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Full Length Research Paper

Impact of urbanisation on the Mingosso watershed in the Yaounde periurban zone

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In the peripheral quarters of Yaounde city, population settlement is not regulated according to particular standards of land-use. The Mingosso watershed, which covers a surface area of 3.856 km² and which is administratively located in the Yaounde 6th district, was studied to identify the impacts of this type of settlement upon the flow and the quality of groundwater. The physico-chemical variation of groundwater, a bacteriological analysis of water and a survey named "water-population-habitat" were carried out. The population growth rate between 2000 and 2005 was 24.55%. Without town planning, 91.2% of the population settled within the watershed, are not connected to piped supply network of drinkable water, leading to an increasing demand for groundwater wells and the degradation of overall aquifer quality. Groundwater has a diffuse mineralization, which is higher in densely populated zones than in zones under construction with a low population density.

Keys words: Urbanisation, groundwater, Yaounde, periurban zone, pollution, bio-indicator.

INTRODUCTION

Urban growth and galloping demography are major problems of all developing countries. Between 1945 and 1970, third world's urban population has experienced a 4.5% per annum increase (Kouam et al., 2006). In Africa, big cities are subjected to urban boom. Between 1977 and 1999, the growth rate of the Yaounde urban population had passed from 3.5 to 6.2% meanwhile at the same time the urbanisation rate had increased from 12 to 34% as evocated in the National Directorate for Statistics and Accounts of Cameroon (DSCN, 1999). In Sub-Saharan African cities, shanty towns and periurban zones are dominant.

Because of the difficult mastery of urban growth, decentralized urban communities, inefficient and less adapted land management strategies induce population to build and reside in less or not viable zones. Within those zones, construction is law-less, with no respect of any urban rule. The consequence is the lack of basic urban services like a portable drinking water network (Djeuda et al., 2001). To remedy the deficiency in basic urban services, particularly water consumption, inhibitants are compelled to dig wells.

The periurban zone is controlled by the proliferation and the inadequate individual cleansing systems (Le Jalle, 1998). The domestic sewage is directly discharged in nature without any previous treatment, due to the absence or the disfunctioning of the purifying stations (Njiné et al., 2001). This water is capable of polluting soil, subsurface and groundwater because of it is high biodegradable organic matter content and micro-organisms of faecal origin which can attain 6 x 10^{-7} CFU/100 ml (Njiné et al., 2001). The physico-chemical and microbiological quality of groundwater sometimes undergoes spatio-temporal variations depending on human activities, weather and the geological factors of the region considered (Korkka-Niemi and Laikari, 1994).

The situation is common in periurban zones of Cameroon, particularly the Mingosso watershed which elucidates an unruly occupation of urban space. The aim of this paper is to present the habitat and demographic growth in a periurban zone, their consequences on consumable water supply and the evolution of groundwater quality based on space occupation.

The general objective of this work is to assess the effect of urbanisation on groundwater. The current work has been carried out following two approaches: 1) the study of the habitat and population evolution, and the

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water supply situation; 2) the study of groundwater pollution dynamics.

MATERIALS AND METHODS

Study site

The Mingosso watershed (3°50' - 3°52'N; 11°27' - 11°30'E), with a surface area of 3.856 km² is administratively located within the Yaounde 6th district. This watershed is a part of Mefou river up-stream watershed that drains across Yaounde town which is the capital city of Cameroon. It is limited Northwards and West-wards by the Abiérgué watershed, East-wards by the Mingoa water-shed, at the South by Biyeme watershed and at the South-East by the Ezala watershed (Figure 1).

METHODOLOGY

Without demographic statistical data of the concerned Mingosso watershed, a "water-population-habitat" evaluation was done from September to December 2005 in that watershed. The data obtained have enabled an appraisal of the situation of water consumption.

The survey was carried out through inquiry questionnaires and also semi-structured interviews allowing an apprehension of the population's standard of living and to quantify the average ground-water consumption per house and per day within marginal habitat zone of the watershed. Rubrics of the questionnaire include the knowledge of habitat, of the population and the water problem.

Knowledge of the state of the habitat

The objective in this case study was to quantify habitat, determine density and to assess the populations' land of living from the house type.

The land occupation per habitat assessment was based on the construction of houses per year within the watershed. Meanwhile observed houses which are almost completed and unoccupied were carried over for the year 2006, while unfinished ones (half raised walls, and incomplete roof and house foundations) were manifestedly considered for the years after 2006. The appraisal of the habitat density was assessed according to the formula proposed in statistical descriptive analysis of the demographic (Godard, 2005):

$$D_{Hab} = \frac{\eta i}{A} \qquad (1)$$

Where D_{hab}; habitat density, ni ; total number of houses for considered period and A ; watershed's surface.

The acquaintance of the habitat extension was done by progression rate determination of the space occupation by houses between the considered periods, by geometrical mean of the occupied surface by houses according to the formula following (Godard, 2005):

$$\bar{X}_g = \sqrt[N]{\prod_{I=1}^{J} x_1^n} \qquad (2)$$

Where $\bar{X}_g$ **;** mean annual increase rate, N ; number of years and $\prod_{i=1}^{J} x_i^n$; product of annual increase or the quotient of the final quantity per initial quantity.

Knowledge of the state of the population

This rubric had as objective to quantify and determine the population density of the watershed. Questions concerning the number of persons within houses and the number of children under five years old within houses have allowed the population estimation. The density of the population was deduced from the formula proposed in statistical descriptive analysis of the demographic:

$$Dp = \frac{Np}{A} \qquad (3)$$

Where Dp ; density of populations, Np ; number of resident and A; watershed's surface.

Knowing the population's installation per year within one of the watershed quarters, the population growth rate was deduced by:

- Cumulating all the population up to the year 2000 and subtracting the total number of children below 5 years old residing within the watershed, in order to assess installed population at the end of the year 2000.
- Cumulating all the population of the watershed up to December 2005 (date of the end of investigation).
- Calculating the geometrical average of the population between 2000 and 2005 according to the formula (Godard, 2005):

$$\bar{X}_g = \sqrt[N]{\prod_{i=1}^{J} x_i^n} \qquad (4)$$

Where $\bar{X}_g$; annual average progression rate, N ; number of years and $\prod_{i=1}^{J} x_i^n$: product of annual increase or the quotient of the final quantity by the initial quantity.

Population's estimation for the year 2010 is done according to the formula:

$$\bar{X}_g = \sqrt[J]{\left(\frac{X_f}{X_i}\right)} \qquad (5)$$

Where j ; number of years between estimation period, x_f ; final state value, ; initial state value and ; increasing rate value.

Knowledge of the state of the water problem

The main objective here is to count the consumers of water distribution network of concessionary CDE, to determine the drinking water type (spring water, public drinking fountain and / or of wells), determine the average quantity of groundwater used per house and per day, to assess the population pressure upon the upper aquifers;

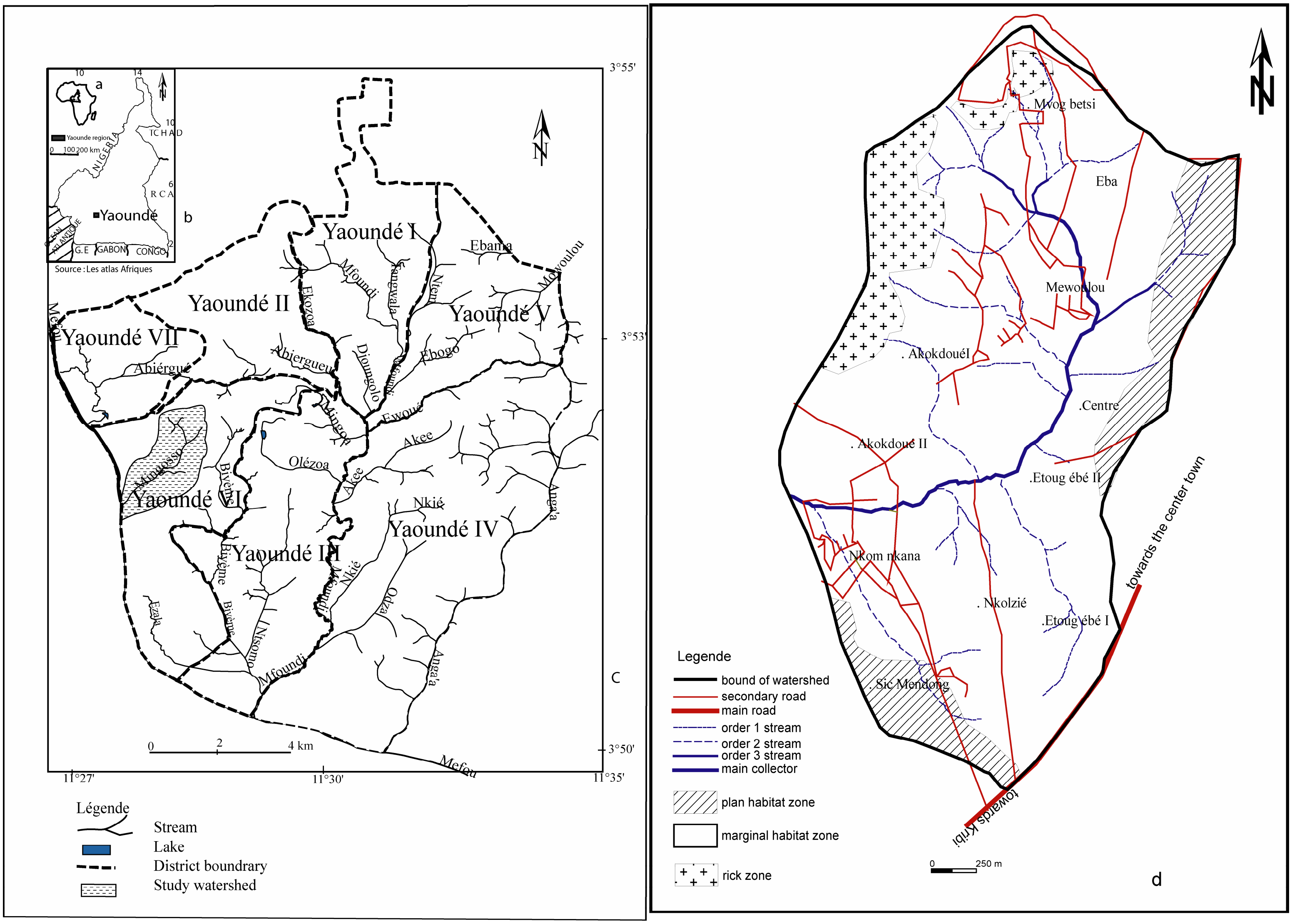

Figure 1. Location of studied watershed in the Yaounde town: a) Cameroon in Africa; b) Yaounde in Cameroon; c) location of the Mingosso watershed; d) the Mingosso watershed.

upper aquifers; for this reason, an exhaustive counting of wells and water supplying springs was done.

The groundwater pollution evolution analysis within the watershed was based on:

1) The follow-up of physico-chemical parameters such as: electric conductivity (EC) obtained using positive apparatus of HANNA Instruments HI 8733 trade mark.

2) The hydrogen potential (pH) and redox potential (Eh) obtained from pH-meter SCHÖT GERÄT trade mark CG 818 model first standardized using plug solution of pH= 4.75.

3) Temperature taken with a scientific thermometer reading values from -10℃ to 150℃.

The bacteriological analysis was done in October 2005 at the Catholic Private Nursing School of Yaounde, by colorimetric method upon a filtering membrane, according to recommendations according to Louis Pasteur standard preparation method (Marchal et al., 1987).

Culture media used are: the Slanetz and Barthley media to search for and count streptococcus: the PCA standard gar (Plant Count Agar) for aerobic germs counting total mesophile flora (TMF), TTC lactosed agar (tetrazolium triphenyl 2,3,5 chloride) and Tergitol 7 (dehydrated base) to look for and count coliforms.

The counting germs and coliforms adopted limits are: 0 to 300 CFU/100 ml for TMF; 0 to 100 CFU/100 ml for total coliforms (TC), faecal coliforms (FC) and faecal streptococcus (FS). Beyond these values, one supposes that values are high for use as drinkable water supply.

54 waters holes among which 47 wells and 7 springs were the subject to follow up for physico-chemical parameters during one year (March 2005 to February 2006). For the bacteriological analysis, 34 waterholes among which 7 springs and 27 wells were analysed.

The basic selection criteria of well waters for bacteriological analysis are: 1) high frequenting of that waterhole by populations; 2) the distance between the waterhole and latrines.

The drinkable water supplying spring for the surrounding populations were all selected. Concerning wells, apart from the above mentioned criteria, habitat density was added. Therefore, wells were selected within zones of high, average and low house density

Table 1. Adopted indication for the mineralization and chemical pollution of water from the study watershed.

Conductivity value (µS/cm)	Type of mineralization	Pollution appraising
<50	Very weak	
50 - 100	weak	
100-200	average	
200-400	Moderately high	Weakly polluted
400-600	considerable	Averagely polluted
600-1000	high	Highly Polluted
>1000	Very high	Very polluted

within the watershed.

Criteria for physico-chemical assessment

The knowledge of geochemical background of water on humid tropical crystalline basement shows that the pH ranges between 5 and 6.5 (Ngo, 1997; Olivié et al., 1999; Ewodo, 2001; Ntep, 2005). Apart from these values, the zone is to be considered as contaminated either by supplied organic matter (pH > 6.5), or by acidification of the milieu due to the oxidation of the organic matter that yields carbon dioxide (CO_2), leading to the decrease of the hydrogen potential (pH < 5).

The mineralization was appraised based on conductivity values (Table 1). Water conductivity values over 200 µS/cm were considered as pollution values.

Bacteriological appraisal criteria colony formation unit for 100 ml (CFU/100 ml) were subdivided into classes;

1) For the TMF, three classes were retained: 0-20 CFU/100 ml corresponding to the classes of very high-quality in aerobic germs; 20-300 CFU/100 ml the class of the average quality in aerobic germs; > 300 CFU /100 ml class of worst quality in aerobic germs.
2) For TC, FC and FS four (O4) classes were adopted: 0-1 CFU/100 ml corresponding to very good water quality; class 1-20 acceptable water quality; 20- 100 CFU/100 ml corresponding to poor water quality and the class > 100 CFU/100 ml corresponding to waterholes of very poor quality.

RESULTS AND DISCUSSION

Spatial analysis

The study of the space occupation dynamics obtained through the analysis results has allowed the establishment of the actual reference state of the watershed which corresponds to the situation of a given zone or milieu at a moment of its evolution (Yonkeu et al., 2003). The description aims is to see the main characteristics of the studied zone in evolutive and temporal perspective that existed before the change. It therefore helps to describe and to better understand the different physical, social and economic components and their interactions that characterise the studied area. This reference state was obtained by population interview during the census and by the achievement of georeferential maps.

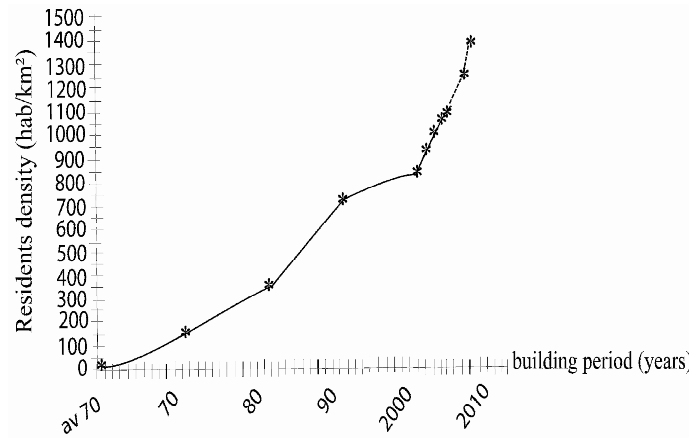

Figure 2. Habitat density evolution rate within the Mingosso watershed:
____ Straight line evaluated according to the data; --------- estimated line based on predictions.

Habitat density of the watershed

A significant evolution of habitat density was noticed between 1970 and 1990 (Figure 2), where it increased from 146 houses/km² to 708 houses/km² (Table 2). That habitat density follows geometric progression portraying stabilization during the 90's around 800 houses/km² and an important recovery of habitat densification since the year 2000 (Figure 2). The progressive densification between 2000 and 2005 is very high, where one passes from 811 houses/km² to 1086 houses/km².

Habitat extension within the Mingosso's watershed

The annual progression rate of the space occupation is positive during the 70, 80 and 90's (Figure 3), it is more important during 70 decade with a rate of 15.85% that progressively decreases and stabilized around 5% during 80 and 90 decades as presented in Table 3. That positive rate of the space occupation indicate important suitable for cultivation land conquest (Figure 4).

During 2000 and 2001 years, progression rates are negative indicating the suitability of farmland conquest stoppage; it is the densification of occupied spaces that is rather important (Figure 4). The year 2002 shows a light recovery of the space occupation (Figure 3), actually the tendency seems instead to be habitat densification of the watershed (thus, the negative value of the space occupation). The land conquest seems to be displacing towards the more or less uneven slopes and towards low level ground. That type of space occupation within the Mingosso basin is similar to the general extension of the Yaounde town (Mougoue, 2001); in fact, urbanisation starts from villages that once existed near the township. High well drained plateaus close to town inlet roads are the first to be occupied. Progressively, low ground and more or less uneven slopes are occupied next. That ur-

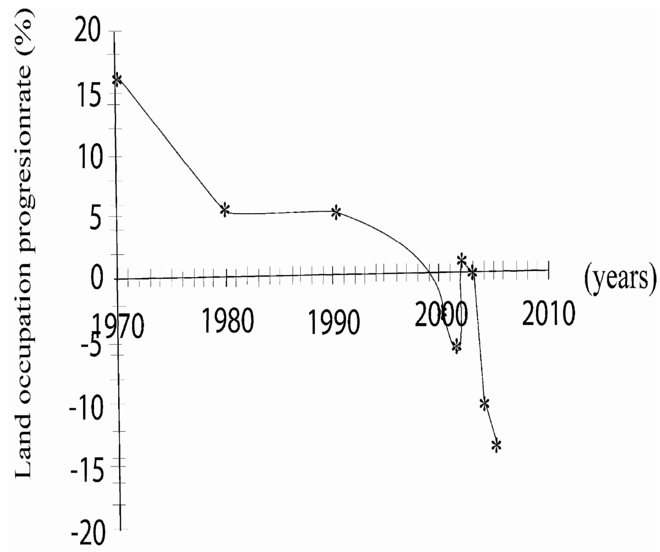

Figure 3. Habitat progression rate within the Mingosso watershed

Table 2. Evolution of the habitat density within the Mingosso watershed.

Decade or year	Nber_hab	Nber cumul_ hab	Density (hab/km²) amount to excess
Before the 70 decade	53	53	14
70 Decade	511	564	146
80 Decade	766	1330	343
90 Decade	1413	2743	708
Year 2000	401	3144	811
Year 2001	375	3519	907
Year 2002	267	3786	976
Year 2003	205	3991	1026
Year 2004	122	4113	1061
Year 2005	99	4212	1086
Year 2006	408	4719	1217
Up Year 2006	499	5218	1346

Surface area of the Mingosso watershed: 3.8786 Km²., Nber_ hab: numbers of residents or concessions. Nbre cumul_ hab : cumulative number of residents or concessions.

Table 3. Habitat progression rate within the Mingosso watershed.

	Surface area (Km²)	Progression rate	Progression rate %
Before the 70 decade	0.115615	-	-
70 Decade	0.503479	1.1585	15.85
80 Decade	0.84271	1.0529	5.29
90 Decade	1.37873	1.0505	5.05
Year 2000	0.877518	0.9558	-4.42
Year 2001	0.791759	0.9499	-5.01
Year 2002	0.799823	1.0051	0.51
Year 2003	0.71519	0.9456	-5.44
Year 2004	0.571735	0.8941	-10.59
Year 2005	0.422333	0.8595	-14.05

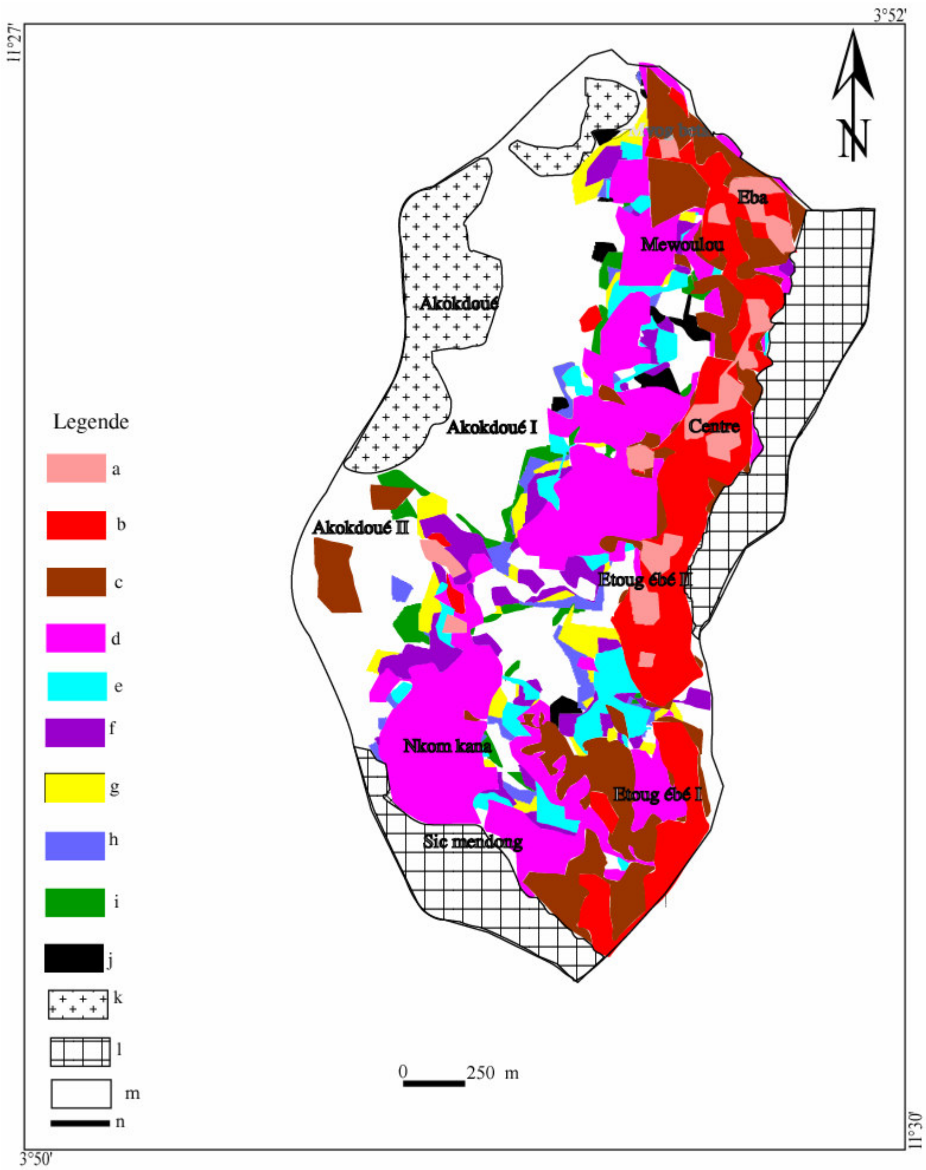

Figure 4. Map of the habitat evolution within the Mingosso watershed: a) progression of the occupation before 1970; b) Progression of the space occupation during 70's; c) Progression of the space occupation during 80's; d) Progression of the space occupation during 90's; e) Progression of the space occupation during 2000 year; f) Progression of the space occupation during 2001 year ; g) Progression of the space occupation during 2002 year; h) Progression of the space occupation during 2003 year; i) Progression of the space occupation during 2004 year; j) Progression of the space occupation during 2005 year; k) rick zone; l) plan habitat zone; m) cultivation lands; n) boundary of the Mingosso watershed

banisation ends later on by the densification and/or space building up.

Population density and population increasing rate within the basin

The population densification within 2005 in the Mingosso watershed (Table 4) is estimated as 13 655 residents/km² for a total population of 52 645 residents. The annual increasing rate of the population within the watershed between 2000 and 2005 is 24.55%. For that annual increasing rate, the population is estimated as 155 789 residents up to 2010. Consequently, a probable population density is 40 925 residents/km².

Problem of water supply

Within the area of study, the CDE water distribution net-

Table 4. Estimated population, increasing rate values and evaluated population density in relation to their installation periods in the Mingosso watershed.

year	Population total	Population children ≤ 5 years
≤ 70	1539	211
80 Decade	4182	682
90 Decade	14671	2685
2000 year	7164	1421
2001 year	6073	1212
2002 year	8422	1711
2003 year	6073	1212
2004 year	2903	581
2005 year	1618	276
Population to the end of 2005	52645	9991
Population up to 2005	157789	
Increasing population rate : 24.55%		
Population density : 13655 residents/km²		

Table 5. Residents drinking water supply mode of the Mingosso watershed.

Situation of the resident in comparison the CAMWATER network	Number of residents	Subscriber receive regularly water from CAMWATER (%)	Supply alternative mode of drinking water (%)		
			Springs	Drinking fountain	Springs and drinking fountain
Subscriber	372	YES : 17.7			
		NO : 83.3	2.2	95.6	2.2
Unsubscriber	3840		24.35	54.64	21.01

work covers just a minor part (15%) of the watershed. This low water supply of that concessionary is due to the fact that: 1) many residents desiring to acquire water do not fulfil the required conditions (Ngnikam, 2001; Djeuda et al., 2001). Such as land title or other official papers that can prove that they are house proprietor; 2) houses are far away from tarred roads (or road suitable for motor vehicles) beyond 200 m and the CDE can't supply them.

So, on a sample of 4212 censured 372 (8.8%) are CDE network subscribers and 82.3% of these subscribers do not regularly receive water from their concessionary (Table 5). These subscribers are compelled to get drinking water from springs (2.2%) and public drinking fountains (95.6%), springs and public drinking fountains at once (2.2%), (Table 5). Among the 3 840 of unsubscribe residents, 24.35% get drinkable water from springs, 54.64% from public drinking fountains and 21.10% from spring and public drinking fountains at once (Table 5). This drinking water supplying mode takes time because they are very far from households and time to get served is fairly considerable.

Average quantity of water used for housework's coming from groundwater catching installations

The results of the inquiry on the daily groundwater consumption in the case of normal functioning of CDE network (in case of water cut, the number of user of groundwater catchment installations increases), showing that the quantity of used water depends on the size of the family within the house (Table 6). The percentage of houses supplying in wells vary between 25 and 100% and that of houses supplying both from wells and springs vary between 15 and 50% (Table 6). Average water quantity used per house and per day varies between 170 and 1425 l/day according to number of persons per house and also to economic activity conducted by persons within the house.

Installation of catchment groundwater

The census has allowed identifying 623 water wells corresponding to a density of 163 wells/km² and 11 drink-

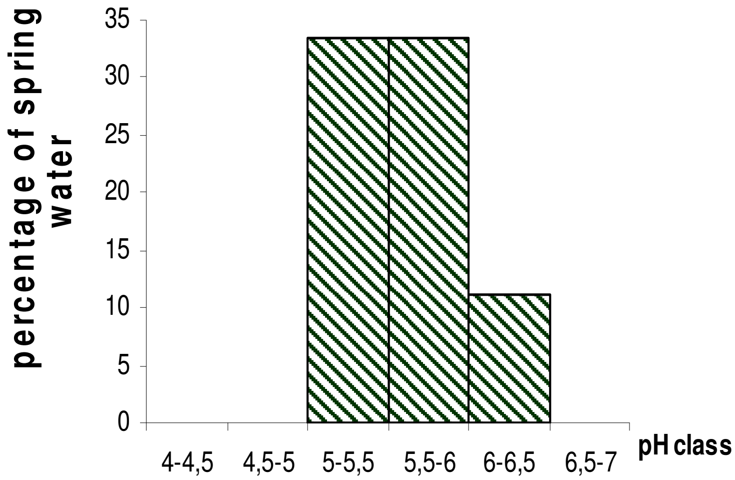

Figure 5a. Spring water pH variation within the Mingosso watershed

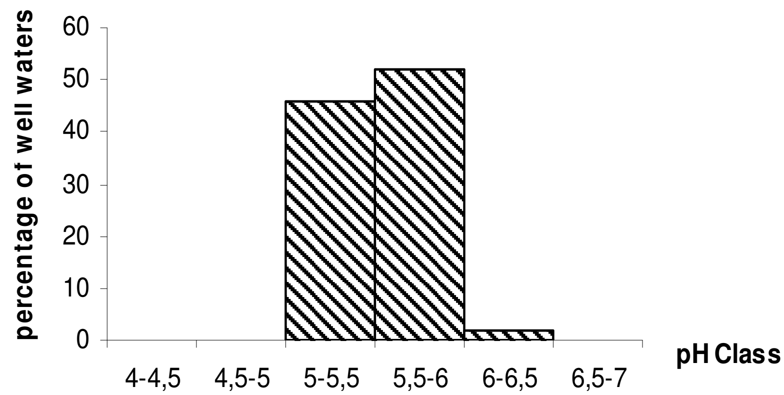

Figure 5b. Well water pH variation within the Mingosso watershed

able supplying springs. These installations are acceptable in the technical plan of protection against pollution: 78.95 of wells have curbs; 63.16% have hillock (anti-slough) and 28.95% have covers (Table 7). These wells are feeble in the sanitary point of view. Wells are not protected against erosion and contamination from micro-organisms and other pathogens. The general appraisal of the maintenance is approximate as presented in Table 8.

Physico-chemical quality of groundwater in the Mingosso watershed

Water pH

The spring water pH oscillates between 5.06 and 6.150. The mean is 5.57 ± 0.36 (Table 9). Spring water pH modal classes are 5 - 5.5 and 5.5 - 6 (Figure 5a). Concerning wells, these values fluctuate between 5.02 and 6.10. Well water pH modal class is 5.5 - 6 (Figure 5b). The average is 5.51 ± 0.25 (Table 9). These results show that, in the Mingosso watershed, water has a pH range that conforms to the geochemical background of the region (Olivié et al., 1999). But the pH variation rank is not found within recommendation domains of both European Union (E.U) (6.5 - 9) and WHO (6.5 - 8.5). The pH is slightly acidophic as proposed by Nola et al. (1999).

Water Eh

Spring waters have a redox potential (Eh) variation between 103 and 198 mv.

The average value is 147.46 ± 28.22 mv (Table 9). Concerning well waters, Eh varies between 113 to 177 mv. The average value is 145 ± 23.2 mv (Table 9). The redox potential values of the Mingosso watershed are relatively high, thus revealing the important oxidation phenomenon that takes place in this ecosystem.

Table 6. Quantity of consumed water and alternative supply mode by CAMWATER network unsubscribed houses.

Resident's class per house	Number of residents per house		Daily average water quantity (l/j)			Water supply mode per habitat					
	number	(%)	Max	average	Min	% houses carrying water from springs	% houses carrying water from wells	% houses carrying water from drinking fountains	% houses carrying water from spring and wells	% houses carrying water from springs and drinking fountains	% houses carrying water from wells and drinking fountains
1-4	89	2.32	330	170	50	3.37	32.58	11.24	39.33	3.37	9
5-9	1096	28.54	565	198	80	1.19	36.50	8.21	38.50	6.11	9.12
10-14	1501	39.09	1240	228	100	0.6	25.72	15.46	37.64	7.60	12.26
15-19	475	12.37	625	270	120	0.21	44.63	0	18.32	28.32	8.21
20-24	597	15.55	795	318	200	4.36	48.58	10.22	28.48	2.18	6.20
25-29	36	0.94	1050	388	165	0	52.78	11.11	30.56	0	2.78
30-34	6	0.16	880	427	200	0	66.67	0	16.67	0	16.67
35-39	10	0.26	1425	675	230	0	50	20	20	0	10
40-44	1	0.05	965	625	375	0	100	0	0	0	0
45-49	2	0.05	1250	745	425	0	50	0	50	0	0
50-54	0	0	0	0	0	0	0	0	0	0	0
55-59	0	0	0	0	0	0	0	0	0	0	0
60-64	0	0	0	0	0	0	0	0	0	0	0
65-69	1	0.05	1345	725	385	0	100	0	0	0	0

Table 7. Technical measures of the protection against the pollution and the contamination.

Curb of wells			Hillock (anti-slough)		Cover		Cover knoc with key		Protected wall	
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
percentage	19.7 %	78.03 %	36.84 %	63.16 %	71.05 %	28.95 %	84.2 %	15.8 %	98.7 %	1.3 %
Number	131	492	175	393	443	180	525	98	622	1

These results show that the Mingosso watershed waters are not much influenced by atmospheric conditions as postulated by Lallahem (2002).

Water electric conductivity

The annual average conductivity of spring water for the year of the follow-up varies between 21.33 and 90.08 µS/cm. The mean is 45.83 ± 23.22 µS/cm (Table 9). A diagram representing water

Table 8. Sanitary measures.

Planning of maintencnce										Desinfection of waterholes				
Does it exist ?			Is it respected?	The rhythm of annual maintenance frequency (number of time per year)						No	Yes	Desinfection mode		
					0	1	2	3	4			bleach	Bleach grain	Kitcken salt
	No	Yes		percentage	1.4 %	23.92 %	31 %	25.35 %	18.31 %	50.72 %	49.28%	52.77 %	12.70 %	34.44%
percentage	98.59 %	1.4 %	No	Number	9	149	193	158	114	316	306	162	39	106
Number	614	9												

conductivity classes (Figure 6a) highlights two main classes: the conductivity class < 50 and (50 - 100) µS/cm class. These results show that the Mingosso watershed waters are weakly mineralized (Table 1). The average conductivity of well waters varies between 18.22 and 429.67 µS/cm and mean conductivity is 86.79 ± 80.72 µS/cm (Table 9). A conductivity data analysis of well waters class shows that well waters of that watershed region are divided into four classes (Figure 6b) from < 50 to 1000 µS/cm. The average class of conductivity between 50 and 100 µS/cm represents the modal class. This represents anthropogenic contamination of the aquatic system as presented by Ajeagah et al. (2007).

Geographical representation of water conductivity

The annual average conductivity of the Mingosso watershed can be subdivided into two major geographical areas (Figure 7): 1) the Northern and western parts of the basin are of low to very low mineralization dominance; 2) the central part and that at the proximity of the river show fairly to fairly good mineralization. Therefore, one can say that the Mingosso watershed has low mineralization waters that highlight the chemical signature of the basin. This is characterized by zones of high mineralization showing the evolution of chemical

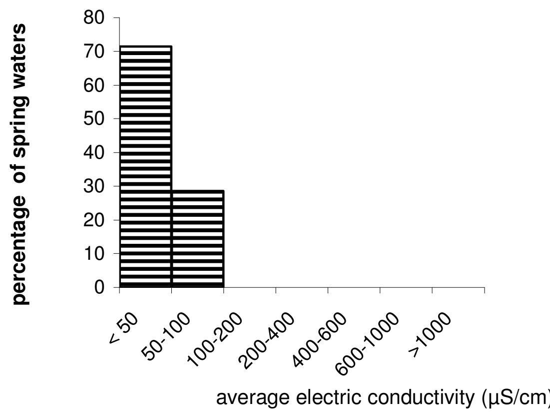

Figure 6a. Annual average electric conductivity of spring water within the Mingosso watershed

pollution of groundwater due probably to direct contact between this groundwater and the highly polluted surface waters (Nola et al., 1999). This stressing of the EC supports the colonization of the medium by *A. hydrophila* (Burton and Lanza, 1987).

Bacteriological quality of groundwater

The results of bacteriological analysis were subdivided according to the type of water adduction mechanism (wells and springs). In order to better appreciate of the pollution effect: FS are more significant within 0-1.

CFU/100 ml class, average within 1-20 CFU/100 ml class and weak to very weak within 20-100 CFU/100 ml class and > 100 ml class of the groundwater in the study watershed; the distribution of the studied bacteriological variable.

Case of spring water for domestic use

An abundance of the TMF and the absence of FS were noted. This water is of average quantity with respect to the FC (32.5 CFU/100 ml) and the TC (26.25 CFU/100 ml) (Table 11). The TMF of this water is important in the class 20-300 CFU/100 ml and absence in the class 0-20 CFU/100 ml (Figure 8a). The FC is more represented in the class 1-20 CFU/100 ml (Figure 8b). The absence of the FS in the spring water illustrates that these waters are not polluted by animals (man, hog, beef …). The presence of the FC in this water points out that the springs are not protected from the proliferation of strange bacterial flora (Nola et al., 2001, 2002; Rodier, 1996).

Case of well waters for domestic use

The results of water analysis show that some wells

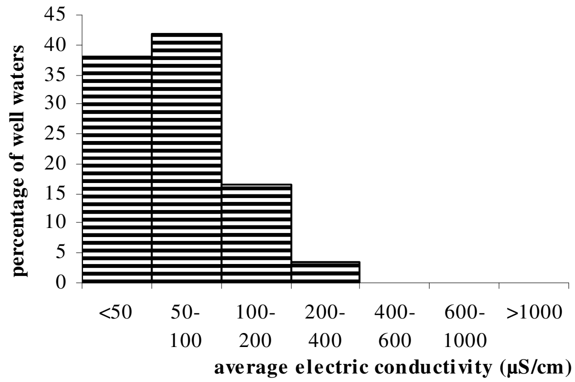

Figure 6b. Annual average electric conductivity of well waters within the Mingosso watershed

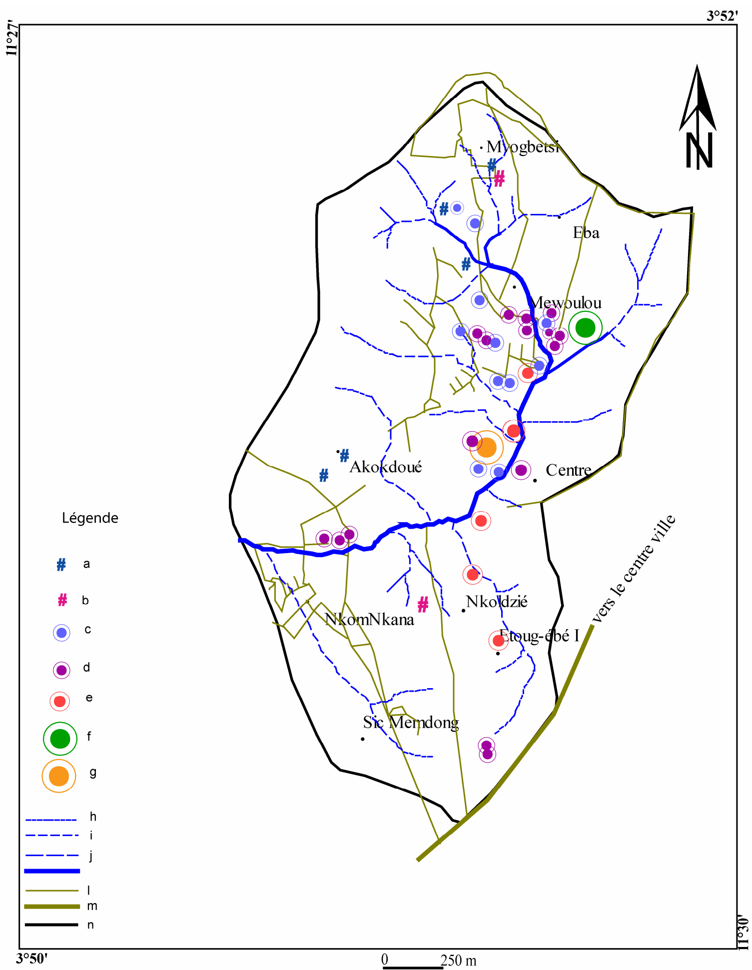

Figure 7. Map of electric conductivity (EC) of groundwater within the Mingosso watershed: a) EC average of spring water < 50 µS/cm; b) EC average of spring water 50 to 100 µS/cm; c) EC average of well water < 50 µS/cm; d) EC average of well water 50 to 100 µS/cm; e) EC average of well water 100 to 200 µS/cm; f) EC average of well water 200 to 400 µS/cm; g) EC average of well water 400 to 600 µS/cm; h) order 1 stream; i) order 2 stream; j) order 3 stream; k) main collector; l) secondary road; m) main road; n) boundary of watershed.

Table 9. pH, Eh and EC values of springs and Well water within the Mingosso watershed.

	Springs		Wells	
pH	**average**	**ecartype**	**average**	**ecartype**
Maximum sampling	6.15	0.57	6.1	0.98
Minimum sampling	5.06	0.07	5.02	0.01
Average sampling	5.57	0.18	5.51	0.26
Standard deviation sampling	0.36	0.18	0.25	0.2
WHO standard	6.5<pH<9.5			
Eh (mv)				
Maximum sampling	177		198	
Minimum sampling	113		103	
Average sampling	145		147.46	
Standard deviation sampling	23.21		28.22	
E. C (µS/cm)				
Maximum sampling	90.08	9.14	429.67	126.47
Minimum sampling	21.33	2.31	18.22	0.71
Average sampling	45.83	4.82	86.79	15.16
Standard deviation sampling	23.22	2.15	80.72	20.7

pH; hydrogen potential; **Eh**; redox potential; **E.C**; electric conductivity.
Number of wells: 47; number of springs: 7.

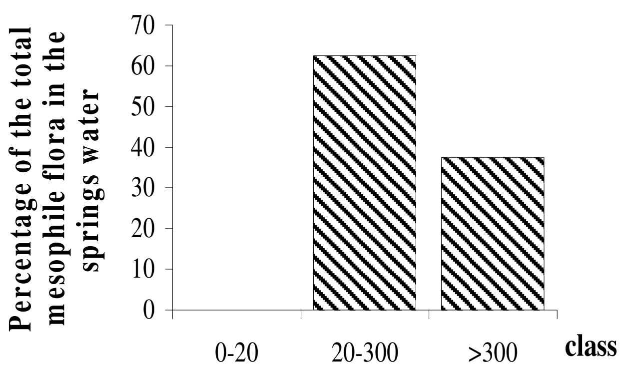

Figure 8a. Total mesophile flora (TMF) distribution within spring water of the Mingosso watershed: Notice the absence of the TMF in the class 0-20 CFU/100 ml.

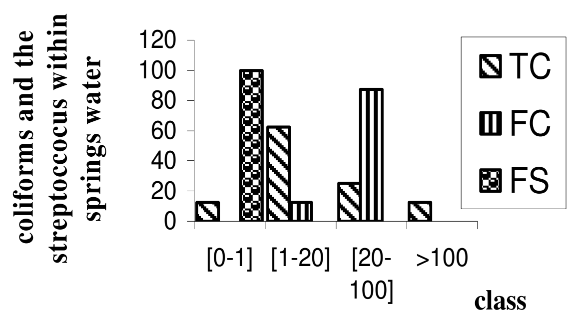

Figure 8b. Coliforms and streptococcus distribution within spring water of the Mingosso watershed: TC:Total coliforms; FC: faecal coliforms; FS: faecal streptococcus. Remark that all springs are represented in the class 0-1 CFU/100 ml for faecal streptococcus, illustrating the not water pollution by the human activity

have the FS. The FC, TC and TMF are abundant in the wells. The average values of the variable (Table 11) are for: the TMF (116. The results of water analysis show that some wells have the FS. The FC, TC and TMF are abundant in the wells. The average values of the variable (Table 11) are for: the TMF (116.15 CFU/100 ml); the TC (60.92 CFU/100 ml); the FC (34.12 CFU/100 ml) and the FS (7.85 CFU/100 ml). The TMF of this water is important in the class 20-300 CFU/100 ml and absence in the class 0- 20 CFU/100 ml (Figure 9a).

The TC, are nearly in the class 1-20 and 20-100 CFU/100 ml; the FC are abundant in the class of 20-100 CFU/100 ml; average in the class 1-20 CFU/100 ml, weak in the class > 100 CFU/100 ml and leave in the class 0-1 CFU/100 ml (Figure 9b); the FS are representative in the class 0-1 CFU/100 ml, average in the class of 1-20 CFU/100 ml and weak to very weak in the class 20-100 CFU/100 ml and > 100 CFU/100 ml.

The bacteriological quality of groundwater in this watershed shows that the concentrations of FC and TC are higher than those of FS in most of the studied sites. These results are in conformity with those proposed by Nola et al. (1998, 2000, 2002) in the evaluation of the bacteriological quality of groundwater of the equatorial region of Cameroon. This could be probably due to the direct faecal contamination of the aquifer in the study region as result of unsewered practices: latrines opened to water table, wells and springs unprotected and poor

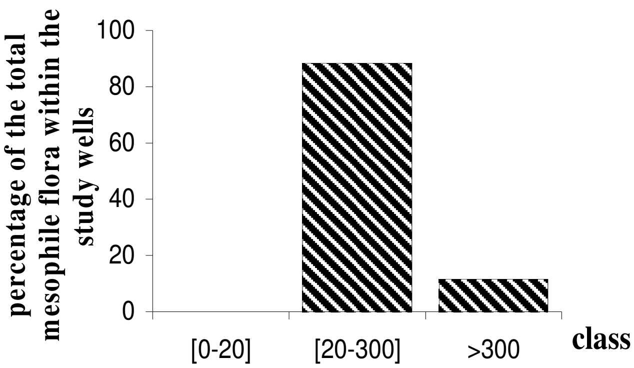

Figure 9a. Total mesophile flora (TMF) distribution within well water of the Mingosso watershed: Notice the absence of the TMF in the class 0-20 CFU/100 ml and little represented in the class 300 CFU/100 ml.

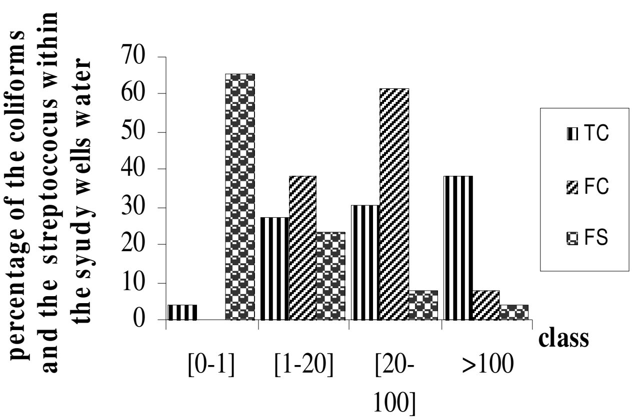

Figure 9b. Coliforms and streptococcus distribution within well waters of the Mingosso watershed: TC:Total coliforms; FC: faecal coliforms; FS: faecal streptococcus

Table 10. Water temperature values within the Mingosso watershed.

Température en (°C)	Average	Ecartype
Maximum sampling	24.17	0.41
Minimum sampling	23.25	0.08
Average sampling	23.7	0.23
Standard déviation sampling	0.29	0.08
WHO standard	25°C	

Number of sample : 54

drainage system. The numerical prevalence of the faecal bacteria coliforms compared to FS in groundwater of this region often characterized by a strong rainfall (Suchel, 1988). This results in the weak retention of the TC in the soil horizons and the water table.

Table 11. Spring and well water pollution bio indicator variations within the Mingosso watershed.

	Bio indicator	Max	Min	Average
Springs	TMF	300	30	208.75
	TC	100	0	26.25
	FC	72	2	32.5
	FS	0	0	0
Wells	FMT	300	35	116.15
	TC	100	0	60.92
	FC	100	7	34.12
	FS	100	0	7.85

TMF; total mesophile flora, **TC**; total coliforms, **CF**; fecal coliforms, **SF**; fecal streptococcus, **Max**; Maximum sampling, **Min**; minimum sampling. Number of spring waters: 7; number of well waters: 27.

Conclusion

The evaluation analysis results obtained has allowed us to establish the reference state and the actual state of the space occupation dynamics, water supply problems and groundwater pollution evolution in the Mingosso watershed.

From the chemical and the bacteriological quality of water, it appears that groundwater in zones of high density witness degradation. This study has enabled us to know the physico-chemical and bacteriological quality of water in the studied region (springs water) so as to follow up the evolution of groundwater pollution according to the age of space occupation and demography to the age of space occupation and demography explosion.

The results reveal that the springs require a physical protection (building of tight reservoir with siphons and enclosure around springs) in order to avoid foreign bacterial flora irruption; the wells deserve a reinforced chemical treatment (treatment with bleach) every month and they require to be consolidated in order to avoid erosion and contaminations by dirty water. In zones of high habitat density with lost base latrines, some wells must be proscribed according to their proximity with latrine and protected areas as determined by the pumping test.

Residents of periurban zone must be aware of sanitary methods, particularly of drinking water; and the introduction of basic urban service and planning measures by authorities.

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