuming that the daily water intake is 1.5 L and the average chloride concentration in Senegalese drinking water is 10 mg/L, the average daily intake of Chloride from drinking water should be about 15 mg per person. Intake from water is therefore only about 0.25% of daily intake from food.

However, Chloride is an essential element and the primary extracellular anion of the body. It is a highly mobile ion, which easily crosses cell membranes and provides appropriate osmotic pressure, water balance, and acid-base balance.

Table 5.9: Chlorides

Parameter	F2	F3	F4	Unit	WHO Standards
Chlorides	95,8	63,9	59,5	mg/L	<250

Fluor

Being the central issue of our concern, fluorine is an abundant element in the earth's crust. When combined with sodium (sodium fluoride), it becomes dangerous to health to the point of killing the individual when consuming a dose of 5 g. Because of these dangers, the fluoride levels must be carefully controlled in water intended for human consumption. The toxicity of sodium fluoride is related to the precipitation of calcium (essential for coagulation) and to the complexation of iron and magnesium, elements necessary for the action of certain enzymes. However, one should not develop a fluoride psychosis but monitor the doses ingested in the human body. The table 5.10 below indicates that for all water samples the fluoride value is close but not exceeding the limit fixed by the WHO.

Table 5.10: Fluor

Parameter	F2	F3	F4	Unit	WHO Standards
Fluor	1,48	1,36	1,38	mg/L	<1,5

The total iron 5.11 and the nitrates 5.12 turn respectively around 0.01 mg/L and 3 mg/L thus respecting the WHO standards.

Total Iron

Table 5.11: Total Iron

Parameter	F2	F3	F4	Unit	WHO Standards
Total Iron	0,0	0,01	0,02	mg/L	<0,2

Nitrates

Table 5.12: Nitrates

Parameter	F2	F3	F4	Unit	WHO Standards
Nitrates	3,9	3,7	2,9	mg/L	<50

Table 4 contains the information of different water samples collected from different sites and the time and date they were collected.

Table 3 shows the results of microbiological analysis performed at the University of Bambey. The parameters analyzed include the coliform bacteria, streptococcus and escherichia coli at 37 degrees celsius which all present a null value in 100 ml.

Tables 1 and 2 contains the information of parameters analyzed such as the Total hardness, the TA, the TAC, the total iron, Fluorine, Nitrates.

5.1.2 Laboratory analysis performed at Czech University of Life Sciences

Table 5.13 below show the results of the analysis of anions performed at the laboratory of Dr. Vymazal, at the Faculty of Environmental Sciences of czech University of Life Sciences using an ionic chromatograph 883Basic IC Plus Metrohm with a column Metrosep A Supp 5, 15 cm x 4mm I.D., 5 µm particles (Metrohm 6.1006.520) and their calibration points 5.14.

Table 5.13: Results of laboratory analysis by CZU

	F-	**Cl-**	**NO2-**	**Br-**	**NO3-**	**PO43-**	**SO42-**	**Unit**
F2	0.828	61.964	0	0	13.503	0	7.42	mg/L
F3	0.782	23.276	0	0	4.503	0	4.153	mg/L
F4	0.81	15.995	0	0	3.139	0	3.652	mg/L

The F2 borehole has the highest values of Fluoride (F−), Chloride (Cl−), Nitrates(NO2-), Nitrites(NO3-), and Sulfates (SO42-), respectively: 0.828, 61.964, 13.503, and 7.42 mg/L. The F3 borehole has the lowest values of Fluoride (0.782). Still, it has higher values of Chloride (23.276), Nitrates (4.503), and Sulfates (4.153) than F4, which has higher Fluoride amount (0.81) but lower values of Chloride (15.995), Nitrates (3.139), and Sulfates (3.652).

Units are displayed in mg/L.

Table 5.14: Calibration points

	calibration points						
min	0.04	0.2	0.02	0.04	0.23	0.1	0.2
max	10	50	5	10	50	25	50

for F-
r2=0,999864

The rest of the anions (NO2-, Br-, PO43-) are null in all the water samples. Other elements pH and temperature are not measured in this analysis.

Values are not an order of magnitude lower than you expected. It is essential to be precise that the results that are presented concern the fluoride anion (F-) and not total fluorine. Fluorine in water samples could be present in some other form.

Chapter 6

Discussion

In the previous chapter, results obtained from laboratory analyses were presented. Results of laboratory analyses show fluoride concentrations near the limits established by the WHO for drinking water confirming thus confirmed our hypothesis. In this chapter a critical view on the results is provided and a discussion on the process selection of a proper defluorination technology.

6.1 Critical view on the results

The analysis of anions was performed using an ionic chromatograph 883 Basic IC Plus Metrohm with a column Metrosep A Supp 5, 15 cm x 4 mm I.D., 5 µm particles (Metrohm 6.1006.520). The 883 Basic IC plus allows anions, cations, and polar substances to be determined in different matrices. The concentrations may be up to four orders of magnitude apart.

Even though the anions analysis by the chromatograph 883 Basic IC plus is very reliable and precise, it is important to precise that the result obtained is relatively modest since water collection, transport, and storage conditions prior the analysis were not standard conditions.

The water collected from Tassette (Senegal) in normal temperature conditions was stored in small bottles of pure drinking water sold in the supermarket after emptying them. Then the water samples were transported to Dakar for three days before the flight to Prague, where they were stored and frozen before being analyzed in the laboratory in CZU at standard conditions.

The predictions thus based on previous data statistically elaborated over some period do not necessarily match with a the average values of the samples, due to fluctuations of water quality. Improper storage might affect the properties of a sample.

Another element to take into account is with the chromatograph analysis, we obtain the fluoride anions and not total fluorine that can be present in another form in the water.

The laboratory analysis performed at Bambey University gives information about fluorine and other physicochemical characteristics that might negatively impact human health when not respecting the WHO guidelines.

An interrogation can also be done about some hazardous physico-chemical elements such as Arsenic that are not present in the laboratory analysis results but can cause more damage to human health than the excess fluorine does.

6.2 Proposal of proper technology

To make a categorical choice on a method is quite challenging. Without financial consideration it is obvious to favor the methods giving the best results. But often a quality / price compromise is necessary as long as the treated water meets the standards in force. Another challenge lies in defining the actual financial margins that can be allocated for solving this problem. This depends on several factors including the distribution of budgets between the different sectors of activity and the importance given to each sector. Even if we know that health is priceless, the fact remains that it has a cost. The best method will be the one that can be supported by the state or by humanitarian organizations.

The review of defluorination methods applied throughout the world, we notice that chemical processes have been much preferred to membrane techniques. Indeed, in countries where the majority of the affected population live in rural areas, large-scale installation poses the problem of developing a water supply network, in a setting where communities are also dispersed apart from each other.

Membrane processes appear to a certain extent more efficient than conventional chemical processes, especially when the latter allow the problem of excessive mineralization of water to be solved.

However, only medium and large-scale applications are concerned.

And even in this case, the installations require very high investments, a qualified workforce but also a frequent renewal of the membranes, the cost of which is already quite expensive (20% of the price of the installations). All these factors thus constitute an important limitation to the development of membrane techniques. Their use will therefore result from a reduction either in the cost of the membranes or in energy consumption. In addition, the studies in progress could lead to an improvement in the performance of the membranes; which would allow their possible use for the purposes of defluoridation.

With regard to chemical methods, the main difficulty lies in the fact that we cannot predict the behavior of all chemical species in solution. It is only through laboratory tests that we can get a fairly precise idea of the procedure and the quantity of material necessary to obtain optimal defluorination while respecting the limits of potability.

For the moment, these are the methods that seem to be the most within our reach. As a result, the techniques proposed in the context of this report will be essentially chemical. In the long term, the latter could be the subject of study for large-scale use, in the same way as membrane processes. However, for short-term solutions, given the urgency of the problem and the dispersed distribution of the population, it seems more reasonable to us to opt for the solution of defluoridation at the domestic level.

Table 6.1 is a General summary of different fluoride and salt treatment methods, their advantages, disadvantages and costs.

Table 6.1: General summary of the different fluoride and salt treatment methods

Method	Benefits	Disadvantages	Costs
Precipitation			
Sulfate aluminum and lime (Technique of Nalgonda)	Fairly known procedure Mainly applied in India Possibility of treating water on a large and small scale	Does not address the problem of salinity Residual presence of aluminum Mud production High consumption of reagents	High investment cost Moderately high running cost
Adsorption			
Activated alumina	Efficient and well-known procedure Reference technique in the USA Possibility of treating water on a large and small scale	Only partially addresses the salinity problem Consumption of reagents that are not available in Senegal Requires specialized personnel	High investment cost High running cost
Charred bones	Reagent cheaper	Does not address the problem of water salinity Bacteriological quality problem linked to the use of bones Regular bone supply is a problem	Low-medium investment cost Low investment cost
Membrane Techniques			
Reverse osmosis	Jointly addresses the problem of water salinity Good bacteriological quality of the treated water	Requires maintenance monitored by qualified personnel High running cost High energy consumption Wastewater production Total demineralization of water	High investment cost Very high running cost
Nano-filtration (reverse osmosis at low pressure)	Jointly addresses the problem of water salinity Consumes less energy than reverse osmosis	Requires maintenance monitored by qualified personnel Fairly high running cost Wastewater production	High investment cost High running cost
Distillation			
Solar distillation	Fairly low running cost Jointly addresses the problem of water salinity Good bacteriological quality of the treated water	Fairly high investment cost Little known technique Requires a lot of space Total demineralization of water	High investment cost Low running cost
Alternative sources			
Water transfer	Simple and durable Simultaneous solution for the water salinity problem	Very high investment cost Lack of information on groundwater	High investment cost - very high High average cost of operation
Impluvium	Simple and durable Simultaneous solution to the problem of water salinity	Limited capacity or requires greater investment	High investment cost Low running cost
Mini hand drilling in shallower water tables.	Simple Simultaneous solution to the problem of water salinity	Lack of information on the tablecloths Limited areas Often requires additional bacteriological treatment	Low investment cost Low running cost

The USEPA found the following processes to be effective for the removal of fluoride:

- Adsorptive media (up to 100 percent removal) including activated alumina (up to 100 percent removal);
- chemical treatment by the Nalgonda technique (> 86 percent removal),
- calcium phosphates (>90 percent removal),
- magnesium oxide (>86 percent removal), or alum (>90 percent);
- ion exchange with anion exchange resins (up to 85 percent removal);
- membrane separation with reverse osmosis, nanofiltration, and electrodialysis (> 95 percent removal); and
- an electrocoagulation process (> 95 percent removal).

Table 6.2 is a matrix summarizing the fluoride removal methods adapted from Feenstra et al. 2007. The colors in the matrix indicate the method's suitability for the particular situation:

Table 6.2: Fluoride removal methods (Feenstra et al. 2007)

Methods	domestic + low costs	community + low costs	domestic + high F removal	community + high F removal	domestic + brakish water	community + brakish water
Activated Alumina	Yellow	Yellow	Green	Green	Red	Red
Ion exchange	Yellow	Yellow	Yellow	Yellow	Red	Red
Reverse osmosis	Red	Red	Green	Green	Green	Green
Electrodialysis	Red	Red	Red	Green	Red	Green
Nalgonda process	Green	Green	Red	Red	Red	Red
Contact precipitation	Yellow	Yellow	Yellow	Yellow	Red	Red
Bone Charcoal	Green	Red	Red	Red	Red	Red
Calcined Clay	Green	Red	Red	Red	Red	Red
Water Pyramid/Solar Dew	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Green indicates the technique is very appropriate, Yellow color means average suitability,Red color means that the method is unattractive or not applicable for the given situation.

Domestically, the Nalgonda process, bone charcoal, and calcined clay are all low-cost techniques. The Nalgonda method is also a low-cost alternative on a community level. If a significant amount of fluoride must be removed, activated alumina, reverse osmosis, or electrodialysis are recommended techniques. For brackish water, only reverse osmosis, electrodialysis, and the Water Pyramid/Solar Dew technique are suitable.

Table 6.3 show the differences in characterization of water treatment methods between Industrialized and developing countries adapted from Fawell 2006. We can deduct from it that more sophisticated technologies are used in industrialized countries while classic treatment methods are used in developing countries. This introduces the notion of affordability.

Table 6.3: Differences in characterization of water treatment methods in conventional systems in industrialized and developing countries (Fawell 2006)

Criteria	Industrialized Countries	Developing countries
Set-up and water flow	Always continuous, often in columns	Often discontinuous in columns Fill and draw in batch
Scale and treatment site	Always at water works, usually close to water source	At water works At village community level At household level
Treatment media/process	Contact precipitation Activated alumina Synthetic resins Reverse osmosis Electrodialysis	Bone charcoal Contact precipitation Nalgonda Activated alumina Clay Other naturally occurring media

Table 6.4 is a general comparison of the most promising defluoration methods used in developing countries according to Fawell 2006. It can be seen that the Contact Precipitation (CP) technology seems to have more advantages followed by the Nalgonda (Nal) technique and Bone Charcoal (BC). After come the Activated Alumina (AA) and the Calcined Clay (Cl) techniques.

Table 6.4: General comparison of the most promising defluoridation methods used in developing countries (Fawell 2006).

	Methods				
Advantages	**BC**	**CP**	**Nal**	**AA**	**CI**
No daily dosage of chemicals, i.e. no daily working load	+	-	-	+	+
Dosage designed for actual F conc. Independent of unit or plant	-	+	+	-	-
No risk of false treatment due to break point	-	+	+	-	-
Removal capacity of medium is independent of F concentration	-	+	-	-	-
No regeneration or renewal of medium is required	-	+	+	-	-
High removal efficiency can be ensured	+	+	-	+	-
Easy to construct, even by the users	+	+	++	+	+
Construction materials are cheap and widely available	+	+	++	+	+
Can be sized for one or several families or a group, e.g. a school	+	++	+	+	-
No risk of medium/chemicals unacceptability	-	-/+	+	+	=
No risk of deterioration of the original water quality	-/+	+	-/+	-/+	-

BC = bone charcoal; CP = contact precipitation; Nal = Nalgonda technique of aluminium + = advantage sulfate and lime; AA = activated alumina; Cl = calcined clay; "risk" means in some cases - = disadvantage

6.3 Experiments carried out in Senegal

For several years, research has been carried out in Senegal to find solutions to an excess of fluorides in the waters of some areas of the country. However, these steps were taken by the S.O.N.E.E.S. in collaboration with structures such as the Department of Geology of the Faculty of Sciences of the Cheikh Anta Diop University of Dakar (UCAD).

The Polytechnical university of Dakar (ESP) , the Polytechnical University of Thies (EPT) were limited carry out some laboratory tests and sometimes satisfactory results were deemed too costly.

Until 2004 (Samb 2004), the only treatment used by the SDE consists of mixing the fluorinated water with non-fluorinated water sources, which only prevents the fluoride level in these water, although tolerated, remains well above the standards (2 to 3 mg/L).

In 1982, a pilot station was installed at Bambey to treat the water from borehole with alumina phosphate taken from LamLam as the primary reagent.

However, the technique has not made it possible to reduce the fluoride content appreciably.

It has even been observed a few times an increase in the fluoride content. In addition, the treated water was enriched in particular elements such as arsenic, cadmium, chlorides, and sulfates, although these elements remained within the permissible limits.

The reagent costs estimated per MJ of defluorinated water varied between 157 and 215 FCFA from Bambey to Kaolack. However, according to I.G.I.P.(Samb 2004), the adsorption capacity could be improved by 10 to 20% by using alumina phosphate freed from particles with a particle size of 0.8 to 1.2 mm.

From 1983 to 1984, orientation studies had been undertaken by the SONEES, in collaboration with the ENSUT and the Faculty of Sciences. A complete analysis of the water from 2 boreholes at Kaolack and Fatick showed that these waters were saturated with fluoro-apatite; which means that the methods of precipitation by calcium were not possible; tests on Fatick's water whose initial fluoride content was 6.8 mg/L, are tried with various products such as attapulgite (found locally from Travi 1993), talc, iron, potassium and ammonium alums, magnesia.

Magnesia turned out to be the most interesting by lowering the F concentration from 6.8 g/l to 0.6 g/l; potassium and ammonium alums make it possible to reach 1.2 mg/L. But for the disadvantages of an organoleptic nature and increase in the pH of the water, magnesia was not retained for the continuation of the experiments.

In January 1985, a research agreement between ENSUT and SONEES on the defluorination of drinking water allowed ENSUT to test several products on 200 ml of Fatick water (activated carbon: calcium carbonate, Ca nitrate, lime, magnesia, attapulgite, talc, aluminum oxide, potassium alum). Only aluminum sulfate and ammonium, and potassium alums gave interesting results:

- 1 g / l of alumina sulfate gives a residual of 0.9 mg/L but with a final pH of 5.9;
- 1 g / l of ammonium alum and potassium alum gives respectively 2.6 and 2.9 mg/L for an initial content of 6.8 mg/L, the final pH being 6.6.

In November 1985, an amendment to this convention was established for a period of eight months in order to define the optimal conditions for the use of potassium alum or alumina sulfate. It came out that with 0.75 g/l of alumina sulfate, the fluorides of the water could go from about 6.8 to 1 mg/L, and the pH goes from 8.2 to 6.25.

However, this concentration was considered quite significant. The process comes down to precipitation with alumina sulfate, followed by settling and filtration on sand (of all the filter materials used). It is the sand that has given the best results. From the point of view of final quality. of water, the sulphate and aluminum contents increase considerably (from 42 to 320 mg/L for sulphates 0.05 to 0.015 mg/L for aluminum).

In 1986, a study project was carried out on water defluorination at the Ecole Polytechnique de Thiès. Raw water came from a well at Mont Rolland with a fluorine content of 6 mg/L. The products used were: potash alum, alumina sulfate, activated alumina, and bone powder.

According to the results, 3.2 g/l of potassium alum allowed defluorination of water containing 6.2 ppm of fluorine. 0.9 g of aluminum sulfate combined with 500 mg/L of lime makes it possible to reduce the fluoride content to the admissible level. With activated alumina, the results obtained were quite satisfactory. The bone powder gave acceptable results, although its capacity was lower. To solve the odor and color problem, a pre-chlorination of the raw water, adsorption on charcoal, and rinsing of the material with 1% sodium hydroxide had been carried out. It was then proposed to use activated alumina for water defluorination in urban centers and bone powder as a filter material in individual defluorination units in rural areas.

A second SONES - ENSUT (Samb 2004) was established in December 1987 for six months. The work was entrusted to a student as the subject of a final thesis. The physicochemical analyzes of the various waters did not reveal any notable differences in their composition. Then, comparative defluorination tests between alumina sulfate and aluminum polychlorosulphate were carried out and concluded that for the same quantity of product used, the defluorination power of technical alumina sulfate is greater than 50 to 60% to that of polychlorosulphate of alumina. The alumina sulfate considerably increases the sulfate content of the treated water, for example, for the borehole of Fatick, this content goes from 94.6 mg/L for raw water to 389.8 mg/L for treated water. The polychlorosulphate of alumina increases the value of the chlorides: 531.4 mg/L to 652 mg/L for the borehole n1 of Fatick. The choice for this study, however, fell on the polychlorosulphate of aluminum which gives clear water after settling, whereas with the sulfate of alumina, it was necessary to carry out a filtration.

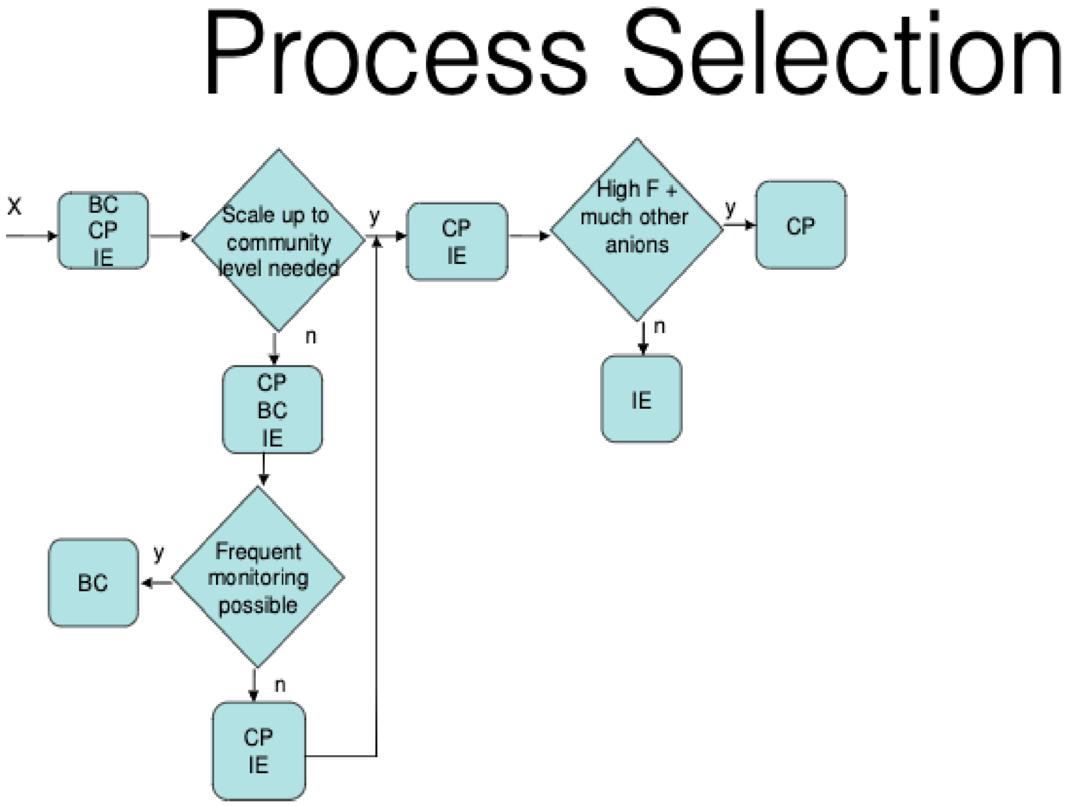
A very recent study was carried out on the use of nanofiltration and ultrafiltration for the retention of fluorides contained in drinking water consumed in France and Senegal. According to this study, nanofiltration appears as ”the only process which allows both sufficient reduction in fluoride ions and also partial demineralization of brackish water.” It has also been proposed among the membranes of ”Dow” (nanofiltration membranes marketed by the company Dow Chemical), NF270 for the treatment of water from France containing 3.76 ppm, and NF90 for water from Senegal hyperfluorinated and salty.

6.3.1 Process selection: Decision tree

Figure 6.1 Feenstra et al. 2007 represents a decision tree for fluoride removal techniques applicable in developing countries according to the circumstances and the availability of the resources.

Activated alumina is an excellent method for developing countries that need high removal efficiency and capacity. The Nalgonda method is suitable in circumstances when modest removal efficiency is adequate. In other instances (high removal efficiency, small scale), contact precipitation or ion exchange (only with high F-ions) are recommended. Additionally, if regular monitoring is feasible, bone charcoal may be utilized.

Figure 6.1: Decision tree for fluoride removal techniques applicable in developing countries (Feenstra et al. 2007)



Chapter 7

Conclusions

This study investigated an up-to-date review of fluorine treatment methods that exist given the reduction of the fluoride content in water and propose solutions adapted to the economic context of Senegal. For this purpose, several methods, notably those used in India and Tanzania, had been targeted for developing countries such as Senegal.

The elimination of excess fluoride ions in drinking water is a complex scientific topic that requiring multidisciplinary approach. There are many defluorination techniques that have been undertaken (ion exchange, chemical precipitation, adsorption, electrodialysis, electrocoagulation, ionic dialysis, reverse osmosis, and, more recently, nanofiltration).

Senegal is a particular African country characterised by immense potential in surface waters (Atlantic Ocean, Senegal river, Gambia river, Casamance river, Sine Saloum, and so on) and groundwaters.

Indeed, these resources are inequitably allocated because they are located too distant from major consumption centers and development poles or are difficult to mobilize. In addition to this issue, Senegal's aquifers are afflicted by many illnesses, including overexploitation in the west, salinization (deep Maastrichtian, deltaic zones, marine intrusion), and excess fluoride in the groundnut basin, specifically in our research region.

The PEPAM-AQUA programs tend to launch solutions to enhance physicochemical water quality in Senegal to respond to excess fluoride and salt in water at the same time.

An example is the impluvium presently in operation in Walalane, as well as low pressure reverse osmosis facilities in a number of Senegalese communities. To continue with the dilution, the potential of water transfer is being explored in the Nioro area to ease the issue in Senegal.

For developing countries such as Senegal, the Activated alumina is an apporpriate method that need high removal efficiency and capacity. The Nalgonda method is suitable in circumstances when modest removal efficiency is adequate. In other instances (high removal efficiency, small scale), contact precipitation or ion exchange (only with high F-ions) are recommended. Additionally, if regular monitoring is feasible, bone charcoal may be utilized.

This study has thus contributed to give a wide range of treatment possibilities that exist, their advantages as well as their limitations. In reality, no panacea obeys all the combined cost, quality, and ease of implementation criteria. A compromise is always necessary to make a practical choice. In the case of Senegal, our selection focuses on methods based on aluminum sulfate, activated alumina, and bone powder in the context of domestic-type defluorination.

However, additional studies are necessary to optimize the development of these methods regarding their implementation in the field. In addition, a good structuring of the research is needed so that the problem can be solved. This necessarily involves developing policies for the planning and sustainable management of natural resources and the adoption of bold measures in forecasting, evaluating, and monitoring the environmental impacts of the various sectoral policies. Hence the need for continuous monitoring and evaluation through the involvement of all stakeholders during implementation.

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Appendices

Table 1: Results of microbiological analysis

TABLEAU N°2 : RESULTATS MICROBIOLOGIE

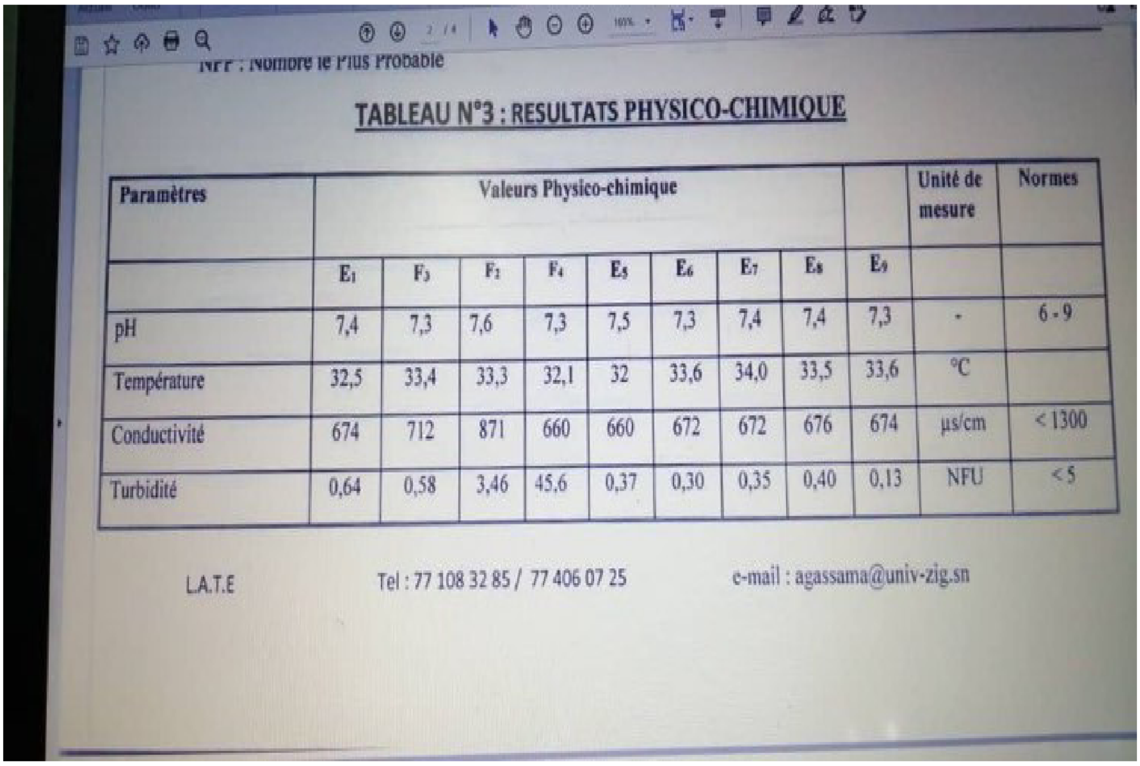
PARAMETRES	METHODES	E_1	F_3	F_2	F_4	E_5	E_6	E_7	E_8	E_9	Normes
Bactéries coliformes à 37°C dans 100ml	NPP Kit Colilert	0	0	0	0	0	0	0	0	0	0
Entérocoques à 37°C dans 100ml	NF EN ISO 7899-2	0	0	0	0	0	0	0	0	0	0
Escherichia Coli à 37°C dans 100ml	NPP Kit Colilert	0	0	0	0	0	0	0	0	0	0

NPP : Nombre le Plus Probable

TABLEAU N°3 : RESULTATS PHYSICO-CHIMIQUE

Paramètres	Valeurs Physico-chimique									Unité de mesure	Normes
	E_1	F_3	F_2	F_4	E_5	E_6	E_7	E_8	E_9		
pH	7,4	7,3	7,6	7,3	7,5	7,3	7,4	7,4	7,3	-	6 - 9
Température	32,5	33,4	33,3	32,1	32	33,6	34,0	33,5	33,6	°C	

Table 2: Results of physico-chemical parameters analysis



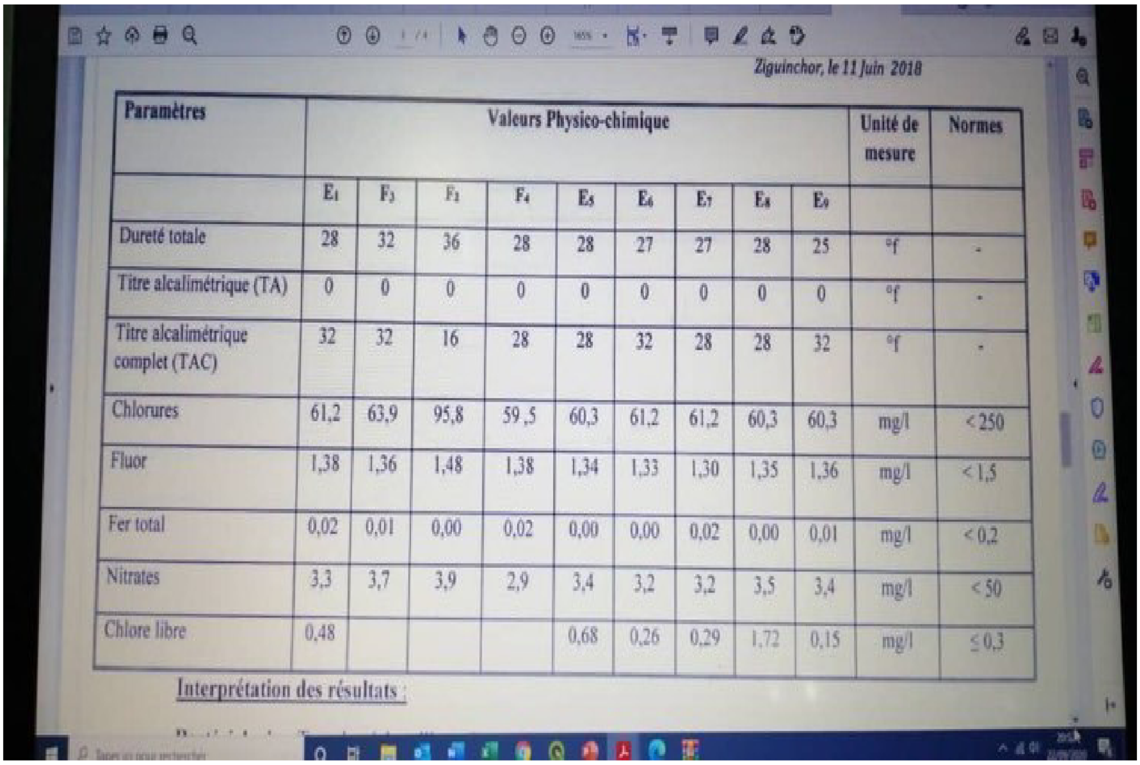
NPP : Nombre le Plus Probable

TABLEAU N°3 : RESULTATS PHYSICO-CHIMIQUE

Paramètres	Valeurs Physico-chimique									Unité de mesure	Normes
	E_1	F_3	F_2	F_4	E_5	E_6	E_7	E_8	E_9		
pH	7,4	7,3	7,6	7,3	7,5	7,3	7,4	7,4	7,3	-	6 - 9
Température	32,5	33,4	33,3	32,1	32	33,6	34,0	33,5	33,6	°C	
Conductivité	674	712	871	660	660	672	672	676	674	µs/cm	< 1300
Turbidité	0,64	0,58	3,46	45,6	0,37	0,30	0,35	0,40	0,13	NFU	< 5

L.A.T.E Tel : 77 108 32 85 / 77 406 07 25 e-mail : agassama@univ-zig.sn

Table 3: Results of physico-chemical parameters analysis

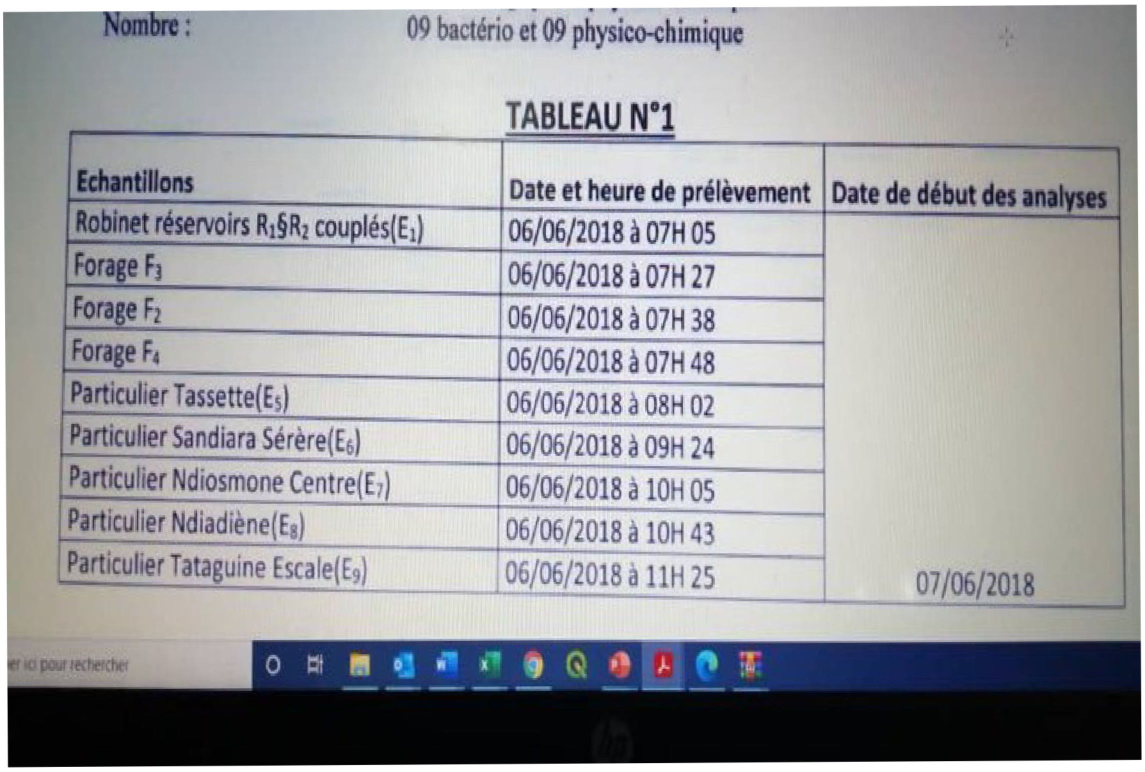


Ziguinchor, le 11 Juin 2018

Paramètres	Valeurs Physico-chimique									Unité de mesure	Normes
	E_1	F_3	F_2	F_4	E_5	E_6	E_7	E_8	E_9		
Dureté totale	28	32	36	28	28	27	27	28	25	°f	-
Titre alcalimétrique (TA)	0	0	0	0	0	0	0	0	0	°f	-
Titre alcalimétrique complet (TAC)	32	32	16	28	28	32	28	28	32	°f	-
Chlorures	61,2	63,9	95,8	59,5	60,3	61,2	61,2	60,3	60,3	mg/l	< 250
Fluor	1,38	1,36	1,48	1,38	1,34	1,33	1,30	1,35	1,36	mg/l	< 1,5
Fer total	0,02	0,01	0,00	0,02	0,00	0,00	0,02	0,00	0,01	mg/l	< 0,2
Nitrates	3,3	3,7	3,9	2,9	3,4	3,2	3,2	3,5	3,4	mg/l	< 50
Chlore libre	0,48				0,68	0,26	0,29	1,72	0,15	mg/l	≤ 0,3

Interprétation des résultats :

Table 4: Results of laboratory analysis



Nombre : 09 bactério et 09 physico-chimique

TABLEAU N°1

Echantillons	Date et heure de prélèvement	Date de début des analyses
Robinet réservoirs R_1§R_2 couplés(E_1)	06/06/2018 à 07H 05	
Forage F_3	06/06/2018 à 07H 27	
Forage F_2	06/06/2018 à 07H 38	
Forage F_4	06/06/2018 à 07H 48	
Particulier Tassette(E_5)	06/06/2018 à 08H 02	
Particulier Sandiara Sérère(E_6)	06/06/2018 à 09H 24	
Particulier Ndiosmone Centre(E_7)	06/06/2018 à 10H 05	
Particulier Ndiadiène(E_8)	06/06/2018 à 10H 43	
Particulier Tataguine Escale(E_9)	06/06/2018 à 11H 25	07/06/2018

Czech University of Life Sciences Prague
Faculty of Tropical AgriSciences

OFOR
Office des Forages Ruraux

ČESKÁ ZEMĚDĚLSKÁ UNIVERZITA V PRAZE

Name and surname: **Doudou BA**		
Date of birth: **19.03.1993**	Address: **Kolej Na vetrniku, 162 00**	
Phone number: **+420777190234**	Email: **xdoub002@studenti.czu.cz**	
Study field: Sustainable Rural Development in the Tropics and Subtropics		Year of study: **2**

APPLICATION FOR PRACTICAL TRAINING

Brief structure of the application:

Research for diploma Thesis in Proposal of technology treatment of fluoridated waters, Senegal

Place of the Practical Training: Office des Forage Ruraux (**OFOR**), Senegal

Term of practical training: August 2019

Activities:

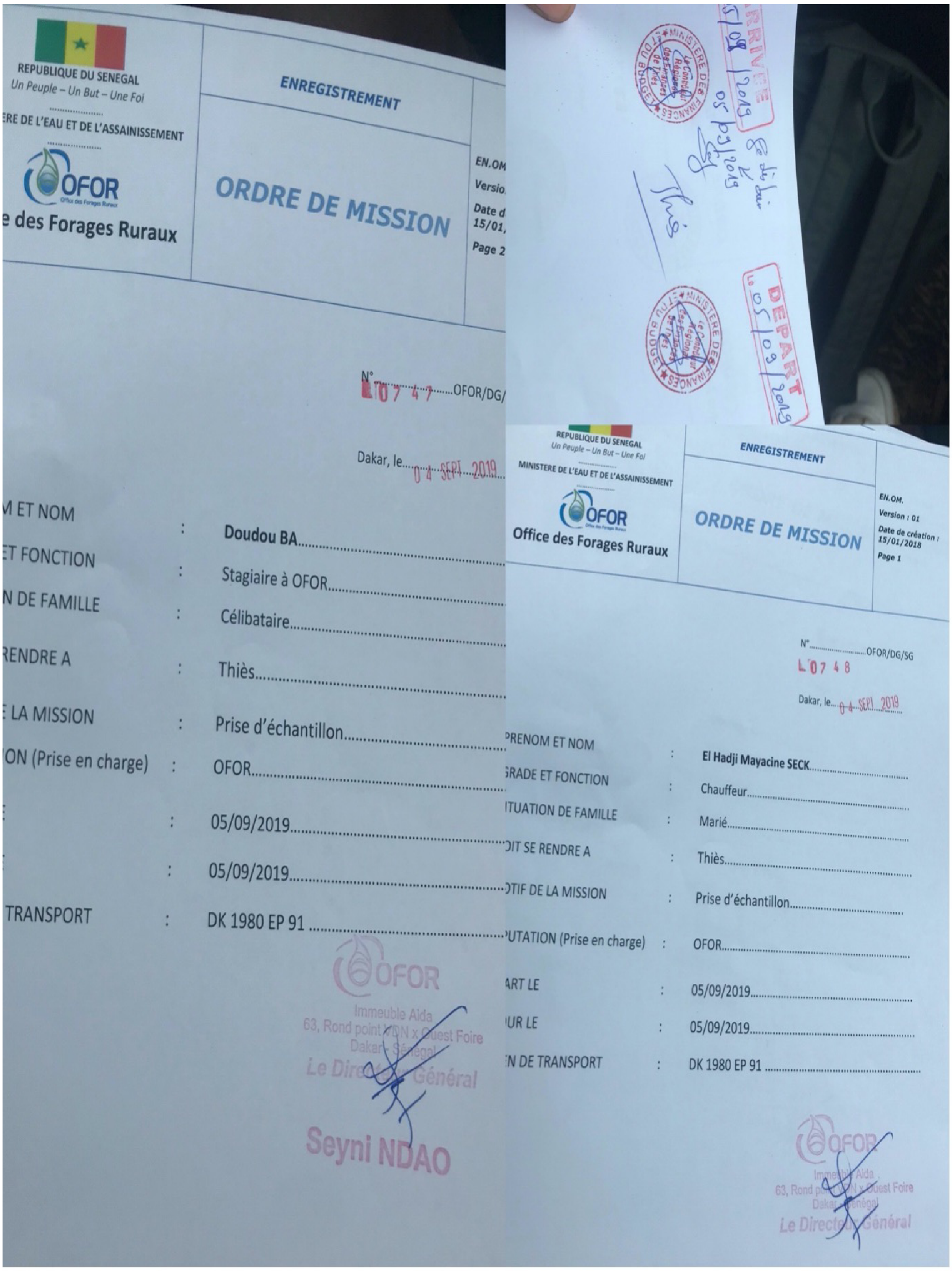
- Office Work performed at OFOR head office (Liberte 6 extension, Dakar Senegal):
  - Data collection,
  - Review of monthly, semi-annual, annual reports of laboratory analysis from the NDP Water network managers (OFOR - SEHO)
  - Programs and policies of Senegal, WHO and NGO's regarding the situation of water contamination.
- Field Work (Tassette, Thies, Senegal West, Source of the NDP network)
  - Carry out a mission in the NDP area in order to collect water samples intended to perform Laboratory analyzes in the Czech University of Life Sciences in Prague.
  - Use of OFOR assistance, people, means and resources that can help facilitate the data collection.

Date:	Student's signature:

Statement of the master's thesis supervisor:	Date and signature:
I fully agree with the practical training plan	23/05/2018

Statement of the guarantee:	Date and signature:

OFOR= OFFICE DES FORAGES RURAUX (OFFICE OF RURAL DRILLINGS), it is a National Office charge with the management of water in rural areas in Senegal.
NDP = Notto Diosmon Palmarin, it's network of 3 villages in Senegal set up as a network of potable water



REPUBLIQUE DU SENEGAL
Un Peuple – Un But – Une Foi
ERE DE L'EAU ET DE L'ASSAINISSEMENT
OFOR
e des Forages Ruraux

ENREGISTREMENT

ORDRE DE MISSION

EN.OM
Versio
Date d
15/01,
Page 2

N° L 07 47 OFOR/DG/

Dakar, le 04 SEPT 2019

M ET NOM	:	Doudou BA
T FONCTION	:	Stagiaire à OFOR
N DE FAMILLE	:	Célibataire
RENDRE A	:	Thiès
LA MISSION	:	Prise d'échantillon
ON (Prise en charge)	:	OFOR
	:	05/09/2019
	:	05/09/2019
TRANSPORT	:	DK 1980 EP 91

OFOR
Immeuble Aida
63, Rond point VDN x Ouest Foire
Dakar, Sénégal
Le Directeur Général
Seyni NDAO

ARRIVEE 05/09/2019
DEPART le 05/09/2019

REPUBLIQUE DU SENEGAL
Un Peuple – Un But – Une Foi
MINISTERE DE L'EAU ET DE L'ASSAINISSEMENT
OFOR
Office des Forages Ruraux

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Page 1

N° L 07 48 OFOR/DG/SG

Dakar, le 04 SEPT 2019

PRENOM ET NOM	:	El Hadji Mayacine SECK
GRADE ET FONCTION	:	Chauffeur
SITUATION DE FAMILLE	:	Marié
DOIT SE RENDRE A	:	Thiès
MOTIF DE LA MISSION	:	Prise d'échantillon
IMPUTATION (Prise en charge)	:	OFOR
DEPART LE	:	05/09/2019
RETOUR LE	:	05/09/2019
MOYEN DE TRANSPORT	:	DK 1980 EP 91

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