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ORIGIN, PROCESS AND MIGRATION OF NITRATE COMPOUNDS IN THE AQUIFERS OF DAKAR REGION, SENEGAL

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Abstract - *Dakar is a peninsula inhabited by a population of about 2 million people in 1996. With population growth, water demand has increased, inducing seawater intrusion in some dug wells and piezometers of the peninsula. The* NO_3 *content in the groundwater is above the WHO allowable concentration of 50 mg/l. In the unconfined part of the aquifer, all the samples from wells are contaminated by high* NO_3 *contents which rose from 100 mg/l in 1987 to more than 250 mg/l in 1996. Only a limited area is affected by* NO_3 *pollution in the confined layer. The significant correlation between Cl and* NO_3 *in the unsaturated zone indicates an anthropogenic pollution, a fact which indicates the increasing risk of pollution of potable water resources. Studies in the unsaturated zone and familiarity with the sanitation practices in the area indicate that the horizontal and vertical flux are linked mainly to the defective septic tanks and direct organic waste elimination into the soil by more than 40% of the inhabitants. The correlation between tritium values and nitrate shows that the source of nitrate is recent.*

1. INTRODUCTION

Dakar, the capital city of Senegal with estimated population of 2 million people in 1996, is one of the urban centres in west Africa. In the past, 80% of the water supply was drawn essentially from local aquifers at a rate of 3,000 cubic meters per day. Demographic expansion (Table 1) has led to an increase in water demand. This situation induces sea water intrusion in several parts of the local coastal aquifers.

In order to avoid continuing contamination by sea water intrusion, it was recommended to reduce or stop abstraction in some wells and tap the water supply from Thiaroye area, east of the peninsula. In this area, the inhabitants (Table 1) are faced with the lack of facilities for water supply and sanitation. A combination of poor sanitation practices and drought in recent years have induced a severe groundwater pollution by nitrate [1, 2]. To investigate this, around one hundred analyses comprising the major inorganic constituents, faecal coliforms and isotopes (^{18}O, ^{2}H, ^{3}H, ^{14}C, ^{13}C) were carried out on yearly water samples taken from piezometers, hand-pumped wells and dug wells in different area of the peninsula from 1987 to 1997 (Fig.1). The results are intended to help water suppliers evolve short and long term solutions for the management of groundwater.

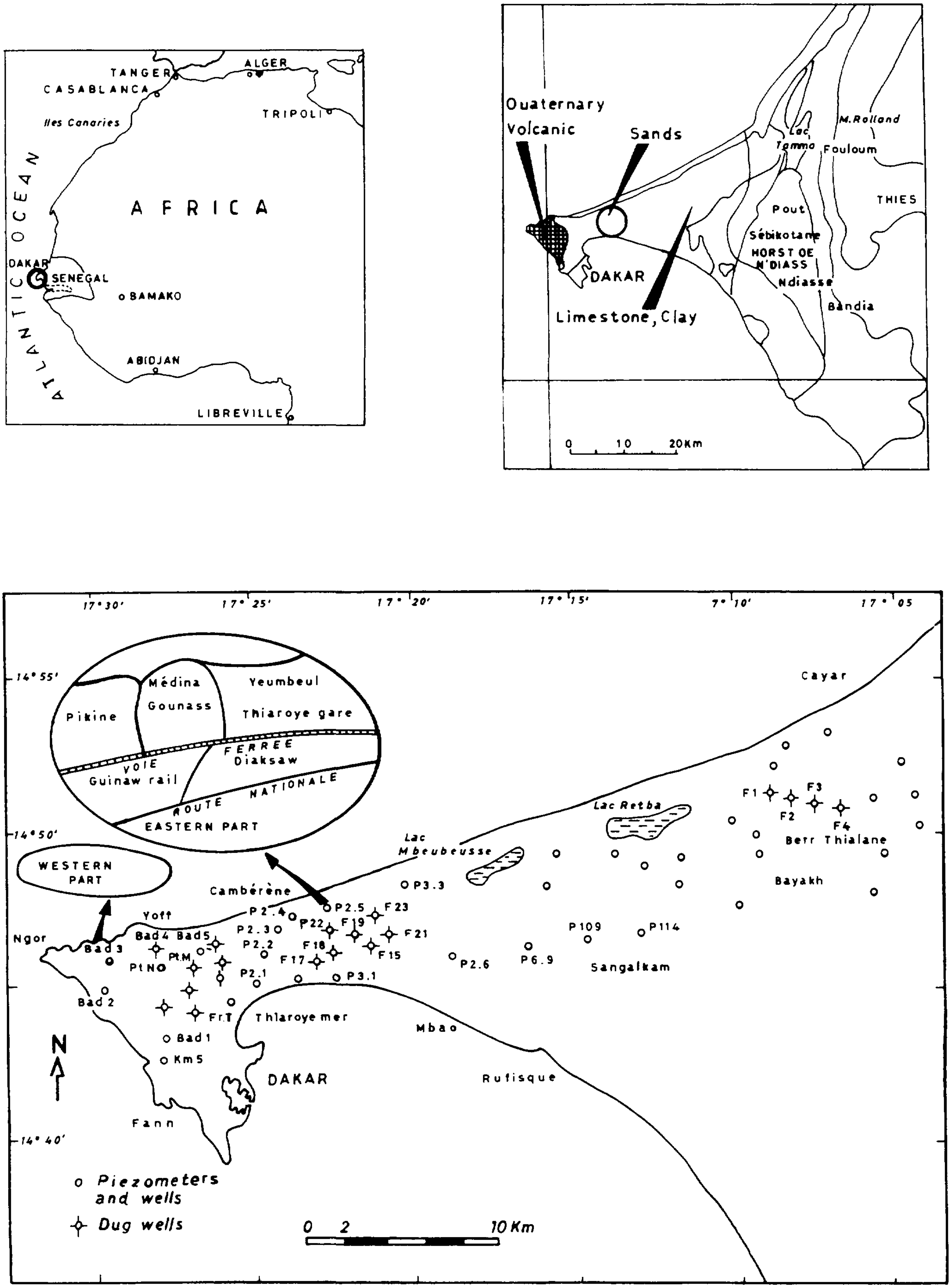


FIG 1. Location of the study area and wells in Dakar region

Table 1: Increasing of population in the eastern part of the peninsula (Thiaroye) [3].

DATES	POPULATION
1955	8,300
1959	23,000
1960	28,800
1964	55,500
1966	76,000
1967	82,000
1969	132,200
1970	132,500
1973	200,000
1976	280,000
1980	420,000
1983	500,000
1990	700,000

2. METHODS OF INVESTIGATION

The samples were collected after the wells were pumped for 1 to 2 hours. They were analysed for NO^-_3, Cl^-, SO_4^{2-} were done by using the high performance liquid chromatography method (HPLC - Dionex QIC analyser), Ca^{2+}, Mg^{2+}, Na^+ by spectrometry method (JASCO, model 7800, UV/VIS) and HCO_3^-, CO_3^{2-} by volumetric method. The chemical analyses were done at the Department of Geology of Dakar University while the isotope analysis of the water sample was done in the IAEA Hydrology Section in Vienna. The samples for Coliform bacteria were stored under cooled conditions and analysed at the Ecole Supérieure Polytechnique (ESP) laboratory in Dakar University.

3. HYDROGEOLOGICAL CONDITIONS

The peninsula has two aquifers systems [4], a semi-confined infrabasaltic aquifer in the western part and the unconfined Thiaroye aquifer in the eastern part (Fig. 2). The infrabasaltic aquifer is composed of pure sand capped by volcanic lavas while the Thiaroye aquifer varies from coarse to clayey sand. The thickness of the aquifer varies from 50 to 80 meters from west to east. Previous studies, using isotopes [2] showed that the recharge by rainwater occurs mainly in the eastern parts between July to October (Fig. 3). Some recharge could also occur through infiltration in the basalt. Transmissivities range from 10^{-2} to $9 * 10^{-3}$ m^2/s in the western part and from $1.6 * 10^{-3}$ to $6.75 * 10^{-3}$ m^2/s in the eastern part [5]. Although eighty percent of the drinking water supply for Dakar comes from groundwater (Fig. 4) as a consequence of drying of wells, the production from the eastern part has gradually decreased.

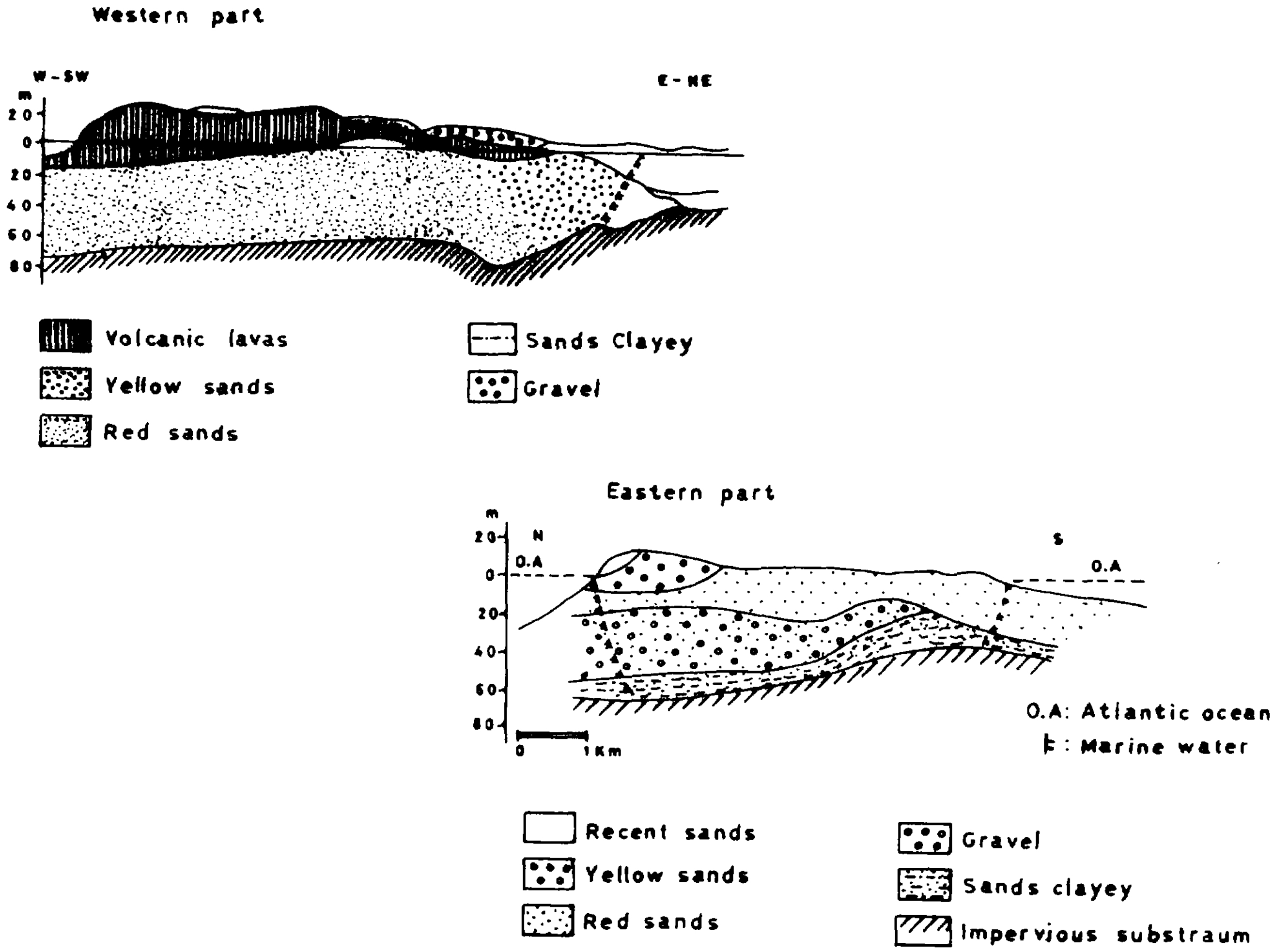


FIG. 2: Geology of the Dakar area aquifer system

4. RESULTS AND DISCUSSIONS

The major chemical constituent of groundwater in Dakar area (Tables 2 and 3) indicates that the water is of the Na-Cl type (Fig.5) of the sodic-chloride type. Electrical conductivities range from 500 to 2700mS/cm and the pH from 4.5 to 7.0. The quality of the water in wells in the eastern and western parts is generally acceptable with the exception of widespread nitrogen and bacteriological contamination. However, water from the city distribution network is of excellent quality and conforms with the international drinking water standards.

Table II: Some major chemical constituents of the groundwater in the eastern part of Dakar area (July 1996 - mg/l)

Code of well sampled	Ca	Mg	Na	K	Cl	NO3	SO4	HCO3	Fecal coliforms (/100ml)
1	90.3	31.1	146.2	87.6	224.9	307.9	129.5	0	0
2	121.6	38.5	154.5	78.5	222.7	265.4	137.0	176.9	0
3	136.3	39.4	141.4	82.9	237.1	320.9	178.6	48.8	0
4	103.1	41.1	118.2	38.0	200.8	264.4	65.2	201.3	7200
5	80.0	40.9	174.8	135.9	297.4	45.5	8.7	578.5	39800
6	101.7	44.5	117.4	42.7	167.5	233.0	94.2	183.0	100
7	109.2	59.4	143.5	24.3	193.4	260.8	56.2	176.9	n.m
8	70.9	30.3	108.6	21.1	179.9	283.9	29.2	48.8	n.m
9	58.6	22.3	116.8	36.5	182.3	231.9	29.8	48.8	n.m
10	98.7	19.0	131.2	39.8	167.4	209.8	175.8	183.0	n.m
11	93.6	39.9	122.4	33.1	186.7	229.7	39.7	0	n.m
12	30.2	14.1	54.6	5.8	163.5	220.3	56.0	170.8	1800
13	71.1	21.6	108.1	17.0	170.7	102.4	144.4	183.0	6300
14	54.6	17.3	85.2	8.5	92.3	109.9	22.7	183.0	200
15	35.6	18.6	99.9	14.0	115.0	186.8	18.3	61.0	0
16	38.2	19.5	95.3	8.9	147.0	249.7	15.7	91.5	0
17	79.4	31.4	125.4	36.8	220.6	359.6	66.0	183.0	3300
18	99.5	58.8	137.5	29.6	224.9	188.3	252.1	117.8	0
19	199.8	57.2	151.3	80.0	221.2	367.5	205.2	152.5	700
20	169.8	81.1	162.4	88.5	258.1	74.1	262.4	610.0	50100
21	157.7	61.6	153.3	45.8	216.9	178.3	326.0	176.9	400
22	42.0	19.3	104.8	19.1	115.7	221.7	25.7	48.8	n.m
23	38.0	18.2	78.2	21.3	89.5	161.7	22.5	54.9	n.m
24	41.0	18.4	48.6	14.9	66.8	132.2	13.4	48.8	00
25	49.2	28.3	89.3	14.3	102.7	215.4	13.6	122.0	200
26	78.2	20.4	93.2	24.9	143.9	261.3	19.9	54.9	n.m
27	71.8	24.5	106.2	29.7	163.7	182.5	33.9	176.9	n.m
28	48.7	18.4	85.6	22.9	113.8	191.2	23.7	140.3	n.m
29	45.6	16.7	89.1	16.3	111.4	184.4	23.2	122.0	11700
30	61.9	21.2	96.0	20.3	123.1	140.0	58.1	146.4	n.m
31	34.7	18.2	30.4	8.5	45.4	89.9	13.7	57.9	n.m
32	60.4	18.1	97.2	19.2	157.9	284.3	25.6	0	n.m
33	100.6	35.8	114.6	38.7	173.9	250.0	81.7	152.5	5700
34	55.0	35.4	66.7	19.2	100.8	42.9	116.2	140.3	500
35	80.9	27.8	92.5	35.4	138.1	257.0	37.9	152.5	n.m
36	47.8	22.2	69.0	13.7	95.7	128.3	30.3	161.6	n.m
37	50.1	25.9	95.1	13.4	124.6	124.3	74.1	148.0	200
38	79.1	23.6	123.6	37.7	170.5	209.9	83.0	146.4	n.m
39	70.1	28.4	115.6	27.7	166.4	168.2	63.7	130.2	n.m
40	35.1	13.7	66.1	9.7	101.6	133.0	15.8	30.5	n.m
41	51.6	24.2	98.7	12.5	153.1	146.2	52.1	152.5	0
42	58.4	15.2	83.5	12.2	112.1	118.4	94.0	152.5	0
43	51.6	20.9	103.1	37.4	158.9	127.4	88.4	170.8	n.m
44	33.2	13.0	70.3	8.7	71.8	101.0	15.5	128.1	n.m
45	32.5	15.8	67.9	11.2	99.8	120.9	19.1	0	n.m
46	28.5	13.2	65.4	8.2	78.5	111.8	20.4	128.1	n.m
47	11.1	14.9	90.6	11.1	130.5	153.2	28.7	140.3	n.m

n.m = not measured

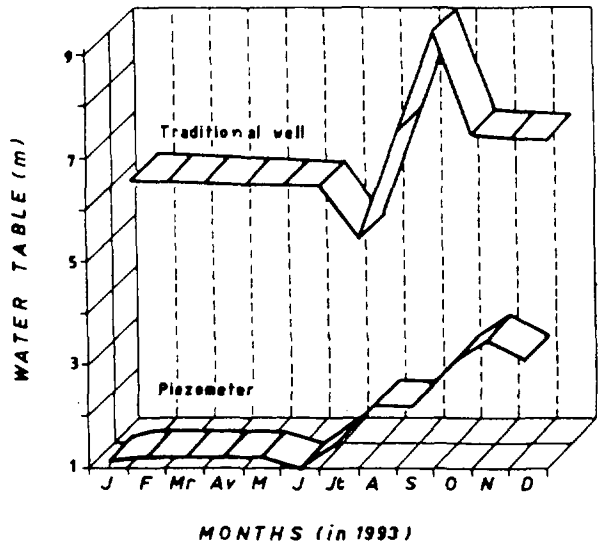


FIG. 3: Relationship between water table of groundwater and the rainy season. Recharge occurs from June or July to October.

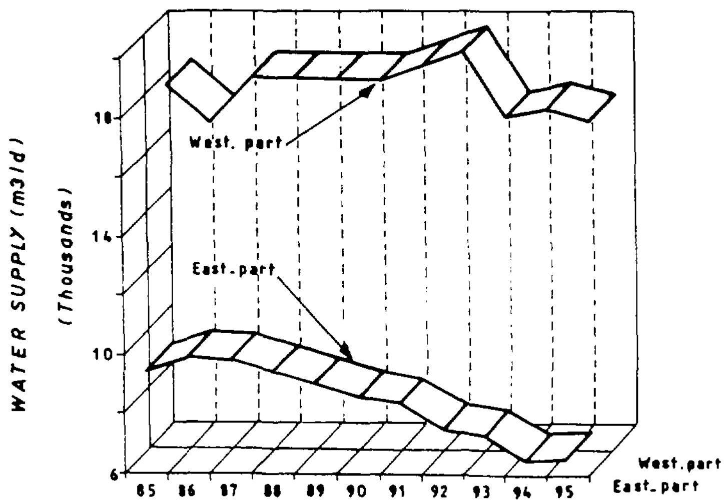


FIG. 4: Production of drinking water supply from the dug wells (in western part and eastern part, from 1985 to 1995.

Table III: Some major chemical constituents of the groundwater in the western part of Dakar area (May 1995 - mg/l)

Code of well sampled	Mg	Ca	Na	K	NO3	SO4	Cl	HCO3
Bad1	7.2	48.0	85.0	11.0	13.4	17.2	204.7	19.6
Bad2*	46.1	140.0	97.0	9.0	31.0	46.9	261.6	315.7
Bad2	36.4	220.0	284.0	30.0	71.8	95.3	484.8	502.7
Bad3*	21.8	80.0	431.0	13.0	71.4	150.9	807.9	282.0
Bad3	47.3	228.0	580.0	28.0	103.7	242.9	1049.7	349.5
Bad4*	12.1	100.0	66.0	6.0	69.5	23.0	139.8	233.0
Bad4	18.2	90.0	58.0	6.0	96.1	22.8	113.3	197.4
Bad5	12.1	40.0	57.0	9.0	8.7	11.8	107.0	116.5
Bad6	2.4	20.0	32.0	4.0	16.7	15.4	38.5	45.9
Point N	41.5	65.6	130.0	6.0	129.6	59.3	303.1	30.6
Point M	19.4	20.0	43.0	3.0	18.5	14.1	66.7	91.9
Front T.	39.6	34.8	52.0	3.0	107.6	19.6	123.1	85.8
Camp pénal	14.5	48.0	49.0	3.0	15.3	13.8	92.7	159.4

* double piezometer

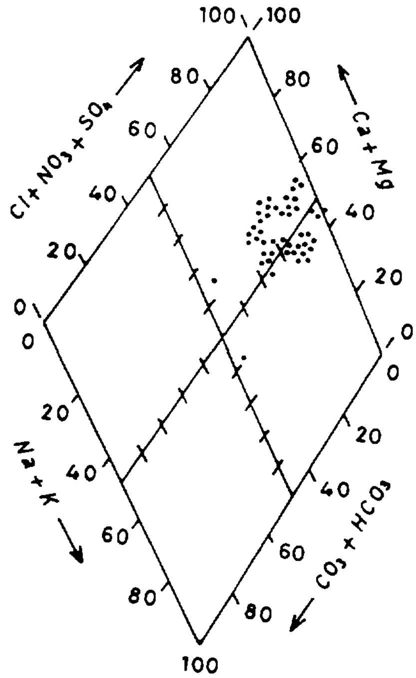


FIG. 5: Piper diagram of the groundwater

The mean nitrate content in the groundwater in the western part of the peninsula is about 50 mg/l while it is much higher at 400 mg/l in the eastern part (Thiaroye area) and 20 mg/l beyond Thiaroye area. In all well samples, nitrate concentration in the groundwater is higher in the eastern part than in the western part. The nitrate values are above the OMS limits of 45 mg/l (Fig.6 and Fig.7) and increases each year: from 100 mg/l in 1987 to 200 mg/l in 1990 (Table IV).

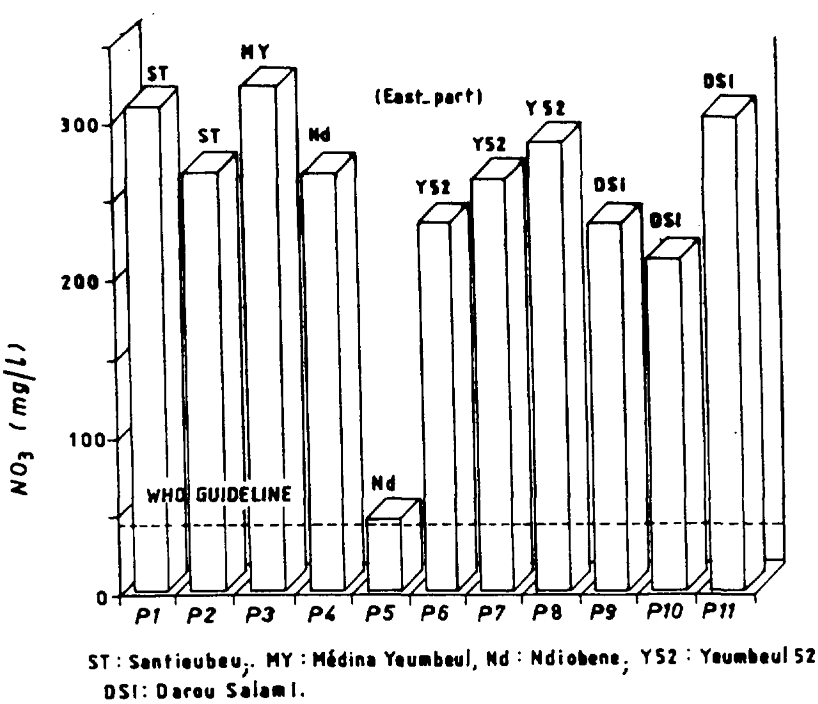


FIG. 6: Nitrate content in traditional wells

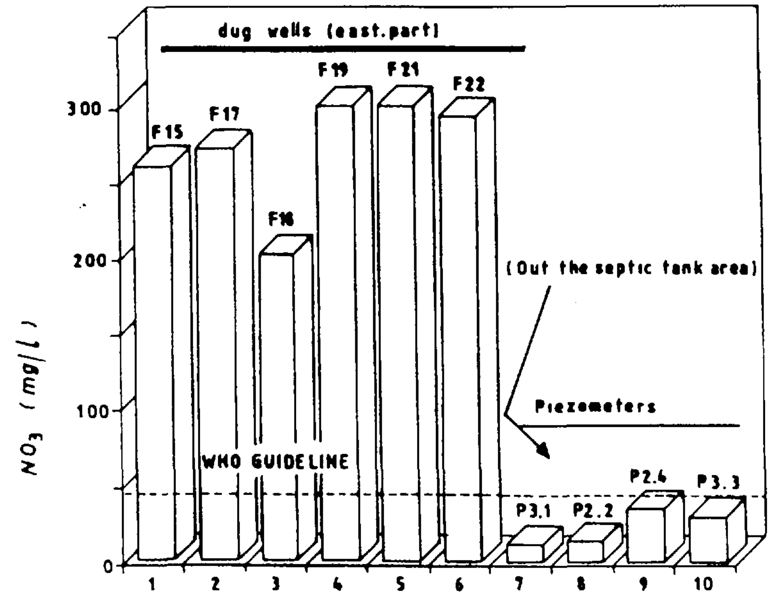


FIG. 7: Nitrate content in dug wells and piezometers

Table IV: Nitrate concentration in dug wells , in mg/l.

Dug wells	Nov. 87	Jan. 88	Mar. 88	May 88	Jul. 88	Sep. 88	Nov. 88	Jan. 89	Mar. 89
F19	100	130	140	160	170	180	205	220	33
F18	120	132	141	148	168	170	173	270	71
F17	-	121	195	205	220	223	235	250	10

The nitrate content in rainfall which is around 1 ppm [6] is extremely low when compared to those in groundwater. The relation NO_3^- vs Cl^- of groundwater indicates a significant correlation corresponding to an anthropogenic pollution. The relation NO_3^- vs distance between wells and latrines (Fig. 8) confirm this interpretation. It shows elsewhere that nitrate concentration increases in the wells which are located near the latrines and for the same distance wells/latrines, nitrate concentrations are higher when the latrine is older.

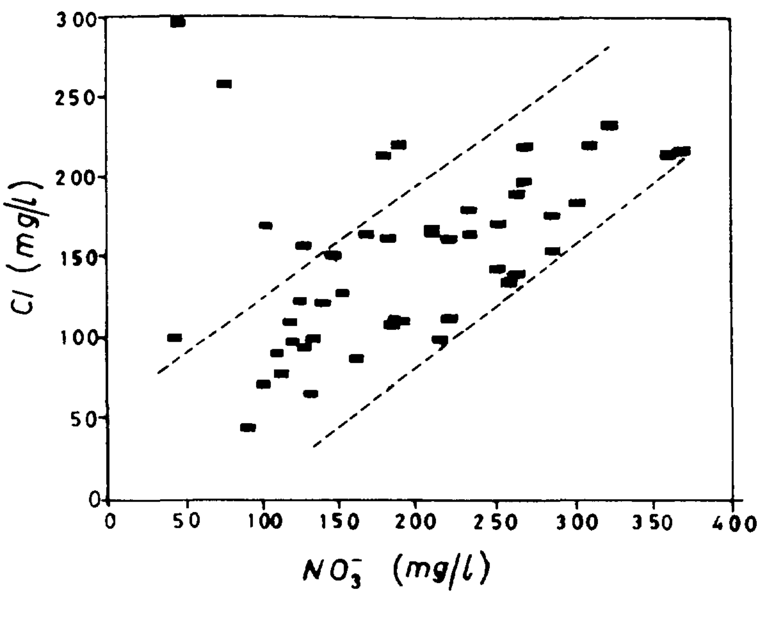


FIG. 8: NO_3^- vs Cl^- of groundwater

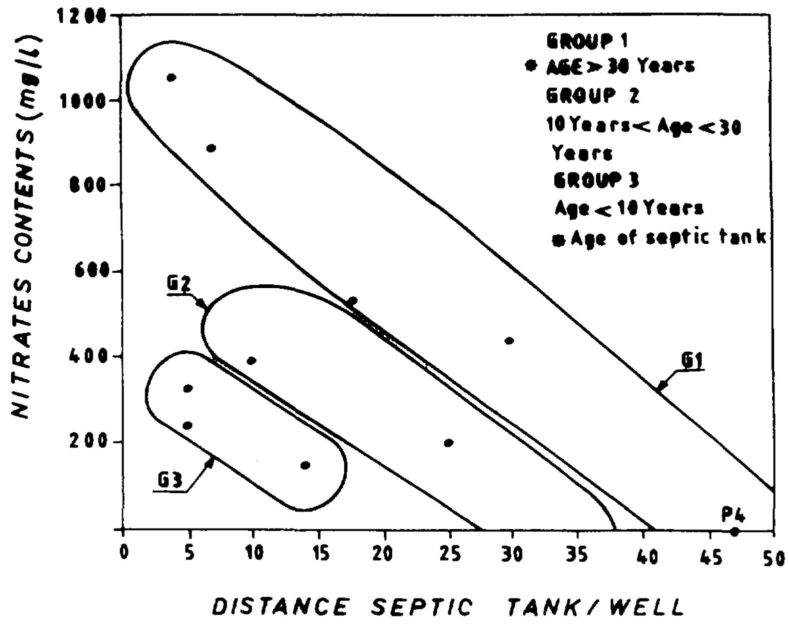


FIG. 9 : NO_3^- vs distance between wells and septic tank

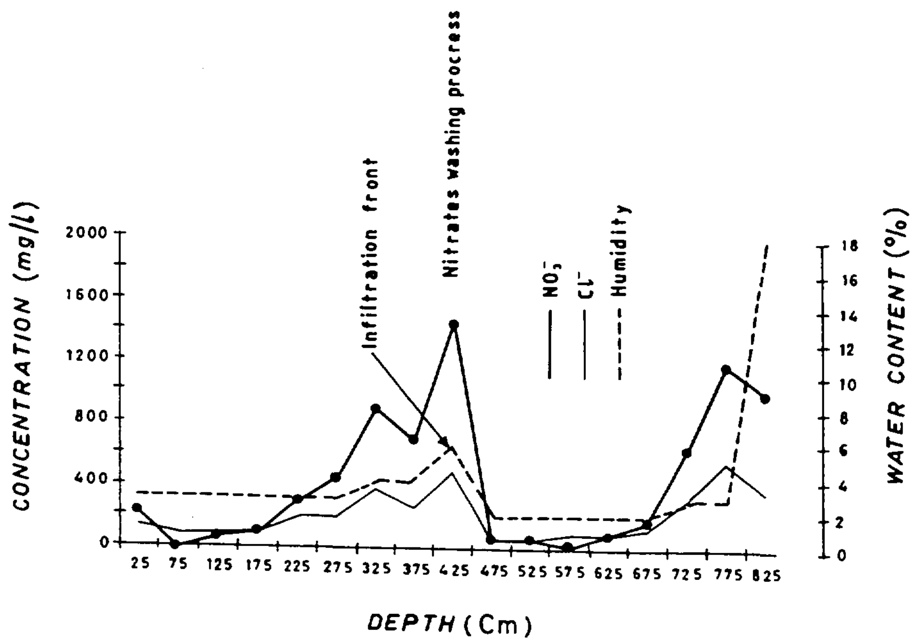


FIG. 10 shows a vertical movement of rain water in the unsaturated zone.

The high nitrate content at 4.5 m (Fig. 10) represents the influence of human activity. In the same way, there is another peak at 8 m which corresponds to the previous rainy season. The soil water shows in the same period the front of infiltration towards the groundwater. The mean value of nitrate content in the unsaturated zone is around 800 ppm. It indicates the function of Thiaroye soil in the basin to absorb nitrates. This high level of nitrate is mainly due to 3 causes (Fig.11): domestic waste, waste waters and excrement.

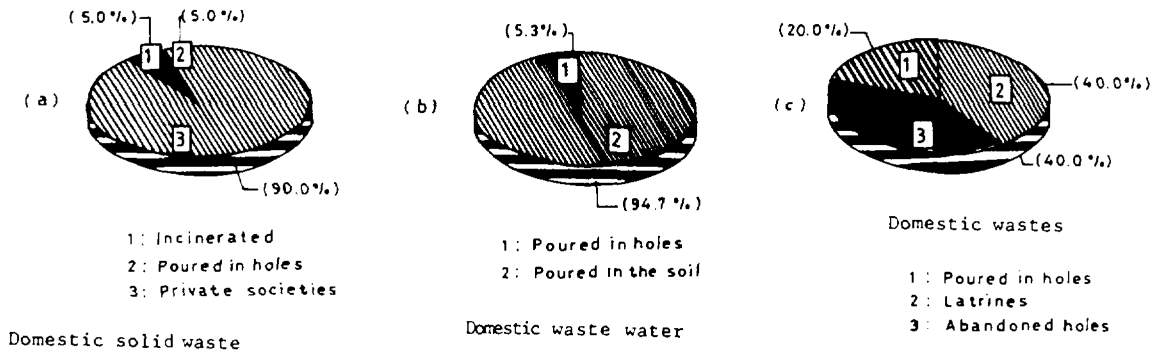


FIG.11: Sanitation practice in Thiaroye basin

Table V: Some isotopes in groundwater of Dakar area, May 1995

Code of station sampled	Deuterium delta per mill	Oxygen -18 delta per mill	Tritium UT	C-13 per mill PDB	C-14 (%)
Western part					
Bad1	-35	-5.1	0.53		
Bad2*	-24	-4.6	0.80		
Bad2	-29	-3.9	5.06		
Bad3*	-35	-5.5	4.15		
Bad3	-38	-5.4	1.62		
Bad4*	-37	-5.3	7.98		
Bad4	-37	-5.6	6.79		
Bad5	-37	-5.9	1.15		
Bad6	-34	-5.3	3.60		
Point N	-35	-5.6	2.77		
Point M	-36	-5.5	0.48		
Front T.	-38	-5.4	1.77		
Camp pénal	-37	-5.9	0.93	-16.33	95.2
Autoroute	-36	-	-		
P2.2	-37	-5.7	2.55		
Eastern part					
P2.4	-40	-5.5	3.94		
P3.1	-36	-6.4	0.60		
P3.2	-40	-5.8	-		
P2.6	-36	-5.8	-		
P2.2	-38	-5.3	2.55		
P2.4	-36	-5.4	3.94		
P3.3	-35	-5.6	0.78		
F15	-40	-4.9	5.94		
F17	-35	-5.4	4.87		
F18	-36	-5.6	6.57		
F19	-34	-5.3	4.92		
F21	-31	-5.1	4.35		
F22	-37	-5.3	4.74		

* = double piezometer

According to Table V, the δ^2H content of -35.6 per mille and the $\delta^{18}O$ concentration of +5.2 per mille in groundwater are the typical isotopic signature characteristic of phreatic water in the Sahelian area where the evaporation is high [7].

The relationship between ^{18}O and ^2H (Fig.12) indicates the following linear regression equation:

$$\delta\,^2H = 4.2\,\delta\,^{18}O - 12$$

The distribution of the values around the World Meteoric Water [8] confirms that the recharge of the Dakar aquifer comes from monsoon rains. It indicates the flow of the groundwater from the eastern part to western part of the peninsula. This phenomenon contributes to generalise the nitrate pollution along the flowpath from eastern part to western part where the nitrate content is around 50 mg/l. Figure 13 shows that the nitrate content and deuterium in rainfall which are around 1 mg/l and -54%o [3], respectively are extremely low when compared to those from evaporated groundwater and which has probably undergone microbiological reactions (Group 2) [1]. It is very likely, therefore, that dug wells located west of the peninsula (Bad 2 with 71.8 mg/l, Bad 3 with 103 mg/l, Point N with 129.6 mg/l and Front T. with 107.6 mg/l) where the nitrate content is only around 10 mg/l (Group 1), are contaminated by groundwater flowing from eastern part.

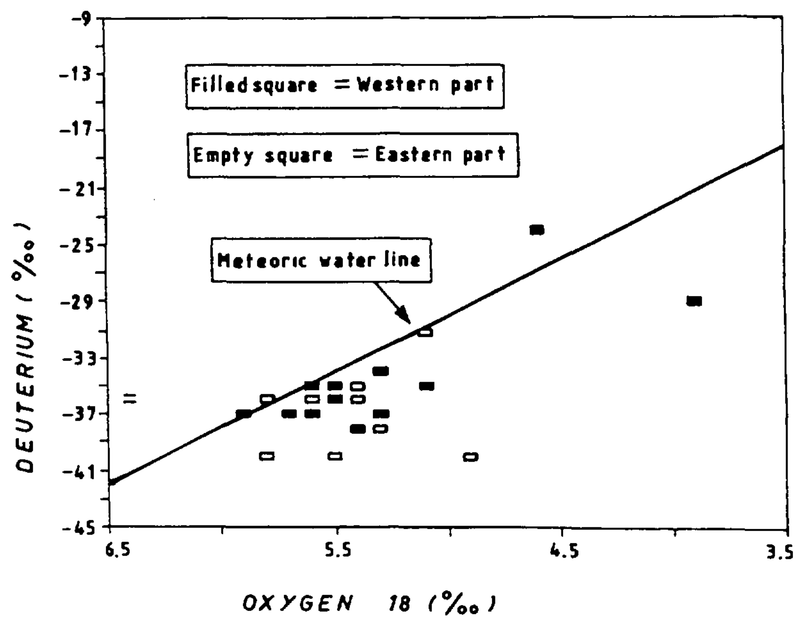
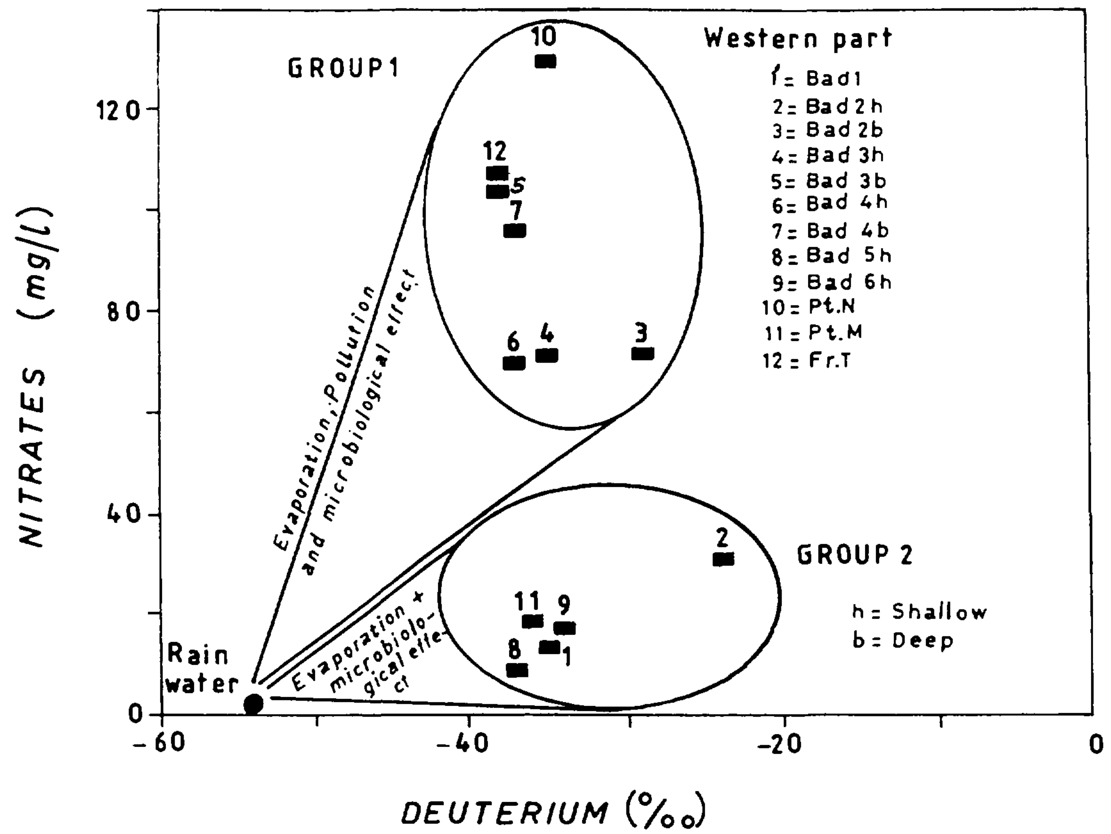


FIG. 12: Deuterium versus ^{18}O for Dakar area groundwater.

High concentrations of nitrate have also been identified in some evaporated points of the unconfined aquifer (Fig.14) suggesting an evaporation effect on nitrate content. In fact, the recharge of the aquifer occurs after rainfall has evaporated, a phenomenon that is



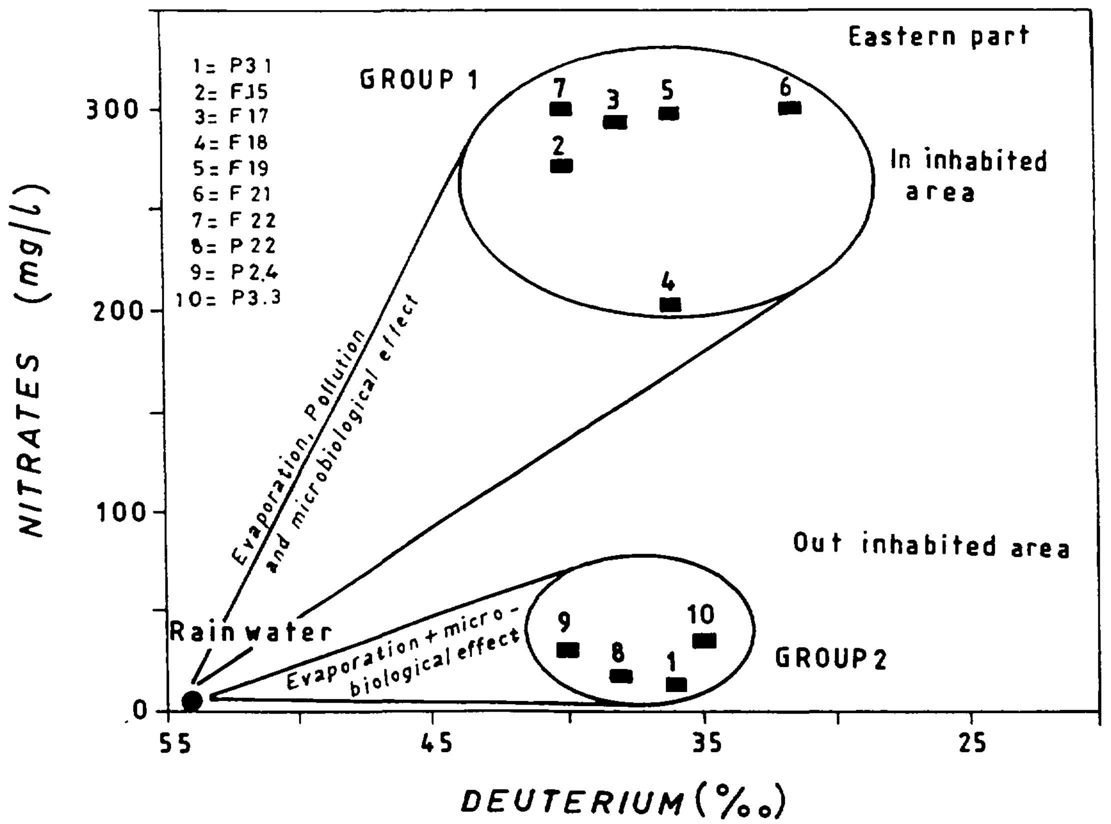


FIG. 13: Deuterium versus nitrate in groundwater. The microbiological effect reflect all processes which produced NO_3 from organic matter by bacteriological action. The contamination for Group 1 is induced by groundwater flowing from the east while wells in Group 2 are unaffected by pollutants.

generally observed in arid and semi-arid region when the groundwater is shallow. Likewise, high nitrate concentrations (>45mg/l) must be recent because previous studies in 1972 [5] have shown low level of nitrate (<45 mg/l) indicating an increase in time. The relation of NO_3^- vs ^3H shows a significant correlation with high values of tritium which characterises the actual rainfall (Fig.14). The presence of high activities of ^{14}C (80%) is in good agreement with this recent recharge of groundwater.

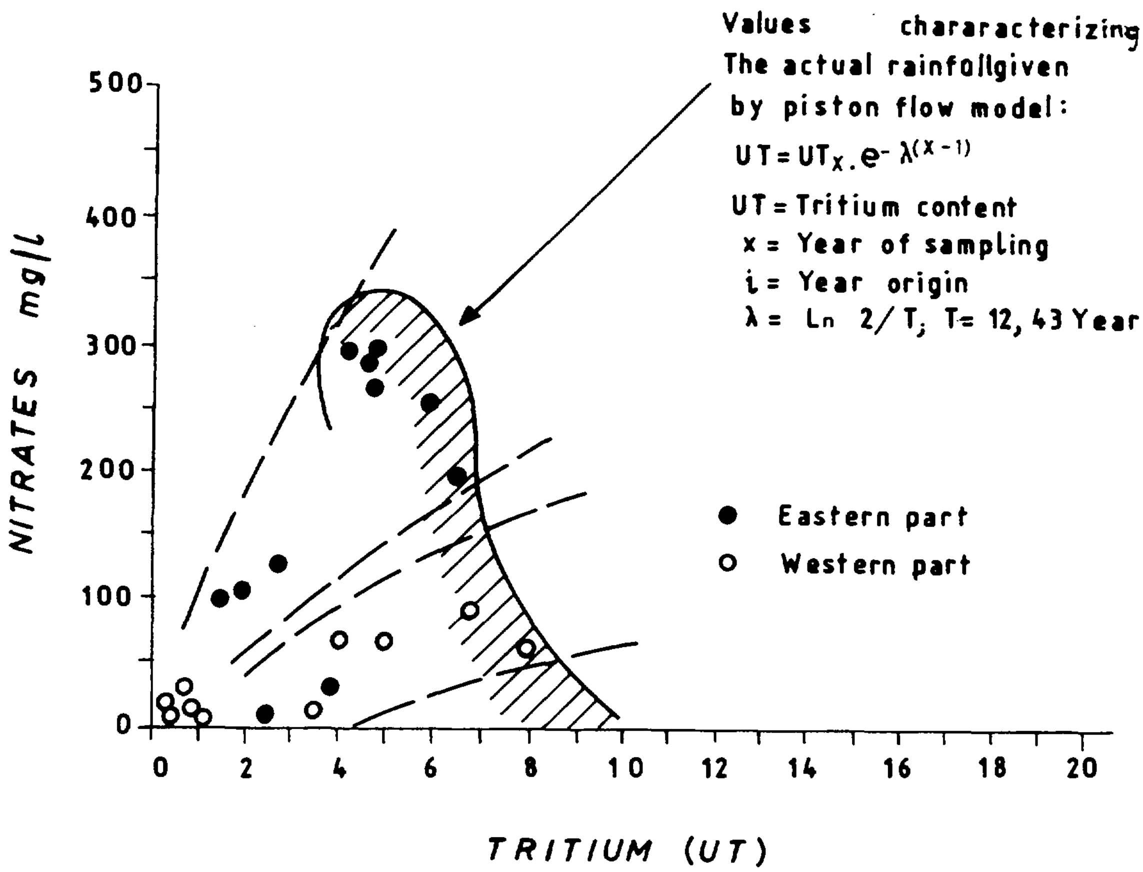


Figure 14: Nitrate concentrations versus tritium. Groundwater affected by recent pollution showing the trititum content in rainfall.

5. CONCLUSION

The groundwater of Dakar region is contaminated by nitrates and faecal coliforms from anthropogenic sources. The mechanisms of contamination are mainly the soil washing and nitrate injection from latrines. The results obtained during this study show that the proper construction of dug and hand-pumped wells as well as a safe distance between septic tanks and wells are necessary. Its also necessary to implement an education programme or modify the well modernisation process (sealing of the opening with concrete and installation of a water hand or foot pump).

Stable isotopes, tritium and carbon 14 are used to obtain a better understanding of nitrate contamination of groundwater; tritium in groundwater indicates that nitrate concentration is recent. This has been confirmed by the presence of high activities of ^{14}C (80%), in good agreement with recent recharge of groundwater. The distribution of the values of ^{18}O and ^{2}H around the World Meteoric Water Line [3] indicate that the recharge of the Dakar aquifer system originates from the monsoon rainfall after it has been exposed to evaporation process. The cluster of points relating ^{18}O and ^{2}H indicates the flow of groundwater from the east to the western part of the peninsula. This situation contributes to nitrate pollution along the flowpath from the east to west where nitrate pollution in groundwater is more serious.

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