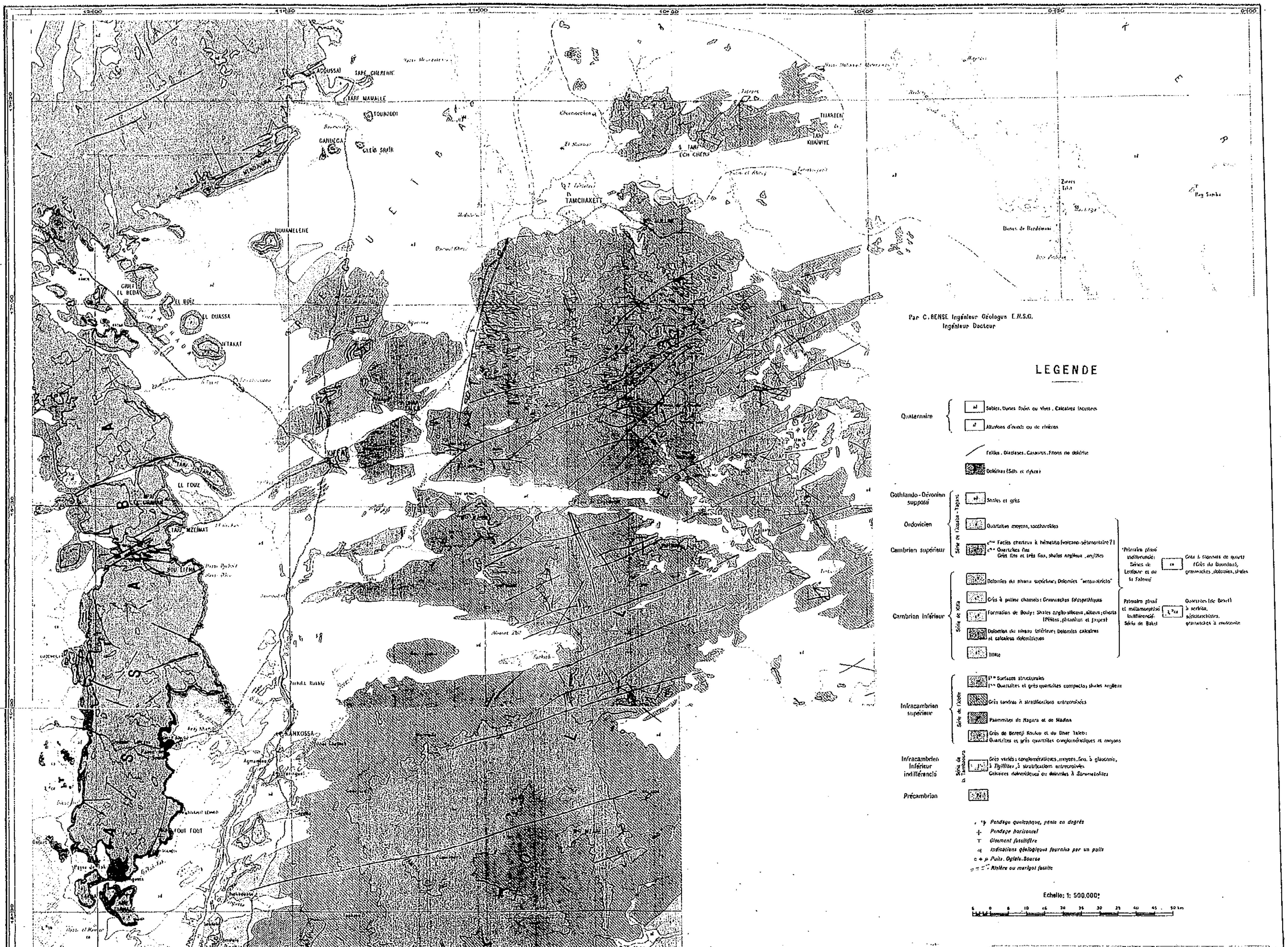


Fig. 3.2-1 Geological map around Kiffa

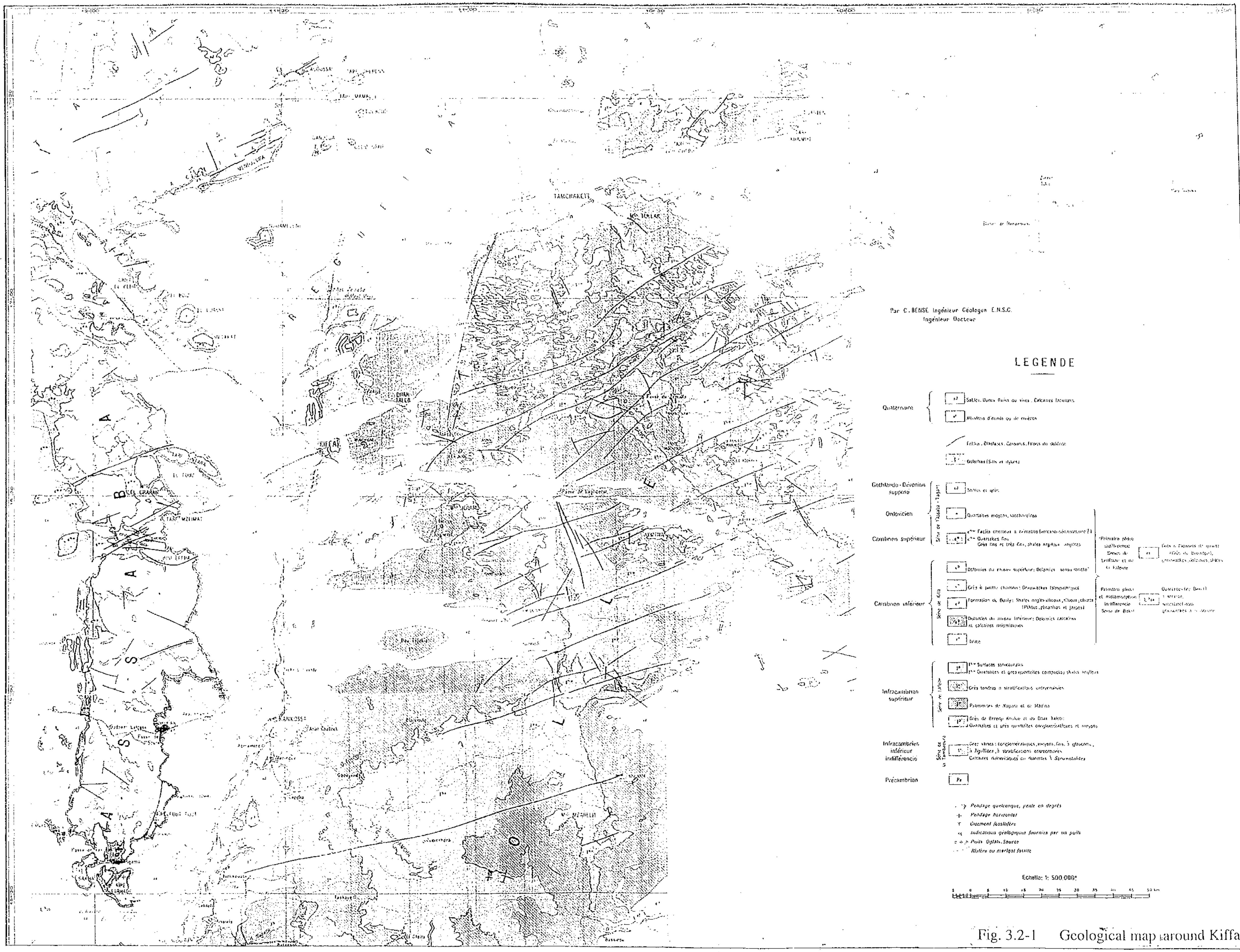


Fig. 3.2-1 Geological map around Kiffa

3.2.2 Results of interpretation of air photos

Interpretation of air photos around the study area was carried out. Monochromic air photos on a scale of 1 to 50,000, taken in 1956, were used. The range of interpretation was a zone within an approx. 20 km radius from Kiffa city. Results of the interpretation are shown in Fig. 3.2-2.

(1) Classification of geographical features according to interpretation of air photos

According to the interpretation of air photos, the following ten characteristic geographical features are distributed around the study area.

a. Fixed sandhill
b. Area covered by a sand stratum
c. Terrace
d. Steep cliff
e. Area with base rock cropping out
f. Monadnock
g. Peneplain
h. Depressed ground
i. Grassland
j. Damp ground

1) Fixed sandhills

Fixed sandhills are universally distributed around the study area. A fixed sandhill consists of hills around 10 m to 30m high made of aeolian sand and an aggregation of glens sandwiched between hills. Hills and glens extend straightforward in parallel from the west-southwest to the east-northeast. The interval between hills is around 100 m to 300 m. The fixed hill is sparsely dotted with plant life. As indicated by the name fixed sandhill, it is relatively stable with movement of sand little observed.

As a result of a study of wells, it was found that the fixed sandhill doesn't consist of sand strata only; the thickness of the sand strata here is up to about 10 m, and the interior of the hill is composed of a rock bed. It is presumed that fixed sandhills were formed as a result of the Aeolian sand strata covering a group of mountain chains of the base rock bed extending in parallel from the west-southwest to the east-northeast. Most of glens, which are distributed between hills, represent areas with base rock outcroppings. Many of them are depressed ground without outlets where many wadis flow in.

2) Areas covered by a sand stratum

These areas are mainly distributed in low ground along the main wadis and among fixed sandhills. They form a plain landform where the base rock is thinly covered by rambling aeolian sand strata with the thickness of 1 m to 3 m. The areas covered by sand strata are sparsely dotted with small-sized areas of base rock outcroppings.

Fig. 3.2-2 Results of interpretation of air photos

3) Terraces

Terraces are extant parts of old river courses of wadis. Several terraces are confirmed along the Wadi Rhouda, which is a main wadi in the study area. The relative height of terraces from the existing river courses is around 2 - 3 m, and their width is 400 - 500 m. The surface of the terraces is covered by rambling aeolian sand strata.

4) Steep cliffs

Steep cliffs, formed by erosion by wadis, have developed mainly behind riverbanks of wadis and terraces. The relative height of the steep cliffs is about 3 m.

5) Area with base rock outcroppings

Areas with base rock outcroppings are widely distributed mainly in the glen parts in fixed sandhills. In these areas, as the outer layer of the base rock become conglomertic due to weathering, there is the look of so-called "gravel desert".

6) Monadnocks

A monadnock is a characteristic landform in the area with Taleb sandstone. They are widely located in the eastern part of the study area. Monadnocks of steepled or circular sandstone project in the plain areas covered by sand strata. The height of large-sized monadnocks is 10 m or more.

7) Peneplains

Peneplains are the remains of past plains that were free of erosive action. They are widely distributed on heights with a relative height of about 50 m called the "Tarf Tintara," located 30 km west of Kiffa city. On fixed sandhills at the foot of the Tarf Tintara, places where the top of hills are plain are observed. It is judged that they are paneplains a tier lower than the height mentioned above.

8) Depressed ground

Depressed ground is observed in the glens of fixed sandhills and in lowlands in the areas with roof sand strata. There are formed by water systems where a lot of wadis flow in, and are closed. Surface running water flows into depressed ground, and water flowing in evaporates because there are no runoff water systems, so it infiltrates underground. Therefore, it is presumed that these areas will be an important cultivation source of underground water around the study area.

9) Grasslands and damp ground

In places where the basin area is wide and the amount of water flowing in is large, among the depressed ground mentioned above, grassland and damp ground are formed. The grassland is depressed ground where shrubs and grasses grow thick. Damp ground is depressed ground that is damp even in the dry season and becomes a pond in the rainy season because the amount of water flowing in is larger than in the grassland. Silt and clay are piled up on the bottom of grassland and damp ground.

(2) Water system

Wadis traced by interpretation of air photos are shown in Fig. 3.2-2. As shown in this figure, the Wadi Rhouda, the main wadi in the study area, winds its way through the study area from the north to the south. However, almost all of the small wadis developing within fixed sandhills and the areas covered by sand strata don't flow into the Wadi Rhouda; they disappear in depressed ground. Generally, these kinds of wadis have developed within fixed sandhills. They form typical parallel pattern drainage systems because they run along a glen extending from the east-northeast to the west-southwest.

Based on confirmation of the actual place with the results of the interpretation of air photos, the following was determined: Even in the Wadi Rhouda, the main wadi, water doesn't flow continuously other than during great floods. In the case of normal rainfall, water stagnates in the wadis, and ponds are intermittently formed along wadis.

As mentioned above, systems in the study area are formed by the aggregate of small closed systems, which is a very characteristic flowing situation. In other words, in this study area, runoff water doesn't flow over a long distance, and evaporates and infiltrates underground in depressed ground or a wadi.

(3) Lineament

A remarkable number of lineaments extending from the east-northeast to the west-southwest are observed in the northern and eastern parts of the study area. As shown in the figure of the interpretation of air photos, the direction of these lineaments generally corresponds to the direction of the extension of fixed sandhills. Those with good continuity have an extension as long as 15 km. In the southern part of the study area, there is an area where lineaments from the south to the north and from the north-northeast to the south-southwest are densely aggregated. They have poor continuity.

In the northern part of Kiffa city, two lineaments with good continuity running from the east-northeast to the west-southwest are observed. The distance between these two lineaments is about 10 km, and many small lineaments are observed between them. Many of these small lineaments extend from the west-northwest to the east-southeast. From this, it is estimated that these two lineaments extending from the east-northeast to the west-southwest have a degree of right lateral slippage.

As a result of tracing the end in the western side of these two lineaments, as shown in the following figure, a large fault was found, as shown in the existing hydrogeological map. It is estimated that this fault crosses a height (the Tarf Tintra) and a fixed sandhill (the Dune de Hassel Nkhcile) at its foot and branches off to these two faults.

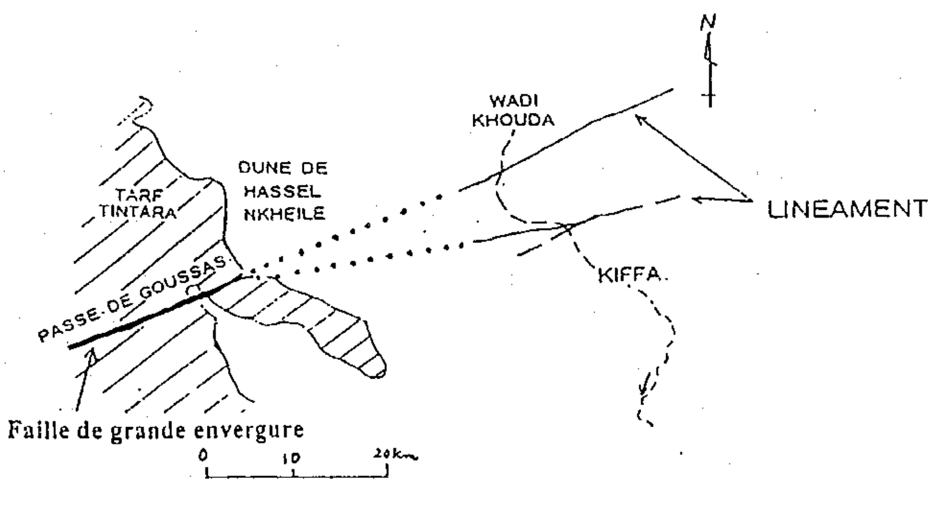


Fig. 3.2-3 Relation between lineaments and the main fault

3.3 Quality of underground water

3.3.1 Quality of underground water at shallow aquifer in Kiffa

(1) Summary of the study

This study found that the importance of underground water at shallow aquifer in Kiffa city is increasing more and more among poor water resources. It thus becomes necessary to evaluate the groundwater quality for consumption. The number of existing wells in Kiffa city is approximately 1,000. For all of them, electrical conductivity (concentration of salt) and colon bacillus groups in the well water were measured in the well survey stage. For nitrate nitrogen, an important index to show the conditions of underground pollution, about 90 wells were selected and their water was analyzed. Based on the results, an outline of the regional distribution of underground water quality was developed. However, information that would allow a detailed evaluation was insufficient. Therefore, a detailed additional water survey was carried out in the third on-the-spot survey stage.

The detailed water survey was made for the 200 existing shallow wells in Kiffa city. The period of the survey was one month (June 1998). The following 6 items of analysis were determined.

a. Outdoor analysis items: Water temperature, pH, electrical conductivity
b. Indoor analysis items: Colon bacilli, nitrate nitrogen, ammoniacal nitrogen

For the items stated in a. above, pH meters (HM-12P made by Toa Electronics Ltd.) and electrical conductivity meters (CM-14P made by Toa Electronics Ltd.) were used. Colon bacilli test pieces (TPA-CG made by Kyouritu Rikagaku) were used for colon bacilli, and DREL/2000 spectrophotometers (made by HACH Co., Ltd., an American company) were used for nitrate nitrogen and ammoniacal nitrogen.

In order to determine the relation between the quality of water in shallow wells and hygienic conditions around the wells, at the time of taking water, surveys were carried out for hygienic conditions around wells. These included distance between a well and an excrement container, hygienic conditions on the ground surface, conditions of existence of excrement of domestic animals, etc. (See "S-3 Water Analysis" in the Supporting Report.)

(2) Results of surveys

Fig. 3.3-1 shows the location of the 200 shallow wells in Kiffa for which water surveys were carried out. These places were selected in consideration of the following points.

a. To cover the whole area that is dotted with shallow wells.
b. To place importance on the area (north side of the central market) with many wells whose concentration of nitrate nitrogen seemed to be low as a result of the previous water survey.
c. To select wells usually used.

Since June was just changing from the dry season into the rainy season, water levels of all wells were much lower than those at the time of the previous water survey (November 1997). In carrying out the surveys the bucket hit the bottom at more than half the wells, and water could be taken out only little by little. A lot of wells where water could be taken during the previous survey were dry at the time of these surveys. The results of the measurement of water quality at the 200 existing wells are shown in "S-3 Water Analysis" in the Supporting Report.

(3) Analysis of results of measurement

Fig. 3.3-2, 3.3-3 and 3.3-4 show the concentration of salt (electrical conductivity), nitrate nitrogen (as nitrate, NO_3) and ammoniacal nitrogen, respectively. Distribution of colon bacilli is shown in Fig. 3.3-5, where the results of the measurement are shown classified by relative amount because absolute quantitative expression is impossible.

1) Concentration of salt

Distribution of the concentration of salt expressed as electrical conductivity was almost the same as that in the rainy season. Wells with high concentration of salt are located mainly in the central, north and south parts of the urban district. Particularly in the northern part of the urban district, there is a peak of over 8,000 μ S/cm. Though there are wells with much higher concentration of salt also in the south, they were not chosen for this survey because they were not used often.

The detailed water surveys were carried out with the urban district, where wells are densely located, as a central part. As a result, the following noticeable element was found, regarding distribution of salt concentration in underground water. Depressions are formed in three parts in Kiffa city. As shown in the Fig. 3.3-2, underground water with high or low electrical conductivity (salt concentration) becomes belt-shaped, is carried in the flow of underground water from areas surrounding the city, and is drawn into these depressions. Therefore, we conclude that the areas with high electrical conductivity distributed in a belt shape results from a natural cause. On the other hand, on the left bank in Kiffa city, there were areas with high concentration of salt that showed island-shaped distribution, which is different than the above-mentioned one. It is assumed that this contribution has resulted from artificial pollution because it corresponded well to the zone with high concentration of nitrate nitrogen.

Another viewpoint, different from this, considers the fact that the area, where high salt concentration was distributed, showed a lattice pattern in the two directions, the south-southwest - north-northwest and the east-northeast - west-southwest. Therefore, it is possible that lineament systems regulate the distribution.

In either case, there are a number of still unknown factors regarding the factors of formation of the distribution of salt concentration in underground water at the shallow aquifer in Kiffa city. One certainty is that there is a tendency that salt concentration in underground water at the shallow aquifer in the densely-populated areas is generally high.

2) Nitrate nitrogen

It was observed that on the whole the concentration of nitrate nitrogen tended to be higher than in the previous survey in the rainy season. This seems to be related to the low amount of water at the end period of the dry season and to the most disadvantageous conditions of water quality. On the other hand, there was little change in concentration of salt because of season. This suggests that pollution by nitrate nitrogen in underground water is mechanically different from salification of underground water. The former is primarily related to artificial activities and has a high possibility of local occurrence, while it is supposed that the latter is much influenced by elements in a wide area (e.g., hydrogeologic structures of aquifers, flows of underground water, etc.).

A well where the highest concentration of nitrate nitrogen was detected was Well No. 350 in the densely-populated area in the central part of the urban district. Concentration of nitrogen was 319 mg/L. It is converted to concentration of nitrate of 1,400 mg/L, which is very high. There were wells with nitrate nitrogen concentrations of 400-700 mg/L in the surrounding places. This area represents a peak in the figure of distribution.

Areas with the highest concentration of nitrate nitrogen were the central part of the urban district, a wide area in the south, some places in the north part and some places in the west and northwest. The tendency of distribution did not differ from that in the rainy season.

3) Ammoniacal nitrogen

Ammoniacal nitrogen is the first state of nitrogen contained in human and animal excrement. It should not exist in underground water unless a large amount of sewage, etc., flows into well from the ground surface. Ammonia is unstable, and easily becomes nitrate nitrogen in the oxidation state by action of microorganisms in the soil, such as nitrate-forming bacilli. As a result of the water surveys, only ammoniac nitrogen in extremely low concentration was detected in more than half wells. Wells where ammoniac nitrogen was in higher concentration were centered in the northeast area near the central part of the urban district, as shown in Fig. 3.3-4. Though there was water in these wells, they were in such situations that rocks on the bottom could be seen because the water level was low, or rubbish, insects, etc., floated on the water, or foul odors were emitted. These may be abnormal phenomena that occur in the season with very little water. However, corruption seems to be generated because the openings of the wells are not protected well.

Another possible reason that ammonia was left in water without being oxidized is because the underground was in the state of remarkable deoxidization. Pyrite, FeS, is often contained in pelite that is a aquifer. In aquifers which containing a large amount of pyrite, it is possible that nitrate and iron hydroxide are formed by oxidization of pyrite and the state of remarkable deoxidazation is formed.

4) Colon bacilli group

The colon bacilli groups were detected in all wells, and the concentration was high. In some cases, when a sample was put directly on s test piece, the number of bacilli groups could not be counted because the whole piece became red after cultivation. Then it was determined that samples would be cultivated after 10-time dilution with uncontaminated water. A well with the smallest number of colon bacilli groups was Well No. 127, which was a source of water for water-supply wagons in the city. Concentration was about 10/mL. Almost all other wells had a concentration of several hundreds/mL. There were 14 wells with a concentration over one thousand/mL. Though it is impossible to clarify the characteristics of regional distribution because the figures were greatly different, there is a tendency that the number of colon bacilli group is larger in wells in areas with more houses and a higher density of population.

(4) Valuation of groundwater quality at shallow aquifer in Kiffa

When underground water is used as drinking water, it is required to satisfy the quality standards of the World Health Organization (WHO) in principle. For concentration of salt (residue after complete evaporation), the standard value of the WHO is 1000 ml/L. The values of electrical conductivity (in μ S/cm) are as high as 1.5 times that of salt concentration (in mg/L) in most cases. Therefore, it is assumed here that electrical conductivity of 1500μ S/cm is equivalent to salt concentration of 1000 mg/L. For nitrate nitrogen, the WHO standard value is 50 mg/L(as to NO_3). Ammonia is not included in the items of the WHO standards for water quality. As allowable concentration is 0.2 mg/L (as to N) in many cases, with this concentration as a criterion, applicability to drinking water is evaluated. For colon bacilli groups, the WHO standard is no detection. This standard will be able to be satisfied by means of sterilization with chemicals of the chlorine group (for example, Javel, a bleaching agent used in Mauritania whose sterilizing effect was confirmed by the survey group). For this reason, it is not considered here as an index of valuation of underground water quality.

When applicability to drinking water is evaluated by adopting the above-mentioned standard values for concentrations of salt, nitrate nitrogen and ammoniacal nitrogen to underground water in the narrow strata in Kiffa city, the "suitable" and "unsuitable" ranges of valuation for each item of water quality can be classified as shown in Fig. 3.3-6. As known from the figure, areas evaluated to be "unsuitable" (shown with oblique lines in the figure) were mainly located in the north and south parts in the urban district. There were places with values exceeding the standards also in the some places in the central part and on the outskirts of the town on the west side. However, in a wide range in the south and east parts, the concentration of salt was under the standard value. The ranges valued to be "unsuitable" in regard of nitrate nitrogen are mainly the central part of the urban district, and on the outskirts of the town in the west, the northeast and the southeast. In the western and eastern areas, including the source of water for water-supply wagons of the city at the present, values were under the standards. As to ammoniacal nitrogen, the concentration of 0.2 mg/L was exceeded in the relatively narrow range in the northeast direction of the central part of the urban district. In other areas, concentration was as low as about 0.2 mg/L.

Quality of underground water at the shallow aquifer in Kiffa city was comprehensively evaluated from the aforesaid. It is considered that underground water in both the west and east sides of the urban district will be able to be used as drinking water because its quality is good. The area where underground water will be able to be used as drinking water is limited to some parts such as the western area in Kiffa city.

The widest area evaluated to be "suitable" is located on the west side of Kiffa city where few people live. According to the figure of ground water level contours shown in "3.4 Analysis of Hydrogeologic Conditions," this area is the catchment area of the upper stream of underground water. If this area is polluted, obviously, polluted underground water will flow into the area of Kiffa city and pollution of underground water in Kiffa city will be expanded. Therefore, in order to preserve quality of underground water in the western area in Kiffa city, it will be necessary to take measures including regulation of land use in this area in the future.

As shown in Table 3.3-1, 296 wells in total are identified from listing-up in each zone of all wells in the areas evaluated to be "suitable." These account for 28% of all wells (1061) in Kiffa city. It must be remembered that there are a number of wells that go dry in the dry season.

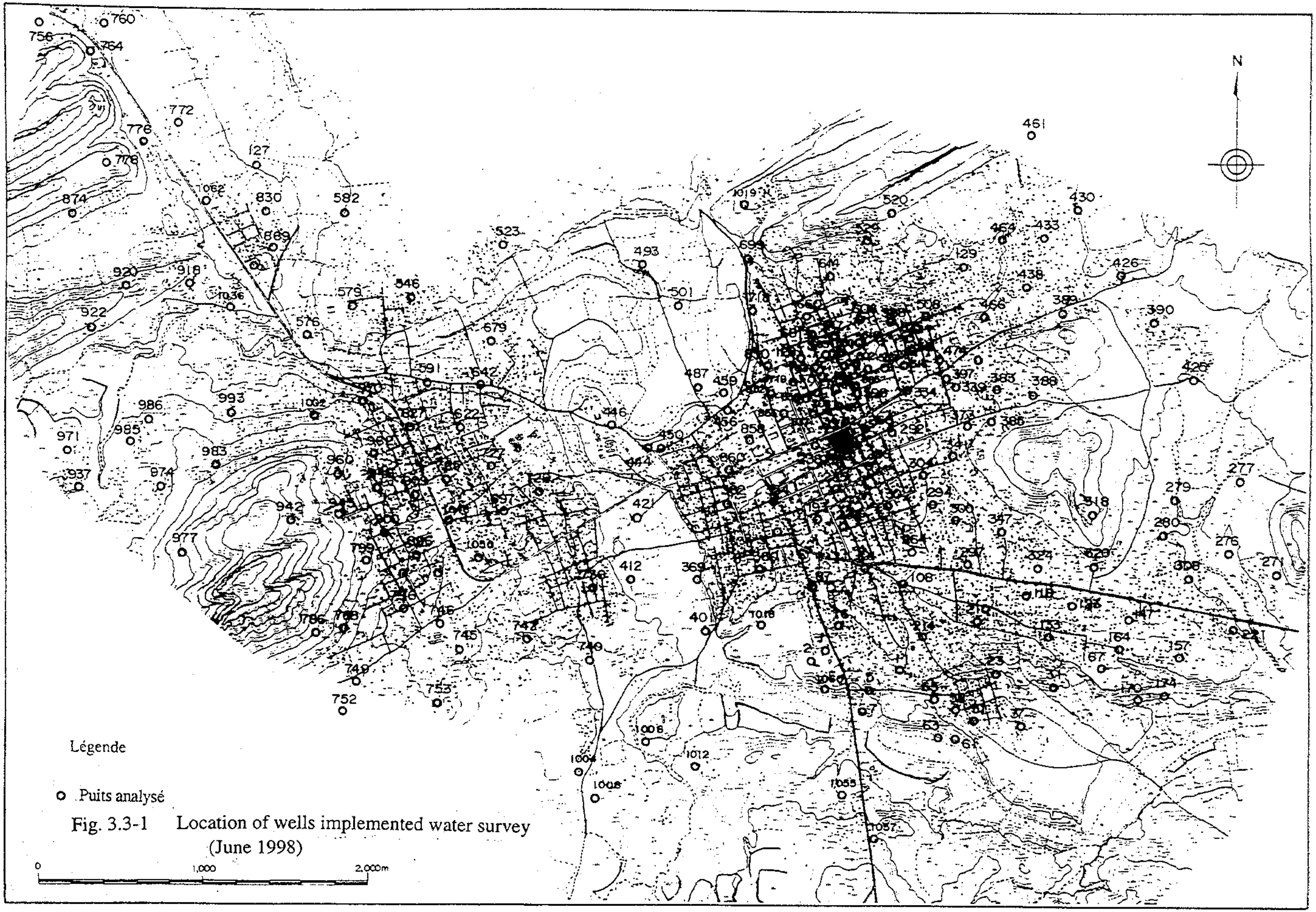


Fig. 3.3-1 Location of wells implemented water survey (June 1998)

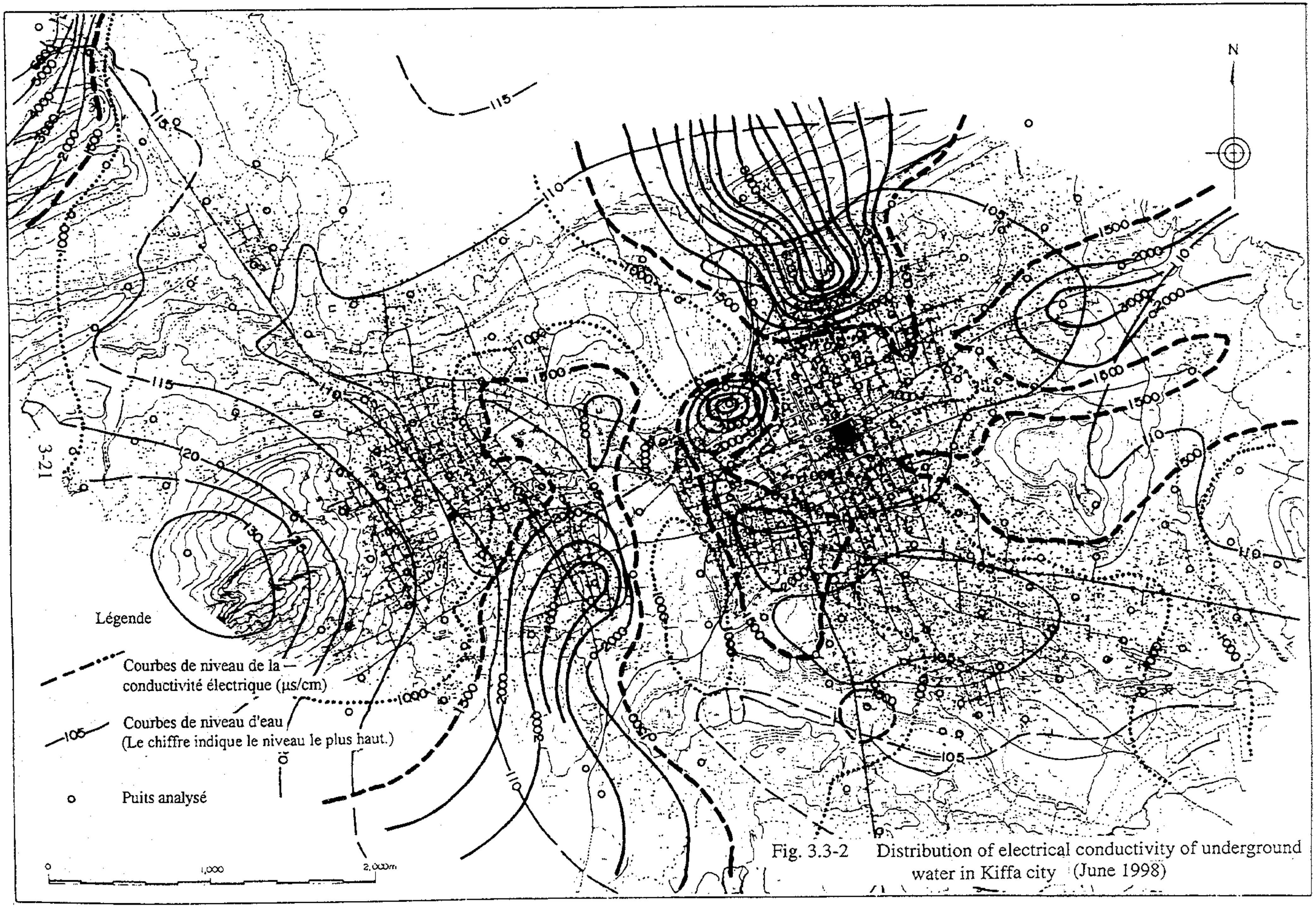


Fig. 3.3-2 Distribution of electrical conductivity of underground water in Kiffa city (June 1998)

Fig. 3.3-3 Distribution of nitrate nitrogen concentration of underground water in Kiffa city (June 1998)

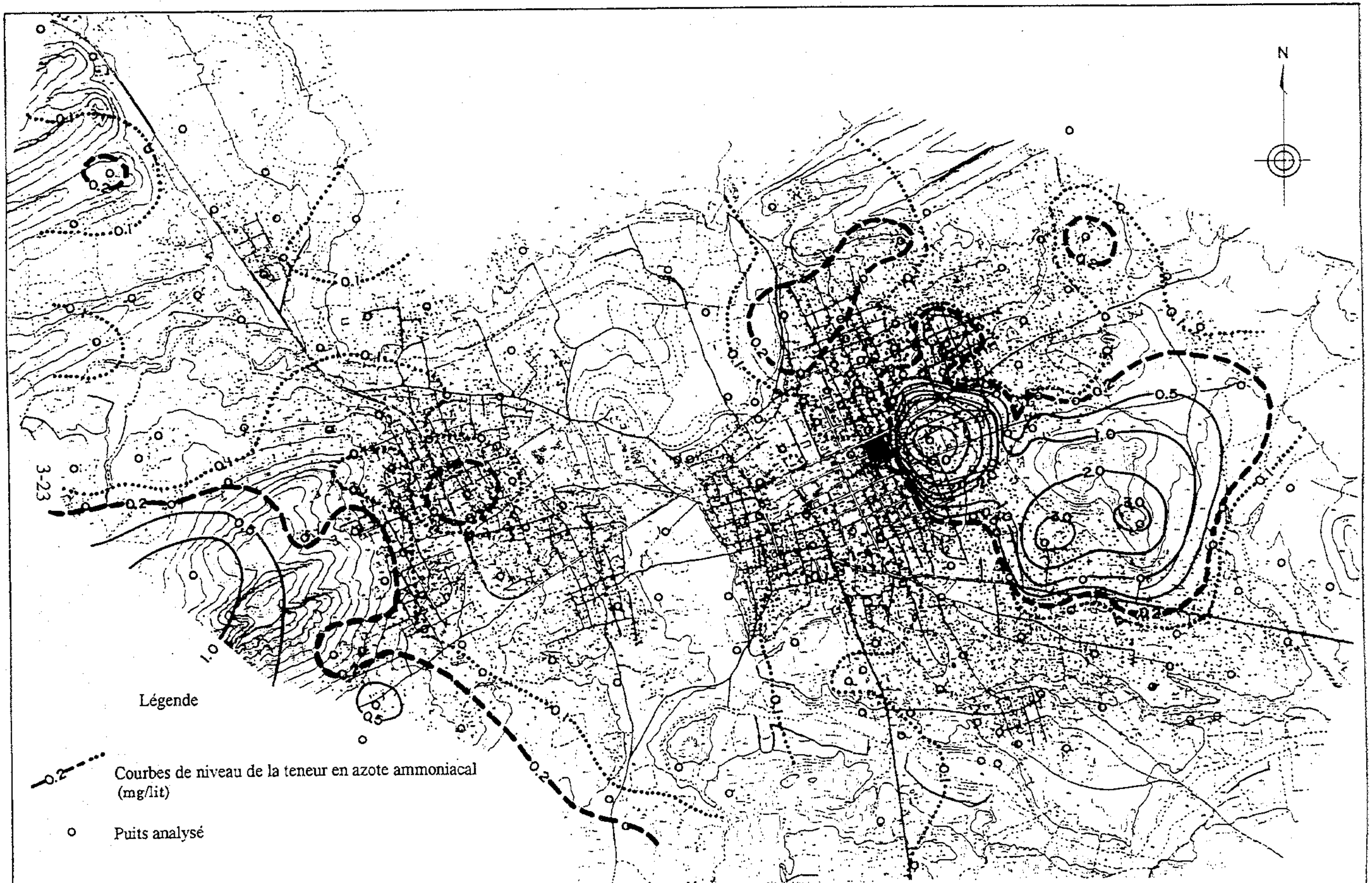


Fig. 3.3-4 Distribution of ammoniacal nitrogen concentration of underground water in Kiffa city (June 1998)

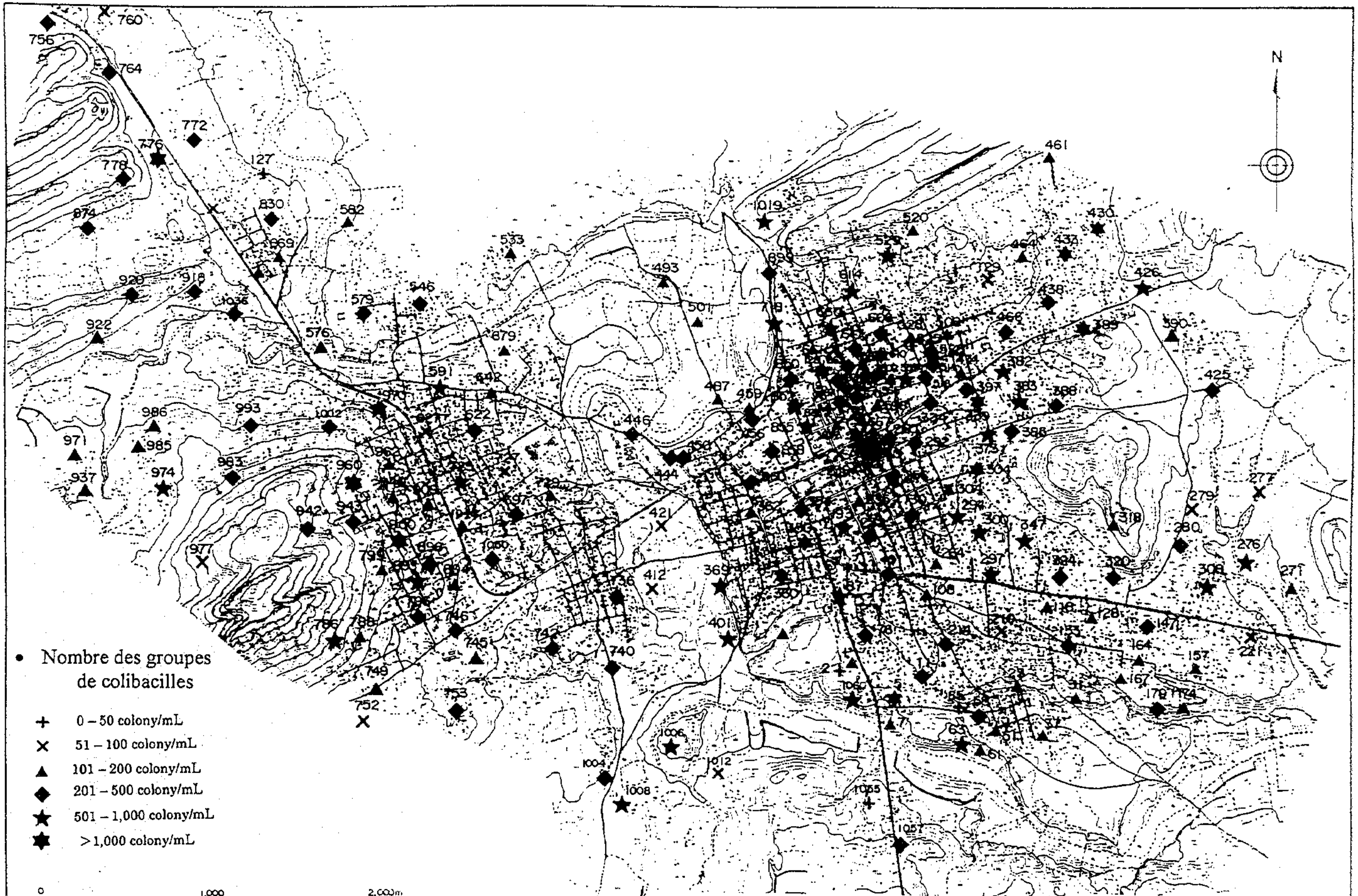


Fig. 3.3-5 Regional distribution of colon bacilli group in Kiffa city (June 1998)

Fig. 3.3-6 Distribution of groundwater quality at shallow aquifer in Kiffa city (June 1998)

Table 3.3-1 List of wells with good quality of water in each zone in Kiffa city

Zone Name	Well No.	Number of Wells
Belemtar East	127,576,577,578,692,693,829,830,831,832,833,834,835,862,863, 864,865,866,867,868,869,870,871,872,873,974,875,876,877,878, 881,882,883,884,885,998	36 wells
Belemtar West	886,887,920,921,922,923,924,1036,1038,1039,1040,1042,1043	13 wells
Boulenwar	531,532,533,534,539,540,541,542,543,544,545,546,547,548,549, 550,551,552,573,574,575,579,580,581,582	25 wells
Kebata	643,673,675,678,679,680,681,682,683,684,685,686,687,688,689, 690,691	17 wells
Kerkeb	937,938,939	3 wells
M'sseigila	969,970,973,974,975,976,978,979,980,981,982,983,984,985,986, 987,988,990,991,992,993,994,995,996,997	25 wells
Segatar I	569,570,571,572,583,584,585,591,592,638,639,641, 695,697,722,723,728,729,731,1048,1049,1050,1051,1052	24 wells
Aleg	444,449,450	3 wells
Wadi	452,460,483,484,485,486,487,488,489,490,491,492,493,494,495, 497,498,499,500,501	20 wells
Gomez	128,617,657,658,663,661,701,702	8 wells
Jedida	653,654,664,672,703,704,705,706,707,714,715,716,717,719,720, 721,836,846,847,848,851,852,855	23 wells
Qlig	527,602,603,604,605,606,607,608,609,610,611,612	12 wells
Ternicha	376,377,378,379,387,388	6 wells
Arafat	280,281,282,283,284,285,286,287,288,289,305,306,307,308,309, 310,311,312,313,314,315,316	22 wells
Taiba	270,271,272,273,274,275,276,277,278	9 wells
Nezaha	121,122,143,144,145,146,147,148,149,150,151,152,154,155,156, 157,158,159,160,161,170,171,172,173,174,218,219,220,221,222, 223	31 wells
Siyassa	7, 39, 48, 49, 50, 51, 52, 58, 59, 61, 62, 63,1061	13 wells
Entou	64, 65	2 wells
Khadima	1060	1 wells
El Hanger	750,751,752	3 wells
	Total	296 wells

3.3.2 Quality of underground water in the northwest water source area

(1) Summary

Among the test-pitting survey wells, water analysis was carried out for following seven wells in total: deep wells with much water pumped up (JF-2, JF-6A, JF-7B and JF-13A), deep wells with high electrical conductivity of underground water in tillite (JF-1, JF-4 and JF-8) and deep wells with low electrical conductivity (JF-12B and JF-10). In addition, for an existing deep well with much water pumped up (F-5) and shallow wells with high frequency of use in Kiffa city (P1 and P661), water analysis was carried out in the same fashion. A total of 11 samples were analyzed for quality of water.

It was determined that water analysis would be carried out for the following 19 items.

a. Items of on-the-spot analysis: Water temperature, pH, electrical conductivity
b. Items of field-office analysis: Colon bacilli groups, thermostable colon bacilli
c. Items of Centre National D'Hygiene analysis :
NA^{+}, K^{+}, Ca^{2+}, Ca^{2+}, Mg^{2}+ Fe (total), Pb^{2+}, Hg^{2+}, HCO_3-, SO_4^{2-}, No_3^{-}, NO_2^{-}, F-, CO_2

Among these, five items, i.e., pH, water temperature, electrical conductivity, colon bacilli groups and thermostable colon bacilli, were measured by the survey group. Measurements of the other 14 items were consigned to the Centre National D'Hygiene.

(2) Results of analysis

The values of the water analysis are shown in Table 3.3-2. Conversion values to the equivalent of positive and negative ions of the main constituents are shown in "S-3 Water Analysis," in the Supporting Report. Composition of the main constituents is shown in Fig. 3.3-7 (the trilinear diagram). This diagram doesn't include JF-1, with a very bad positive and negative balance, and JF-10, whose sample had a putrid smell.

In this trilinear diagram, the whole is a small composition of Mg^{2+} and SO_4^{2}+NO^{3}-, and other constituents are diversified. However, the number of equivalent positive and negative ions was almost the same. The samples whose accuracy of analysis was judged to be good (JF-2, JF-12B, JF-13A and F-6) are distributed around the center of the diagram. Samples from JF-8, JF-4 and JF-2 are in the division of water quality of the non-carbonate type.

As to electric conductivity, pH, natrium ions, calcium ions, iron ions, chlorine ions and nitrate nitrogen mentioned below, some exceeding the WHO's guideline are seen. However, the quality of water in the test-pitting survey wells planned to be diverted to production wells (JF-2, JF-5A, JF-7B and JF-13A) generally satisfy these standards.

1) Electrical conductivity

Electrical conductivity at wells JF-1, JF-4 and JF-8 greatly exceeded 1500 μ s/cm, and the water was not suitable for drinking. All of these three wells had high electrical conductivity in tillite.

2) pH

Almost all samples showed a low alkalinity of pH7.1-8.0. Only the sample from JF-8 showed high a alkalinity of pH11.43, the reason for which is not known.

3) Sodium ions

Values of the JF-1 and JF-4 samples were over the guideline. At these wells, high electrical conductivity was shown, and the concentration of salt was high.

4) Chlorine ions

Values of the JF-1, JF-4 and JF-8 samples were over the guideline. At these wells, high electrical conductivity was shown, and the concentration of salt was high.

5) Iron ions

At the test-pitting survey wells, values exceeding the guideline of 0.3 mg/l were not found, but, at the existing well F-5, the value was 0.31 mg/l, which slightly exceeds the guideline value. However, the guideline value of iron ions has been determined not from the viewpoint of health but from the viewpoint of taste, precipitation in water-supply facilities, soiling of wash, etc. In addition, the value will be made less than the guideline by mixing with other water with low concentration of iron ions. Therefore, it will not be a problem.

6) Nitrate nitrogen

The value of the sample from the shallow well in the city, No.1, exceeded the guideline, but none of those from the test-pitting survey wells exceeded the guideline value.

7) Colon bacilli

Colon bacilli groups and thermostable colon bacilli have not been detected from the test-pitting survey wells.

(3) Conclusion

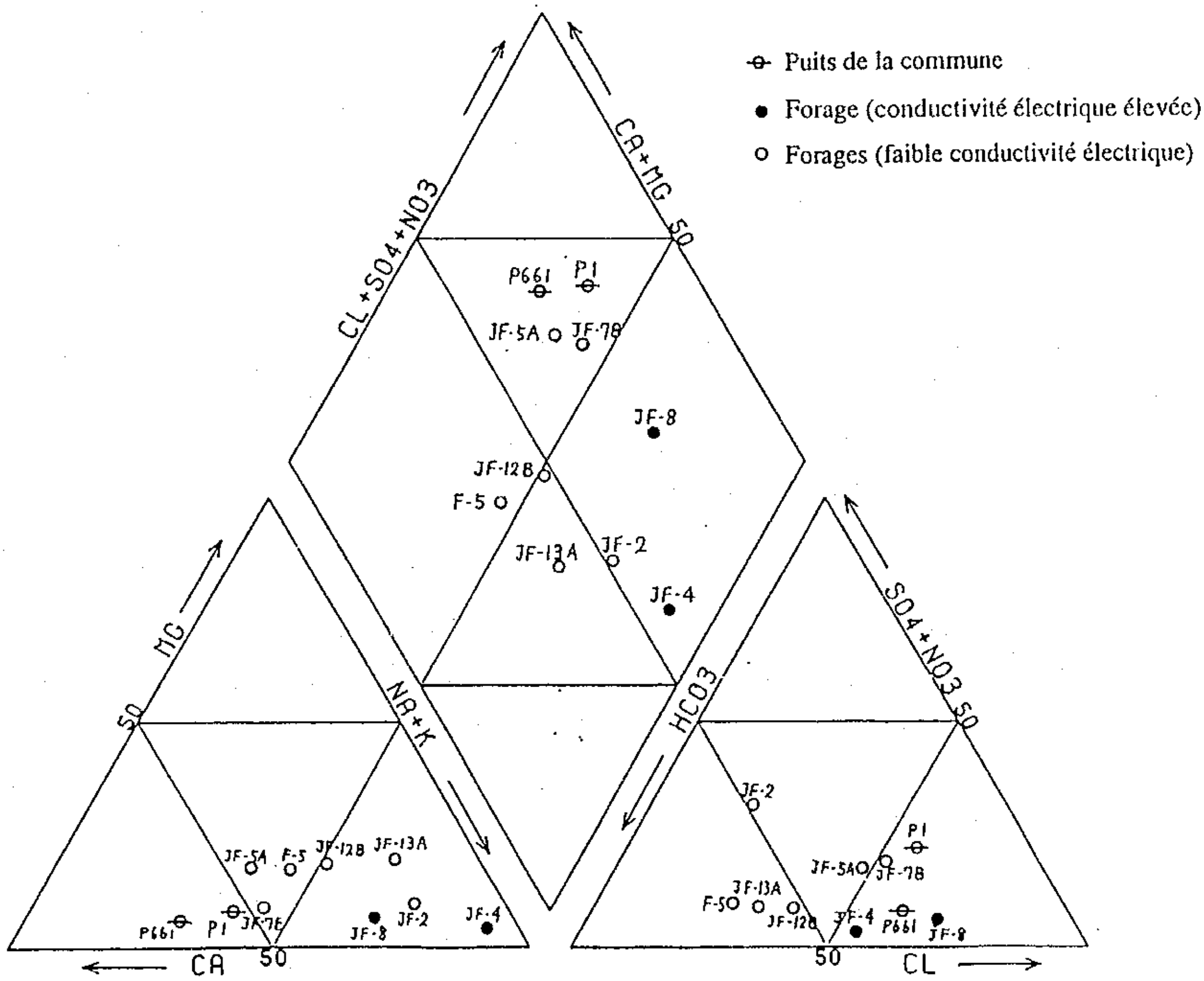
According to the results stated above, Wells JF-1, JF-4 and JF-8 will not be able to be used because of high salt concentration resulting from high electrical conductivity, natrium ions and chlorine ions. The quality of water at other test-pitting survey wells is suitable for drinking, including the test-pitting survey wells planned to be diverted to production wells.

As mentioned, the northwest water source is dotted with underground water with high concentration of salt. As it is impossible to deny the possibility that production wells will take them in, it is necessary to monitor the quality of water regularly.

Table 3.3-2 Results of quality analysis of underground water in the northwest water source area

	JF-1	JF-2	JF-4	JF-5A	JF-7B	JF-8	JF-10	JF-12B	JF-13A	Puis No.1	Puits No.661	F-5	O.M.S. Guideline
CE (µs/cm)	**15030**	985	**4610**	816	953	**2560**	1092	241	654	1421	974	814	(1500)
pH	7,93	7,86	7,99	7,12	7,20	11,43	8,3	7,54	7,52	7,18	7,61	7,2	6.5-8.5
T (°C)	33,1	34,1	34,1	34,6	32,9	33,5	33,2	33,8	32,8	32,5	32,4	-	-
Na^+ (mg/l)	**390**	101	**238**	47	48	133	108	23	64	57	50	92	200
K^+(mg/l)	17	2	6	2	3	32	2	2	17	3	4	4,2	-
Ca^{2+}(mg/l)	**245,29**	20,04	13,62	48,20	45,54	52,10	13,62	12,02	16,83	70,26	96,12	68	100
Mg^{2+}(mg/l)	24,81	7,78	6,32	12,00	5,47	8,03	8,75	4,86	12,16	6,41	5,58	20	50
Fe;total(mg/l)	0,05	0,06	0,07	0.08	0,05	<0,05	<0,05	0,07	0,06	0,08	0,05	**0,31**	0.3
Pb^{2+}(mg/l)	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	-	0.05
Hg^{2+}(mg/l)	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	-	0.001
HCO_3^-(mg/l)	143,07	183,32	410,12	90,78	70,22	198,85	305,10	67,90	189,16	118,41	90,63	370	-
Cl^-(mg/l)	**3500**	43	**302**	75	72	**305**	60	30	60	193	100	91	250
SO_4^{2-}(mg/l)	3,60	72,40	0	6	10	6,40	0	1,2	6,00	7	12	45	400
NO_3^-(mg/l)	gené par Cl	27,42	32,16	39,73	33,62	32,16	13,12	10,20	21,1	**129**	8,36	0,74	50
NO_2^-(mg/l)	<0,001	<0,001	<0,001	0,035	0,028	<0,001	<0,001	<0,001	<0,001	0,022	0,025	-	
F^-(mg/l)	0,03	0,01	0,02	0,05	0,05	0,01	0,02	0,03	0,02	0,05	0,05	0,25	1.5
CO_2(mg/l)	0,0	0,0	0,0	0,02	0,0	0,0	0,0	0,0	0,0	0,68	0,0	<0,5	-
Coliforms	ND	ND	ND	ND	ND	ND		ND	ND			ND	
Thermotolerant Coliform	ND	ND	ND	ND	ND	ND		ND	ND				

Fig. 3.3-7 Triliner diagram of underground water in the northwest water source area



3.4 Analysis of hydrogeologic conditions

3.4.1 Characteristics of changes in the ground water level

(1) Selection of observation wells

Based on the results of the well survey, 90 wells, where simultaneous observation of water levels would be conducted in the middle period between the rainy and dry seasons and in the dry season, were selected. Another 10 wells, where regular observation would be done every two weeks other than simultaneous observation, were also selected.

Upon selection of wells for simultaneous observation, uniform placement of observation wells throughout the area of Kiffa city, determination of changes of water levels on profiles and so on were taken into consideration. Upon selection of wells where regular observation would be carried out, it was considered to place them uniformly in the city and to determine the difference of changes in ground water levels in low areas located along wadis and located in high areas on sandhills.

Fig. 3.4-1 shows locations of the selected observation wells. Since observation Well No. 126 (F5) is located 10 km northwest of the city, it is not shown in this figure. For its location, see "3.5 Valuation of Recharge Storage".

(2) Results of regular observation of water levels

1) Seasonal changes in ground water levels

The results of regular observation of water levels are shown in Fig. 3.4-2. Because wells for regular observation of water levels are used in daily life, it can't be said that changes in water levels in the wells indicate changes in ground water levels. Some of them presented irregular changes in water levels, as shown in Observation Well No. 493. Although changes in water levels in each well were not completely the same, it was found that water levels tended to raise from June when the rainy season started. Observation Well No. 493 is a well for agriculture that is equipped with a pump and is located in a wadi. Though water had been pumped up until February 1998, pumping-up was stopped in March 1998 because all the crops had died then. For this reason, the water level has risen since March.

It is judged from these characteristics of seasonal changes in ground water levels that underground water in the study area is unconfined underground water cultivated by rainfall.

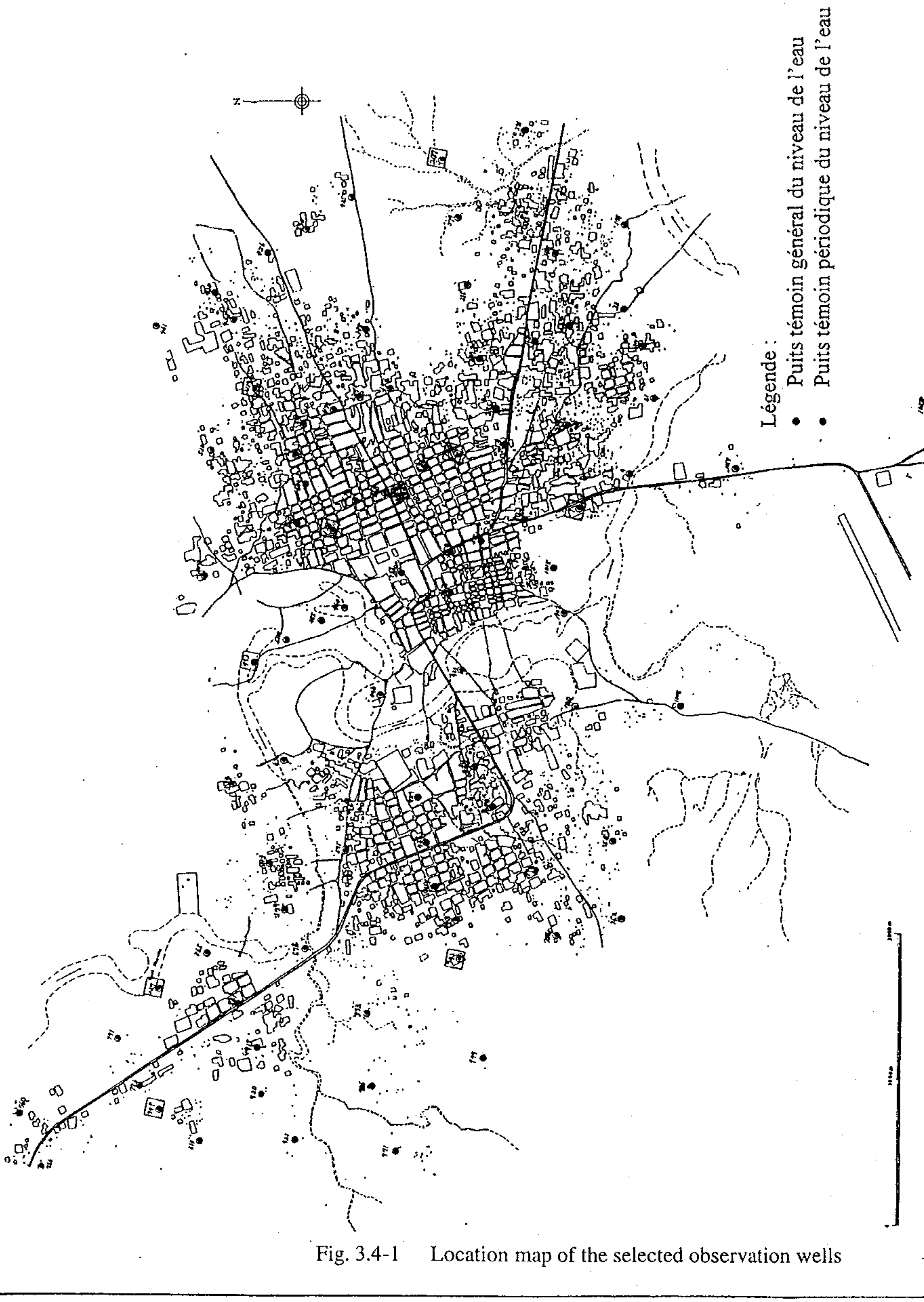
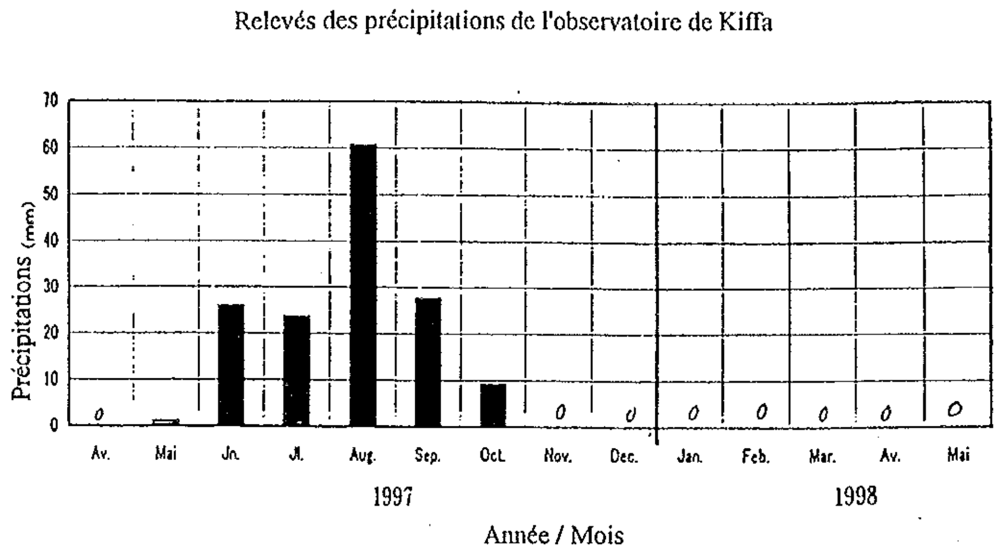


Fig. 3.4-1 Location map of the selected observation wells



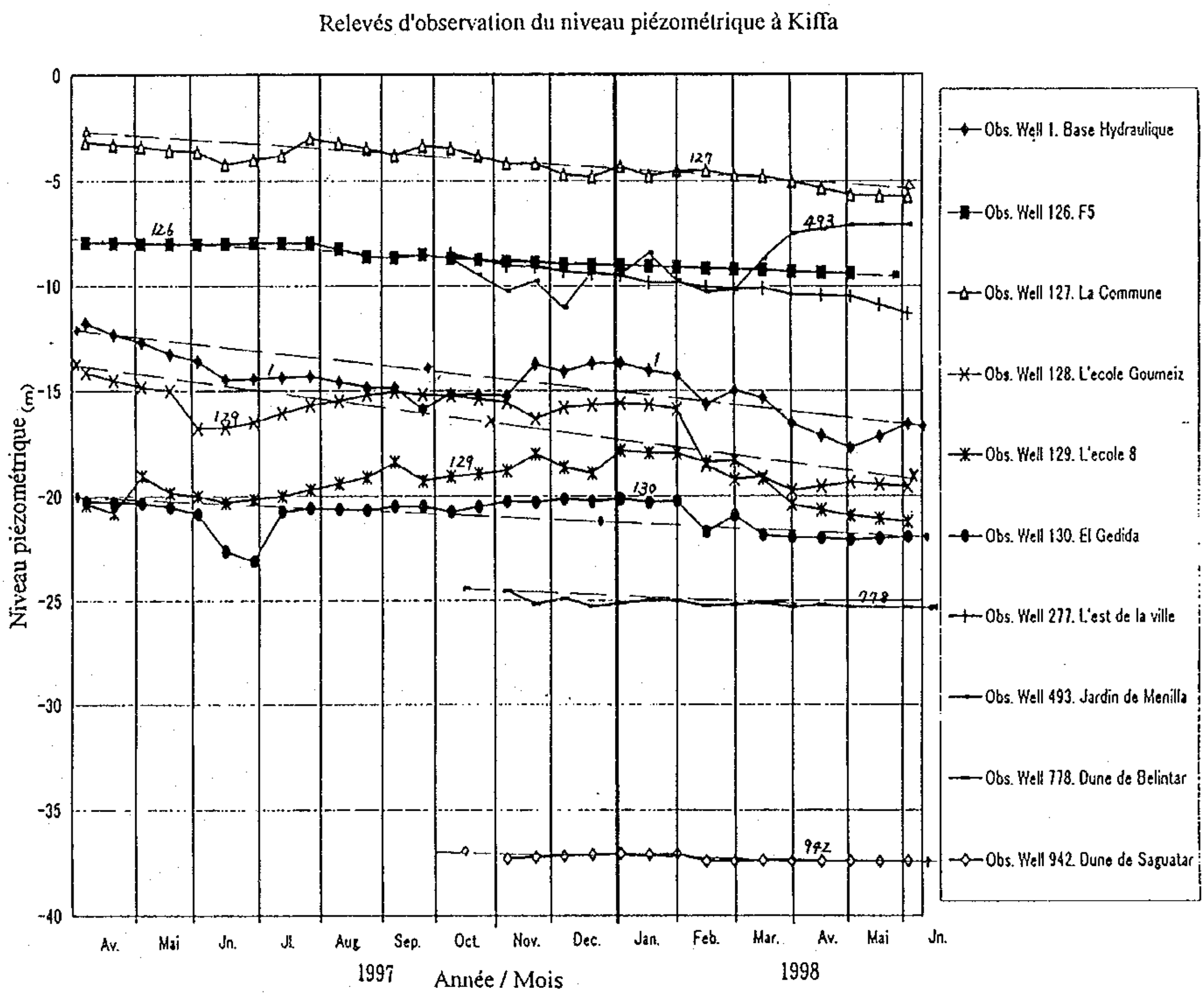


Fig. 3.4-2 The records of regular observation of water levels

2) Long-term tendency of changes in ground water levels

As shown in Fig. 3.4-2, it is obvious that the ground water level in Observation Well No. 126 (F-5) lowers throughout the year although there are no existing wells around it. A possible reason for this is the tendency of lowering of the ground water level in a wide area. Fig. 3.4-3 shows changes in annual precipitation at the Kiffa Observation Station for the past 11 years.

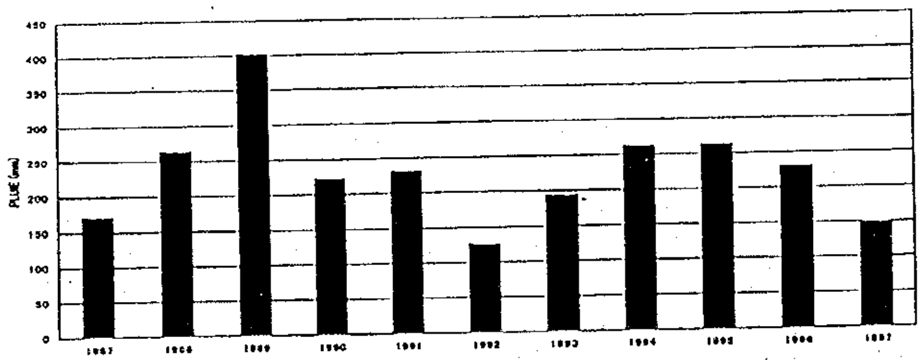


Fig. 3.4-3 Long-term changes in annual precipitation in Kiffa city

As shown in Fig. 3.4-3, the records of the past 11 years show that periods with much precipitation have alternated with those of little precipitation on an about-5-year cycle. According to this cycle, the year 1997, when the observation of the water level was carried out, fell in the period when annual precipitation was low.

For the reasons mentioned above, it is judged that underground water levels in the study area lower widely in the study area due to the decrease in annual precipitation for the past two years. The amount of the lowering is not influenced by pumping-up of water at all. It is supposed from the records of changes in water levels in Observation Well No. 126 (F-5) that the amount of the lowering is approximately 1.5 m/year.

3) Tendency of lowering of the water table

As shown in Fig. 3.4-2, a tendency is observed that water levels in the existing wells in Kiffa city lower throughout a year on the whole while showing a changing pattern that the water levels raise in the rainy season and lower in the dry season. It is considered that, in this phenomenon, there is influence by the lowering of the water table in the wide area accompanying the decrease in precipitation stated above. However, some observation wells in the city had a greater amount of the lowering of the water level than that of the lowering of the water table in the wide area.

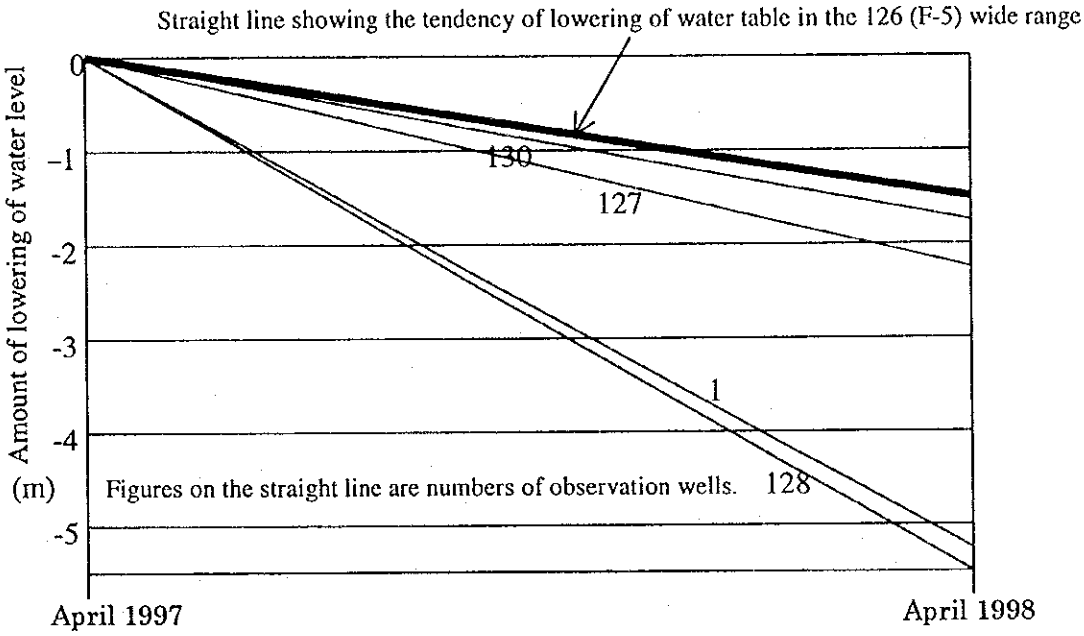


Fig. 3.4-4 Tendency of lowering of water levels in observation wells (with the beginning of April 1997 as a yardstick)

Among 4 observation wells shown in Fig. 3.4-4, Wells 1 and 128 are located in two depressions mentioned later, and Well 130 is located between these two depressions. Well 128 is a pumping well for the supply of water-supply wagons in Kiffa city. Other observation wells show the tendency of annual lowering of the water level, which is almost the same as the tendency of lowering of the water level in Well 126 (F-5) that is considered to indicate the tendency of lowering of the water table in the wide area.

It is judged that, in areas where the water level lowers much more than the rate of annual lowering of the water level in Observation Well No. 126 (F-5), water is being pumped up excessively. According to Fig. 3.4-4, with the rate of lowering of the water level in Observation Well No. 126 (F-5) as a yardstick, lowering of the water level of approximately 4 m for the past year is observed in the central part of the depression in Kiffa city. As stated later, there is the possibility that, if intensive pumping-up of water continues in the manner similar to the present, lowering of the water level will advance at this rate and a number of wells will go dry. At Observation Well No. 128, a pumping well for water-supply wagons in Kiffa city, the tendency of annual lowering of the water level of about 1 m is noticed. Although it is not as severe as in the depression in the city, it is necessary to monitor its water level from now on.

(3) Results of simultaneous observation of water levels

The simultaneous observation of ground water levels was carried out for 90 wells in the city four times; in September 1997 (the rainy season), November 1997 (the middle period between the rainy and dry seasons), December 1997 (the middle period between the rainy and dry seasons) and April, 1998 (the dry season). These results are shown in contour maps of ground water table (Fig. from 3.4-5 to 3.4-7). Differences in ground water levels between the rainy season (September) and the dry season (April) are shown in Fig. 3.4-8 (Cross-sectional view of ground water levels).

1) Shape of ground water table

As shown in the contour map of the ground water table and the cross-sectional view of ground water levels, the ground water table in Kiffa city is generally along the geomorphic surface. It is high in sandhills whose altitude is high and dips towards a place along the Wadi Rhouda. In short, underground water flows from both banks to the wadi and flows down along the wadi. This means that underground water in the study area is unconfined underground water cultivated from the ground surface and the shape of the ground table is regulated by the landform.

2) Depressions

As shown in the contour map of the water table, large depressions are formed. Two are on the left bank of the wadi and one is on the right bank. Almost all underground water flowing into Kiffa city runs into these depressions and doesn't flow out. Obviously, these depressions were formed by excessive water-pumping-up from existing wells. In comparison between depressions in the rainy season (September 1997) and those in the dry season (April 1998), depressions in the dry season expanded much more than those in the rainy season. The depression on the left bank became more than twice as wide as in the rainy season.

The range of changes in water levels in the rainy and dry seasons was larger in depressions, as shown in the cross-sectional view of the ground table. The distance of lowering reached 5 m at maximum. As shown in Fig. 3.4-9 (the distribution map of difference in ground water levels between rainy and dry seasons), areas with the greater amount of lowering correspond to depressions and also correspond to the old urban district, a densely-populated area.

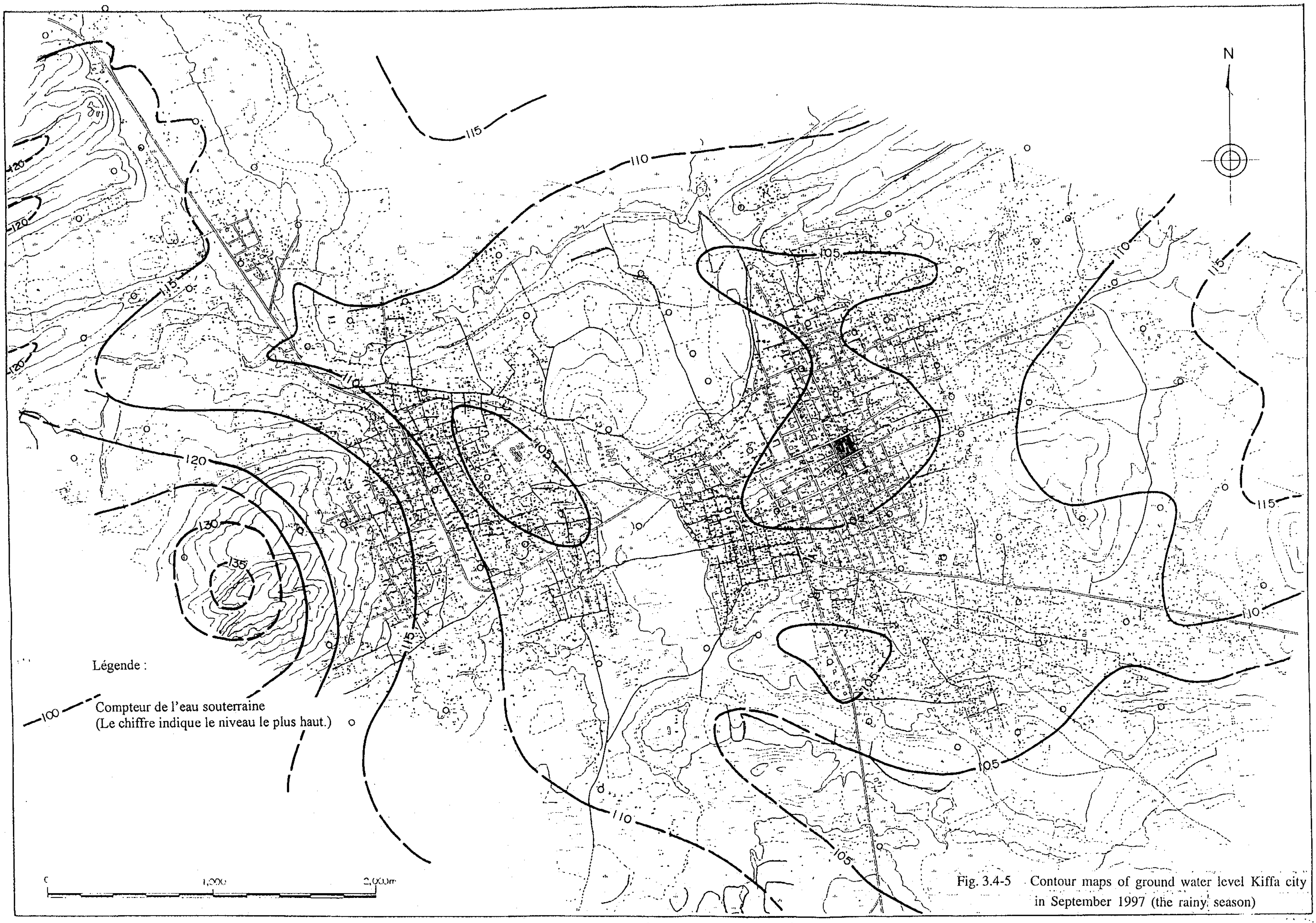


Fig. 3.4-5 Contour maps of ground water level Kiffa city in September 1997 (the rainy season)

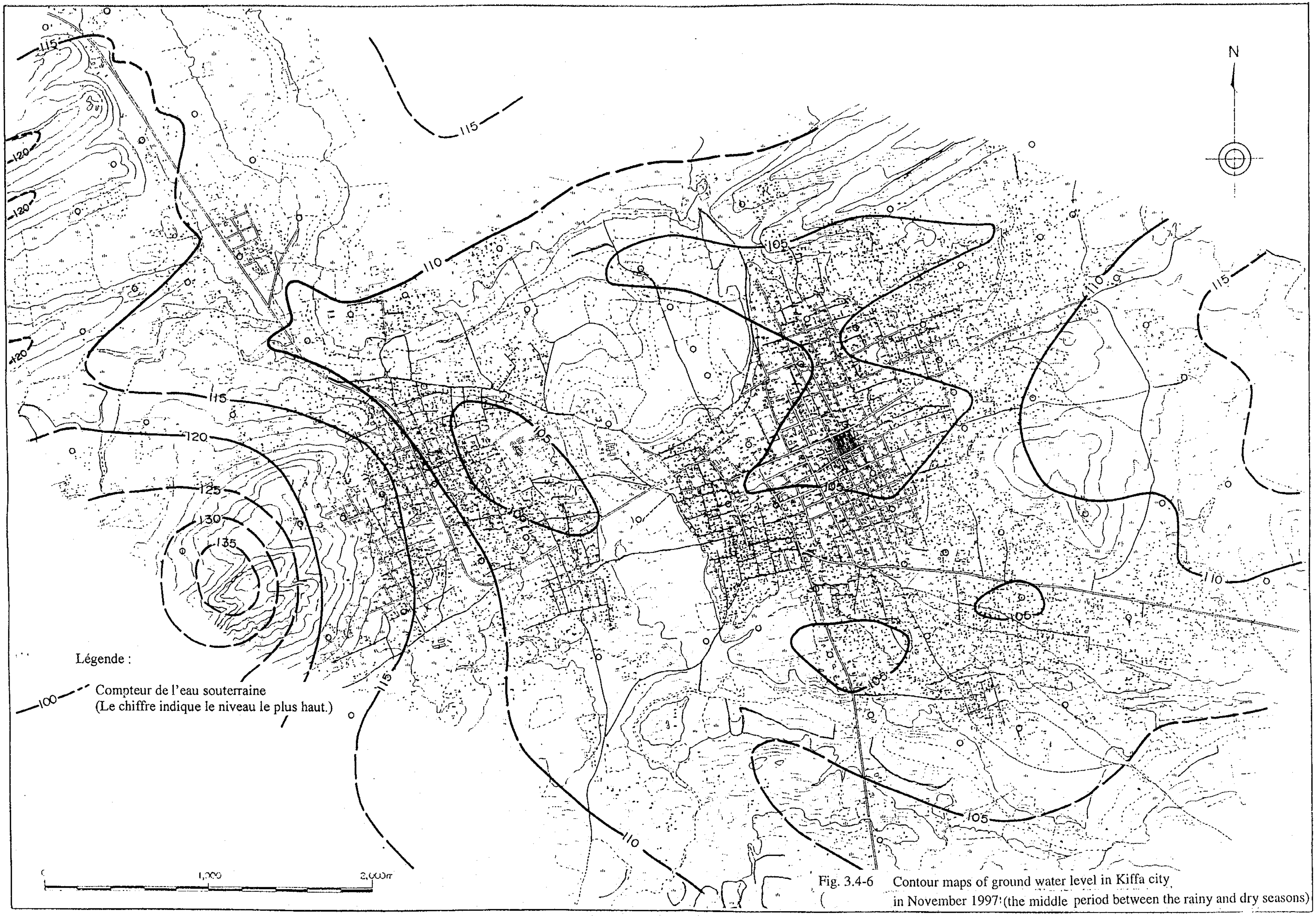


Fig. 3.4-6 Contour maps of ground water level in Kiffa city in November 1997 (the middle period between the rainy and dry seasons)