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Full Length Research Paper

Groundwater Recharge Assessment in the Thiaroye Sandy Aquifer, Senegal: Combining WTF, CMB, and Isotopic Techniques

Ousmane Coly Diouf[1]*, Seynabou Cissé Faye[1], Mathias Diedhiou[1], Mariama Kaba[1], Sérigne Faye[1], Cheikh Bécaye Gaye[1], Abdoulaye Faye[1], Andreas Englert[2] and Stefan Wohnlich[2]

[1]Geology Department, Faculty of Sciences and Techniques, University Cheikh Anta Diop, Dakar, B.P. 5005, Dakar-Fann, Senegal.

[2]Department of Applied Geology, Ruhr University of Bochum, Universitaetsstr. 150, D-44801 Bochum, Germany.

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The quaternary sandy sediments which cover most part of the Cap Vert peninsula bear considerable groundwater resources. The aquifer lying beneath a densely populated suburb zone is encountered with major issues such as induced recharge from anthropogenic surface derived pollution and rising water table to ground surface. The present study was aimed at investigating the recharge in the unconfined aquifer of Thiaroye zone using both water table fluctuation (WTF), chloride mass balance (CMB) methods and environmental isotopes. Seasonal fluctuations of groundwater in response to precipitation are monitored during time period (2010 to 2011) using "Thalimede Orpheus mini" recorders in two piezometers (P3-1 and PSQ1) as well as long term record. Chemical and isotopic characterization of groundwater, rainfall and the unsaturated zone were also carried out using a network of 48 points consisting of 8 rainfall stations, 10 unsaturated zone profiles and 30 dug wells, boreholes and piezometers. The concentrations of chloride in rainwater are between 3.2 and 53.4 mg/L. These unsaturated zone profiles range from 65 and 572 mg/L. The recharge obtained by WTF method ranged between 18 and 144 mm during the rainy season (June to October), whereas the recharge given by CMB method ranged between 8.7 and 73 mm/year. The Thiaroye aquifer recharge obtained from these different methods also showed relatively similar range values. In this study, the WTF method applied computes both infiltration from rainwater and domestic waste water, while the CMB method estimates potential recharge from rainwater. Therefore, in the urban area, the CMB method cannot be applied due to the chloride input from waste water infiltration.

Key words: Thiaroye basin, recharge, isotopes, chloride mass balance (CMB), quaternary sandy aquifer (Dakar).

INTRODUCTION

The Quaternary sandy aquifer located in the region of Dakar plays a major role in supplying drinking and irrigation water in rural areas. Use of this resource began in the 50s with periods of higher and lower exploitation ranging from 15 000 to 1 300 m^3/day. During the past two decades, the pumping was considerably reduced due to nitrate pollution resulting from improper sanitation system in the urbanized region. Thus, the combined effects of the reduced pumping and induced recharge in addition to natural recharge cause rise of groundwater table and flooding in the suburban area.

This present paper aims to investigate recharge processes using various techniques such as water table

*Corresponding author. E-mail: ouscolydiouf@yahoo.fr. Tel: 00221 77 561 19 32, 00221 76 123 20 13.

fluctuation (WTF), chloride mass balance (CMB) and environmental isotopic methods. This latter method is commonly used as tracers in recharge studies since they are integrated in the water cycle and reflect changes induced by natural and anthropogenic processes. The combination of tritium (^{3}H) and chloride (Cl) is also used to trace water flux through the unsaturated zone and recharge process (Gvirtzman and Margaritz, 1986; Philips et al., 1988). The conservation chloride has been widely used as tools for estimating hydrological processes such as recharge and reconstituting of recharge history. The CMB method is based on tracing the geochemical signal from precipitation, unsaturated zone solutions to groundwater; it is particularly used to estimate recharge in arid and semi-arid regions due to difficulties induced by conventional water-balance methods (Allison et al., 1994).

Variations of chloride and stable environmental isotope (^{18}O, ^{2}H) between rainwater and groundwater have been used in several studies to investigate recharge from infiltration of rainwater and to identify the origin of the water, atmospheric processes (advection of water vapour, condensation and evaporation) and processes occurring during recharge (selection, evapotranspiration, mixture and dispersion) (Gat and Tzur, 1967; Gaye, 1990; Allison et al., 1994; Clark and Fritz, 1997; Gupta et al., 2005). These isotopic variations are due to: (1) variations in the isotopic composition of rainwater (Mook, 2000); (2) phenomena due to mixing with different waters (Negrel et al., 2003), and (3) evaporation (Gonfiantini, 1985; Kendall and McDonnel, 1998). In this prospect, this study combines the information provided by the water level fluctuation, chlorine and isotopic (^{18}O, ^{2}H and ^{3}H) contents in rainwater, interstitial and groundwater to investigate the recharge in Thiaroye aquifer.

Description of the study area

The peninsula of Cap-Vert extends over 550 km^2 between longitudes 16°55' and 17°30' west and latitudes 14°55' and 14°35' north (Figure 1). Dakar city is a fast growing metropolitan area; its population increased from 583,000 inhabitants in 1971 to 2.5 million in 2006, with an emergency of suburban zone where the population is estimated at 1 154 316 with a density of 9335 inhabitants/km^2. Evidence of the fast urban expansion was investigated using time series aerial photos and satellite images interpretation (1966, 1978, 1989, 2000 and 2006). Results show that urban occupation increase from 36 km^2 in 1966 to 150 km^2 in 2006. This region is characterized by a semi arid climate with a short rainy season, which lasts from June to October. The annual rainfall has varied between 150 mm (1983) and 664 mm (2005) over recent decades and has become slightly above the mean of 410 mm (1961 to 1990). The maximum temperature recorded in this area between 1980 and 2010 has averaged 29.5°C. It occurs from May to June and October-November corresponding to the beginning and the end of the rainy season respectively; minimum temperatures are observed during the period from December to February (18.5°C). Evaporation estimated by Turc formula ranged between 200 and 500 mm/year between 2000 and 2008.

From the geological standpoint, the region of Dakar belongs to the Senegalese-Mauritanian basin, the largest coastal basin of northwest Africa (Castalain, 1965). Most of the geological formations encountered correspond to thickness reaching several thousand meters. At the outcrop appears almost exclusively quaternary sediments sandy and sandy clay, especially alluvial and wind deposit (Bellion, 1987).

This Quaternary sandy formation constitute the reservoir in the Dakar region; it overlays the impermeable marly of Eocene age. The aquifer extends from the Dakar peninsula to Saint Louis in the north. It is confined beneath a basaltic layer at the peninsula head then unconfined in the region extended from Patte d'Oie toward the East.

This system consists of medium to fine sands, with intercalations of sandy clay in places. Its thickness varies between 5 m (southeast) to 40 m (West) and 75 m (northwest) (Figure 2). The permeability values of the Thiaroye aquifer are variable and range from 10^{-4} m/s at Thiaroye to 5.10^{-4} m/s around the Mbeubeuss lac. Transmissivity values vary as a function of the thickness of the sands and are between 1.10^{-2} and 1.10^{-3} m^2/s.

The general pattern of the groundwater flow is from southeast to northwest towards the ocean. The piezometric map established in 2008 features a dome in Thiaroye area and a depression in the confined aquifer zone (Figure 3). These features are likely related to pumping rates which are respectively low and high in the two zones. The use of the Thiaroye groundwater resource has undergone several changes since 1950. From the initial pumping rate of 15 000 m^3/day (well field of Thiaroye), exploitation had been considerably reduced due to nitrate pollution. It is presently at a rate of 1 300 m^3/day.

METHODOLOGY

The methodology used in this study consists of four parts prior to chemical analysis:

1. Daily monitoring groundwater levels were obtained using "Thalimede Orpheus mini" recorders. This operation was carried out in two piezometers (28 and 29) located in the suburban area during the period 2010 to 2011, in order to determine groundwater fluctuations in response to rainfall events. In addition, long term water table records in few piezometers, located in the inhabited area (PS10, PS11, P2-10, P2-9 and P2-7) and in the urban area (P2-6, P2-2 and P2-5) were investigated to infer the change patterns in relation to geographical area.
2. A water sampling campaign was also performed in March 2007 on a network of 38 points (dug wells, boreholes and piezometers) to determine the physicochemical and isotopic characteristics of the groundwater.

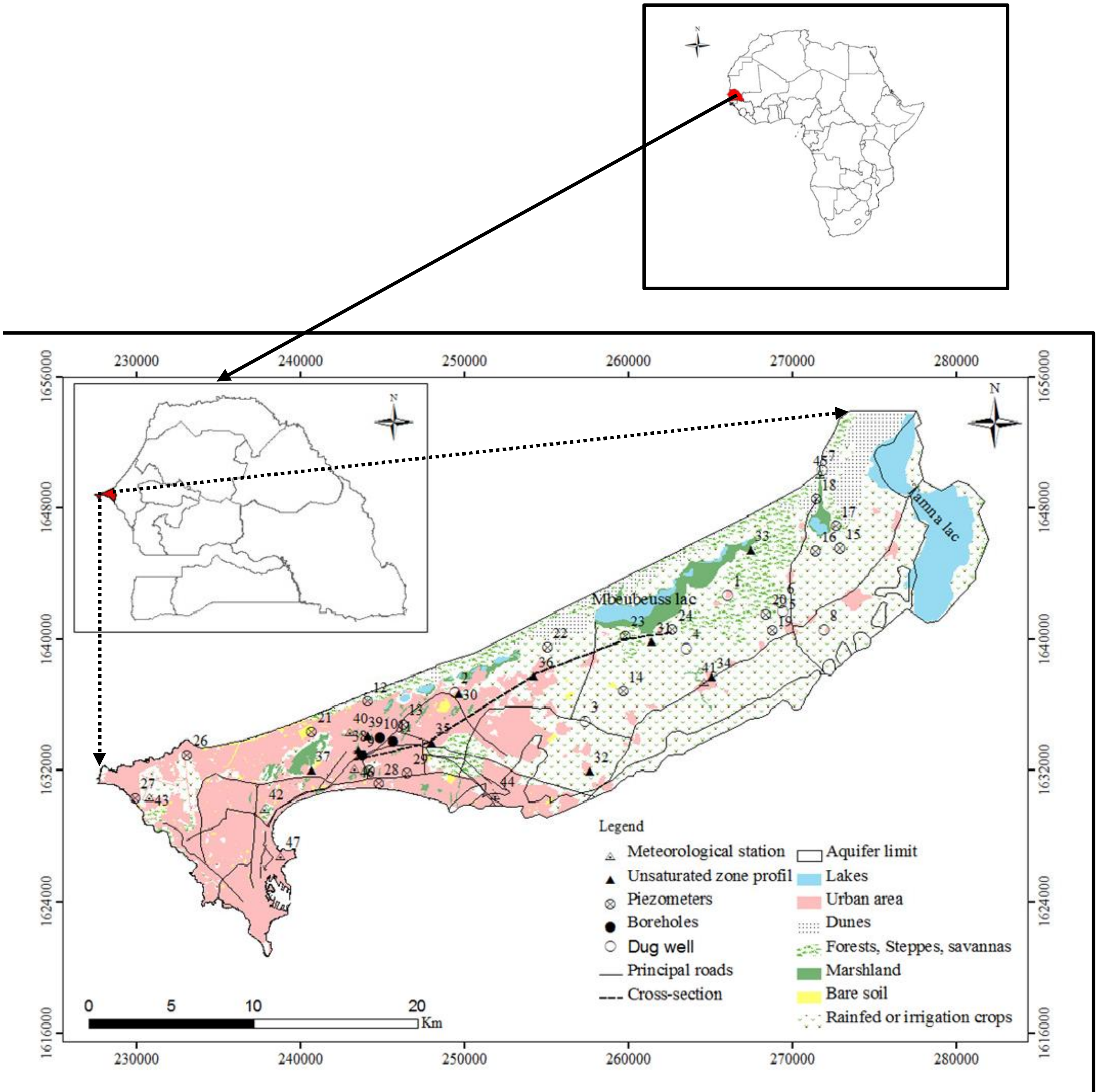

Figure 1. Localisation of the study area.

3. Unsaturated zone profiles were carried out in 10 sites using hand auger device. Soil samples were collected at 0.25 cm interval down to 1 m depth then at 0.5 cm interval down to the water table. Samples were bulked and homogenized for each depth and collected in 500 ml or 1000 ml sealed glass containers. Gravimetric moisture contents were determined by drying 20 g of sample at 110°C for 4 h. For chloride analysis, 50 g sample of moist sediment was mixed with 100 ml of deionized water to elutriate the soluble salts. The solution was then stirred for about 1 h until the conductivity remained constant.

4. A rainwater sampling was performed during the rainy season 2008 in collaboration with the Senegal National Meteorological Agency (ANAMS) to obtain information on quantity and chemistry. Rainwater samples were collected for each event at the rain gauges at Dakar Yoff, Dakar Hann, Bel Air, Thiaroye, Guédiawaye, Mbao, Bambilor and Kayar (40 to 47) (Figure 1).

Water samples of the groundwater, the unsaturated zone and rainfall were analyzed at the Chemistry laboratory of Geology

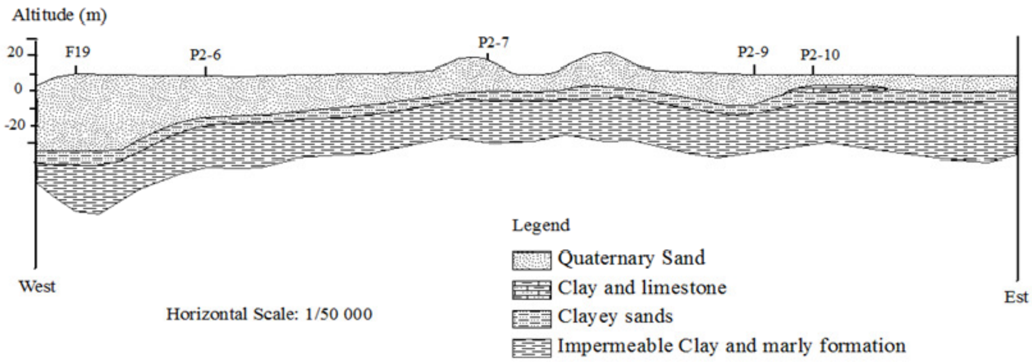

Figure 2. Geological cross-section in the study area (Chaoui, 1996 modified).

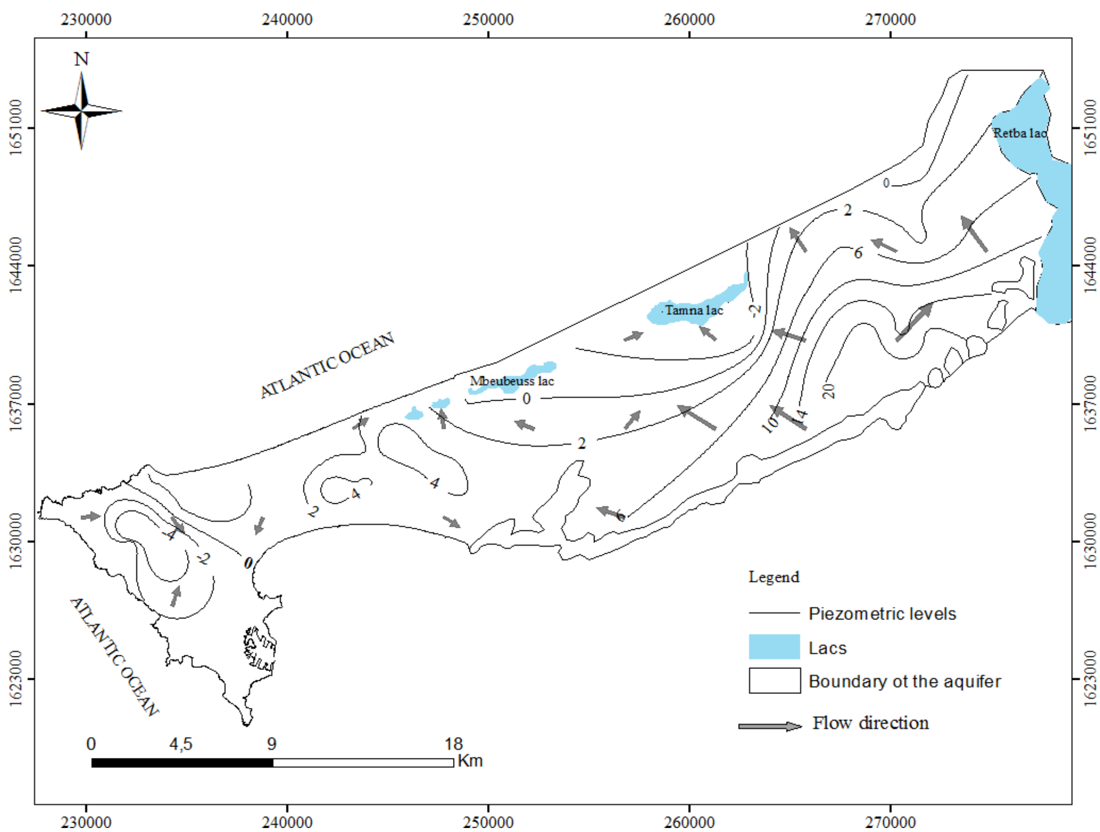

Figure 3. Piezometric map (mars 2008).

Department, UCAD. Major ions were measured by ion chromatography Dionex DX 120. Isotopic analysis (^{18}O, ^{2}H and ^{3}H) were performed for groundwater and rainwater samples at the Institute of Groundwater Ecology (IGE) / Helmholtz Center/Germany. The hydrogen and oxygen isotopes are analyzed by respectively employing the standard CO_2 equilibration (Epstein and Mayeda, 1953) and the zinc reduction techniques (Coleman et al., 1982), followed by measurement using isotope ratio mass spectrometer. All hydrogen and oxygen isotopes analyses are expressed in the conventional δ-per mil (δ ‰) notation referenced to Vienna-Standard Mean Oceanic Water (V-SMOW).The analytical reproducibility is ±0.1‰ for the oxygen and ±1.0‰ for deuterium.

Tritium analyses were performed by electrolytic enrichment and analyzed with a liquid scintillation counting method (Thatcher et al., 1977). The results are reported as Tritium Unit (TU) with an analytical error of ± 0.7 TU.

RESULTS

Water table fluctuation method

Water table fluctuation method was used to estimate the

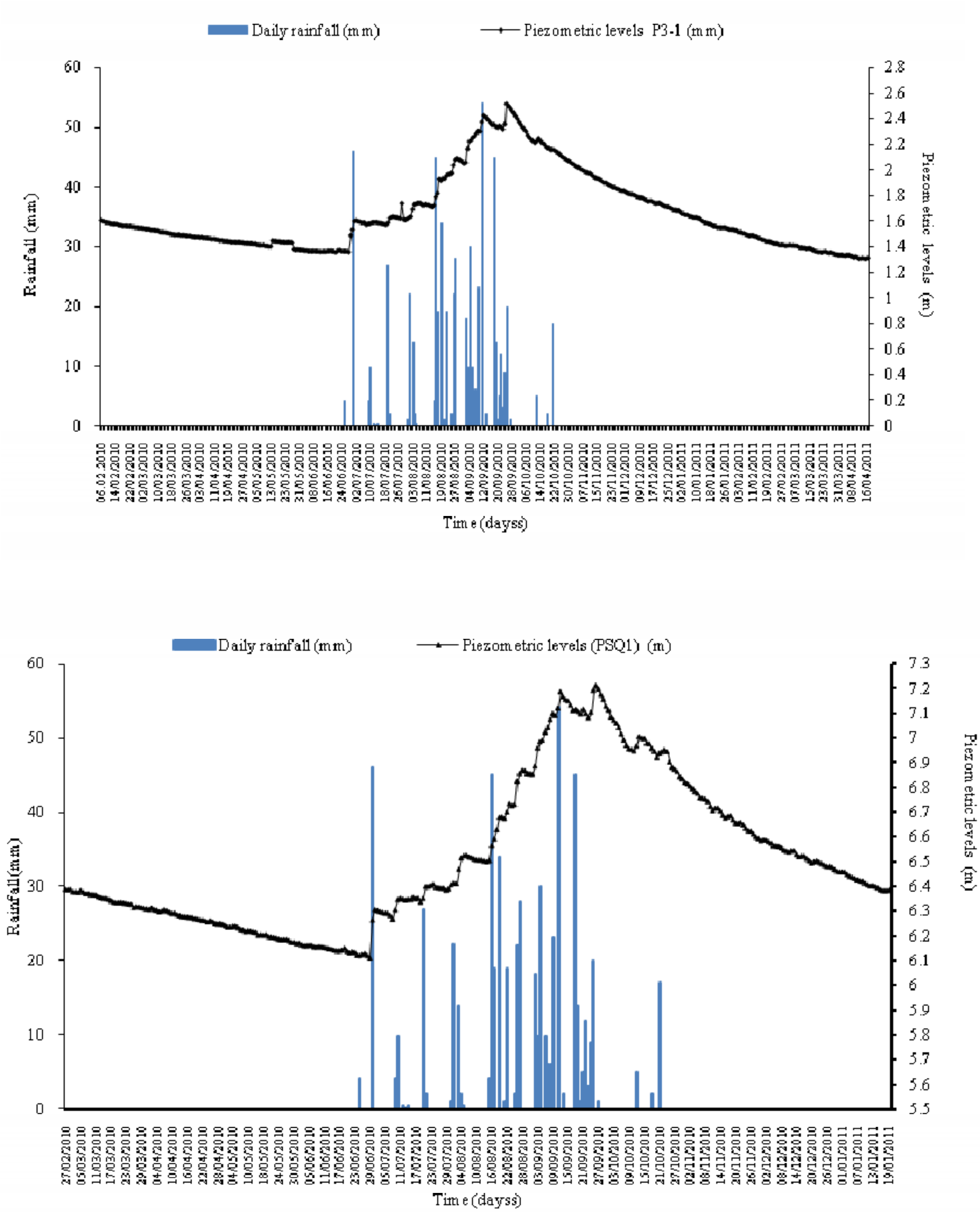

Figure 4. Water level fluctuation in two piezometers (P3-1 and PSQ1).

groundwater recharges (Healy and Cook, 2002):

$$R = S_y \frac{dh}{dt} = S_y \frac{\Delta h}{\Delta t} \quad (1)$$

Where S_y is the specific yield, Δh is the seasonal water level variation and t is time. This method based on the premise that rises in groundwater levels in unconfined aquifers are due to the recharge induced by rainfall infiltration with regard to seasons is suitable for shallow groundwater displaying rise and decline (Healy and Cook, 2002; Scanlon et al., 2002). In this study, the daily groundwater levels records (Figure 4) in response to rainfall were obtained in two piezometers (P3-1 and PSQ1) to estimate recharge. The specific yield for the sandy matrix has been estimated from 15 to 32% by previous studies (Martin, 1970; WHO, 1972; Seck, 1988) and recently by (Diedhiou, 2011) using column experimental filled with soil samples of Thiaroye and Mbeubeuss. The computed values using the column experimental with Weib formula (1998) ranged between 30 and 33%. The groundwater recharge calculated using Equation 1 with an average value of effective porosity equal to 31% is between 18 and 144, 28 and 132 mm, respectively, at P3 -1 and PSQ1 where recharge occurred only during June to September period. The high recharge values were obtained in August; however, September is the wettest month (263 mm of rain).

Long term groundwater levels record is marked by inter-seasonal variation related to rainfall events over time. General trends show a water levels decline in inhabited areas (P2-7, P2-9, P2-10, PS10 and PS11) and rising pattern in the urban area (P2-2, P2-5 and P2-6) between 1990 and 2008. In detail, decline groundwater levels ranged from 1.15 to 0.81 m between 1990 and 2008 in piezometer P2-7 and variations are more pronounced in points P2-9, P2-10 and in piezometers located in the southeastern part (PS10 and PS11). Whereas, rising groundwater levels occurs in the urban area with values ranging from 0.77 to 4.83 m (P2-6) between October 1994 and 2008 (Figure 5a, b). Decline water levels in the inhabited area can be related to rainfall decrease during the 80's and groundwater levels rising in urban areas evidenced infiltration of domestic wastewater into the groundwater due to the poor sanitation system and the reduced pumping.

Chlorine mass balance method (CMB)

In arid and semi-arid regions, to determine the mean annual recharge using CMB, it is assumed that the only source of chloride input is from the rainwater and contribution from other sources such as human activities and weathering are neglected (Dettinger, 1989; Wood and Sanford, 1995; Gaye and Edmunds, 1996; Zagana et al., 2007). Due to the low relief zone and the nature of the aquifer (dune sand), runoff is negligible. Chloride concentrations in soil water extracted by lixiviation from the unsaturated zone and Cl contents in rainwater are used to estimate aquifer recharge according to CMB formula (Edmunds et al., 1988; Allison et al., 1994):

$$D_R = \frac{P[Cl]_p}{[Cl]_{sm}} \quad \text{direct or diffuse recharge} \qquad (2)$$

Where P (mm) is the annual average rainfall, $[Cl]_p$ (mg/L) average chloride concentration, D_R (mm) direct or diffuse recharge and $[Cl]_{sm}$ (mg/l) is the chloride concentration in the unsaturated zone.

$[Cl]_{sm}$ is estimated as average chloride concentration in the unsaturated zone profile within stationary phase (Sharma and Hughes, 1985). The $[Cl]_p$ values correspond to the chloride content in rainwater collected at Mbao, Bambilor and Kayar stations. Figure 6 presents the results of chloride content and humidity at Wayambame, Tivaouane Peulh, Kaniack and Bambilor profiles. In the top profiles, very high concentrations of chloride occur before featuring a stationary condition at depths 300 to 950 cm, 500 to 1050 cm, 250 to 650 cm and 200 to 550 cm, respectively.

The computed recharge values using the CMB method vary spatially across the study area and range from 9 to 73 mm/year, corresponding between 2 and 15% of the average annual rainfall (Table 1). The high recharge value at site 33 (Kaniack) could be linked to the relatively high chlorine concentration for the rainwater of Kayar due to the proximity of the sea. However, in the urban area chloride contribution from various human activities found in the unsaturated profiles (Mbeubeuss, F22, Pikine and P2-6) make the CMB not applicable in this area.

Qualitative estimation of recharge using environmental isotopic data (^{18}O, ^{2}H and ^{3}H)

Groundwater samples have $\delta^{18}O$ values ranging between –5.1 and –1.5‰, with a mean of –3.8‰ and δ^2H values from –38.1 to –19‰ with a mean of –31.1‰. The $\delta^{18}O$ and δ^2H in precipitation range from –7.6 to –4‰ and from –51 to –25‰, with respective mean values of –5.7 and – 36‰ (Table 2). The isotopic composition of the groundwater deviates from the LMWL and GWML with best fit curve of $\delta^2H = 3.97\delta^{18}O - 16.01$ ($r^2 = 0.8$) where a scattered pattern reflect other processes such as evaporation and mixing (Figure 7).

Sampling points located in the urban area have $\delta^{18}O$ values and δ^2H values ranged between –5.1 to –4‰ and –38.1 to –32‰, except points 12 and 37. These isotopic signatures are probably influenced by the infiltration of domestic septic waste water in the suburban area where supply water is pumped from the Guier Lake and groundwater reservoirs from the horst Ndiass system.

Tritium and nitrate contents (Figures 8 to 10) support the admixture of induced recharge from waste water. In fact, the tritium contents measured in March 2007 varies between 1.1 and 5.3 UT, very close to those measured in the rainwater (1.5 and 2.8 UT). The spatial distribution of tritium in the groundwater shows that higher content than 3 UT are mostly located in the rural area (7, 8, 14, 17, 18, 19, and 30) where groundwater table depth is between 7 and 15 m. These areas are characterized by low NO_3 concentrations. However, groundwater wells with high nitrate concentration and located in the urban area are shallow (less than 4 m) and exhibit tritium content similar to that of rainfall.

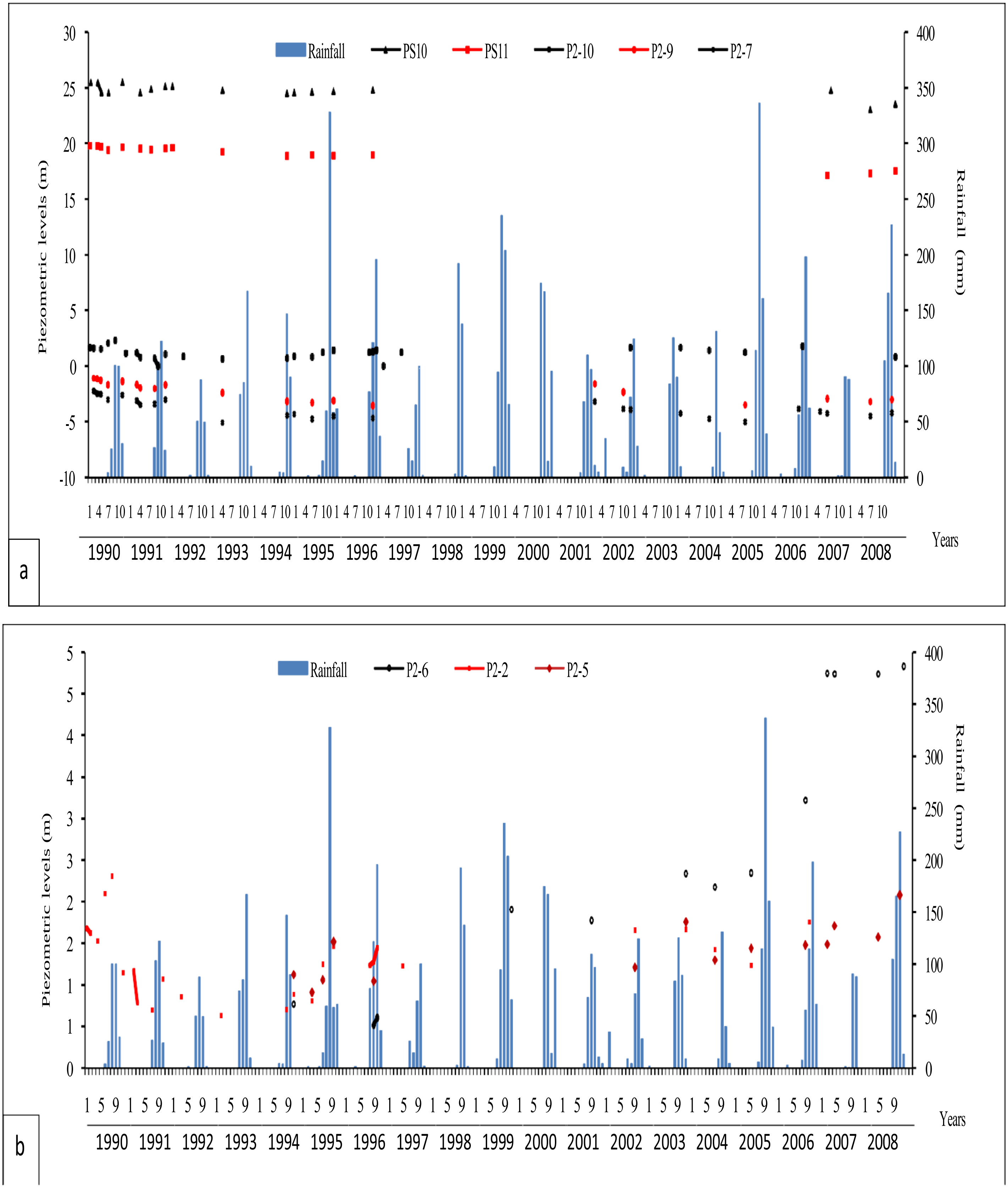

Figure 5. Long term groundwater levels records: a) in the inhabited area, b) in the urban area.

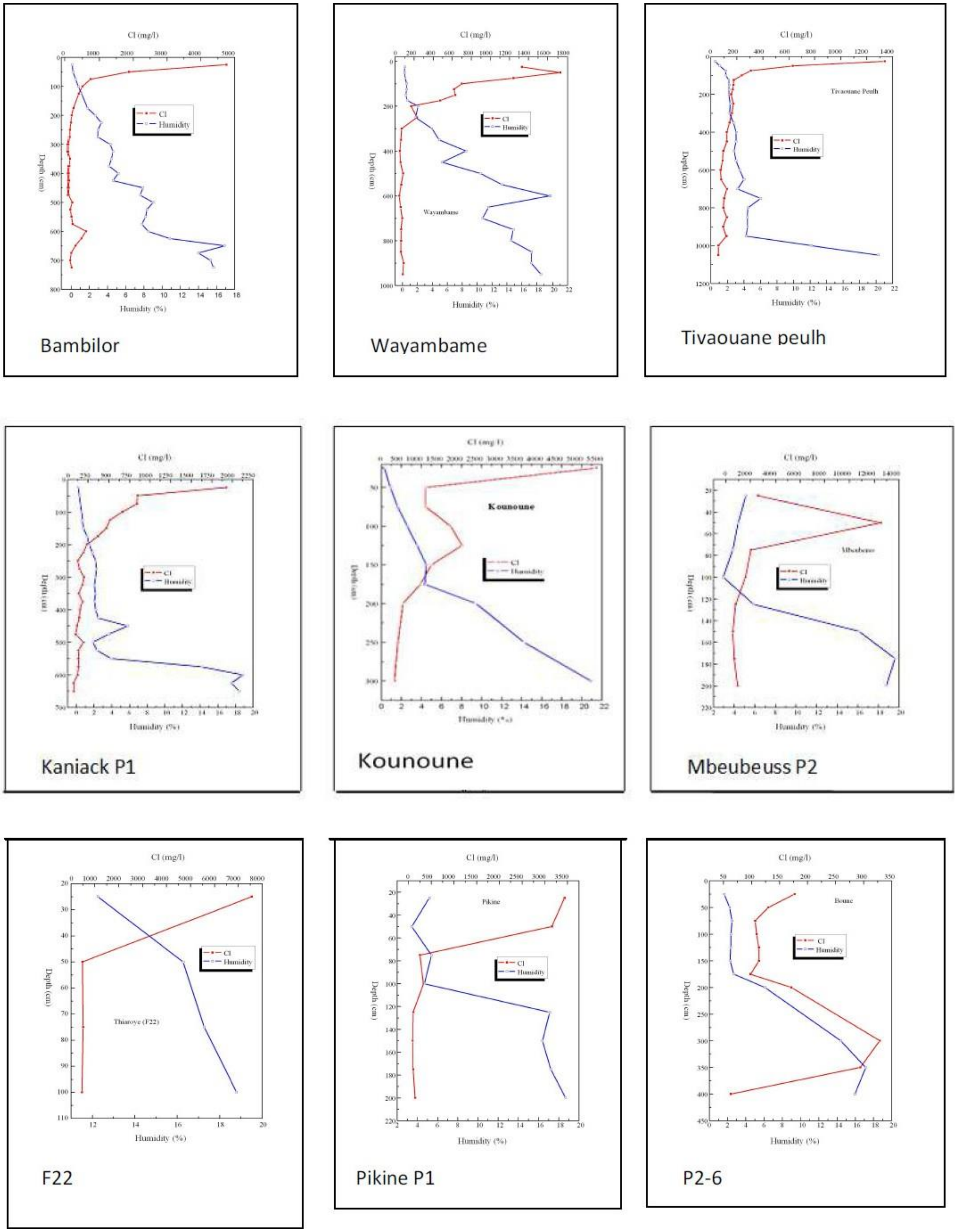

Figure 6. Chloride and moisture contents as a function of depth.

Table 1. Recharge values computed by CMB method.

Site	Borehole	Interval considered(cm)	Annual average rainfall (mm)	Average chlorine content in rainwater (Cp) (mg.l^{-1})	Average chlorine content of boreholes (Cs) (mg.l^{-1})	Average replenishment (R) (mm.an^{-1})
Kounoune	P2	200-350	444.2	14.48	571.89	11.25
Bambilor	P1	200-550	470.8	4.86	124.2	9.86
Wayambame	P4	300-950	470.8	4.86	65.71	34.42
Tivaouane Peulh	P3	500-1050	444.2	5.1	91.91	24.64
Kaniack	P1	250-650	488	20.6	138.38	73.71
F22	P1	50-100	507.3	-	477.10	-
P2-6	P2	75-175	421.5	-	108.11	-
Technopole	P3	100-175	421.5	-	168.5	-
Pikine	P2	125-200	421.5	-	109.8	-
Mbeubeuss	P2	125-200	444.2	-	735.66	-

Table 2. Chemical and isotopic composition of rain and groundwater samples in the study area **(**dw= dug Well; pz= Piezometer; bh= Borehole; rw= Rainwater; ms= Meteorological station).

Well N°	ID	Well type	Location	Longitude (m)	Latitude (m)	T°C	pH	E.C.	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	$\delta^{18}O$	δ^2H	^3H
								(µS/cm)	mg/l	[‰]	[UT]								
1	Pts 02	dw	Déni B. Ndao	266048	1642689	26.1	5.8	2530	271	82.3	36.8	107	326	557	134	24.4	-3.3	-26	2.5
2	Pts 58 b	dw	Mbeubeuss	249456	1636758	26.8	5.5	554	57.2	9.6	11.2	23.7	106	89.1	17.6	3.05	-3.8	-33	2.9
3	Pts 109	dw	Santhiane	257357	1634996	25.9	7.2	107	69.3	5.9	33.3	61.0	135	12.9	40.3	140.3	-4.5	-36	2.4
4	Pts 209	dw	Bayakh	269448	1641733	24.8	7.0	665	10.9	0.7	5.9	10.2	107	0.05	47.7	176.9	-4.6	-34	< 0,8
5	Pts 128	dw	Wayambame	261444	1639874	27.6	6.9	720	39.8	8.9	9.2	92.1	66.2	9.8	148	198.25	-5.0	-38	4.8
6	Pts 210	dw	Darou Bayakh Sylla	269303	1642257	26.6	5.7	238	9.6	1.1	1.6	3	39.1	16.3	9.7	12.2	-4.1	-31	4.3
7	Pts 234	dw		271802	1650319	26.7	7.4	2000	189	61.8	30.4	188	299	53.2	378	366	-3.4	-26	3.5
8	Pts 215	dw	Golam	271919	1640603	25.6	6.5	739	31.2	5.4	12.1	39.0	77.2	128	86.0	57.95	-4.6	-34	5.1
9	F17	bh	Marché Thiaroye	243752	1632922	29.6	4.9	1684	157	22.8	38.1	70.4	267	298	85.1	15.25	-4.6	-33	2.6
10	F19	bh	Thiaroye	244841	1633987	28.6	4.8	2100	113	16.8	30.3	72.2	188	280	71	9.15	-4.7	-33	2.1
11	F21	bh	Thiaroye	245647	1633794	28	4.7	2160	80.4	13.3	21	54.7	137	221	40.4	9.15	-4.6	-35	1.8
12	P2-5	pz	Corniche Guediawaye	244116	1636209	30.6	7.4	1465	70.6	5	17.4	55.9	169	111	56.1	222.65	-1.5	-18	2.3
13	Pz21	pz	Yeumbeul	246286	1634833	27.4	3.9	2890	222	55	36.8	123	430	743	139	91.5	-4.1	-32	2.2
14	PS1	pz	Sangalkam	259709	1636848	25.1	7.0	242	17.9	2.4	2.7	25.7	49.8	1.32	3.2	51.85	-3.8	-32	4.1
15	PS4	pz	Santhe Mame Gor	272923	1645543	24.2	5.6	508	29.8	3	9.4	45.4	55.8	1.39	169	0	-2.3	-26	2.3
16	PS5	pz	Mbawane	271456	1645373	24.2	9.0	418	37.7	3.8	7.2	26.9	65	55.5	8.1	24.4	-3.3	-30	< 2,0
17	PS6	pz	Santhe Mame Gor	272667	1646899	25.4	6.3	236	11.1	1.3	2.5	10.4	39.5	8.2	21.6	30.5	-2.9	-29	3.8
18	PS7	pz	Kayar	271457	1648570	31	7.6	606	20.8	2.8	10.5	39.5	48.4	0.6	25.5	274.5	-2.9	-30	5.0
19	PS 10	Pz	Gorom 1	268779	1640602	24.6	6.0	363	30.8	3.5	8.4	17.4	67.4	41.1	29.9	15.25	-2.7	-32	5.3

Table 2. Continued.

20	PS 11	Pz	Gorom 1	268429	1641559	25.4	5.1	861	77.1	3.6	17.6	38.3	117	2.8	240	0	-2.8	-28	3.1
21	P2-3	pz	Croisement Bethio	240716	1634369	29	8.2	689	25.5	1.9	5.4	9.9	129	80.7	22.3	70.15	-4.7	-37	3.5
22	P2-8	pz	Tivaouane Peulh	255070	1639539	26.1	7.9	639	47.5	6	10.3	38.4	138	0.2	1.1	155.55	-4.4	-34	< 1,2
23	P2-9	pz	Niaga Peul	259803	1640260	23.8	7.9	555	36.2	33.1	16.4	26.9	28.7	16.6	139	85.4	-2.2	-25	2.1
24	P2-10	pz	Gouye Guewel	262708	1640631	28.9	7.0	1993	145	6.2	26.3	129	524	6.3	142	183	-4.4	-33	1.1
25	P3-2	pz	Camp militaire Thiaroye	244222	1632026	24.7	6.3	1797	133	33.2	29	71.3	346	327	70.6	24.4	-3.4	-28	3.0
26	Bad4B	pz	yoff	233100	1632945	30.1	7.1	1324	75	11	58	88	229	111	51	250			
27	Bad2h	pz	Ouakam	229928	1630305	26	7	2310	187	7	79	98	468	17	72	348			
28	P3-1	pz	Thiaroye sur mer	244781	1631189	26.4	6.7	1060	102	6.4	6.6	95.9	95.5	0.8	32.5	91.5	-4.6	-32	1.3
29	PSQ1	pz	Forail	246544	1631816														
30	Pts 58	dw(uzp)	Mbeubeuss	249655	1636673	25.9	5.2	1766	175	13.2	35.1	107	382	278	132	6.1	-4.2	-33	2.3
31	Pts 128	dw(uzp)	Wayambame	263534	1639423	25.4	6.3	1376	69.3	5.9	33.3	146	134	7.9	440	54.9	-4.4	-33	2.8
32	Pts 202	dw(uzp)	Kounoune	257656	1631980	24.3	6.6	4770	469	68.3	113	348	852	855	439	179.95	-3.2	-28	2.1
33	Pts 232	dw(uzp)	Kaniack	267480	1645411	27	6.2	301	40.4	4.0	3.6	8.4	45.9	54.9	18.3	15.25	-4.4	-33	2.5
34	Pts 235	dw(uzp)	Bambilor	265102	1637717	24.5	7.5	3180	335	55.4	68.1	294	334	471	790	195.2	-3.8	-29	2.1
35	P2- 6	pz(uzp)	Boune	247980	1633708	26	6.5	1487	138	13.0	47.1	81.6	253	362	36.7	48.8	-5.0	-33	2.1
36	P2- 7	pz(uzp)	Tivaouane Peulh	254245	1637794	27.8	7.9	484	56.8	17.9	18.4	57.9	71.1	153	44.8	100.65	-3.5	-28	2.4
37	Pz1	pz(uzp)	Technopole	240690	1632002	22.9	6.9	1772	70.9	12.8	16.6	40.1	286	254	156	161.65	-2.1	-22	1.5
38	Pz4	pz(uzp)	Pikine	243576	1633262	24.7	6.0	2850	231	53.3	46.1	139	478	308	329	228.75	-4.0	-32	3.0
39	F22	dw(uzp)	Thiaroye	244095	1634149	29.1	5.1	1950	94.2	15.7	22.6	64.5	155	200	90.7	9.15	-4.7	-34	2.2
40	Guédiawaye	ms	rw	243045	1634375												-5.4	-35	2.6
41	Bambilor	ms	rw	264613	1637427												-5.5	-36	2.5
42	Dakar-Hann	ms	rw	237822	1629686												-6.1	-38	2.6
43	Dakar-yoff	ms	rw	230826	1630326												-5.8	-37	2.3
44	Mbao	ms	rw	251902	1630448												-5.6	-34	1.8
45	Kayar	ms	rw	271696	1650074												-6.2	-41	2.2
46	Thiaroye	ms	rw	243335	1632105												-5.2	-33	2.0
47	Bel air	ms	rw	238815	1626829												-5.4	-33	2.2
48	P2-2	pz	Croisement camberene	238560	1632570														

These sampling points are also characterized by groundwater levels rise induced by infiltration of domestic waste water (Figures 8, 9 and 10).

DISCUSSION

Thiaroye aquifer recharge obtained from these different methods show relatively similar range values. Analysis of long term groundwater levels records; nitrate and isotopic contents suggest that water levels rising in the urban area are due to infiltration of domestic waste water and reduced pumping. In this order, WTF method applied in this study compute both infiltration from rainwater and domestic waste water. However, CMB method based on chlorine contents in rainwater and in unsaturated zone estimate potential recharge from rainwater. Recharge values estimated using this latter method were consistent with previous research made in sand dunes of Louga located in northwestern Senegal (29 to 34 mm/yr) (Gaye and Edmunds, 1996).

However, input of chloride from various human activities found in the urban area make the CMB inapplicable in this area. Nonetheless, the rechargevaluesgivepointinformationandcannot be spatialised due to the limited number of analyses performed on rainwater, unsaturated zone and groundwater.

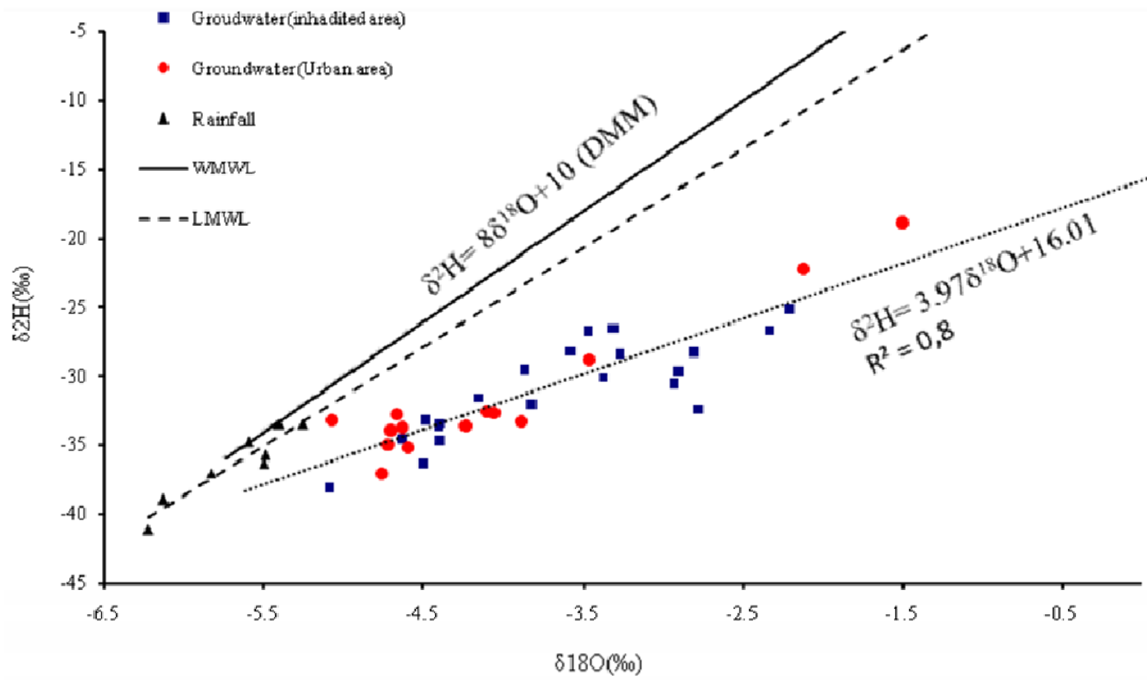

Figure 7. ^{18}O versus Deuterium (^{2}H) plots of rainwater and groundwater (March 2007).

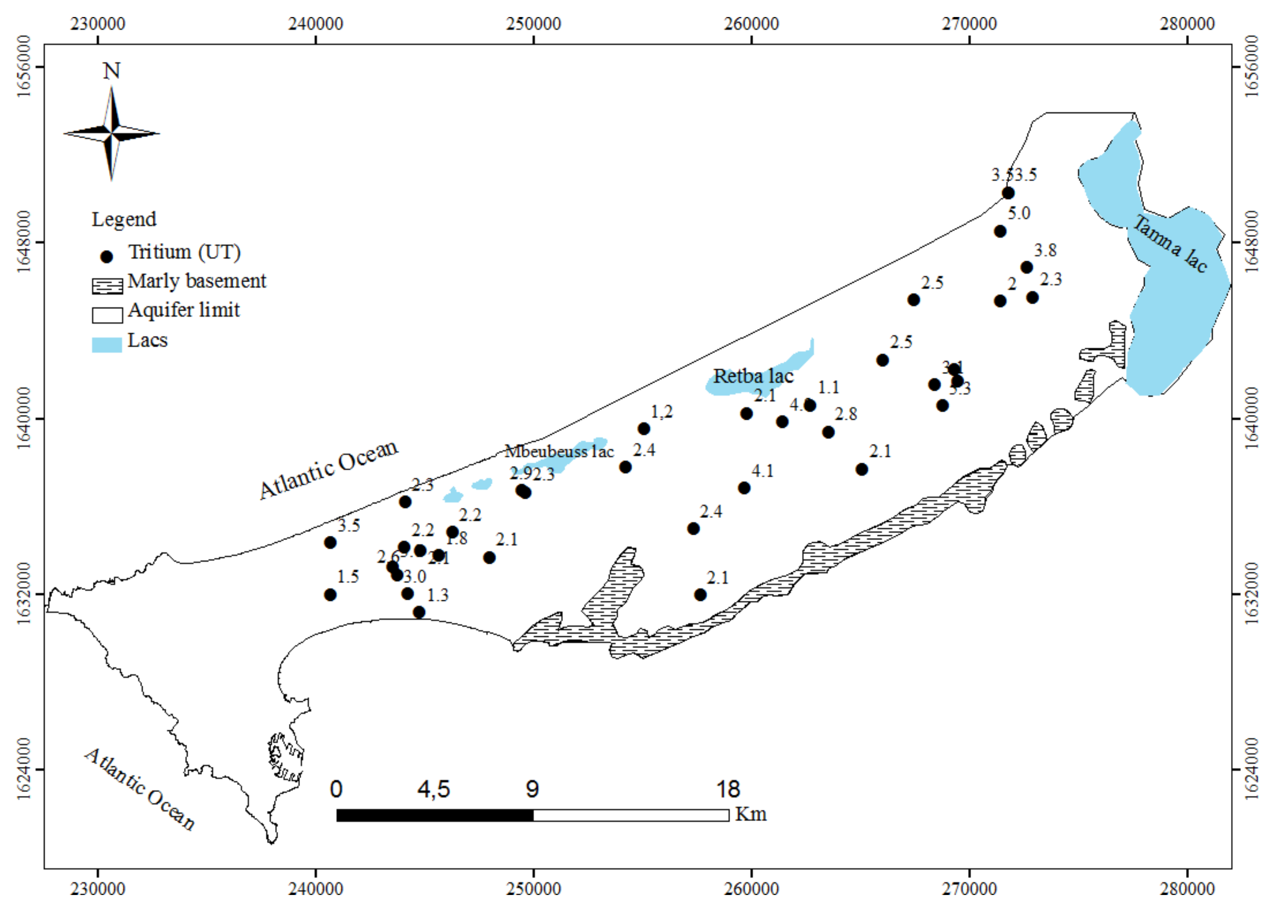

Figure 8. Distribution of tritium values of the quaternary sand aquifer (March 2007).

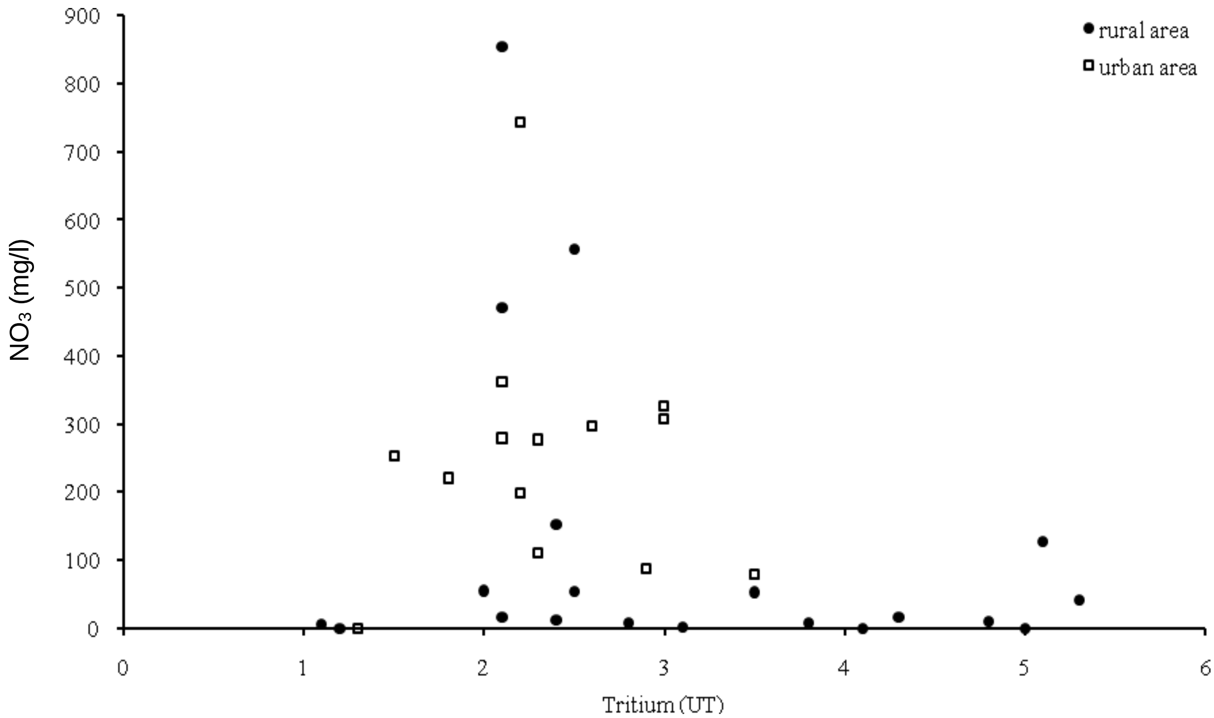

Figure 9. Tritium content vs NO_3.

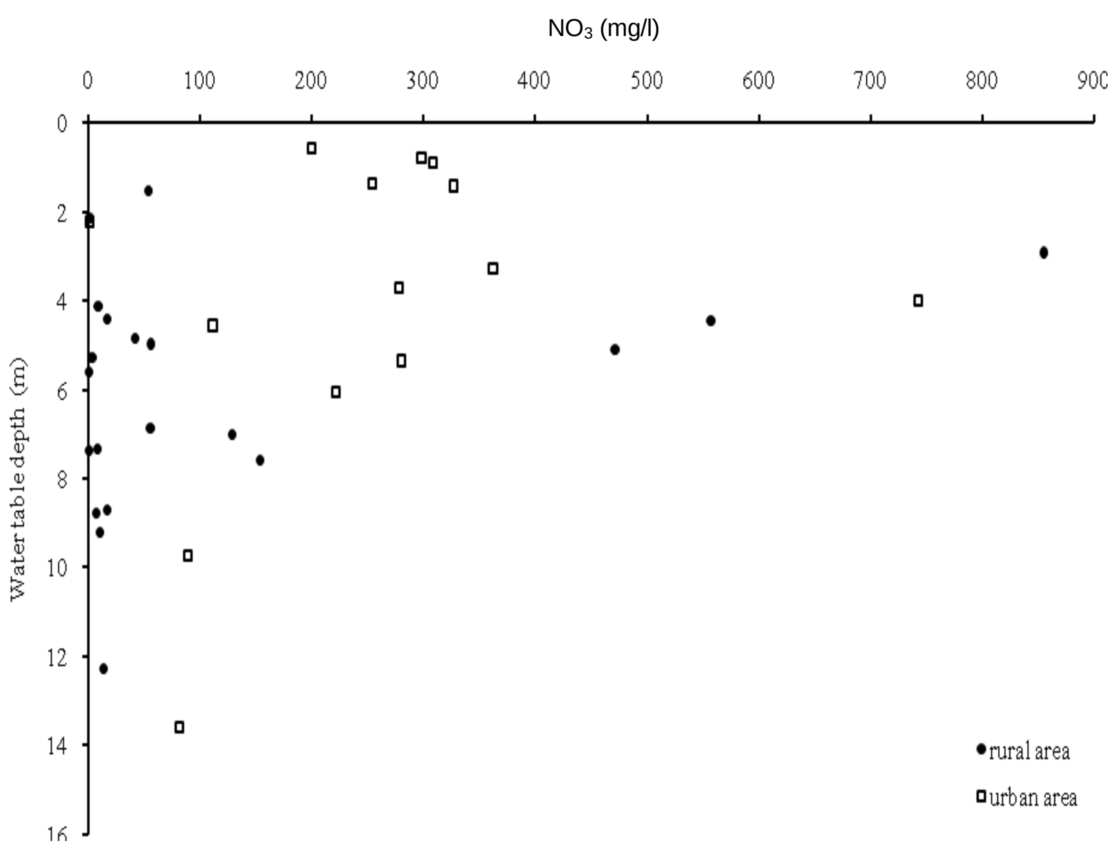

Figure 10. NO_3 versus water table depth.

Conclusion

This study focused on the Quaternary sandy aquifer of Thiaroye located at the western part of Senegal, and led to quantitative and qualitative recharge estimation. Computed recharge by WTF occur only in the rainy season and ranged between 13 and 139 mm. There are relatively similar to the CMB recharge representing 2 to 15% of the annual precipitation. Environmental isotopic data (^{18}O, ^{2}H and ^{3}H) of rainwater and groundwater showed that the recharge area was localised in the southeast part of the aquifer. However, in the suburban area high nitrate concentrations, groundwater levels rising and tritium values similar to that in precipitation suggest infiltration of domestic waste water and relatively rapid groundwater recharge. In fact, computed recharge may be biased by the waste and irrigation water infiltration and the pumping rate.

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