THE SEMY-ARID GROUNDWATER RECHARGE STUDY (SAGRE)

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ABSTRACT

A groundwater recharge study has been carried out by the Institute of Hydrology (Wallingford) and the Sahelian Centre of ICRISAT on the right bank of the Niger. The 600 km^2 study area is located on the Say plateau, which forms an outlier of the Continental Terminal formation. Groundwater levels within a network of 53 monitoring wells and boreholes have been monitored on a monthly basis since March 1991, and will provide data to allow estimation of regional recharge by groundwater modelling. Samples for full chemical analysis, including tracer elements, have also been taken from all wells during both the dry and wet seasons. Experiments to calculate site specific recharge rates through soil water balances have been conducted at three sites on contrasting land use (tiger bush, millet and fallow). Finally historic recharge figures are being obtained from the results of unsaturated solute profiles for a 60 m deep dug well being constructed within the area.

RÉSUMÉ

Une étude de la recharge des nappes dans la zone expérimentale de HAPEX-Sahel, en rive droite du Niger, a été entreprise conjointement par l'Institut d'hydrologie de Wallingford et par le centre sahélien de l'ICRISAT. La zone d'étude couvre 600 km^2 et est située sur le plateau de Say qui appartient aux formations du Continental Terminal. Les niveaux de l'aquifère ont été relevés mensuellement depuis mars 1991 sur 53 sites. La recharge sera estimée par modélisation de l'aquifère. Des analyses chimiques complètes, incluant les éléments traces, seront effectuées sur des échantillons prélevés en saison sèche et en saison humide. La recharge locale sur les sites de brousse tigrée, mil et jachère du Super-Site Sud de HAPEX-Sahel, sera aussi évaluée par le biais du calcul du bilan hydrique local. Enfin, le creusement d'un puits de 60 mètres de profondeur permettra d'analyser le profil des solutions de la zone non saturée et d'estimer les taux de recharge des dix dernières années.

1. GENERAL OBJECTIVES

In 1990, the Institute of Hydrology (UK) began a five year groundwater recharge study on the right bank of the Niger river, approximately 45 km to the south of the capital Niamey. The project, which is being carried out in collaboration with the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), is known as the Semi-Arid Groundwater REcharge study (SAGRE). The study has three major objectives:

- to compare and evaluate three different techniques of measuring recharge: **chemical** (solute profiling and groundwater chemistry), **physical** (soil moisture measurements), **groundwater modelling** (groundwater levels);
- to quantify direct recharge taking place below the major land use types in the area; tiger bush, millet fields and fallow land.

Groundwater recharge corresponds to deep drainage taking place from the soil below the root zone. It, therefore, constitutes an important element of the sub-surface water balance and of the wider land surface - atmosphere energy balance, which is the subject of the HAPEX - SAHEL investigation. By quantifying the deep drainage component and providing information relating to regional groundwater levels and fluctuations, SAGRE links directly to, and complements, the HAPEX study.

2. GEOGRAPHIC AND TEMPORAL COVERAGE

2.1. Study area

The study area forms part of the Say plateau on the right bank of the Niger river and lies approximately 45 km south of the capital, Niamey (Figure 1). Investigations have been concentrated within a 35 km x 17 km rectangle, centred around the ICRISAT experimental farm at Sadore. The northern and southern boundaries lie between latitudes 13° 10′ and 13° 17′ N, the western boundary is marked by longitude 2° 5′ E and the eastern boundary by the Niger river. The boundaries mark the limit of the regional groundwater level study. Within the area three sites, representative of the major land use types, tiger bush, millet and fallow land, were selected for point measurements of recharge using soil moisture techniques (Figure 2).

The Say plateau forms an outlier of the Continental Terminal formation, of Mio-Pliocene age, resting directly on a weathered pre-Cambrian basement of granites, gneiss and schists. The principal aquifer is an oolitic ironstone horizon found at the base of the Continental Terminal formation. The oolite dips gently eastward (Figure 3) varying in thickness from less than 2 m to 9 m, with a marked thickening between Diakindi and Sadore (BURRI, 1987). In the west, geological information is very scarce, but indications from the logs of recently dug wells suggest that the oolite thins to less than 2 m, and in many places is absent.

On the eastern side of the plateau, the water table lies either within, or just above the top of the oolite, but toward the west it dips steeply into the underlying basement (Figure 3). Where present, the oolite is overlain by a poorly permeable, variable sequence of sandstones, silty sandstones, mudstones and laterites up to 50 m thick.

2.2. Previous work and scope of study

Prior to the start of the SAGRE/HAPEX study a limited amount of groundwater level monitoring work had been carried out by the Ministry of Hydraulics (Direction des ressources en eau - DRE) in the vicinity of the ICRISAT experimental farm at Sadore (BURRI, 1987; CALOZ, 1990). The DRE have also compiled a series of atlases showing the distribution of water sources in the arrondissements covering the study area (DRE, 1990, 1992a, 1992b). Most of the geological information is from four sources; BOULANGER (1962), GREIGERT (1966), BRGM (1983) and BURRI (1987). Some groundwater chemical analyses were published for the region in BRGM (1983), while JOSEPH and OUSMANE (1988) and JOSEPH and GIRARD (1990) have reported on problems of localized groundwater pollution. Soil moisture studies have been restricted to a number of small-scale experiments carried out within the ICRISAT experimental farm (PAYNE *et al* 1990; KLAIJ and VACHAUD, 1992). These studies have been restricted to the sandy soils which support millet cultivation.

The current project was set up in 1990, but routine monitoring did not begin until March 1991. Since this time groundwater levels have been measured on a monthly basis. It is anticipated that monitoring will continue until the end of 1994, by which time four complete seasonal cycles will have been recorded.

Groundwater samples have been collected during the course of two campaigns carried out in 1992, one at the end of the dry season, the other during the wet season. No further sampling is planned. Pore water samples for solute profile analysis have been taken during the construction of a 75 m deep well in the western part of the study area.

Finally, measurement of soil moisture content at the three selected land use sites began in May 1991 and will be continued until October 1994. Monitoring has taken place on a monthly basis, but during the HAPEX-SAHEL Intensive Operating Period (IOP), intervals were adjusted to coincide with that of the HAPEX experimental plan. More details of the soil moisture campaign will be published in a separate paper.

3. EXPERIMENTAL SET UP

3.1. Groundwater levels

Groundwater levels have been measured on a monthly basis since March 1991 using a monitoring network of 53 dug wells and boreholes. More frequent, weekly readings, however, have been made from November 1991 along a line of 7 wells, extending across the bed of the Damari stream near Diakindi (Figure 2). During the IOP the monitoring schedule remained unchanged, any increase in frequency being considered unnecessary, given the slow rate of water level response to rainfall events. The network gives a density of approximately one point per 11 km^2, although in practice the distribution is very uneven, with some areas having a better coverage than others. In general the lower-lying cultivated regions to the east and along the length of the Damari valley have a more dense coverage than the less populated tiger bush areas in the west. The wells used for monitoring are of the traditional hand dug variety. Older types are usually unlined and in a poor state, whereas more recent examples are lined with concrete and are generally in better condition.

With this information groundwater level maps are being prepared for each month. The data is being used as input into a finite difference groundwater model (MODFLOW ^{EM}) to establish the rate of regional groundwater recharge. Aquifer characteristics, including permeability and storage coefficients have been taken from data published by BRGM (1983) and GLYNN (1991). Measured groundwater levels will be used to calibrate the model.

Rainfall data has been collected from a network of 7 EPSAT-Niger raingauges located within the study area (Figure 2). The gauges log both rainfall totals and rainfall intensity. Four gauges were installed prior to the start of groundwater level monitoring. The remaining three, those at the tiger bush, millet and fallow sites were installed in mid-1991.

3.2. Chemistry

Samples for groundwater chemical analysis have been taken from the network of 53 wells used for groundwater level measurements. Additional samples have been taken from springs along the escarpment near the eastern boundary and from boreholes fitted with handpumps. This has increased coverage to 61 sites. Analysis has included all major elements including (Ca, Na, K, Mg, HCO_3, SO_4, Cl, NO_3) plus a number of selected trace elements (Si, Fe, Mn, Sr, Ba, B, Li).

The solute profile sampling programme has been carried out at a 77 m deep well constructed just outside the western boundary of the study region. Samples have been taken during construction every 25 cm in the top 10 m and at 50 cm intervals below. Water is removed from the samples for analysis in the laboratory by elutriation or extraction using a centrifuge. Pore water collected from 170 samples has been analyzed by ICP-OES[1] for the following elements: Ca, Na, K, Mg, SO^{2-}_4, B, Li, P, Si, Sr, Be, Ba, Y, Mn, Co, Fe, Zn, V, Cd, La, Zr, Cr, Ni, Mo, Al, plus Cl^{-1}, NO_3^{-1}, pH and HCO_3.

The solute profile technique uses variations in the chemistry of unsaturated pore water with depth to determine past fluctuations in the recharge rate. The depth profiles of chloride and nitrate are of particular relevance (ALLISON and HUGHES 1978).

To calculate recharge it is necessary to know the chemistry of the input water to the system, the local rainfall. Rainfall samples have thus been collected every three weeks for analysis throughout the 1992 wet season from a series of seven raingauges scattered around the study area (Figure 2). These data have been supplemented by samples taken on a storm by storm basis between March and September 1992, from five other raingauges on the left bank of the river. All sites form part of the EPSAT-Niger network (LEBEL *et al.*, this issue).

A total of 140 rainfall samples have been collected, of which 28 have been subject to full ICP-OES analysis. Of the remainder 112 have been analysed for Cl^{-1}, 68 for NO^{-1}_3 and 25 for Iodine. All samples have also been analysed for the stable isotopes deuterium (^2H) and oxygen 18 (^{18}O)

3.3. Physical techniques (soil moisture measurements)

A series of experiments to calculate groundwater recharge through soil moisture measurements have been made at three selected sites in the study area. These are not discussed further here, but are described in a forthcoming paper to be published by CUENCA *et al.*

4. MEASUREMENT ACCURACY

The location of each groundwater level monitoring site has been fixed using a Magellan Geographical Positioning System, accurate to a few tens of meters in the horizontal direction. Well head elevations have been determined by altimeter survey with an accuracy of, at best +/- 1 m. The precision of groundwater level elevations is, therefore, more a function of the accuracy of the datum elevation than the depth to water measurements, which are accurate to a few millimetres.

All the wells have water drawn by hand throughout the day, which superimposes a short-term daily fluctuation of water level on the longer-term seasonal trend. Though the scale of these daily fluctuations are generally restricted to a few centimetres they nevertheless have to be taken into account when interpreting seasonal hydrographs.

5. DATA PROCESSED

5.1. Aquifer properties

In the ferruginous oolite, water movement and storage are largely controlled by the presence of fissures and fractures rather than intergranular hydraulic properties. The fracture system imposes a high but variable permeability. Transmissivities calculated from pumping tests carried out by BRGM in the vicinity of the Say plateau (BRGM, 1983) and by the Institute of Hydrology at the ICRISAT farm (GLYNN, 1991) have an arithmetic mean of 310 m^2day^{-1} and a geometric mean

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[1] Inductively Coupled Plasma - Optical Emission Spectrometry.

of 157 m^2day^{-1} (Table 1). There is, however, considerable variability with values ranging from 22 m^2day^{-1} to 1 296 m^2day^{-1}. Assuming an average aquifer thickness of 5 m, the arithmetic and geometric values translate to mean permeabilities of 62 m day^{-1} and 31 m day^{-1} respectively. Information relating to the storage capacity of the aquifer is, unfortunately, more scarce. Only three values are available, all from pumping tests at ICRISAT. Two of these figures, .0004 and .0003 are representative of the confined aquifer storage while the .02 value is more typical of the unconfined storage. Clearly, further data is needed to better define this parameter.

The basement complex granites and gneisses underlying the Continental Terminal are on the whole significantly less permeable, though locally, where fissured, can be very productive. Transmissivities obtained from BRGM pumping tests (BRGM, 1983) show considerable variability, ranging from 4.7 m^2/day to 657 m^2/day. The higher values are most likely related to the presence of local fissure and fracture systems of limited extent. The arithmetic mean transmissivity derived from all test is 139 m^2/day while the geometric mean is 50 m^2/day. The few storage coefficients available are all very low but again show considerable variability ranging from 3×10^{-4} to 1.4×10^{-9}.

5.2. Groundwater levels

Water level data covering the period March 1991 to November 1993 has already been processed. Water level maps are available for each month except for the period from September 1991 to February 1992. The water table map for June 1992 is given as an example in Figure 4.

Dry season water table elevations range from 172 m (IH28) in the east to 215 m (IH40) in the west. Most groundwater movement is eastward from an ill-defined groundwater divide in the western part of the study area; smaller flows take place to the west (Figures 3 and 4). Depths to groundwater vary from less than 1 m along the Damari stream bed, to over 60 m in western parts of the region where ground elevations exceed 270 m.

To the east of the divide the water table has two distinct slopes; from the divide itself to the ICRISAT farm the gentle eastward slope is less than 1 in 600, but from ICRISAT to the base of the escarpment this steepens to 1 in 450. West of the divide groundwater levels initially fall steeply at 1 in 100 as the water table enters the basement complex, however, further west gradients decrease as water flows toward the valley flanking this side of the plateau.

A striking feature of the water table is that the groundwater and surface water divides are not coincident. This is confirmed by the cross-section shown in Figure 3. The groundwater divide is displaced about 5 km to the east of the surface watershed, which lies close to the western boundary of the study area. The principal factor governing the position of the groundwater divide appears to be the elevation and horizontal extent of the ferruginous oolite aquifer, which becomes attenuated and reaches its highest point along the line of the divide. Further west, the oolite pinches out in many places and becomes patchy in distribution. The sinuous form of the divide is probably controlled by the irregular nature of the oolite sub-crop at the point where it begins to pinch out.

The shallow gradients to the east of the divide reflect the relatively high permeability of the oolite. Steeper gradients close to the river are controlled by the increased dip of the oolite in this region and by the low elevation of the discharge point at the base of the scarp flanking the plateau (Figure 3). Immediately to the west of the divide steep gradients are present where the water table drops below the base of the Continental Terminal into the much less permeable basement below.

The passage of the water table from oolite to basement is reflected not only by a change of water table gradient, but also by a difference in the scale of annual water level fluctuation. Within the basement this annual fluctuation is typically of the order of several meters, whereas in the oolite the fluctuation is more subdued, being generally less than 0.5 m. This contrast is illustrated in Figure 5, which shows the change of water level measured between May and August 1992, and Figure 6 where the hydrograph of a basement complex well (IH22) is compared with site IH1 from the oolite. The reason for the contrast is simply that the basement has a much lower storage capacity than the oolite (Table 1), which means water level rises in the basement are considerably larger for any given input of water.

As well as the strong contrast exhibited between basement and oolite areas, the change of water level map (Figure 5) also reveals a distinct trend within the oolite area itself. Groundwater level fluctuations appear to be more pronounced in the vicinity of the Damari stream bed. A zone of increased fluctuation extends for approximately 5 km from the stream bed on the northern side, but for less than 1 km to the south where the flanks of the valley are much steeper. Within this zone annual water level changes range from 0.4 m to 0.2 m. Assuming the storage capacity of the aquifer is reasonably constant, the implication is that the stream bed and/or the areas flanking the stream are providing a focus for recharge by effectively concentrating run-off.

5.3. Groundwater Chemistry

Analyses of water samples collected during the dry and wet season campaigns have not yet been interpreted in detail. However cursory inspection has highlighted a number of significant features related to groundwater composition. These are:

a) The Total Dissolved Solids (TDS) content of water throughout the area is extremely low. Values range from 9 to 326 mg l^{-1}, the average being 43 mg l^{-1}.

b) There is a marked contrast in salinity between groundwater located to the east and west of the groundwater divide. To the west, where groundwater is contained within the basement, TDS values average 129 mg l^{-1} ; to the east, where water is within the oolite aquifer, values are reduced to 32 mg l^{-1}.

c) Localized pollution of water sources is a problem at a small number of sites. At five sources the concentration of NO_3 exceeds 100 mg l^{-1}, considerably above the WHO recommended limit of 50 mg l^{-1}.

d) The dominant water type is Ca-Mg:HCO_3.

The exceptionally low TDS concentrations are surprising given the considerable thickness of unsaturated zone through which infiltrating water has to pass. In places this exceeds 60 m, but is more commonly between 20-40 m. Based on chloride profiles obtained from a well dug during the course of the project, the residence time for infiltrating water in the top 40 m is estimated to be in excess of 150 years. Yet despite being in transit for this length of time very little dissolved solid appears to have been taken into solution during passage to the water table. The implication is that the lithology of the unsaturated zone is dominated by poorly soluble minerals. This is supported by the results of X-ray diffraction analysis of 8 samples taken at depths between 2 m to 40 m at the solute profile site. Results show the major mineral components of the silty sandstone-siltstone-mudstone lithology to be quartz, kaolin, iron oxide and goethite, all of which are poorly soluble and would not be expected to contribute significantly to the dissolved solids content.

Higher TDS concentrations in the basement complex aquifer perhaps reflect the presence of more soluble material within the weathered zone which is developed at the top of the formation. Minerals within the gneiss such as micas, pyroxenes and amphiboles are abundant in calcium, magnesium and sodium. The weathered products of the gneiss provide a rich source from which these elements can be dissolved. Although basement complex waters tend to have a higher TDS concentration the type of water does not appear to be greatly different from that of the oolite aquifer. A Piper plot of the two groups illustrates the point (Figure 7). Both groups plot very closely together, the only difference being that the basement complex water is slightly enriched in Mg, Ca and HCO_3 and depleted in SO_4 and Cl with respect to oolite waters.

In recharge studies the distribution of Cl is frequently used to identify areas in which active recharge is taking place. The conservative nature of the element means that for a given aquifer the concentration can be directly related to the amount of infiltrating rainwater bringing in the chloride. Where little recharge is taking place the Cl concentration tends to be increased; where recharge rates are high concentrations are much lower. The distribution of chloride in waters sampled during the wet season is shown in Figure 8. Lowest concentrations occur to the north of the ephemeral stream; highest levels are in the western regions, and in areas to the south of the stream. The implication is that within the oolite areas to the east of the groundwater divide, most recharge is concentrated in the area to the north of the stream with less taking place on the southern side. In general terms the picture is similar to that provided by the evidence of the water table fluctuation data. Along the stream bed itself a number of wells show anomalously high Cl concentrations which are probably associated with flooding and subsequent pollution rather than low rates of recharge. The high Cl concentrations in the west of the region are possibly due to the water being contained within the basement complex and are not necessarily associated with lower recharge rates. However, more analysis of the chemical data, particularly of the trace elements is needed to confirm the pattern of recharge suggested.

5.4. Solute profile well

The solute profile sampling programme has been carried out at a 75 m deep well, constructed just outside the western boundary of the study region. The technique uses variations in the chemistry of pore water with depth in the unsaturated zone to determine the rate of recharge in the historic past. Depth profiles of chloride and nitrate content in particular are used to identify past fluctuations of recharge rates.

Preliminary interpretation of the upper 45 m, based on the amount of chloride preserved in the profile, suggests the entire record represents a period of up to 165 years. The average recharge rate at the site over this period is estimated to be in the order of 17 mm per year or in other words about 3 % of total rainfall. Further analysis and interpretation is needed, however, before these figures can be confirmed. Analysis of the lower 30 m is yet to be completed.

5.5. Groundwater modelling

Using the groundwater level and aquifer parameter data available a preliminary finite difference groundwater model (MODFLOW ^{EM}) has been implemented for the area to establish the rate of regional groundwater recharge. The basement complex, ironstone and Continental Terminal sandstones, siltstones and mudstones are distinguished in terms of their geometry and hydraulic properties. Best present estimates of these properties are used in the model, together with generalized rainfall input values.

Initial results indicate that a regional recharge of 60 mm per year is sufficient to account for observed water level responses. This is somewhat higher than the 17 mm figure derived from solute profile calculations. It should be remembered, however, that the solute profile result represents direct recharge within a tiger bush region, whereas modelled values integrate direct recharge from all land types and indirect recharge including infiltration from stream beds. The figures are thus not directly comparable. However, these preliminary findings do suggest that direct infiltration below tiger bush areas is one of the least important sources of recharge in the area. Indirect recharge and recharge below other land use types (millet and fallow) are probably more important.

5.6. Data storage

Eventually all data will be transferred to the H2SIS data base in the following form:

- Groundwater Levels. All levels will be given as a depth and elevation for each month or week from March 1991 to November 1993.
- Groundwater chemistry: all samples from both sampling campaigns(dry and wet season) will be reported with all major elements and selected trace elements.
- Rainfall chemistry: this will include the chloride and nitrate content of 140 samples of rainfall collected during 1992.
- Solute profile work. Chloride and nitrate composition of soil water samples taken at 0.5 m intervals from 0-45 m depth at the solute profile well site will be reported.
- Soil moisture data. An extensive series of soil moisture, soil potential and hydraulic conductivity measurements will be reported. Details of the data lodged can be found in a forthcoming paper by CUENCA *et al*.

6. SUMMARY

Three techniques, to measure groundwater recharge are being carried out: groundwater modelling, chemical and physical methods.

- Groundwater modelling will provide information on regional values of current rates of recharge, but will contribute little toward the understanding of the processes taking place.
- Solute profiling will identify historical recharge rates at a single point, but again says nothing of the mechanisms.
- Soil moisture measurements give current rates of recharge at a single point and can also be used to identify the dominant processes operating.

It is anticipated that the combined result of this multi technique approach will provide more reliable values for recharge than would be obtained by the application of a single technique in isolation.

REFERENCES

ALLISON G.B and HUGHES M.W., 1978. The use of environmental chloride and tritium to estimate total recharge to an unconfined aquifer. *Proc. Symp. Isotope Techniques in Groundwater Hydrology*, **Vol. 1**, 57-72. IAEA Vienna.

BOULANGER J. 1962. *Les gîtes de fer de la vallée du Moyen Niger. Etude géologique synthétique.* Rapport inédit BRGM NIA 62 A1 pour le ministère des Travaux publics, des Mines et de l'Hydraulique du Niger.

BRGM, 1983. *Programme 1 000 forages Niger.* Vol. 1 - Implantation des forages. Vol. 2 - Résultats géophysiques (SGN 82 GPH 025). Vol. 3 - C.R. des travaux de forages - Rapport BRGM 83 AGE 030 - (Arch. Dir. Hydraul. du Niger).

BURRI M., 1987. *La bordure orientale du plateau de Say. Etude géologique préliminaire.* Ministère de l'Hydraulique, Direction des Ressources en Eau. Projet IUED.

CALOZ P., 1990. *Aquifère du Continental terminal, zone de Say. Interpretation des fluctuations de niveaux piézométriques de 1987 à 1989.* Rapport préliminaire. Ministère de l'Hydraulique, Direction des Ressources en Eau. PHNS SP1.

DRE, 1990. *Atlas des ressources hydrauliques du département de Tillaberi : arrondissement de Kollo, canton de Lamorde.* Ministère de l'Hydraulique, Direction des Ressources en Eau.

DRE, 1992a. *Atlas des ressources hydrauliques du département de Tillaberi : arrondissement de Say, canton de Say.* Ministère de l'Hydraulique, Direction des Ressources en Eau.

DRE, 1992b. *Atlas des ressources hydrauliques du département de Tillaberi : arrondissement de Say, canton de Gueladio.* Ministère de l'Hydraulique, Direction des Ressources en Eau.

GLYNN M. A., 1991. *Groundwater resorces of the Say Plateau.* Msc. Thesis (unpubl.). Department of Civil Engineering, Imperial College of Science and Technology. 105p.

GREIGERT J., 1966. *Descriptions des formations crétacées et tertiares du bassin des Iullemmeden. (Afrique occidentale).* Editions du Bureau de recherches géologiques et minières.

JOSEPH A. and OUSMANE B., 1988. *Pollution nitratée de la nappe alluviale du fleuve du Niger à Niamey.* Faculté des sciences, département de géologie, Niamey.

JOSEPH A. and GIRARD P., 1990. *Etude de la pollution en nitrate des aquifères du socle : exemple de la nappe de Niamey.* Rapport de contrat de recherche (unpubl.)

KLAIJ M.C. and VACHAUD G., 1992. *Seasonal water balance of a sandy soil in Niger cropped with pearl millet, based on profile moisture measurements.* Agricultural Water Management, **21**, 313-330.

LEBEL T., J.D. TAUPIN and M. GRÉARD, 1994. *Rainfall Monitoring: The EPSAT-Niger Setup And Its Use For HAPEX-Sahel,* in:« Hydrologie et Météorologie de méso-échelle dans HAPEX-Sahel : dispositif de mesures au sol et premiers résultats ». (ORSTOM Ed.).

PAYNE W.A., WENDT C.W. and LASCANO R.J., 1990. *Root zone water balances of three low input millet fields in Niger, west Africa.* Agron. J. **82**, 813-819.

Table 1. Aquifer properties obtained from pumping tests

Continental Terminal Formation

BH Number	Village	Transmissivity(m^2/day)	Storage Coefficient
17724	Sadore	354	
17725	Sadore	73	
17728	-	26	
17719	Ganka Bassarou	22 33	
17740	-	311	
17731	Finare	320	
17738	Oura Senna	1 296	
17734	Diakindi	346	
17716	Boya	63 73	
BH5	ICRISAT	1 123 173 173 259	0.0003 .02 0.0004
		Arithmetic mean: 310 Geometric mean: 157	

Basement Complex

BH Number	Village	Transmissivity(m^2/day)	Storage Coefficient
28604	Garba-Gounga	4.7	0.0000000014
28642	Lontia Kaina	37	0.0000013
28559	Debere Gati	4.7	0.0003
28560	Loa	6.4	0.000011
19210	-	657	
17728	-	26	
17720	Tokei	216 294	
17718	Tiassa Koara	44 86	
17715	Lontia Kaina	293	
17761	-	34	
17762	-	54	
17732	Boudourio	22 15	
17735	Mossare	432	
		Arithmetic mean: 139 Geometric mean: 50	

FIGURE TITLES

Figure 1.	Regional setting of the study area.
Figure 2.	The groundwater level and raingauge monitoring network. The line of section is that shown in Figure 3.
Figure 3.	An east-west geological section showing the Basement Complex and Continental Terminal Formation, including the major aquifer, the ferruginous ironstone. Line of section shown in Figure 2.
Figure 4.	Water table elevation for June 1992.
Figure 5.	Map showing the change of water level between May and August 1992.
Figure 6.	Hydrographs showing difference in response of aquifer to the east (IH1) and to the west (IH22) of the groundwater divide.
Figure 7.	Piper diagram to show groundwater composition of the Continental Terminal Sandstone and Basement Complex.
Figure 8.	Distribution of Chloride during the wet season.

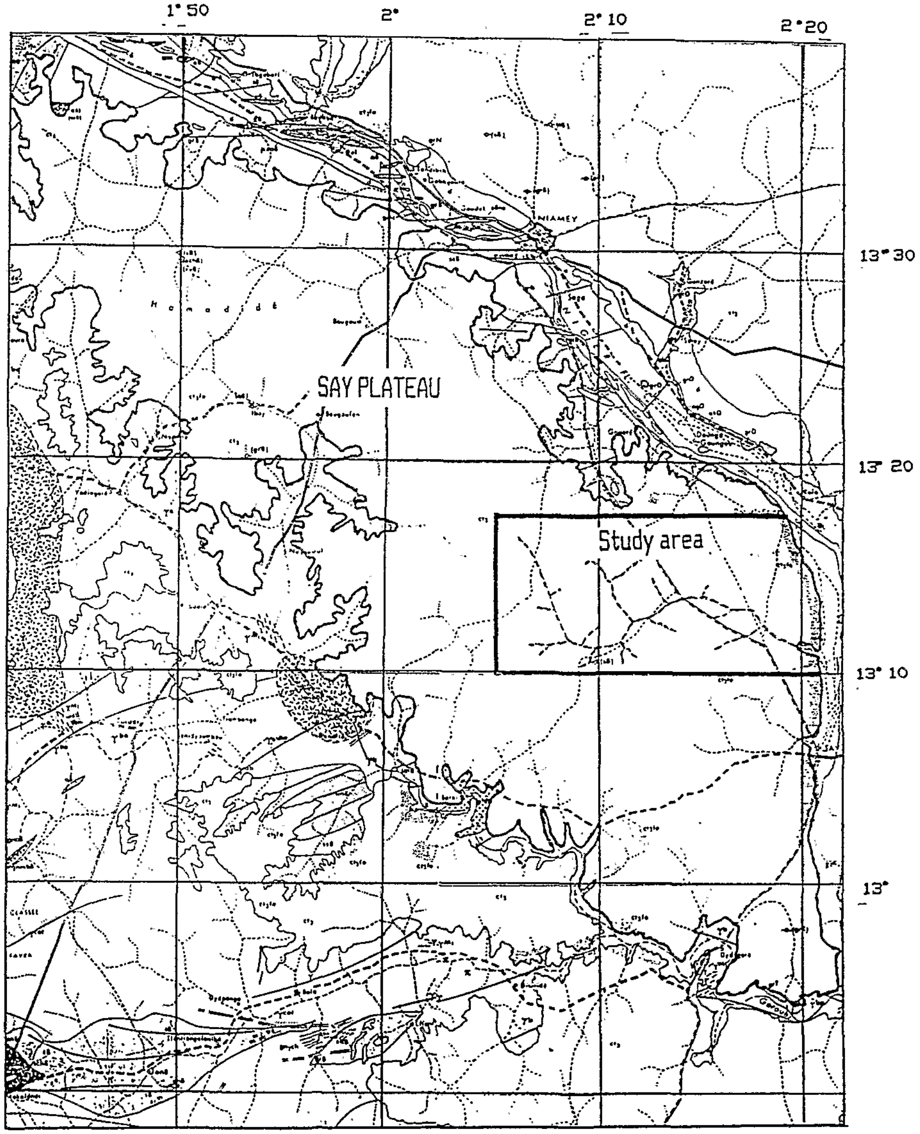

Figure 1. Regional setting of the study area.

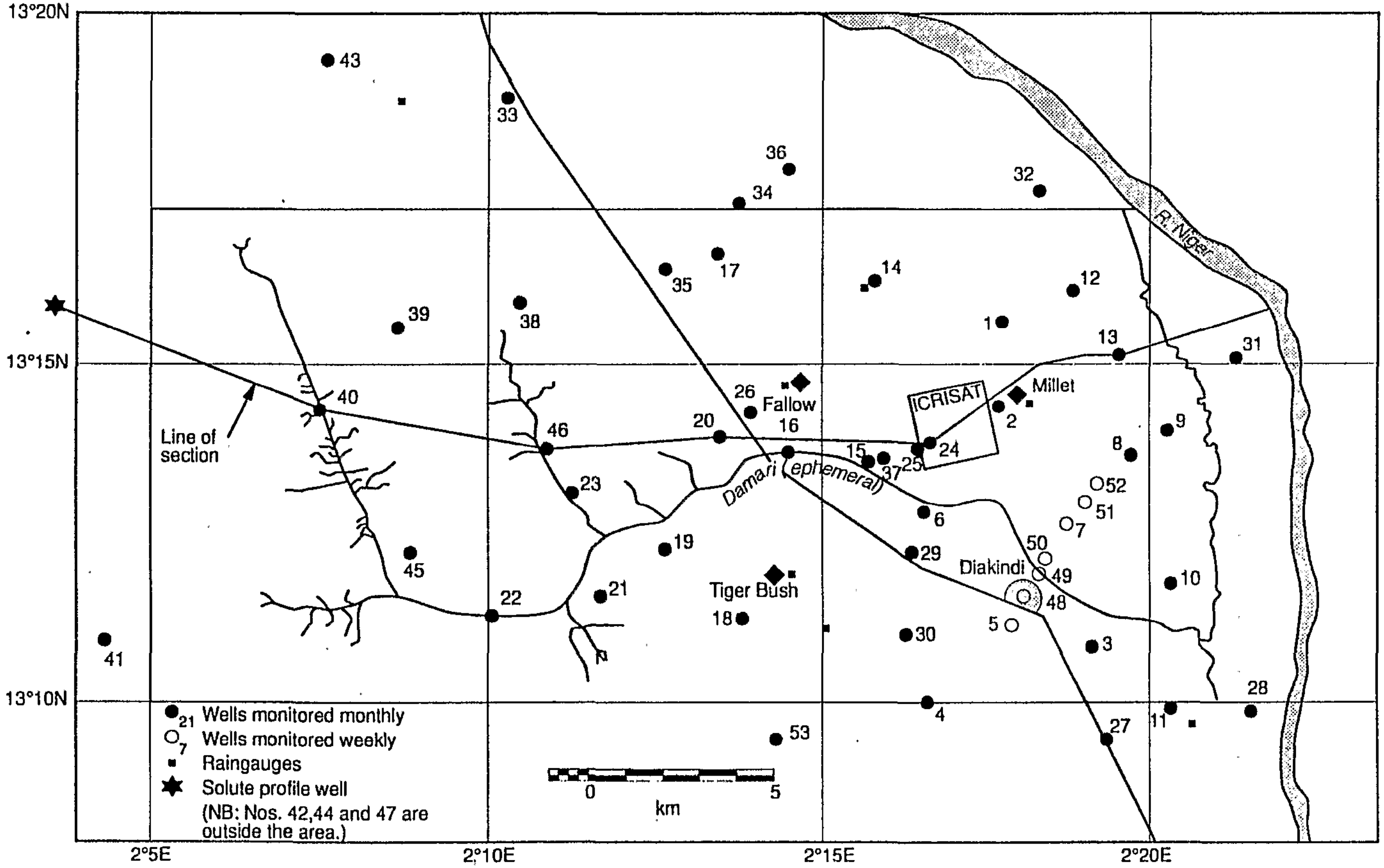

Figure 2. The groundwater level and raingauge monitoring network. The line of section is that shown in Figure 3.

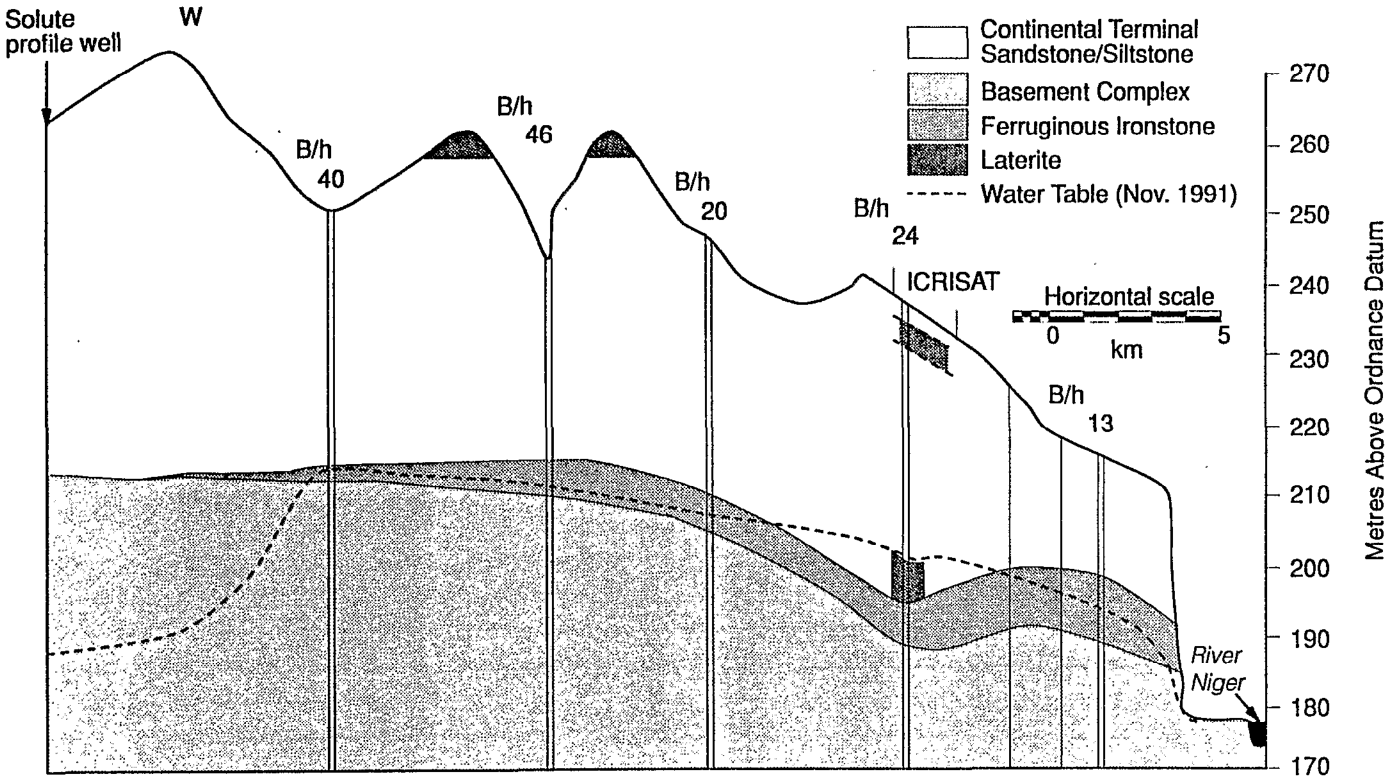

Figure 3. An east-west geological section showing the Basement Complex and Continental Terminal Formation, including the major aquifer, the ferruginous ironstone. Line of section shown in Figure 2.

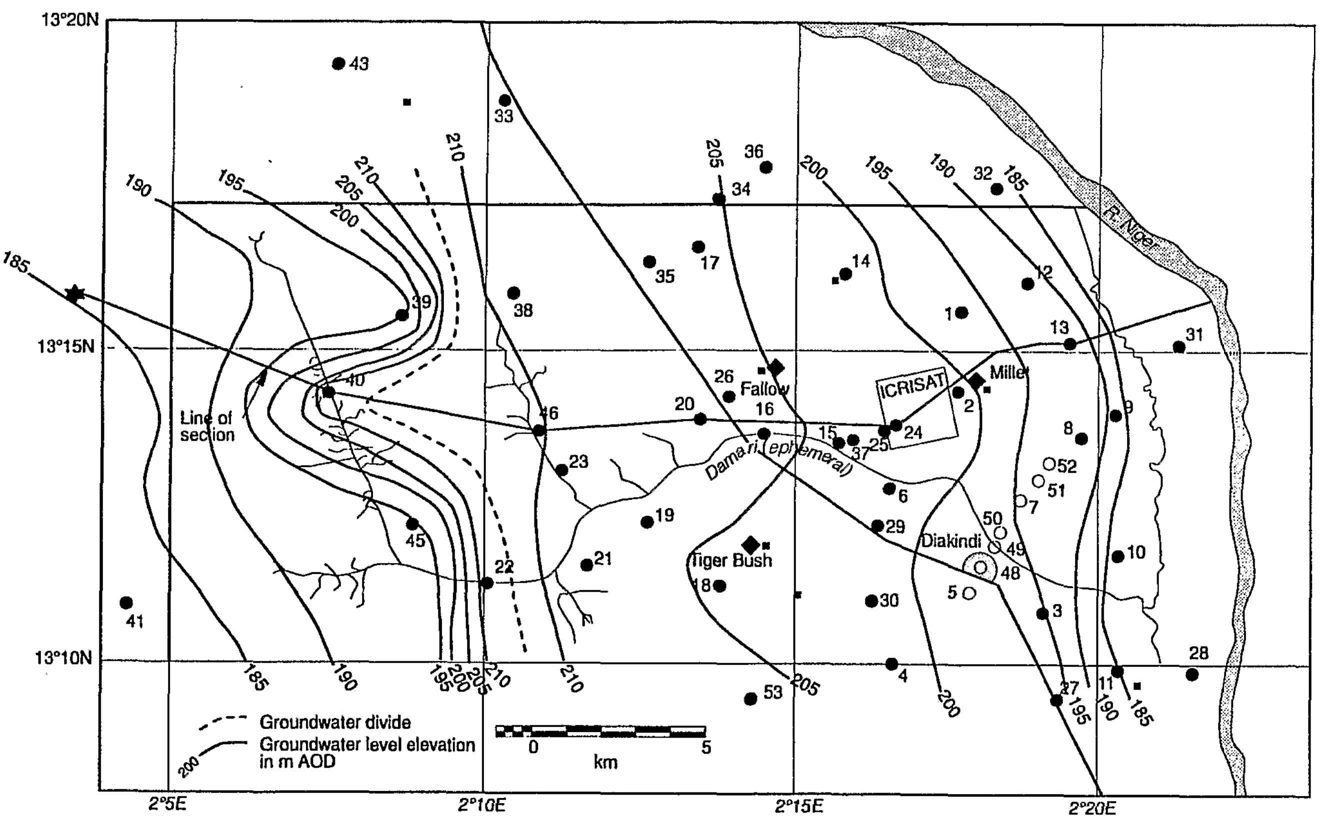

Figure 4. Water table elevation for June 1992.

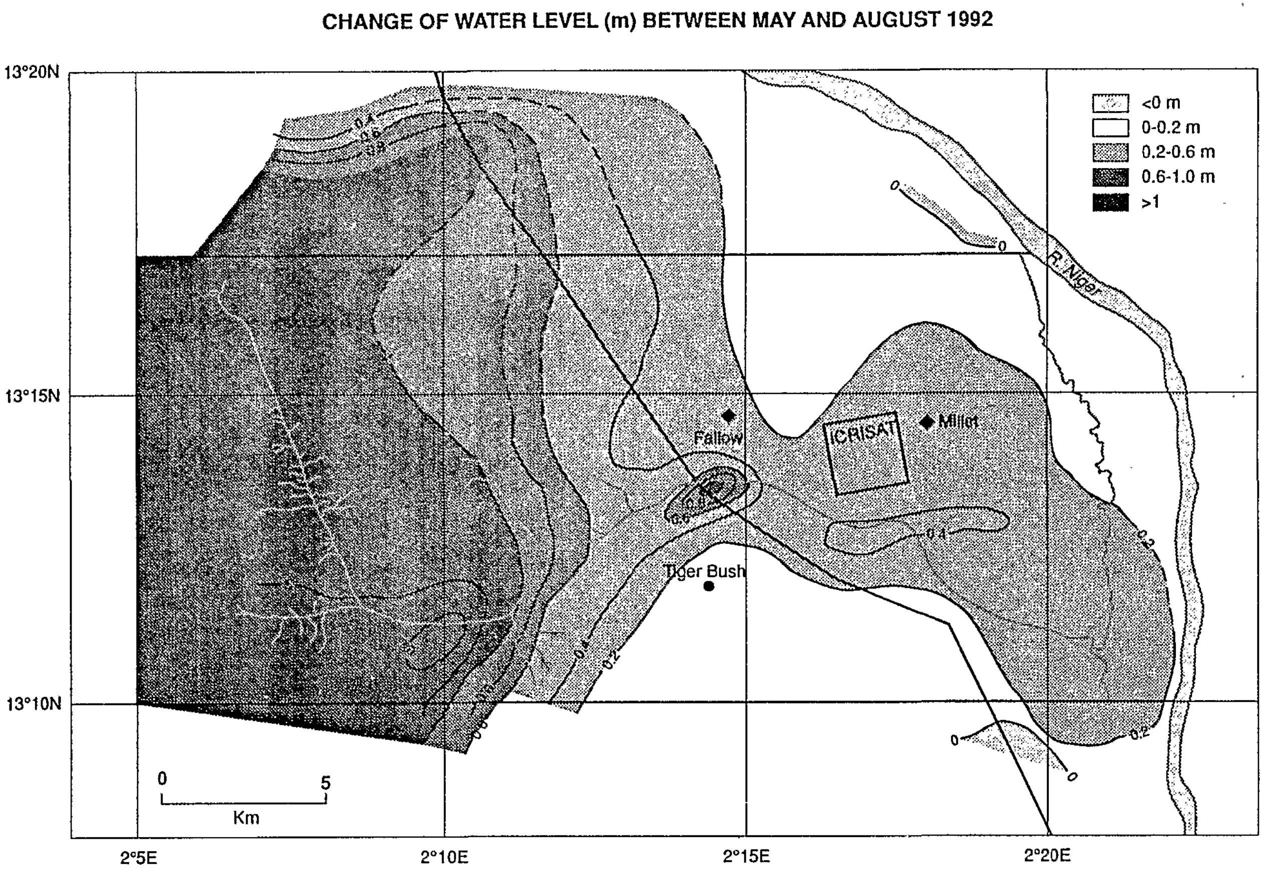

Figure 5. Map showing the change of water level between May and August 1992.

IoH/1/2-93/3D

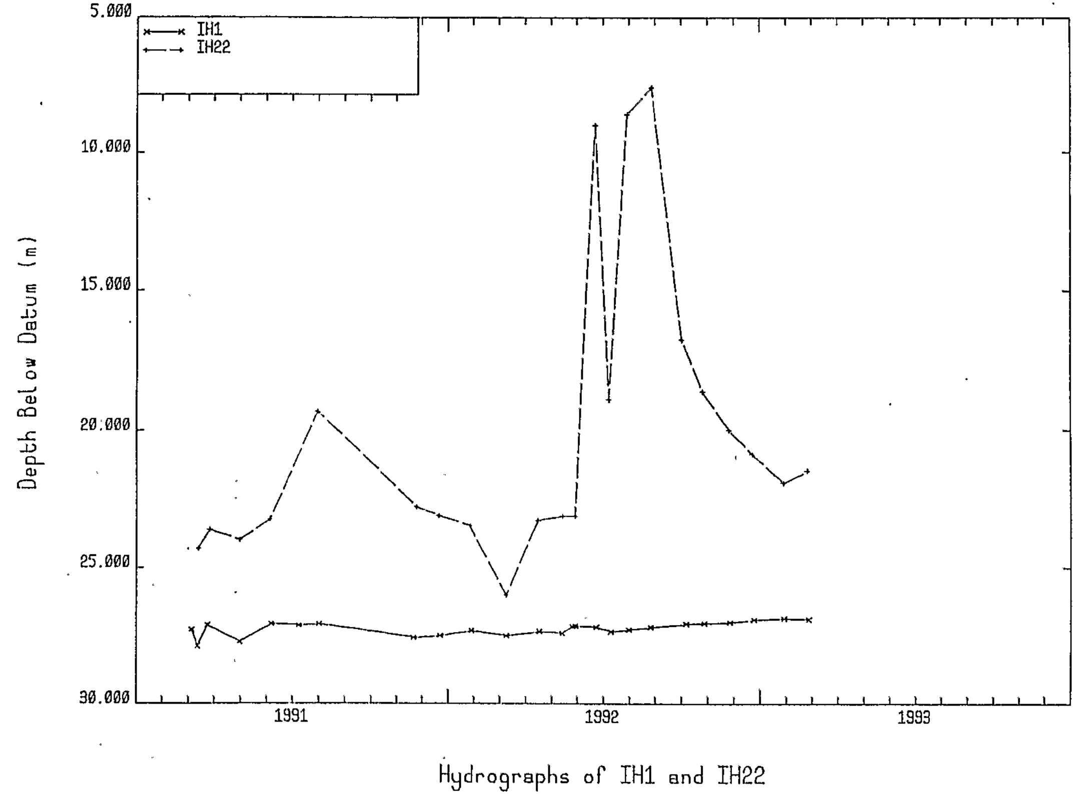

Figure 6. Hydrographs showing difference in response of aquifer to the east (IH1) and to the west (IH22) of the groundwater divide.

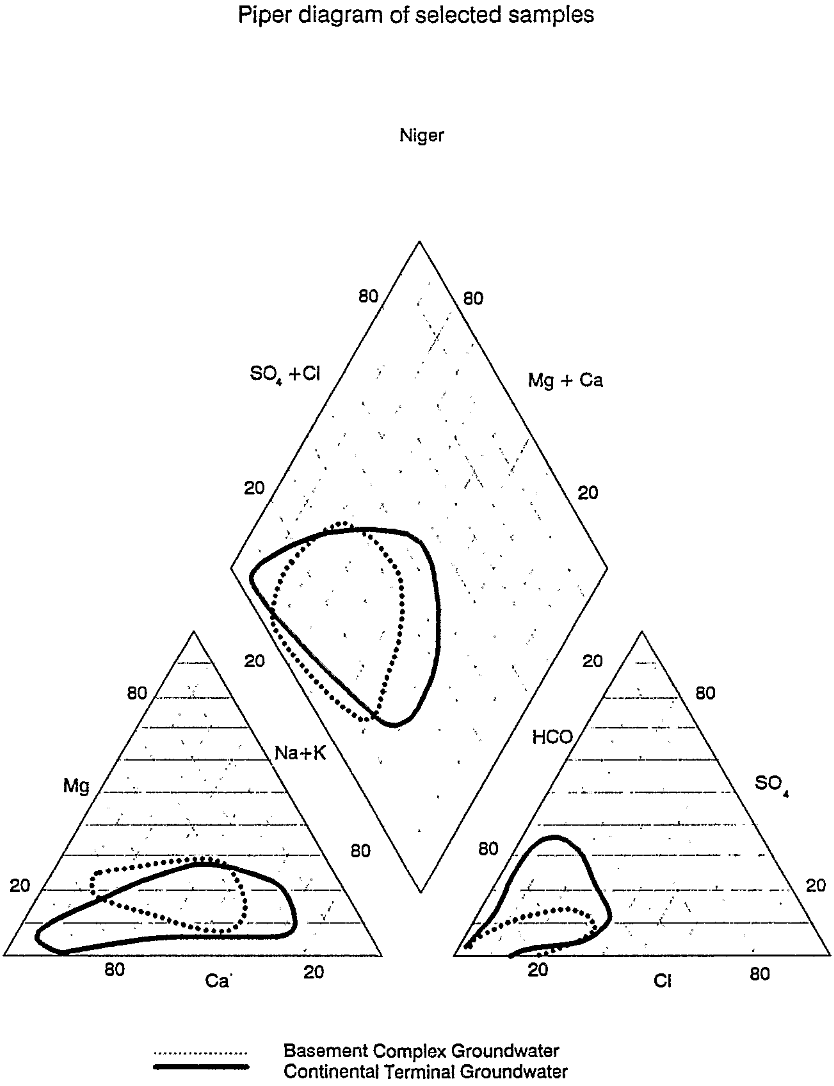

Figure 7. Piper diagram to show groundwater composition of the Continental Terminal Sandstone and Basement Complex.

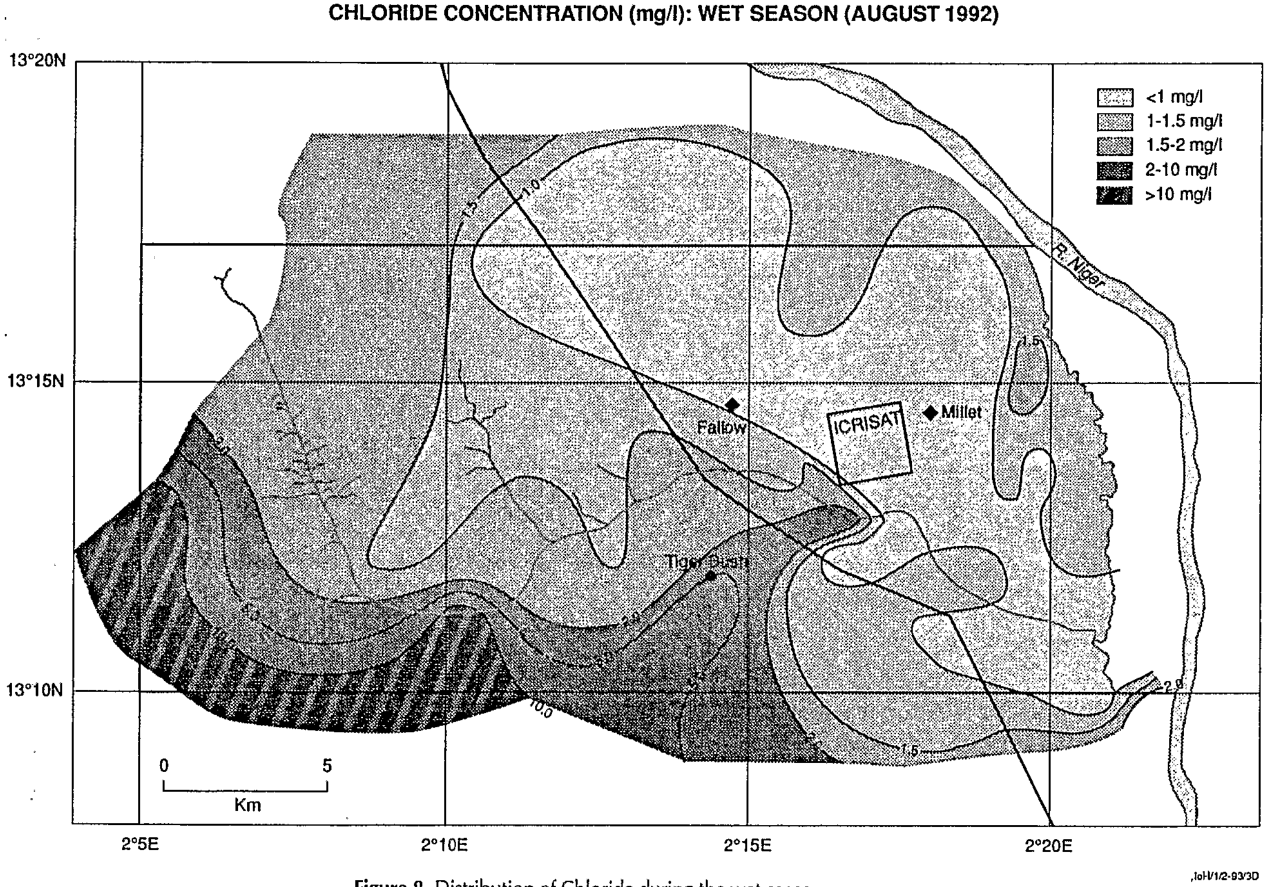

Figure 8. Distribution of Chloride during the wet season.