Water Quality Study
MOGADISHU
and
KISMAYO
Somalia

November 1998

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Introduction

Issues related to groundwater quality cannot be dissociated from those relating to the exploitation of resources [1]. Where such exploitation exceeds the natural recharge of the aquifer, a decline in the water level will necessarily occur. If this overabstraction is heavy and maintained over many years, changes may occur in the underground flow of water and serious deterioration of the water quality may occur. Many cities have experienced widespread depressions of the piezometric surface up to 20 to 50 m (Bangkok, Manila, etc.) and many others between 10 and 20 m (Bejing, Bandung, Madras, etc) and in almost all the cases studied the decline in groundwater levels has been accompanied by a deterioration of the quality of groundwater[2].

Coastal aquifers are particularly vulnerable as sea water intrusion or upconing of saline water may be aggravated by the depletion of the aquifer level. Cities, dependent upon groundwater in recent coastal limestone aquifers, are the most susceptible to sea water or saline intrusion.

Once sea water has contaminated an aquifer it may take many decades to flush out the salinity, even if the movement of groundwater to the sea can be reestablished.
Monitoring of the evolution of the groundwater quality is therefore of paramount importance as it permits implementation of the management practices necessary to control or minimize the movement of the saline gradient.

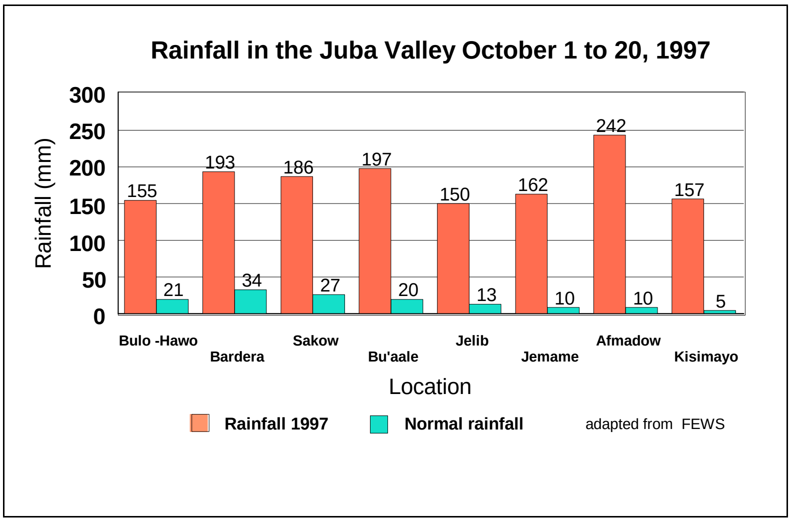
If sea water contamination is widespread, the ingress of polluted surface water of anthropogenic origin is also of concern. This is particularly evident in rapidly growing urban centres and especially in outlying' districts where the better part of the population increase is concentrated. These settlements have only limited access to public water supplies and to sanitation and this may result in serious pollution with a direct migration of the pathogenic bacteria or viruses responsible for disease transmission. The situation is made worse by the tendency of individuals to construct private wells to replace, or augment the existing water sources.

This domestic pollution is then aggravated by the poor design of the wells, by their location in overcrowded areas in close proximity to latrines, leading to infiltration by inadequate drainage, by poorly designed head walls and by a general lack of maintenance[3].

In this report we will present the case of Mogadishu and Kismayo, two coastal cities of Somalia where all these problems occur simultaneously and where civil war and protracted conflicts have put the provision of safe water in danger.

Effect of rainfall on sea water intrusion and on the quality of underground water

We can assume that 1993 was a normal year, as far as rainfall is concerned. This was not the case in 1998, where mean monthly rainfall values up to 10 times the “normal” values were observed [4]. The results of such an unusual rainfall pattern were dramatic, with huge areas flooded, the Shabelle river merging with the Juba, a situation not seen since 1961. Faillace reports that in 1961, as a result of the merging of the two rivers, several villages were flooded and the exceptionally high floods caused the inundation of almost all the areas adjoining the river, practically from the entry of the river into Somali territory up to and beyond the district of Gelib, with enormous damage and heavy losses [5]. In the 1997/98 floods, more than 50’000 families had to leave their homes and were stranded on dikes for months. Even if Kismayo was not as dramatically affected by the floods, almost the whole region was under water. The extent of the 1997/98 rainfall is shown in the next figure where the records made at different pluviometric stations along the Juba river are given. In 1961 too, records in several areas of the country showed annual values up to twice the normal ones, with annual rainfall for Mogadishu up to 1150 mm compared to the normal average of about 400 mm/year. For the Shabelle river as well, the floods were important and many villagers had to leave their homes, as in Belet Weyne, where the entire population had to seek refuge on higher ground close to the airport. The extent of the floods is also clearly visible in the satellite image shown in the next figure, where the size of the temporary lakes south of Jamaame and along the Juba and the Shabelle river can be appreciated. Close to the sea, but also where the wells are affected by saline geological layers, the chemical quality of the water was necessarily affected by the extent of the recharge of the aquifers. In these areas this had certainly helped to push the soft water/brackish wedge toward the sea, improving the water quality but also raising the water level significantly. This was the case of the wells of the two cities studied in this project, even if the last parameter must be taken with precaution. In this type of wells, the water layer is thin and must be thin, otherwise some brackish water will be mixed up with the overlaying soft one.

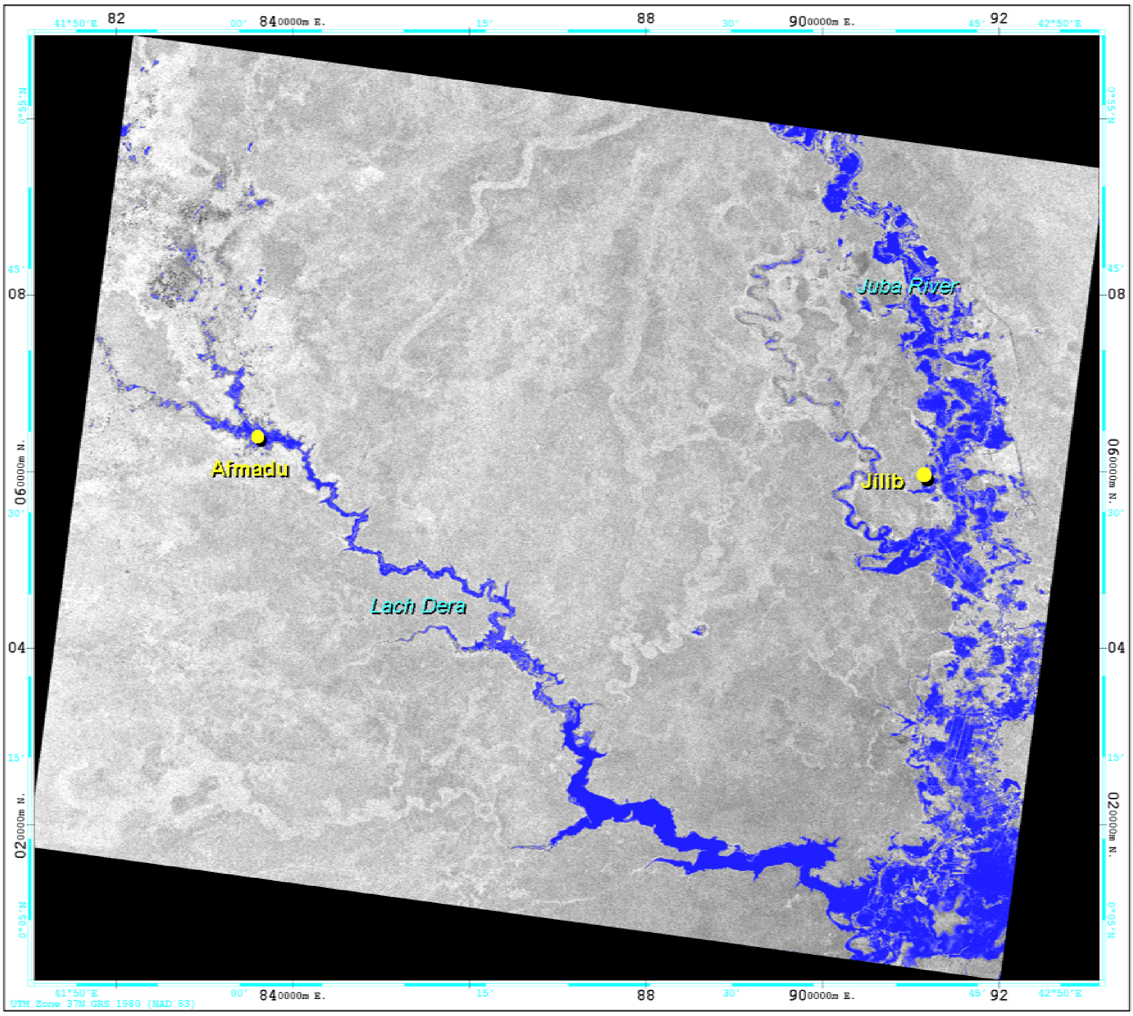


Objectives of the 1998 water quality study

At the beginning of November 1998, a new survey was launched to once again monitor the evolution of the different salinity boundaries. The main objectives of this research were:

- to measure the effects of the 1997/1998 floods on the urban wells of Kismayo and Mogadishu and to monitor the recharge of the aquifer
- to apply computerized methods to plot the evolution of the different parameters studied

- to measure various chemical and bacteriological data to be used as indicators of faecal pollution and relate the results to the state of the wells and their type of protection



Juba River in Southern Somalia, 26 November 1997

RADARSAT S7 Image with FloodTrack Analysis

Kilometres 10 0 10 20 30 40 50

Miles 10 0 10 20

Data recieved by the Canada Centre for Remote Sensing (CCRS)
Processed and distributed by RADARSAT International
Enhancement and interpretation by Vantage Point International

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Material and methods

The wells were surveyed during the month of November 1998. The parameters collected are those included in the datasheet of ANNEXE 1 and are almost the same as those collected during the previous studies, with the exception of the chemical data. During this survey the GPS lat/long coordinates were not measured and the wells were located using the road grid on an A0 map. The collection of data was carried out with the assistance of a local NGO, Community Concern Somalia, which had already completed the 1997 survey. On average, 20 wells were measured and sampled every day, in spite of difficult problems of transportation to the site, and security.

Conductivity values were recorded with the use of a WTW conductivity meter equipped with temperature correction and calibrated with a standard solution. Electroconductivity is a simple way to measure the total effect of the dissolved ions and therefore allows for an estimation of the salinity, expressed as milliSiemens/cm (at a given temperature) or of the total dissolved solids (TDS) in mg/l, calculated using a constant from the conductivity of the solution. The constant is usually close to 0.75 and varies according to the water. We will consider in this work only the electrical conductivity and, when measured, the concentration of specific ions.
As an indication, the conductivity of a solution containing 100 mg/l of NaCl (sodium chloride) is 187 microSiemens/cm at 25 oC, and that of a a solution containing 400 mg/l of NaCl is of 750 microS/cm. Of course, other dissolved ions are present in the water and the measured values reflect the ionic balance of the solution. When the water is contaminated by brackish water the effect of the chlorides and the sodium and potassium ions becomes singificant and the value increases, with sea water having values higher than 30’000 uS/cm. The value is influenced by the temperature with a 10% change from 25 to 30 oC, but the instrument compensates automatically for this variation. All the values are expressed at 25 oC.

The measure is simple and shows, close to the sea or where dissolved salts may contribute significantly to totally dissolved ones, the extent of the concentration of sodium and chloride and the effect of any intrusion of brackish or salty water in the water used as potable water. The limits normally considered as acceptable for human consumption are the following:

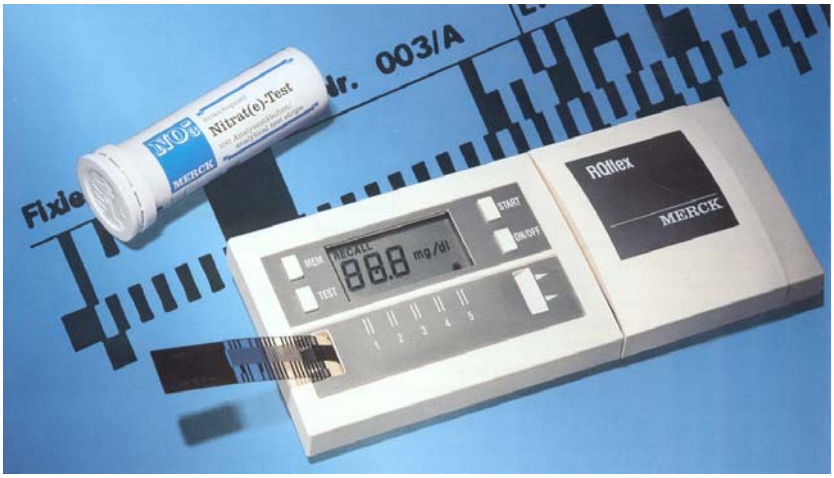
European Commission Directive (EEC 80/778)	1500 microSiemens/cm at 20 oC.
WDA (Water Development Agency for Somalia)	3500 microSiemens/cm at 25 oC

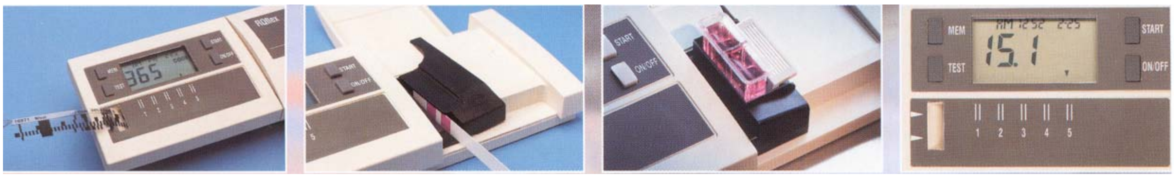
In fact, the 3500 uS/cm upper limit has been chosen for the Central Rangelands (LBI, Faillace)[6], where the electroconductivity is influenced by high concentrations of SO4--. This is probably not the case in the coastal areas, where the main contribution to salinity is due to sodium chloride, at least up to 10-15 km inland, even if the effect of saline layers cannot be disregarded.

In this report we will use this limit to define potable water using E.C. values. In all the figures we will nevertheless indicate the limits of other salinity levels, as they are important for understanding the evolution of the position of the potable/brackish/saline wedge and in quantifying the effects of the recharge or overpumping on the saline water intrusion.

Depths were measured with an electrical dipper equipped with acoustic alarm.

If possible, chemical analyses were carried out the same day with the use of a RQFlex instrument from MERCK, equipped to measure Reflectoquant strips as well as solutions placed in spectrophotometric cells, allowing measurement of relatively large number of chemical parameters. After several screening tests, the following parameters were measured: pH (ion selective electrode), NO3- (3-90 mg/l), NH4+ (from0.2 to 7 mg/l and from 5 to 20 mg/l), PO4-3 (from 0.1 to 5.0 mg/l and from 5.0 to 120 mg/l). Other analyses were dropped as too time consuming, involving several dilutions with deionized water, and of less significance for the purpose of the study. The method can be used in the field and does not require the setting up of a laboratory, but, despite its simplicity, requires specific skills and training. Calibration was carried out with the use of water samples containing certified concentrations of the a/m parameters. Measurements with ion selective electrode (ISE) probes were planned but were not delivered in time due to security problems. If agreed, comparative tests using this method and the previously described one will be carried out later with the assistance of ACF (Action Contre la Faim). The instrument and the simplified procedure is also shown in the following figures.





Geographical information systems software

ARCVIEW GIS (ESRI Environmental Systems Research Institute, Inc.) makes it possible to visualize, explore, query and analyze data geographically. The Mogadishu map was drawn with the assistance of a local cartographer and digitized with the assitance of GRID Nairobi

(UNEP). The map of Kismayo was obtained from UNDOS 1: 100’000 topographic map. For practical use, a simpler digitized map was obtained from the scanned one. The positions of the wells were subsequently located manually on the digitized map using ARCVIEW GIS 3.0a (ESRI) and the databases were then joined by matching identical Id numbers (identification number).

In Mogadishu, wells difficult to locate (about 127) were not positioned and were located voluntarily in the sea or outside the urbanised area. They can be discarded in Arcview using the theme property under the condition Fpos = 0, which leaves only the wells whose position has been established with certainty. When properly identified, they can then be dragged to their exact location. Other wells had to be discarded as some parameters were lacking (116). They can be discarded using the condition Fpos3 = 0. The exact number considered in the surface analyis is 459.

Spatial analyst.

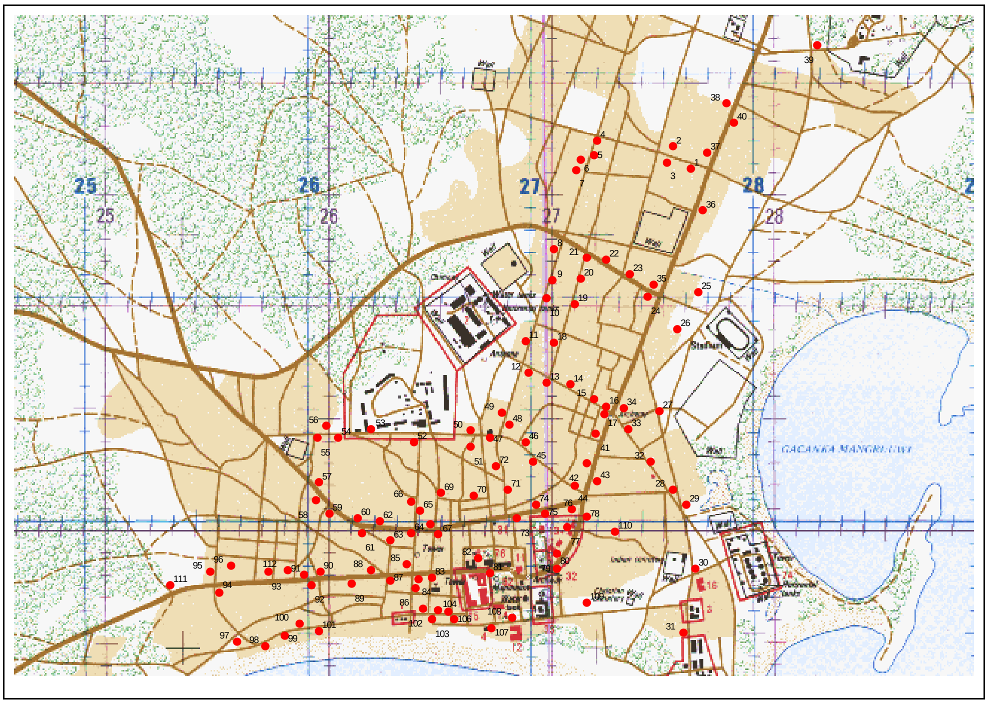
This is an extension of ARCVIEW 3.0a. It can be used for surface interpolation. Basically it assigns an estimated value to all the locations of the selected area [7]. The reliability of the results is a function of the number of points and of their distribution. According to the type of data, different types of interpolators will produce better estimates relative to actual values.

We have used in this study the Inverse Distance Weighted (IDW) interpolator which assumes that each input point has a local influence that diminishes with distance. It gives greater weight to points closer to the processing cell than to those farther away. In this case, the high conductivity (or the concentration of an ion) of the water of one well may influence one close to it, but more distant wells have less influence. The power parameter in the IDW interpolation controls the significance of the surrounding points with respect to the interpolated value. Higher power results in less influence from distant points. The interpolation is carried out between chosen limits and barriers. The external frame is chosen as the limit for the interpolation and the seashore as a barrier. The interpolation can be computed using the neighbors numbers within an identified radius. A neighbours number of 12 has been chosen and the power factor of all the interpolated surfaces is 2.

Results

Kismayo water supply

Kismayo town was supplied by the water treatment station located in Yontown, drawing water from the Juba river brought to the coastal city by gravity. The treatment plant has been out of operation since the civil war and the pipes have been looted. People had to depend entirely on shallow wells dug within the town. Several attempts have been made to rehabilitate the station but finally the cost of replacing the damaged or missing parts of the pipeline was considered too high, bearing in mind the volatility of the security situation in this part of the country.



The resident population had to draw water from the existing shallow wells. The pressure on water resources was increased by the presence of internally displaced people (IDP) and wells had to be dug to improve their access to water. Besides the "normal" construction of wells by private owners, several programmes were launched between 1992 and 1993 to improve the access to water of the displaced population, located in makeshift camps within the town. Most of the dug wells were not protected at all, which means no head walls/ parapets, no drainage platform or hand-pump, and were therefore subject to contamination [8]. There is a little available data on Kismayo wells. In 1994 the ICRC launched a survey to assess the quality of the wells protected under its water and sanitation programme, surveying about 125 wells. Mainly public wells were taken into consideration as access to private wells was difficult. No bacteriological study was conducted and only salinity (electro- conductivity) was measured. Most of these wells were lined with concrete rings of a small diameter (o,6 m), available locally. Lining was improved where necessary and drainage aprons were constructed. Equipment of the wells with hand-pumps was not considered. Well caracteristics, such as depth, water level, type of protection, number of families supplied, etc. were recorded. All the parameters recorded are listed in ANNEX I and are available on CD-ROM [9].

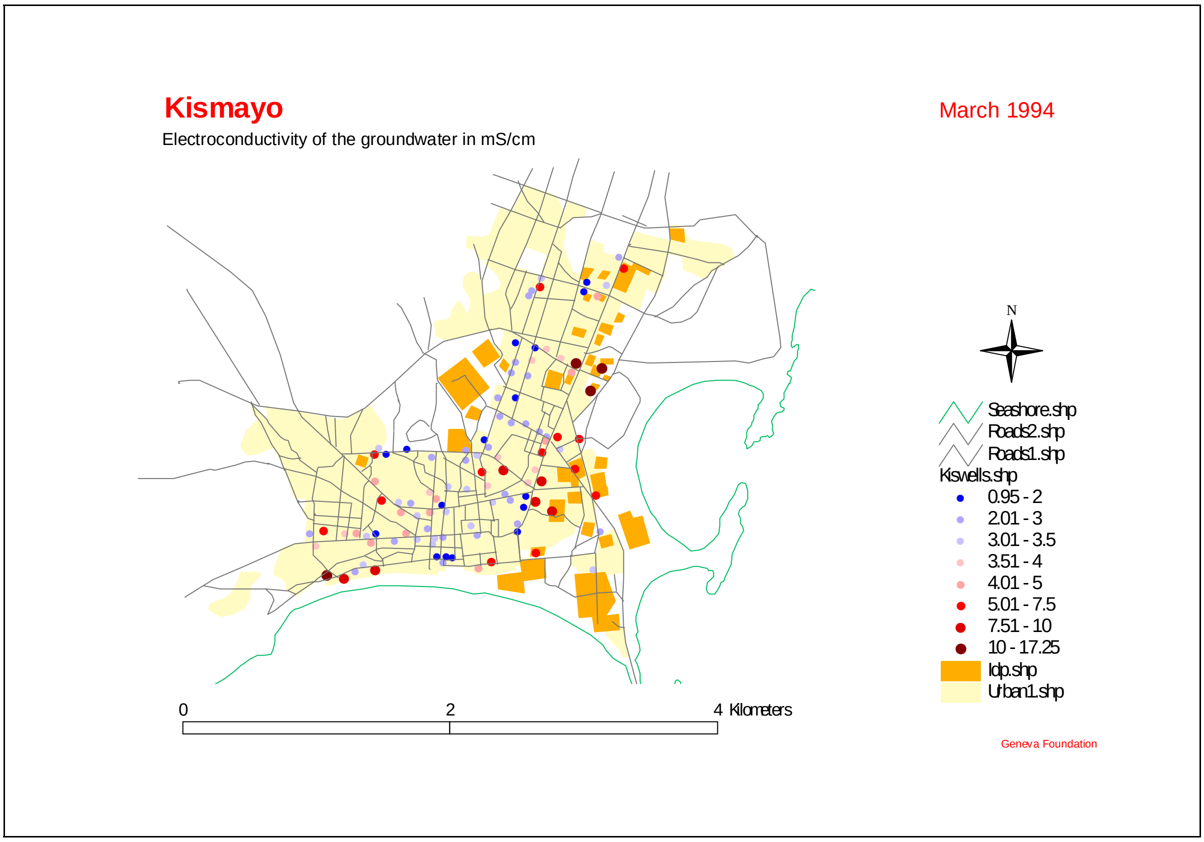
Location of the wells surveyed

The location of the wells studied is shown in the previous figure. They are all located in the urbanised area of the city. Each well is identified by an Id number and this number is used in the database as an identification number. Each well can also be identified by its location and by the name of the owner in the database. Other parameters can be used in case of doubt, such as the total depth, which in principle does not change, unless some deepening is carried out. The type of protection of each well can also be used and, all together, these parameters will provide a sort of fingerprint and will avoid any possible confusion. The original data sheets also provide a simple sketch of the location of each well in the compounds.

Electroconductivity of the groundwater

The next figures show the electroconductivity values of the wells surveyed, for March 1994 and during the present work, carried out in November 1998, expressed as mS/cm.

1994



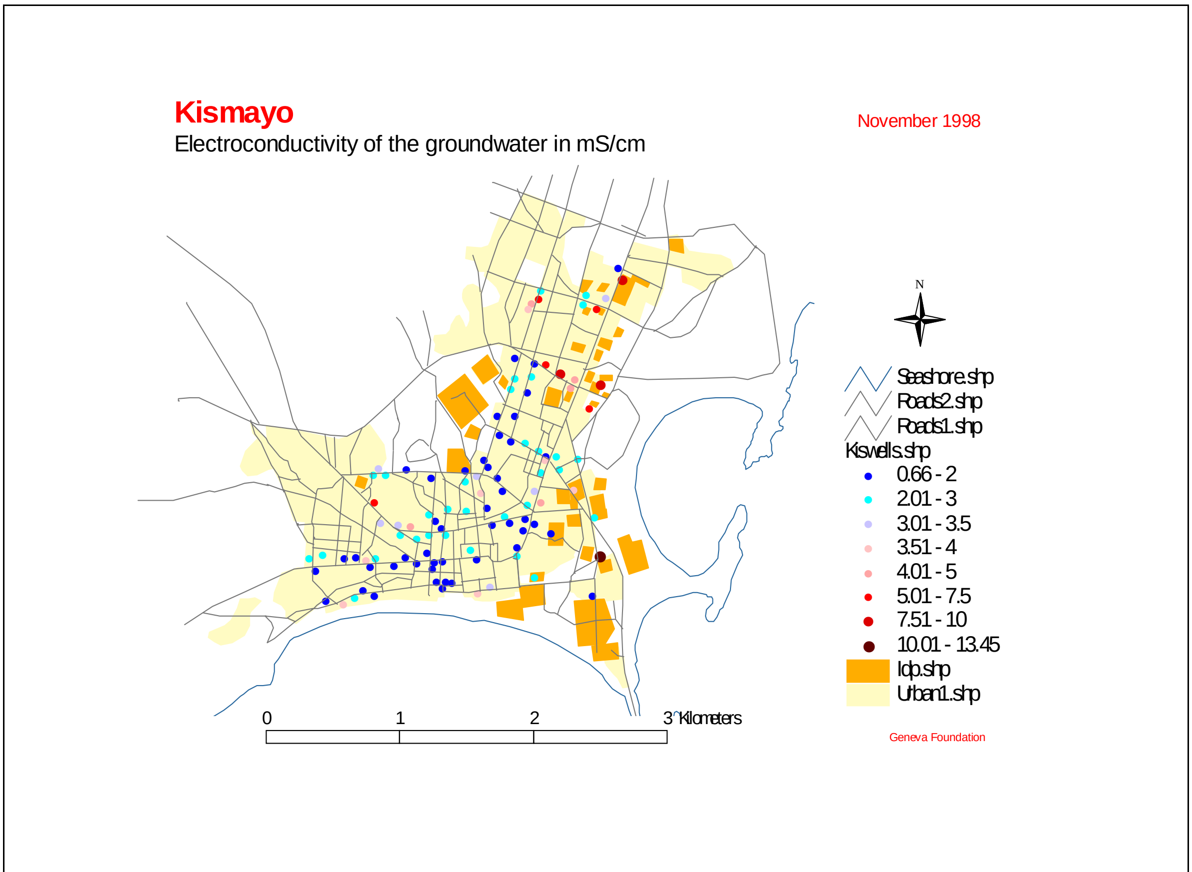
The values of 1994 have been collected by ICRC's technical field officers and have been included in the database to allow comparison. The same wells were been surveyed in November 1998.

Values higher than 10 mS/cm can be observed in the eastern part of the town, adjacent to the Gakanka Mongroowi bay, close to the stadium and in the south-western area of the urbanized part of the town, indicated on the map with a light yellow color. The main and secondary streets are also indicated to allow easier location of the wells studied, which have been positioned on a georeferenced map (UNDOS city plans [10]).

The majority (60) of the wells located within the town have conductivity values below 3.50 mS/cm (indicated in different shades of blue), some of them (13) have conductivities considered as borderline (pink, between 3.50 and 4.0 mS/cm), and quite an important number (33) (red, more than 4.00 mS/cm) have values higher than 400 mS/cm.

1998

This relative proportion of the number of wells having a given conductivity value has changed in the results obtained during the November 1998 survey. The number of wells with an acceptable salinity has increased within the town (84 less than 3.5 mS/cm), more particularly in the south-western area, in the central urbanized area and also in the one located between the stadium and the south-eastern industrial complex area, where the majority of the IDP (internally displaced people) are located.

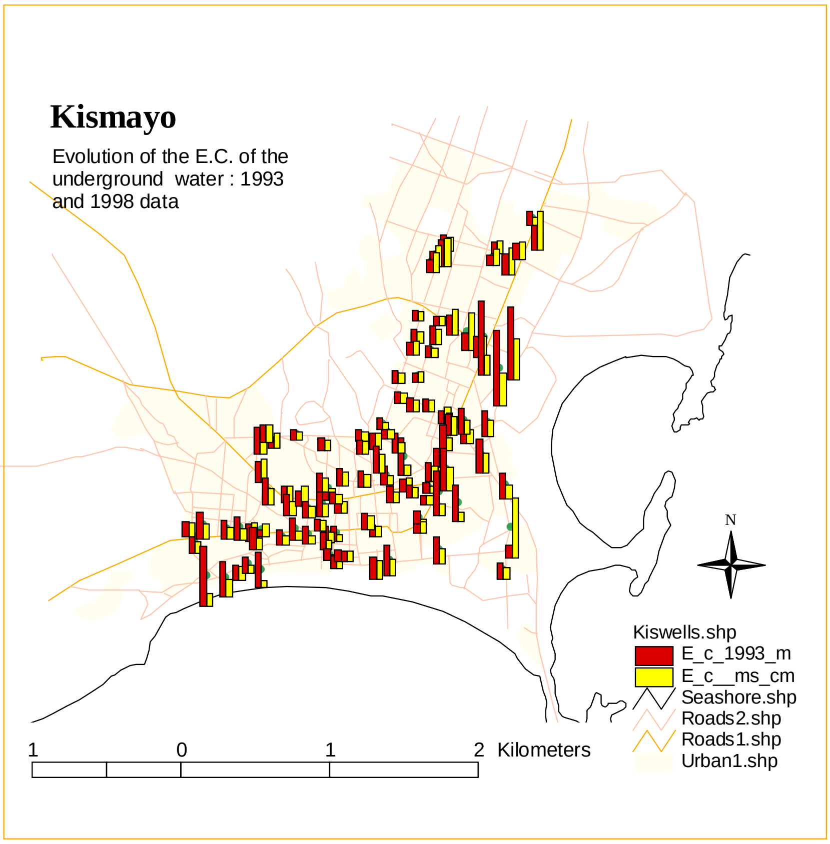


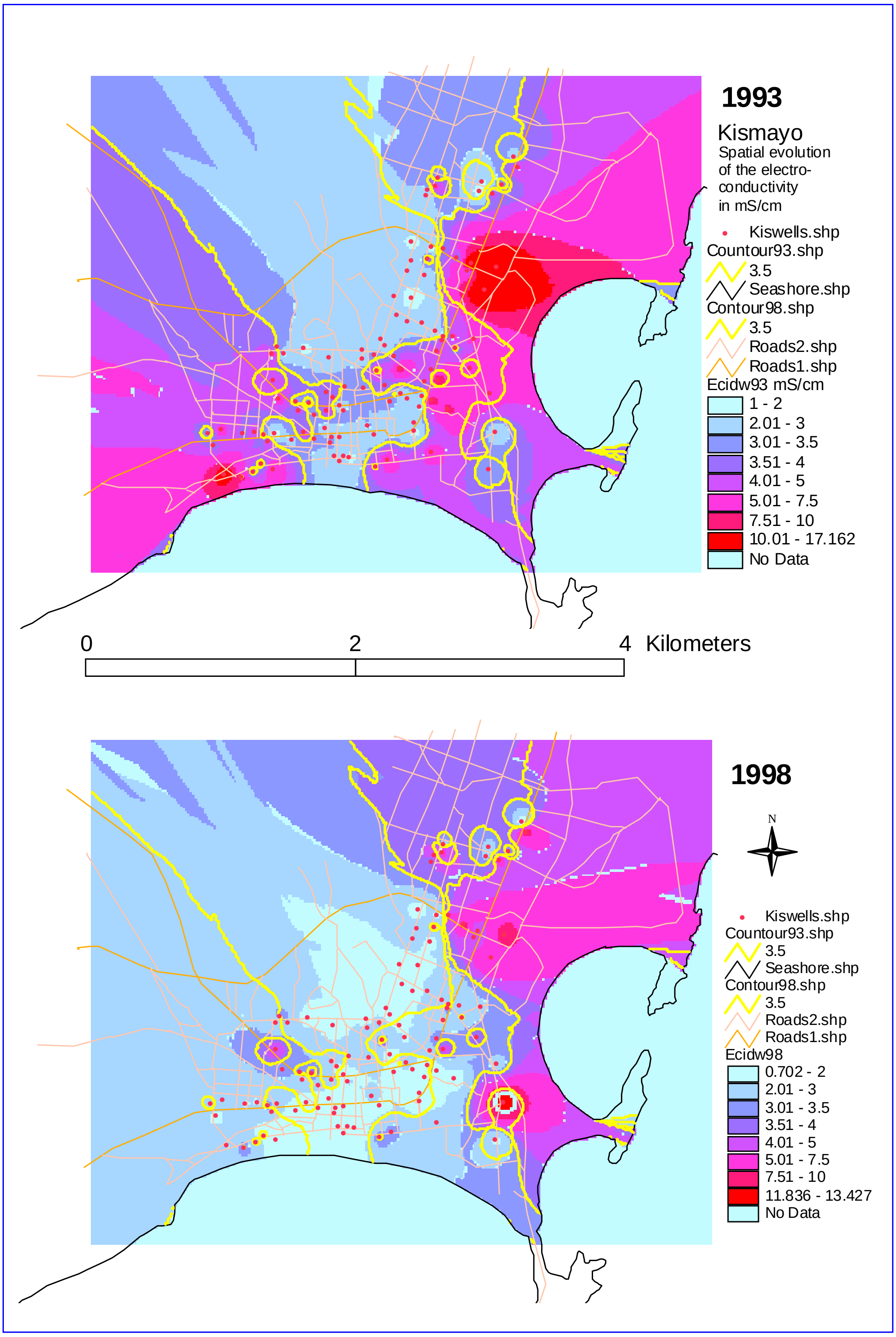
The number of wells with a conductivity higher than 4.00 ms/cm has decreased from 33 to 13, with the number of wells having values between 3.5 and 4 remaining almost the same.

A few wells show an increase in their conductivity. They are located between or close to several IDP camps (well no. 30, close to Big Fuel Tank camp) and in the northern part of the town (wells no. 38, 39, 40, etc.). This evolution can be visualized in the next figure, where the values for each well have been plotted as a histogramme. The evolution of the different categories is also reported in table I.

Table I.
Evolution of the number of wells having a given electroconductivity between 1993 and 1998

Year	**< 3.5 mS/cm**	**3.5 < E.C. < 4.0 mS/cm**	**> 4.00 ms/cm**
1 993	60	13	33
1 998	84	11	13


Kismayo
Evolution of the E.C. of the underground water : 1993 and 1998 data
N
Kiswells.shp
E_c_1993_m
E_c__ms_cm
Seashore.shp
Roads2.shp
Roads1.shp
Urban1.shp
1
0
1
2
Kilometers


1993
Kismayo
Spatial evolution
of the electro-
conductivity
in mS/cm
Kiswells.shp
Countour93.shp
3.5
Seashore.shp
Contour98.shp
3.5
Roads2.shp
Roads1.shp
Ecidw93 mS/cm
1 - 2
2.01 - 3
3.01 - 3.5
3.51 - 4
4.01 - 5
5.01 - 7.5
7.51 - 10
10.01 - 17.162
No Data
0
2
4 Kilometers
1998
N
Kiswells.shp
Countour93.shp
3.5
Seashore.shp
Contour98.shp
3.5
Roads2.shp
Roads1.shp
Ecidw98
0.702 - 2
2.01 - 3
3.01 - 3.5
3.51 - 4
4.01 - 5
5.01 - 7.5
7.51 - 10
11.836 - 13.427
No Data

Evolution of the quality of the water and definition of isoconductivity boundaries and areas

The limits of the different salinity values have clearly shifted between 1994 and 1998. To visualize the area of a given conductivity and to try to understand the effects of the different phenomena influencing the electrical conductivity of the underground water, it is necessary to create surfaces of isoconductivity from point values. These surfaces can be obtained using the data of the wells surveyed, even if they do not represent all the wells of the town. Their location is fairly dispersed within the town and trends can be observed.

The results are shown in the previous figures, where the computed surfaces with the same E.C. can be visualized. In the figure the size of the red surfaces has decreased, which means that the higher values of conductivity are less significant. The software computes the values outside the area where we can find wells, using the values of the closest ones. This is why the area located to the north-west is quite dark, as it has been computed from values of water with quite low conductivities. This is also where the recharge of the aquifer is most probably taking place, but it would be necessary to obtain some data on these locations to improve the validity of the modeled surfaces. The same comment can be made for the surfaces to the south-west, where the model tells us that the situation improved drastically in 1998, most of the values being quite low in this area.

Evolution of the boundaries and the reasons behind it

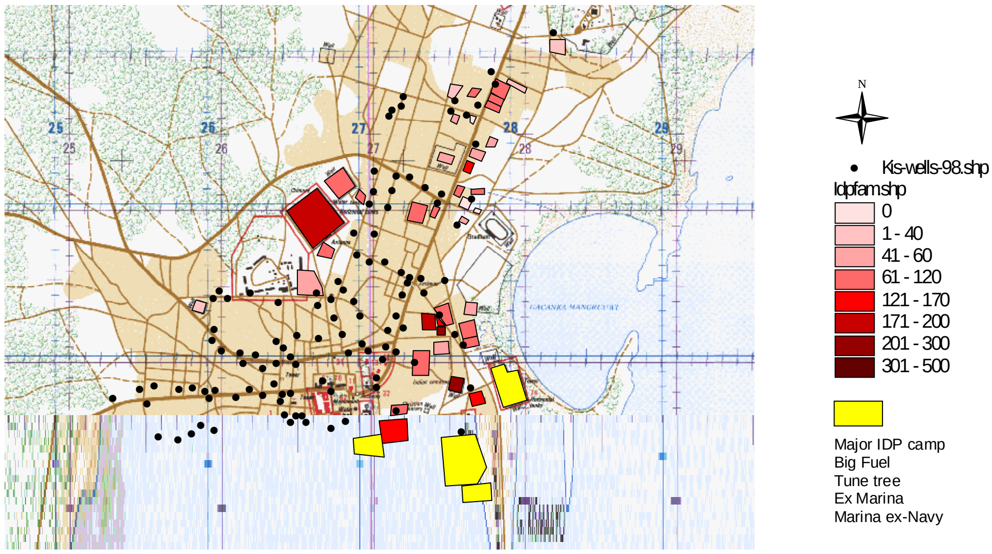
The software can compute the boundaries between two surfaces and we can also select the values of interest. In the present case, the 3500 microSiemens/cm boundaries have been chosen and shown on the two maps with two different colours. The surface between the two 3500 microsiemens/cm boundaries computed for the two years can be considered as at risk.

IDP camp locations, number of displaced and access to water

We have no precise data on the number of families for 1994. The number of IDP was quite high, as people were leaving areas of intense conflict to seek refuge in the town.
This is why the ICRC did launch a programme to dig new wells and to improve the protection of some of the existing ones. Even if the intensity of the conflict is still quite high in this area, the number of IDP did certainly decrease during the period between 1994 and 1998, as many of them left or were integrated in more permanent structures and may now be considered as residents.
The location of the IDP camps is shown in the next figure, together with the location of the wells. Some of the wells are located within the camps but most of them are located in private compounds and scattered throughout the urbanised area. They are considered “public” and are used not only by the displaced people, but also by the resident population and particularly by the donkey cart water vendors to supply the residents. No data are available on this business or on its significance.

Some assumptions can be made on the number of IDP. The location of the camps has been plotted on the map and the number of huts in each camp allows an estimation of the population. If we assume that every hut is used by a family and that the average number of people per family is 5 (UNDOS surveys), we can compute the total number of “displaced”

Kismayo



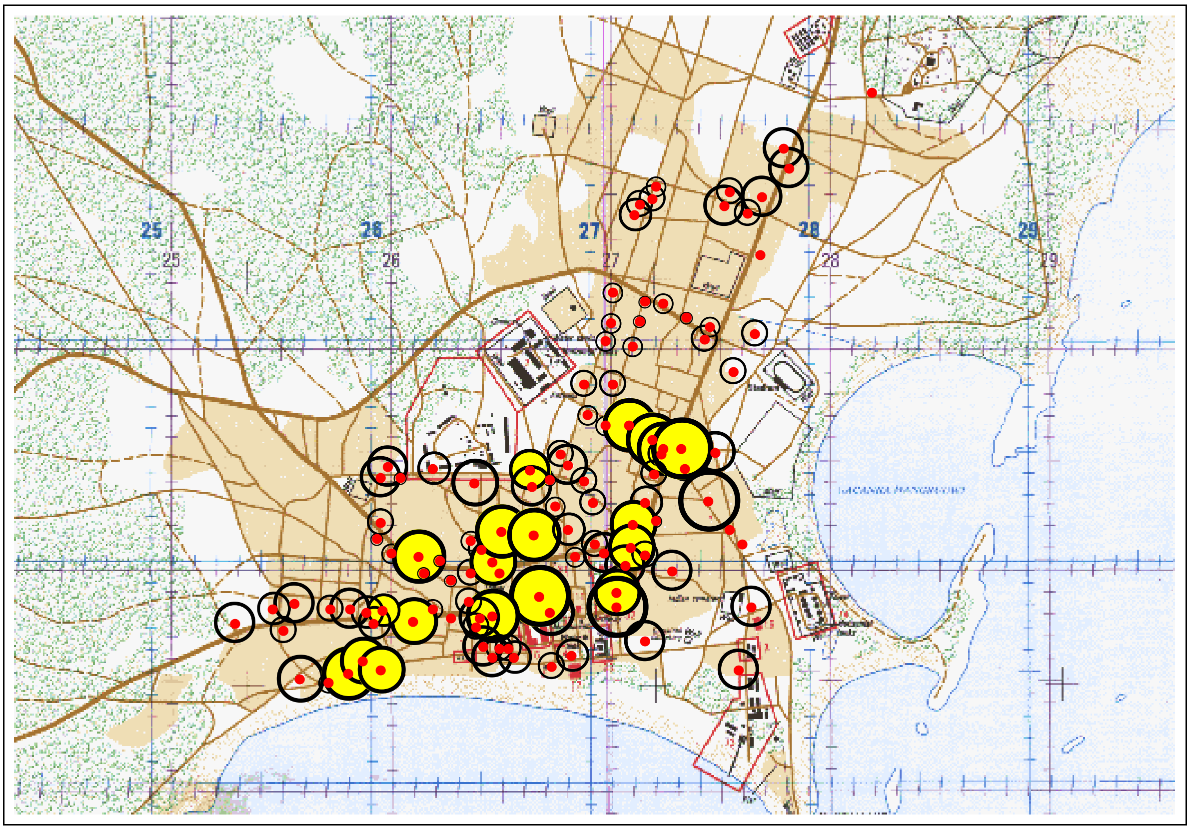
Location of the IDP camp, major ones and location of the accessible wells in November 1998.

people living in camps within the town. The total number of camps is 43, with a total of 5260 huts. The total estimated population is about 26300, with 4 camps (Marina ex-Navy, Tune Tree, Ex-Marina and Big-FuelTanks) totalling about 1600 huts (8000 people). These 4 camps are located in the south-east wedge of the town, where water is less accessible, with a few wells with fairly high salinity. This high salinity can be explained by the location of the wells too close to the seashore, but also by the abstraction due to the high density of the population using those wells.

It is likely that the access of IDP to water is de facto restricted to the wells within or close to the camps and that only part of the water drawn from the “public”wells is used by them. Which means that the average amount of 15 liters/per person/day is probably too high and that a significant part of it is used by residents.

Number of families supplied and quantities

The wells studied supply about 5200 families and daily abstraction is close to 450 m3, with a mean consumption of 15 l/p/day, if we assume that the mean composition of a family is 5. This means that the wells surveyed supply around 30’000 people, representing about 1/3 of the town’s inhabitants, if the 1998 estimates from UN are used (100’000). In the next figure, we have selected the wells with an output higher than 5 m3/day. These 23 wells alone supply about half the families concerned by all the wells studied (112 over 125), some of them delivering amounts up to 20 m3/day.



We have selected these wells for their high productivity, the others being comparatively less important. In 1994, a quite large number of the wells surveyed had an E.C. higher than 5 mS/cm, and only those located quite far from the sea were below the accepted limits. Unfortunately, data for 1993 on the number of IDP and the water abstractions at each well are not available, and we do not know if the number of displaced people, or of the resident population, has changed. If we assume that abstractions have remained close to the level of 1994, may be with a slight increase, the effect of the heavy rains and the consequent floods which occurred at the end of 1997 and the beginning of 1998 had an important effect on the salinity of the underground water, allowing for a shift of the soft/brackish/saline wedge toward the seashore. The the chemical quality of the water has therefore improved and only a few wells show values higher than the accepted limit of 3500 microSiemens/cm. The position of these wells, but also the effect of the abstraction may be important and both are probably responsible for the high E.C, given that a significant number of IDP may use these wells exclusively.

Areas at risk

As far as rainfall is concerned, 1998 must be considered an exceptional year. The effect of the heavy rains on the aquifer was considerable as can be seen from the above results. We do not have data on the rains of the years following 1993 but they were certainly not as important as those of 1998. We can therefore consider that the 3500 microSiemens/cm boundaries for 1998 are the best ones we may observe and that the "normal" situation is closer to that of 1994, which is representative of a rainfall close to the mean yearly values.

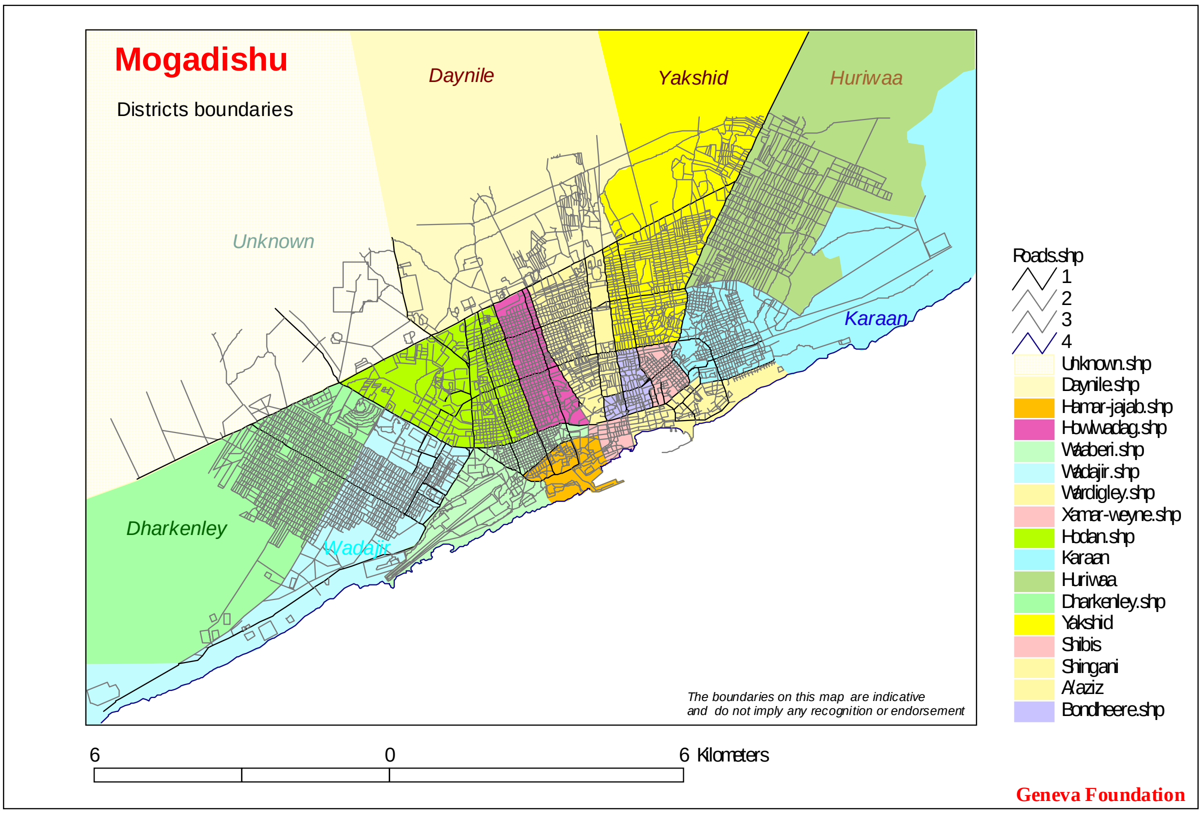
The area in between these two lines must therefore be considered as at risk. Wells dug in these areas are most likely to have a quite high E.C. and will have to be managed with care.

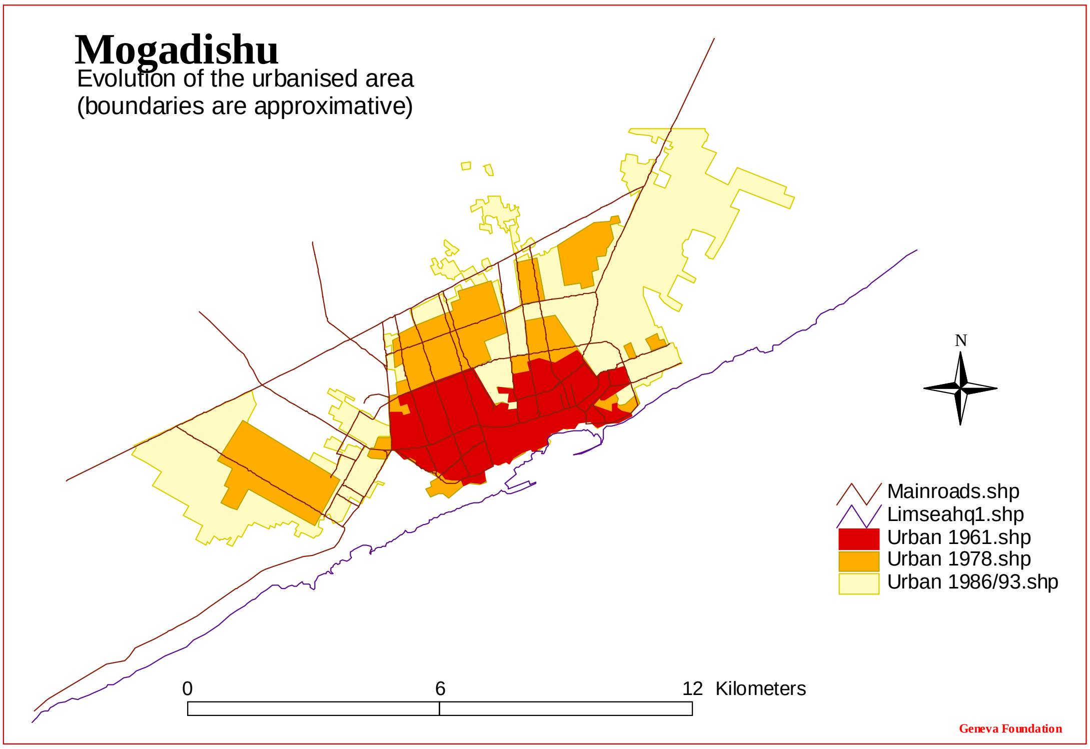
An area considered to be safe can be defined, located between the 3500 microSiemens/cm boundaries of 1993. It is striking to observe that most of the wells supplying the urbanized areas are in fact located within these boundaries and this is probably the case for most of the private wells of the town.

Mogadishu

Introduction

The capital and the largest city of Somalia is located on the Indian Ocean at a latitude of 2 degrees north and a longitude of 45.3 degrees east. In 1963, the city was quite small and occupied an area of only 800 ha [11] The present city extends about 20 km along the sea front and 5 km inland and has an area of about 10’000 hectares. A precise topographic map of the city was prepared in 1993 but was made available only recently [12]. The figure on the next page shows the approximate limits of the urbanized area of the town since 1961. The limits of the present urbanized area are those reported in the more recent map, shown in the following figure. This map is quite heavy (60 Mbytes) and is not suitable for commonly available software. For that reason, a digitized map was prepared from copies available in Mogadishu, with the assistance of GRID (UNEP) Nairobi, and georeferenced to be used with GIS software [13]. For practical purposes, only the main and secondary roads have been digitized. For further uses the topographic isolevels (10 m) have also been digitized and will be used to modelize the evolution of the aquifer. For administrative reasons the city is divided into suburbs and a map of the different suburbs (or districts) of the town is also given. Since 1991 a “green line” divides the “north” from the “south” as a result of the civil war.





Population

In 1962, the population of the town was estimated at 325’000. Using projections made by adopting for Mogadishu the average population growth of some other African countries, an estimated figure of 725’000 was obtained. This figure was used to plan the future water supply scheme of the town, with an estimated demand of about 50’000 m3/d.[14]. The present population is estimated at about 800’000 inhabitants, maybe more, but precise figures are lacking.

The evolution of the Mogadishu water supply

In 1963, the town was supplied by two quite basic independent municipal supply systems. The first supplying relatively fresh water from 4 wells located at km 4 along the Afgoi road to several elevated tanks and the other supplying only brackish water from about 35 wells to three distribution areas. In addition to these systems there were more than 200 private wells selling water to donkey carts, which were in fact supplying most of the inhabitants of the town. The municipal water distribution schemes were already in a bad state and almost at the end of their useful life. The fresh water wells were considered in danger of salinization due to sea water salt intrusion.
Following the different feasibility studies carried out by Hydrotechnic corporation and subsequently by Parsons [15] to improve the water supply of the town, 19 wells were completed in Balcad in 1970, capable of producing about 35’000 m3/h..

In 1978/79, further research was carried out by Gibbs and partners [16] to find suitable locations for additional wells. A productive well field was identified along the Afgoi road from which an amount of 25’000 m3/year could be withdrawn, thus meeting the future needs of the capital. Between 1980 and 1981, 32 boreholes were drilled and equipped. Water was delivered to the town by a gravity pipeline.

The situation before and after the civil war

Already before the civil war of 1991, the Mogadishu water supply was in a precarious state. Fuel shortages, looting and technical breakdowns which went unrepaired for weeks due to lack of spare parts, made water distribution through the poorly maintained network very erratic. Complete breakdown could last for weeks and large areas of the town went without a drop of water for years. The situation was even more precarious in the 1990s due to the damages inflicted by the civil war, even if some attempts to run the system were made in the aftermath of the 1991 war, when some agencies helped the Water Board with fuel, new generators and spare parts.

The well fields of Afgoi are located about 15 km north-west of the town, those of Balcad are located about 17 km to the north-east.

The Afgoi and Balcad well fields could produce about 45'000 m3/day with all the wells operational. Afgoi production decreased from 35'000 m3/day before the war to about 20'000 m3/day end of 1994. Between 1970 and 1978, the Balcad well fields were supplying about 6.5 million m3/year (17800 m3/day), with water flowing to the town by gravity. The Balcad well fields were closed down at the end of 1992 due to the poor condition of the boreholes, generators and equipment: only 2 out of 21 boreholes were still operational. Later the plant was looted. The Afgoi well fields were operational until mid 1995. Of the 32 boreholes, only two have collapsed. Presently, 14 are in principle fully operational, the others need pumps and other equipment. Power is provided by 4 x 325 KVA Cummins diesel generators and by 4 x 600 KVA Caterpillar generators. These generators are old and even though 2 of the 600 KVAs have been replaced by 2 new Detroit generators given by UNOSOM (United Nations Operation for Somalia), the problem of the supply of diesel, consumables and spare parts of course remains.

During the foreign military presence, fuel was provided initially by the US Army and then by UNOSOM, the fields being operated under the supervision of UNDP (United Nations Development Programme). This was mainly because a large part of the water produced was in fact needed to cover the troops’ needs (25% of the consumption of the water produced). The last delivery of fuel by UNOSOM took place in February 1995. Two private companies, Somalifruit and Sombana then delivered quantities sufficient to run the water supply for about two months.

In June 1995, production came to a complete stop and despite several attempts to fund the project by ECHO (European Community Humanitarian Organisation) and again by UNDP, the water supply has not yet been resumed [17].

Now the part of the town supplied by these wells also lives on hand-dug wells, on a few boreholes and on water carriers (donkey carts). Since 1980, a large number of boreholes were drilled within the city in response to industrial and economic expansion and many hand-dug wells were equipped with motorized pumps.

Recent water supply sources improvements

The famine-civil war period (1991- 94)

A total of about 250 hand-dug wells were rehabilitated or constructed by the ICRC throughout the country during this period. The main objective of the ICRC programme was to provide water to the displaced people, there where public kitchens were established to feed them. These people were leaving a drought- affected countryside, made worse by fighting between the factions. In Mogadishu, a total of 70 new hand-dug wells were sunk with the help of local contractors, at a cost of about 100 US $ /m. Most of these wells (43 end of 1994) are now equipped with hand-pumps. In the meantime, the ICRC also supplied the main boreholes with diesel, in order to maintain their delivery to the water sellers and to the poor who could not afford to pay for water. People collecting water with a container not exceeding 10-20 litres were given water for free. Eighteen boreholes or motorized wells were supported during the crisis period and other organizations like SCF took the same approach throughout the country. After long negotiations, this support was then stopped, according to a common policy among the few agencies working in the field. The borehole owners were asked to charge the water sellers enough to cover the running expenses of the pump.

The recent approach (1995-96)

The total collapse of the distribution network of the Afgoi well fields has, however, triggered a more ambitious programme. Besides the usual maintenance of hand-pumps, the ICRC watsan engineers embarked on a drilling programme, wherever it was possible and needed, with the aim of increasing the water supply of larger parts of the city. This was carried out at the sites of former productive boreholes. Other agencies, like ACF, were concentrating their efforts on the rehabilitation of hand-dug wells supplying water to internally displaced people. In fact, most of the work was carried out at the locations of old boreholes, which were dug sufficiently far from the sea to avoid salinisation problems, and were either not operational or in poor condition. The usual balance between the different factions had to be maintained to avoid unnecessary problems.

The ICRC paid for the drilling and equipment of the new boreholes and the “owner” of the borehole was then responsible for the operational costs of the ongoing water distribution. Since the beginning of 1995 up until now, a total of 6 new boreholes have been drilled, tested and equipped with submersible pumps. The diesel generators to power the pumps are installed in protected premises: University Residence camp, Gupta, Muuri, Yakshid, Daynile, Medina. Four have been cleaned and equipped (Black Sea, Livestock, Big Pipe, Gulwadayasha) and 12 further hand-dug wells have been equipped with submersible pumps powered by diesel generators (2 in Medina, 2 in Bermuda, 4 in Mogadishu North and 4 in Mogadishu South). Some boreholes located in critical locations, like the one supplying water to Digfer hospital, have been completely rehabilitated. Others, like the one in Sheikh Adan camp are still operating without any problems since 1992.

While boreholes have to be tested carefully in such a context, they are nevertheless located well away from the coast (about 3 km) and they tap into a fairly deep fresh layer, estimated at a depth of between 40 to 60 m below sea level. Another layer of water of "just acceptable quality" of about 20 to 30 m thickness is found below the fresh aquifer. This layer is easily perturbed by the abstractions of the different wells and mixing of brackish water can occur. This phenomenon is even more pronounced in the hand-dug wells closer to the coast and particularly in those located in the Abdul Aziz, Shingani, Hamar Weyne, Hamar Jajab and Wadajir districts, but also in Karaan, in Bondhere and in Shibis. Here the depth dug below the level of the water table is of paramount importance and the abstraction has to be carefully controlled if one wants to avoid salt water intrusion.

Assessement of the quantity and quality of the water

Previous studies

Before the war, several studies were carried out to monitor the saline intrusion in the underground waters of the city, mainly to try to evaluate the impact of the abstractions at the Balcad wellfields and of the planned ones at Afgoy (Gibbs, 1980, Parsons, 1970, see ref. 9 and 10). These abstractions would have significantly decreased the aquifer recharge, which was considered to occur by underground seepage from the Shabelle river and was expected to vary greatly from one year to another, according to the annual flows of the river.

In recent times, the first attempt to monitor the water supply of Mogadishu was initiated by Sommavilla's group [18] but only part of the results was available. At the beginning of 1994, the ICRC carried out an extensive survey to monitor the characteristics of the existing wells with the aim of identifying the areas at risk and of reacting accordingly. One hundred and eigthy wells were surveyed and located on a map in the districts of Yakshid, Bondhere, Wardigley, Hamar Jabab, Shibis, Shingani, Hamar Weyne and Karaan. Access to Medina was precarious at that period, and still is today. Most of these wells were located in areas where the water was potentially saline which, in such a context, means more than 3500 µS/cm.

The high salinity is not surprising. Most of these wells are located within 2 km of the sea, where the fresh water layer can easily be perturbed by too-deep wells or by overharvesting habits. Moreover, the water layer is fluctuating according to the tide amplitudes and any attempt to deepen the water layer during low tide may result in salinisation during the high tide [19].

Following the complete stop of water distribution from Afgoy, a survey was carried out by UNICEF in October 1995 (Unicef, 1995) whose objective wasto "identify the size of the population with access to an adequate amount of safe drinking water within a convenient distance from the user's dwelling". A total of 598 wells were surveyed, comprising almost 95% of all the wells of the city available to the public. Of these, 22 were deep boreholes (max. 120 m) and a further 8 were identified as having reasonable potential for rehabilitation. The remaining 576 were hand-dug wells, of which 75 were equipped with motorized pumps.

The main conclusions were that there was enough water, approximately 25'000 m3/day, for the city's population, coming from the above mentioned water sources, and this within a reasonable distance. Only a few districts had poor chemical quality water but bacteriological quality remained problematic. Hovever, about 26'000 internally displaced people needed immediate attention.

ICRC survey March 1997

A total of 640 wells have been surveyed. The same parameters as the ones collected during the previous surveys were collected. In addition, GPS lat/long co-ordinates were recorded using a GARMIN 45 GPS in an attempt to ease the location work and to analyze the results with GIS software. ARCVIEW GIS 3.0 (ESRI) was used to plot the data on a digitised map prepared with the assistance of GRID Nairobi (UNEP), georeferenced using ARCINFO. The Mogadishu map was drawn with the assistance of a local cartographer working on behalf of the Somali Red Crescent Society (SRCS). The collection of the data was carried out with the assistance of a local NGO, Community Concern Somalia, supervising 16 teams from the SRCS trained to use a GPS and to collect the information. Conductivity values were recorded with a WTW conductivity meter calibrated with a standard solution. Depths were measured with an electrical dipper or with acoustic dippers. All the positions of the wells were also located on the map to allow comparison with previous recent data, but also to compare them with the results plotted on the georeferenced map.

The results of this study are reported in reference 7 (Nembrini et al). The main conclusion concerned the levels of electrical conductivity measured at each well, expressed as microSiemens/cm (micromhos/cm). The movement of the saline/fresh water wedge of the underground aquifer of the town had progressed inland, already between 1970 and 1978.
The results of the 1997 survey showed a further shift inland and were related to the significant number of new privately owned wells, sunk or equipped with motorized pumps since 1995. The electroconductivity values were plotted on the georeferenced map together with the 3000 and 4000 μS/cm boundaries, adapted from the literature (Parsons, 1970, Gibbs, 1980). If a relatively small shift in the 4000 uS/cm boundary since 1978 was observed, an important one was monitored in the 3000 uS/cm boundary, which was located close to the main road parallel to the coast (21 October Road, located about 5 km parallel to the coast), with a move inland of about 2 km.

In this study it was also pointed out that the 3000 boundary was placed manually at the edge of the 3000 to 4000 uS/cm values, which was a crude approximation, and that computerized boundaries would have to be used to monitor the evolution of the salinity of the underground water.

Results of the 1998 survey

Number of wells surveyed

The number of wells surveyed increased slightly between the two surveys, from 640 to 702 The reason is mainly due to better monitoring of the wells located closest to each other.

Table II. Number and type of wells surveyed.

Type of well	1 99 7	1 998
Hand dug	264	254
Hand dug with hand pump	99	119
Hand dug with motorized pump	247	270
Borehole	23	23
Other	7	36
Total number of wells surveyed	640	702

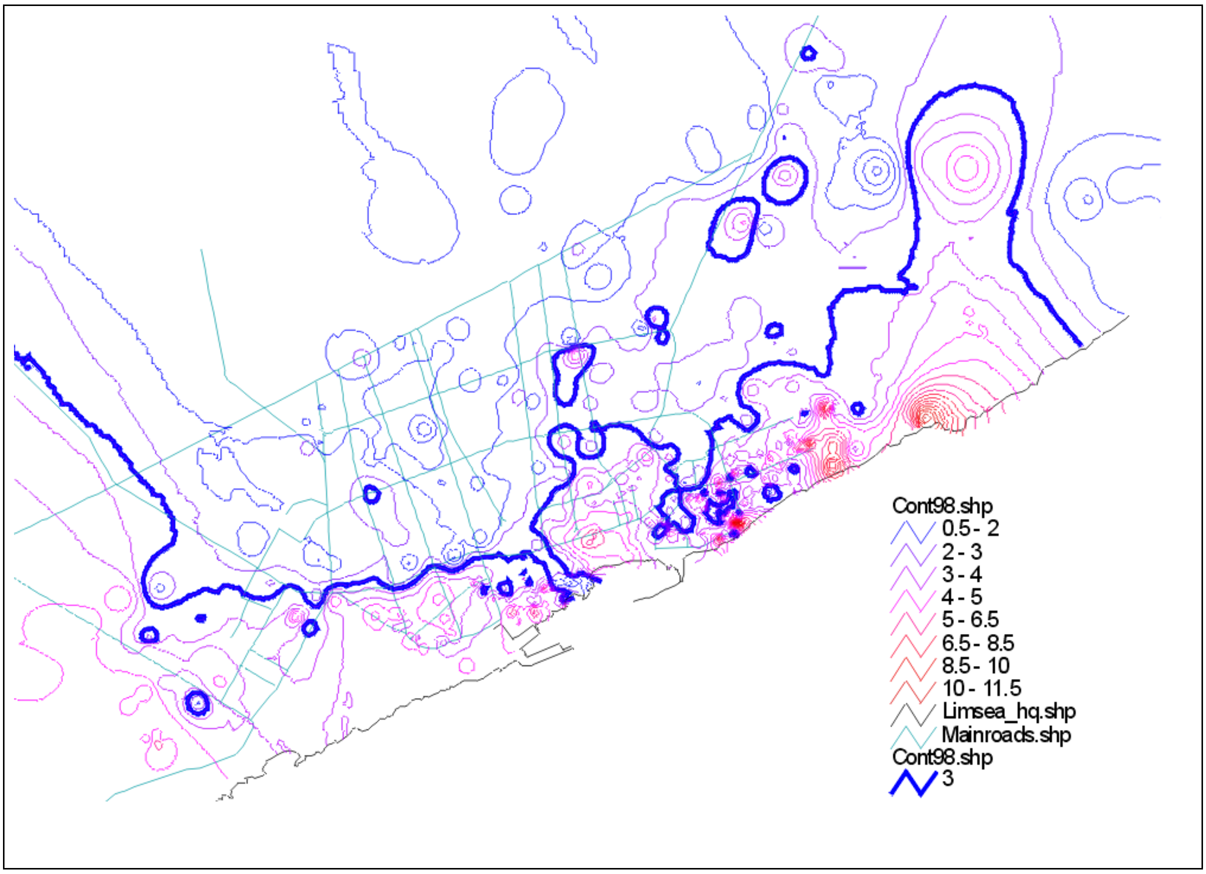
The relative proportion of the different types of wells has not changed significantly, with a slight increase in the number of wells equipped with hand-pumps and in that of the wells equipped with motorized pumps.
Table II gives the number and the type of wells. A few new types of wells have been selected, but to allow comparison they have been included in the

categories used during the 1997 survey. They are mainly wells used for animal watering or using animal lifting devices. Their number is however low. Only about 20 wells have been equipped with motorized pumps since the 1997 study. This probably reflects the fact that most of the wells which could be equipped during the period between 1995 and 1997 have now received a pump and that new wells can be dug only quite slowly, bearing in mind that they have to be located well away from the seashore and are therefore quite deep to dig. A limited number of wells have been equipped with hand-pumps under the different programmes carried out by the few IHO (International Humanitarian Organisations), but even in this category the changes are quite small.

Evolution of the salinity between 1997 and 1998

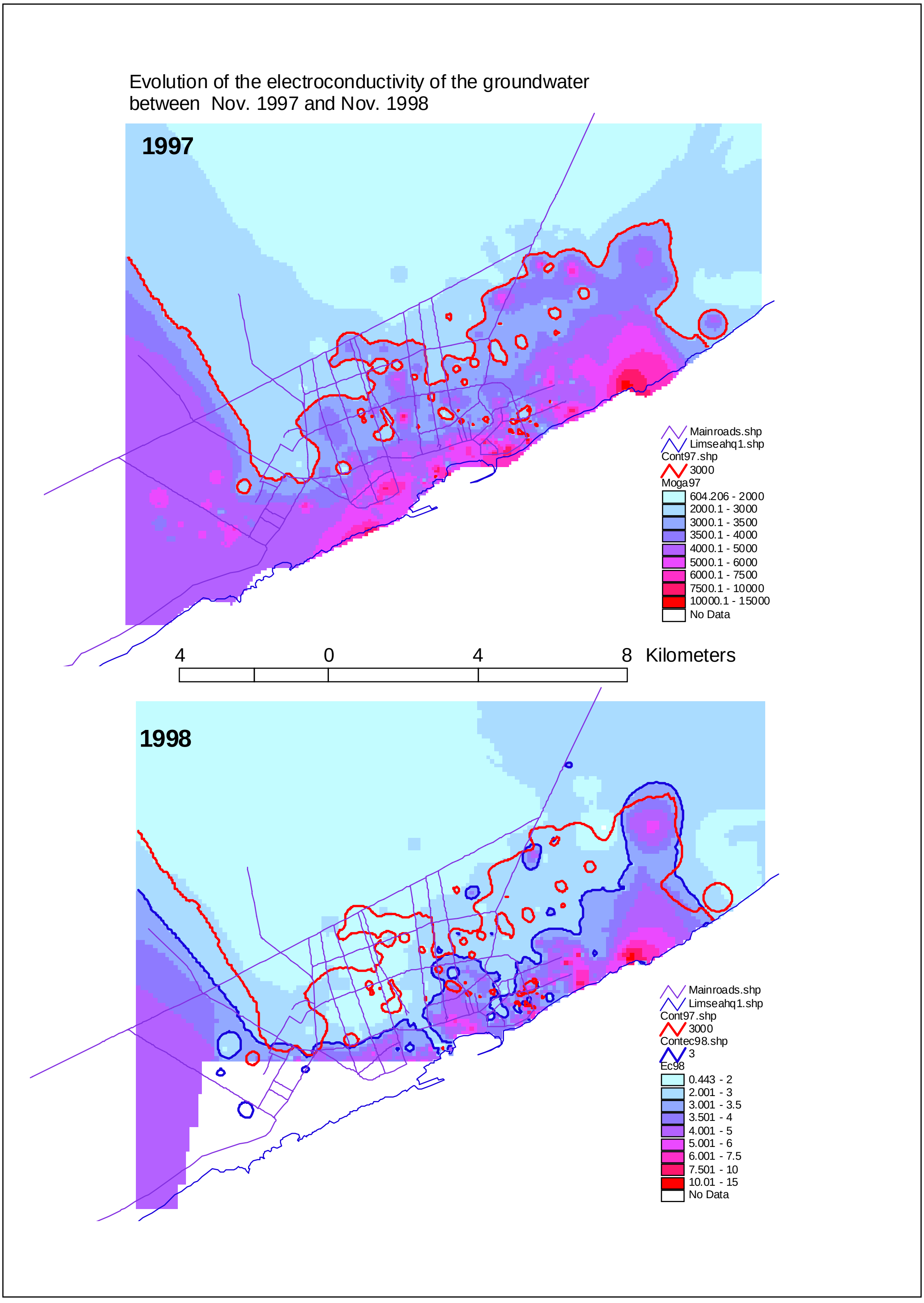
Despite the higher number of wells monitored (702) only about 459 have been considered in the spatial distribution analysis of most of the parameters monitored. This is due to the fact that the positions of 127 wells could not be located with precision. A further 116 wells were also discarded as complete data were lacking. Nevertheless, all the 702 data are reported in the database as some parameters have a higher count and can be used for the analysis. More details are given in ANNEXE I where the database is presented.

The results of the 1998 survey are plotted in the figure of the next page, where the



computerized boundaries are shown. For comparison, the computed isoconductivity curves for 1997 have also been plotted, using the same constraints and parameters described previously. Fresh water from the underground aquifer is shown in different shades of blue and saline water is plotted in red. Intermediate values are yellowish. Other representations can be obtained with the use of the computerized boundaries. Spatial analyst (ARCVIEW ™

3.0a) allows to plot the contours of the isoconductivity surfaces, and specific values can be selected according to the limits chosen for fresh water. The above figure shows the contours between t



he different surfaces obtained for the 1997 data, highlighting the 3000 microSiemens/cm limits.

These results confirm the location of the approximate limits shown in the previous reports (Nembrini et. al [7]), with the 3000 microSiemens/cm boundary located close to 21 October Road, beginning of 1997.

The heavy rainfalls and the subsequent floods described under the previous section have had a significant effect on the position of the different electroconductivity boundaries. Recharge from the Shabelle has pushed back the 3000 limit about 2 km, reaching the position reported in the first studies carried out by Parsons [2] and Gibbs [3]. It is striking to observe that in a large area in Karaan (in the east side of the town) the conductivity levels remain relatively high and their position is not affected by the global shift, suggesting a different geological formation or a slightly different underground layer, allowing for a preferential infiltration of brackish water. This is also supported by the behaviour of the pH values in this area, closer to the values normally measured for sea water, lying between 8.2 and 8.7 (see figure pH of the groundwater). The position of the boundaries at the end of 1998 probably reflects the “best” situation as far as salinity is concerned, but it is most likely that those observed in early 1997 will be reached in the near future, after a series of years with “normal” rainfall.

The area in between can be considered at risk and new wells dug between these boundaries will have an influence on the quality of the others, particularly if its abstraction is carried out with motorized devices. We do not know at which speed the shift will occur but we can assume that the time frame will be in years.

Condition of the wells and disease transmission

If chemical values and particularly salinity, expressed as electroconductivity, are of paramount important for the selection and use of a water source, other parameters are also important, as they may be used as indicators to measure possible faecal contamination. Normally, bacteriological techniques are used to measure the faecal coliform number in the water. The methodology to be used is described in extenso in several references [20],[21].
Presence of faecal coliforms (Escheriscia coli) indicates that the water is contaminated by human or animal waste and that it must be disinfected. In these situations chlorine is added to the water and monitored regularly. If residual chlorine is measured in the sample the water is considered to be safe. Unfortunately, despite regular batch chlorinations of the wells, residual chlorine is seldom measured, as chlorine is consumed quite rapidly and its effects are limited in hot climates and at high pH values. In Mogadishu, despite huge efforts to chlorinate the wells, the chlorine levels found in water samples taken from wells and household storage were far below the recommended values and many samples were faecally contaminated. Water is also contaminated after collection but several samples of water from the same well were found clean one day and contaminated the next, probably due to erratic methods of disinfection.

This activity has been chosen by many agencies as “the answer” to control the transmission of water-based faecal-oral diseases and more particularly cholera, assuming that contaminated drinking water still plays a significant role in their transmission. However, other factors are contributing to the spread of the disease, including consumption of food and drinks bought from street vendors, insufficient quantities of water and poor hand-washing practices [22].

The city has been hit several times by cholera epidemics, as in 1994/95, and has been the point of origin of the last three epidemics. The 4 cholera epidemics that affected Somalia from 1994 to 1997 caused over 55’000 cases and 2100 deaths. The course of the 1997 epidemics has been well documented, even if the number of cases did not reach the proportion of the previous ones. Mogadishu was hit again end of 1997 and beginning of 1998, with people affected by the floods, which also triggered important population movements, and aggravated the contamination of the wells and the spread of the disease. Thousands of people had to be admitted for treatment at several cholera treatment centres scattered within the city and in the outskirts of the town. The figure on the next page [8] shows the extent of the problem for the 1997/98 epidemic in different areas of the country and indicates that Mogadishu bore the brunt of it.
Recently, pot chlorinators have been introduced successfully in Mogadishu by ACF and one may expect a better impact on the quality of the water and eventually on disease transmission, due to more regular and efficient disinfection.

Waste water evacuation

Mogadishu does not have a central waste water evacuation network and most of the buildings are in fact disposing of their wastes through septic tanks. Permanently displaced people use communal latrines when available, or pit latrines. Percolation through preferential infiltration roads may lead to heavy contamination of the underground water and of the water of the wells, particularly where these wells are poorly protected. This is the case of most of the wells used by the displaced people located in the suburbs close to the seashore, where high salinity also allows for longer survival of the cholera vibrio [23].

The condition of the wells

The condition of a well can be described using different criteria. A quite broad way is to classify the wells according to subjective criteria, based on the experience of the person who is carrying out the survey. In our study we have chosen the following categories:

Very poor	Poor	Fair or acceptable	Good	Very good
1	2	3	4	5 [1]

Other criteria have also been added during the 1998 survey:

the presence of a headwall, of an apron, of a cover, whether the well is lined or not. Lining is not really important here because lining is the rule, bearing in mind the specific technique used for digging, and in any case little can be done to improve the state of internal walls. Another important parameter is drainage, particularly for public wells used by a large number of people, or donkey cart vendors, with a high spillage of water. This is certainly the main cause of contamination as the seal between the apron and the lining is usually inadequate.

But one of the most critical parameters is the collection of water, and wells not equipped with a pump are most likely to become contaminated by the unhygienic use of any kind of container, instead of a single bucket, which should be handled in such a way as to avoid the contamination of the water. The high bacteriological contamination of stored water is not

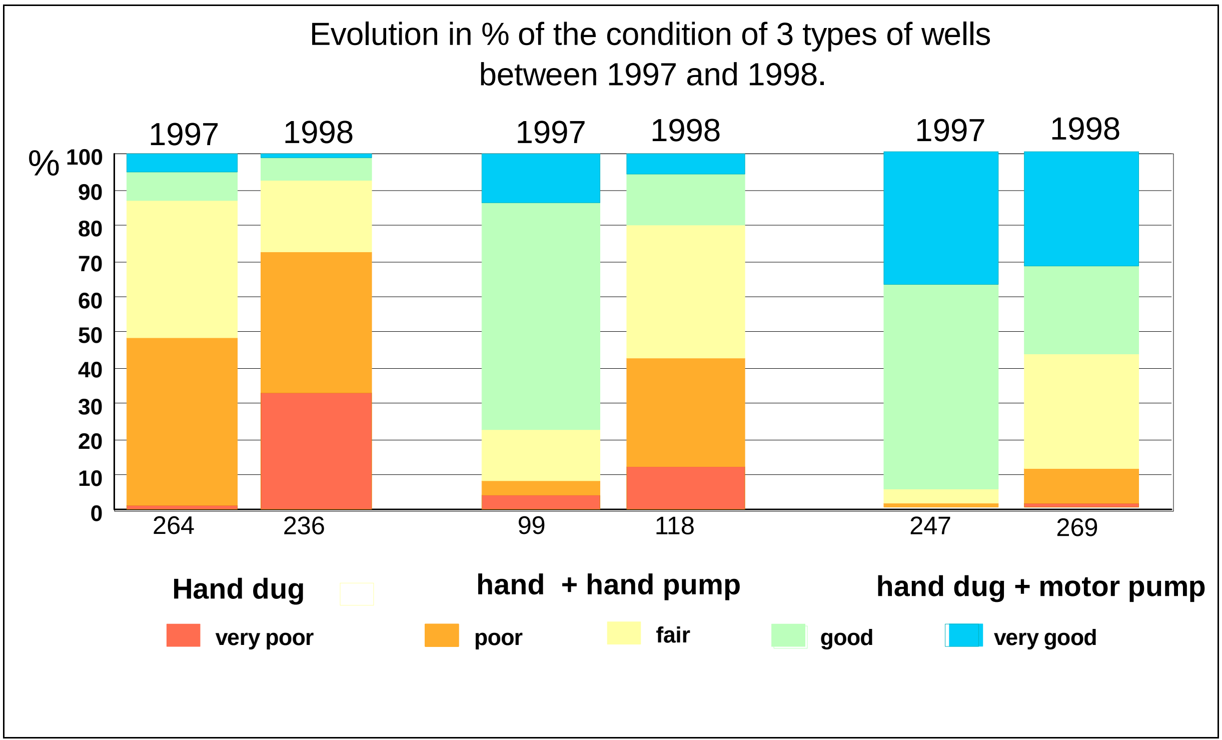
[1] Warning: These are the code numbers given in the 1998 database. In the 1997 database, the numbers mean the opposite, i.e.: Very poor: 5, Poor: 4, Fair:3, Good: 2, Very good: 1.

surprising and has been observed by many authors in similar situations and is due to poor maintenance, bad and unhygienic handling of the water and self-contamination[24].

We have not carried out any bacteriological analyses but have measured several parameters which may give an indication of contamination of human or animal origine, due to the poor protection of the wells. If we combine the condition of the well as described above (from very poor to very good) with the values of the chemical indicators we may be able to show a specific relationship, but what is interesting is to find out which parameter will have the greatest influence on the quality of the water, assuming that the indicators used are the true ones.

The type and condition of the wells

A first attempt to describe the general situation of the wells in the town is to try to associate the broad parameters described above to the type of well. As a first approximation, we would expect that the owner of a well which is used to supply water vendors has an interest in maintaining it in good condition, as this well may represent a significant income for his family. On the other hand, wells which supply water to displaced people are less well cared and therefore fall in a low category. ARCVIEW ™ allows one to query the database using different expressions, such as multiple attributes, operators etc. It is possible to combine different query techniques to select the type of the well and its condition. The results can be plotted on a georeferenced map or selected from the database table. We have applied the same query techniques to both databases obtained from the two surveys and the results are plotted in the next figure, where the percentage of each parameter describing the general conditions has been computed for three types of wells, that is, the hand-dug wells (HD), the hand-dug wells equipped with a hand-pump (HDHP) and finally those equipped with motorized pumps (HDMP). These three categories represent 610 wells for a total of 640 for the 1997's survey and 623 wells for a total of 702 wells for the more recent one.



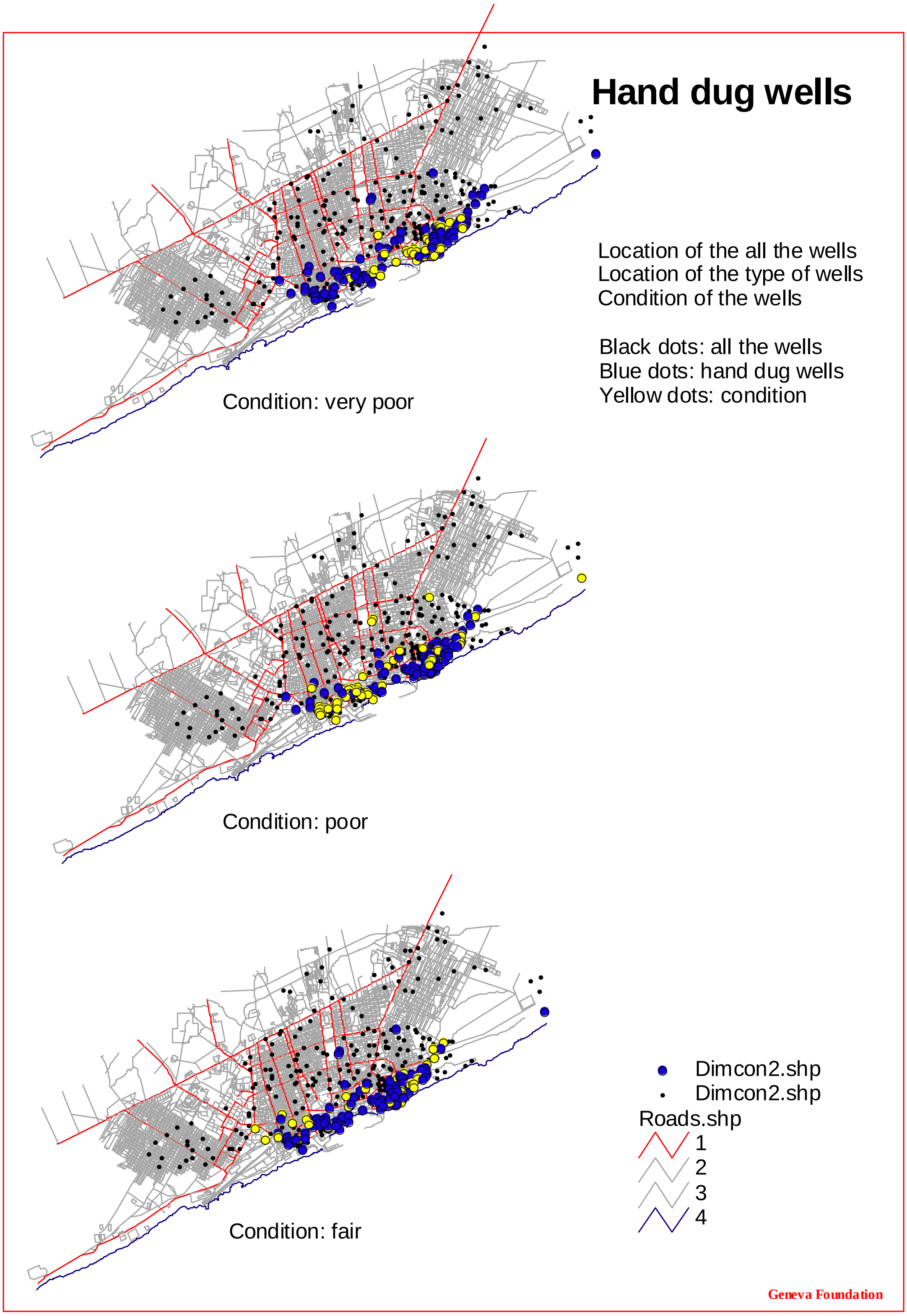
The relative proportion of wells having a given condition, that is, poor or very poor, for example, represents a high proportion for the hand-dug type, up to 50% for 1997 and 70 % for 1998. The same conditions represent only 10 % in 1997 and 40 % in 1998 for the hand-dug wells equipped with a hand-pump and they are hardly measurable for the hand-dug wells equipped with motorized pumps, the values being of less than 10% for 1997 and just slightly higher than 10% for 1998.
These changes can be due to a bias in the appreciation of the conditions but it is more likely that all the wells went through a general degradation, even if the period between the two surveys is relatively short, slightly 1 1/2 years.

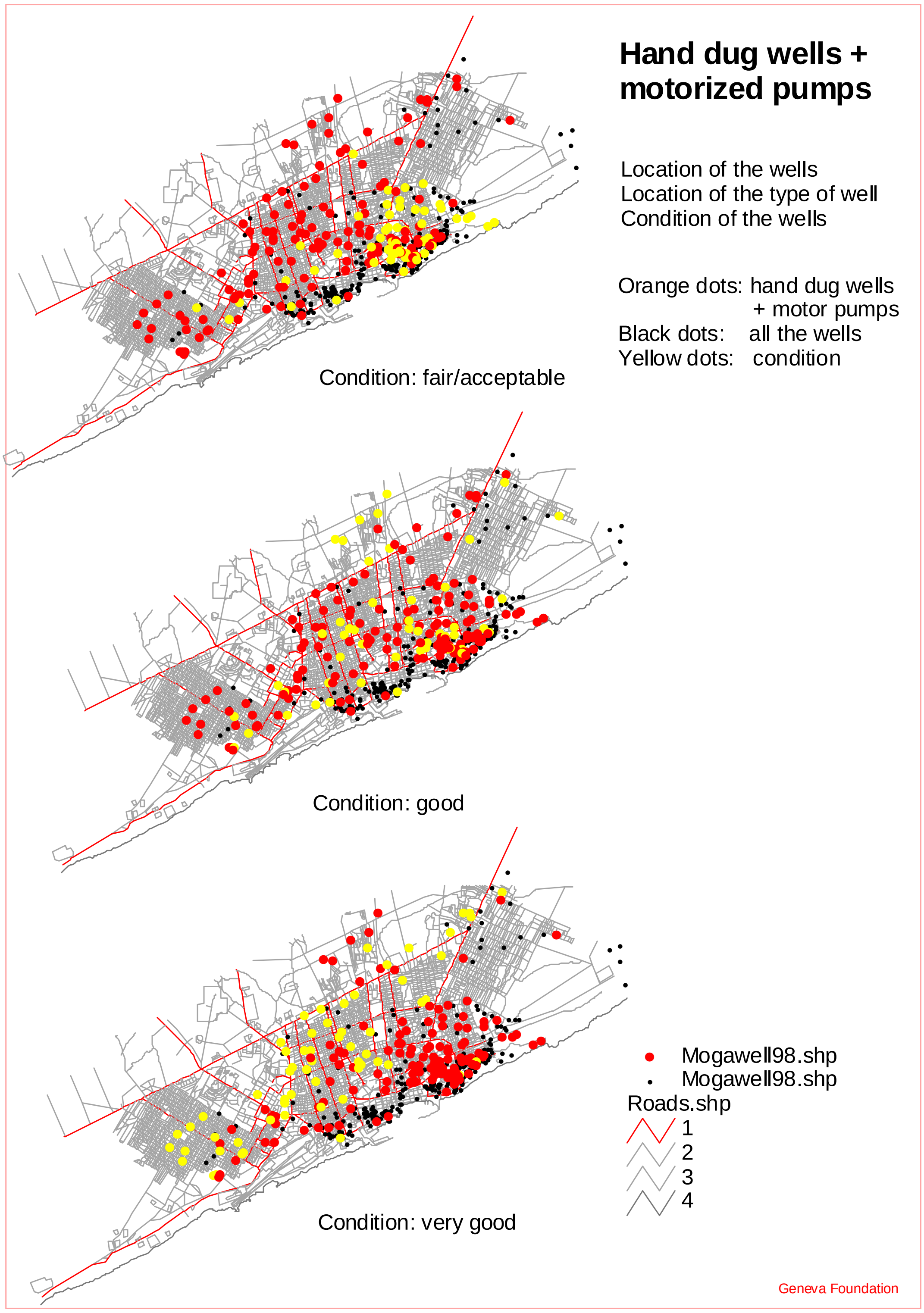
The changes in the proportions are small among the hand-dug wells equipped with motorized pumps where more than 90% of the wells are within the fair to good and very good conditions, with a significant change in the proportions between the categories fair and good, the latter decreasing from 50 % to 25% of the wells. As pointed out before, this can reflect an appreciation bias but the trend is there. The same can be outlined with the other two types of wells. What is evident from these data is that the poorly equipped wells are less well maintained and are in a bad condition, which is of course not the case for the ones used to sell water to water vendors, confirming the hypothesis oulined above.

Location and condition

The majority of the wells in poor condition are used by “permanently” displaced people and are also located closer to the sea, where the water is of higher salinity and where it may be difficult to achieve a better behaviour by the users. These wells are also quite shallow and water can be drawn with the use of buckets and rope. They are located within the suburbs close to the sea shore where the water table is quite high, between 10 to 20 meters from the ground, as in Hamar Weyne, Hamar Jajab, Shingani, Abdul Aziz and in the lower part of Karaan. This can be visualized in the next figures where the location of the unequipped hand-dug wells (blue dots) and those equipped with motorized pumps (orange dots) are shown. The same maps can be obtained for the other types of wells. Together with the type of the wells, ARCVIEW ™ and ARCEXPLORER ™ allow one to select (in yellow) the condition of the well or any other parameter to be examined.

Three conditions have been chosen for the hand-dug wells: very poor, poor and acceptable or fair, representing the majority of the wells. We have seen previously that the proportions of hand-dug wells of very poor or poor condition is large and one of the objectives of this study is precisely to find out why. Unfortunately, from the figures we can hardly observe a trend. The wells are scattered among the suburbs close to the shore, the poorest conditions being associated with those nearer to the shore, with a slight shift toward the inland for those in acceptable condition. It is quite obvious that these wells are less used or used by the poorest people or by the displaced. They can be dug quite easily, but the amount of water to be abstracted is limited by the fact that the fresh water layer is relatively shallow and care must be taken during the digging to avoid any mixing with the brackish water. Water from these wells is probably not used for drinking purposes, bearing in mind the high salinity and poor maintenance. Only a few wells are used to supply donkey cart water vendors.


Hand dug wells
Location of the all the wells
Location of the type of wells
Condition of the wells
Black dots: all the wells
Blue dots: hand dug wells
Yellow dots: condition
Condition: very poor
Condition: poor
Condition: fair
Dimcon2.shp
Dimcon2.shp
Roads.shp
1
2
3
4
Geneva Foundation


Hand dug wells +
motorized pumps
Location of the wells
Location of the type of well
Condition of the wells
Orange dots: hand dug wells
+ motor pumps
Black dots: all the wells
Yellow dots: condition
Condition: fair/acceptable
Condition: good
Condition: very good
Mogawell98.shp
Mogawell98.shp
Roads.shp
1
2
3
4
Geneva Foundation

The majority of the hand-dug wells equipped with motorized pumps are located between the 21 October Road and the above mentioned suburbs, at a mean distance of about 1-2 km from the shore, where the water is of better quality. They are therefore used to supply the water vendors and have a higher output. These wells are in better condition and only those located in the higher parts of Karaan, Abdul Aziz and Shibis are less well maintained. For instance, Karaan has about 38 of these wells out of a total of 183 (database 459) and 24 of these are in fair condition. But the majority is located in the upper parts of the town and the water is quite fresh (at least at the end of 1998). As an example, in Wardigley, half of them are used to supply the water vendors, as well as in Hodan, and the number of donkey cart loads per day is quite impressive, reaching more than 3000 loads in this area and more than 5000 in Yakshid. Other parameters can be selected from the database, such as total depth, depth of the water, salinity, etc., depending on what objective is pursued.

Other parameters

The following parameters have been recorded:

Ammonia which covers both the nonionized form NH3 and the ammonium cation (NH4+), which is found in natural groundwater usually below 0.2 mg/l. Surface water may contain up to 12 mg/l. The presence of higher concentrations than the geogenic level is an indication of faecal pollution. Ammonia is used in fertilizers and in animal feed production. A treshold odour concentration of ammonia (in alkaline pH) is approximately 1.5 mg/l and a taste treshold concentration of 35 mg/l has been proposed for the ammonium cation [25]

Nitrate which occurs in natural surface and groundwater at concentration levels close to a few milligrams/l. In much groundwater high nitrate levels have been linked with the intensification of farming and concentrations can reach several hundred of mg/l. In soil, fertilizers containing inorganic nitrogen and wastes containing organic notrogen are first decomposed to give ammonia, which is then oxidized to nitrite and nitrate. The current guideline value is of 50 mg/l (11 mg of N/l) supported by epidemiological data [26].Studies carried out in several unsewered Indian cities show that the mean nitrate concentrations are in the range of 10 to 25 mg N/l (between 50 and 110 mg/l) but can increase up to more than 1000 mg/l, depending on population density and on the type of aquifer geology. These levels may increase in karstic limestone aquifers, as in Jaffna (Sri Lanka) where concentrations up to 90 mg/l and even more are widespread[27]. Another classic example is that of the city of Gaza, where levels of more than 200 mg/l of nitrate are common [28].

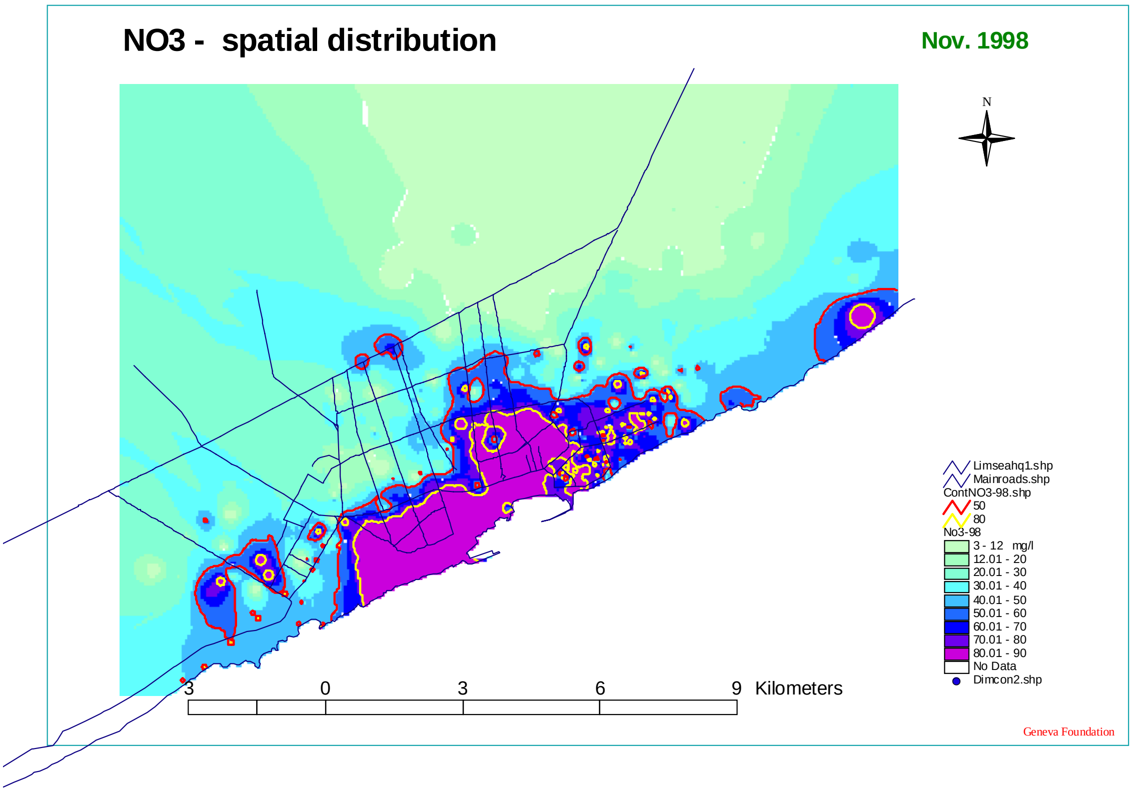
Phosphate occurs in natural water as orthophosphate and as polyphosphate anions and in trace amounts as organically bound phosphorous. Fertilizers and detergents add significant amounts of soluble phosphorous to drainage and waste water, which may contain up to 20 mg/l of phosphate. Sea water contains between 0.01 to 0.1 mg/l of chemically combined phosphorous. The E.C. (European Community) sets the maximum admissible concentration for phosphates in drinking water to 5 mg/l but lists the inorganic constituent as a substance not necessarily harmful to health. Because its low concentration in sea water, phosphate has been included in the test substances as a possible indicator of faecal pollution, possibly allowing one to distinguish between sea water inputs and anthropogenic loads.

pH has been included as it may give an indication of seawater intrusion but also because its value is important when disinfection with chlorine dispensing substances is carried out.

Spatial distribution of the test substances

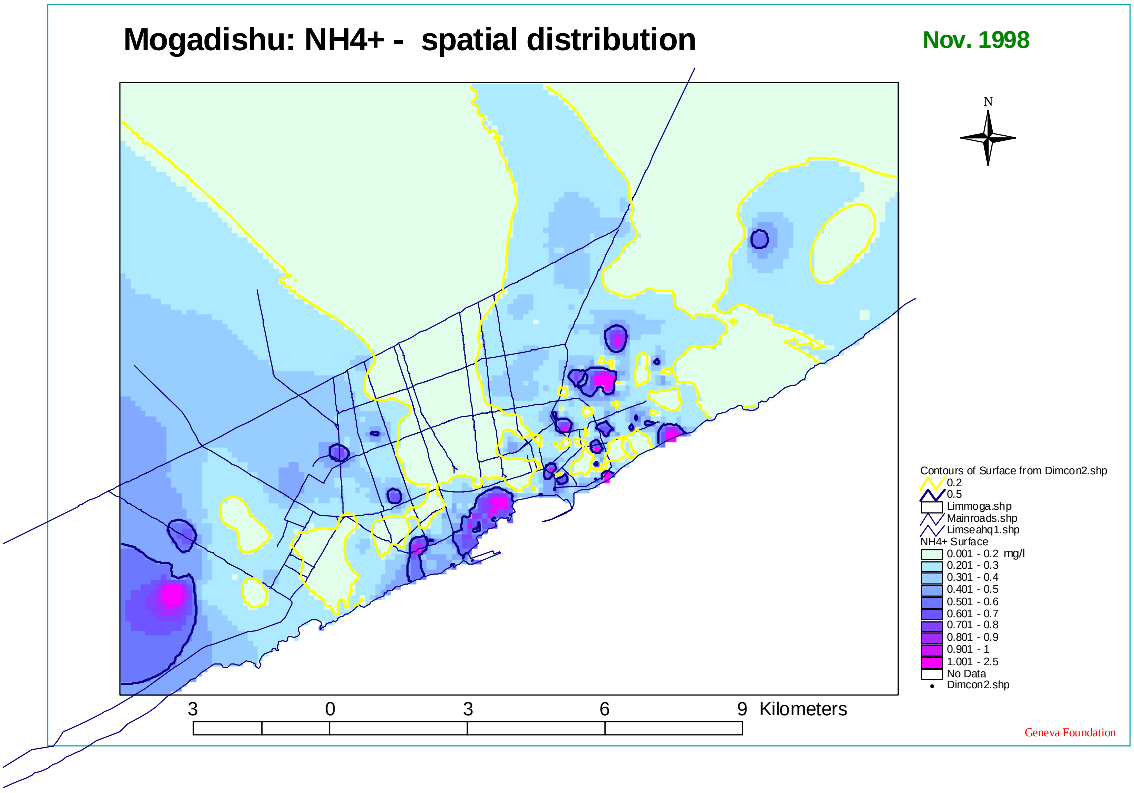
Nitrate

The spatial distribution of the nitrate concentration in Mogadishu wells is given in the next figure. Concentrations higher than 90 mg/l were not measured and are reported in this figure in the 80-90 mg/l class. This explains the large area of high nitrates levels shown in magenta in the figure. This is due to the fact that samples could only be processed once, for financial, technical, logistical and security reasons, and to the necessity of carrying out all the analyses within the same day. According to ACF’s engineer, who is carrying out a similar study this year, the levels may reach values as high as 150 mg/l or even more. Two boundaries have been plotted, the 50 mg/l which corresponds to the WHO guideline and the 80 mg/l, which can be considered the upper limit of the linear detection capacity of the instrument. The 50 mg/l NO3- boundaries delimit an area within the urbanized zone where the nitrate levels are confined and where they are on increase. This area shows a bump towards the inland in front of the harbour, covering the lower part of Wardigley. The 50 mg/l limit then decreases to reach the sea at the eastern boundary of the Abdul Aziz suburb and at the western end of the airport, reaching levels close to 30 mg/l. A few islands of higher concentrations can be observed in the lower areas of Madina and in the extreme western parts of the town.



Ammonium

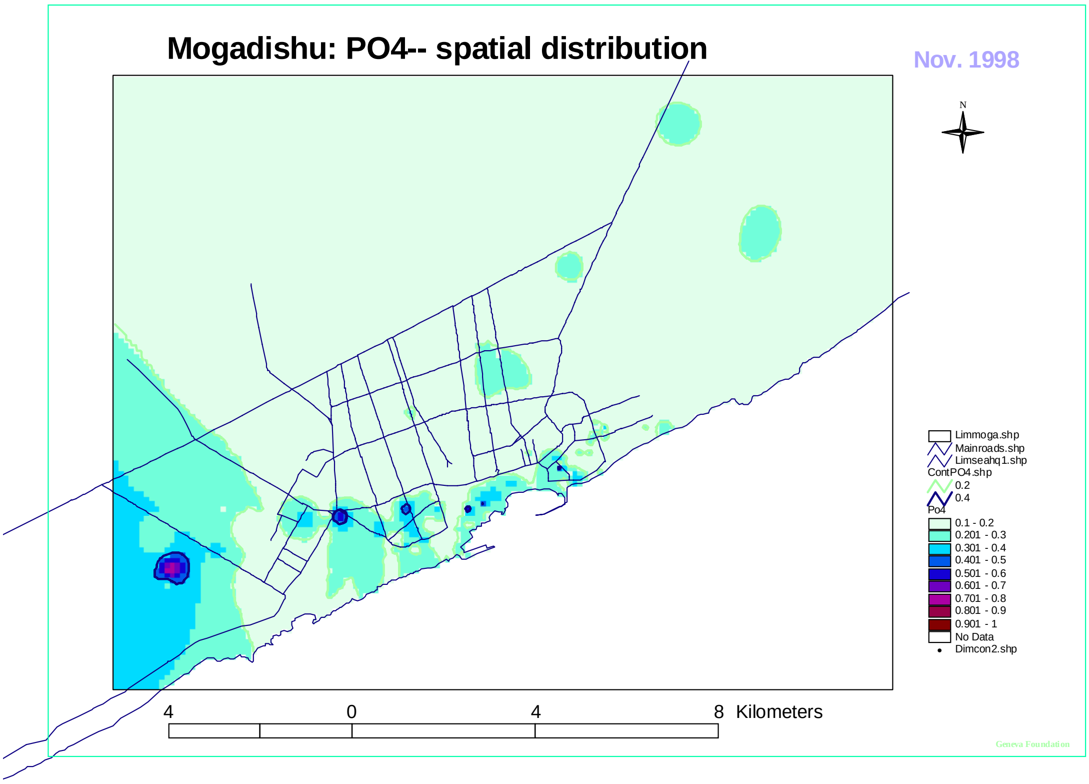
Ammonia is in these pH values almost entirely as ammonium and with ammonia representing only traces. The spatial distribution of ammonium concentrations is shown in the next figure.



Values below 0.2 mg/l are delimited by the yellow boundaries. 0.2 mg/l represents the limit of detection of the method. Significant levels of NH4+, higher than 5 mg/l, delimited by the blue boundary, are scattered in a few suburbs, with a distribution following more or less the E.C. boundaries, even if several islands of higher levels can be observed, where some unwedgings with the salinity patterns seem to occur. High levels of NH4+ can be expected in unequipped shallow hand-dug wells, with poor protection and in poor condition, which are located close to the shore where the water table is high. This is probably the case for those located in Hamar Jajab and Hamar Weyne, but high levels of NH4+ are also found in some areas of Karaan and Huriwaa, where the wells are deeper.
The depth of the wells is therefore not the main reason and other parameters, such as the type of equipment, the protection and probably the number of users, may play a more significant role.

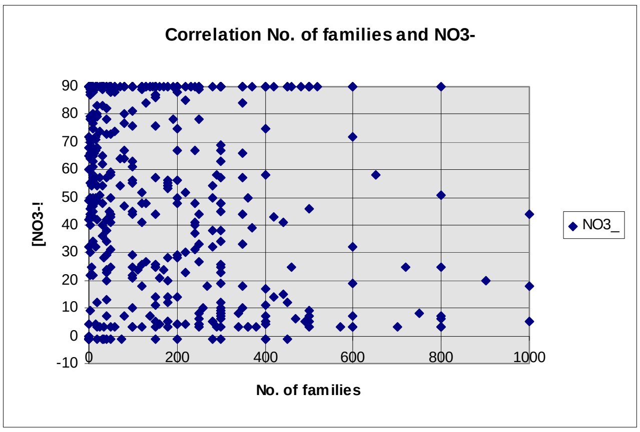
Phosphate

Phosphate shows the same trends as E.C. even if the results are less evident. In the next figure only a few spots with values higher than 0.5 mg/l can be observed, but the trend of the boundaries delimiting those higher than 0.2 mg/l suggests some sort of relationship with the spatial distribution of the E.C., at least for the suburbs close to the harbour and at the western boundaries of the town. As in the case of the above indicators, the relationships with the parameters of the wells may be quite difficult to establish.



PH

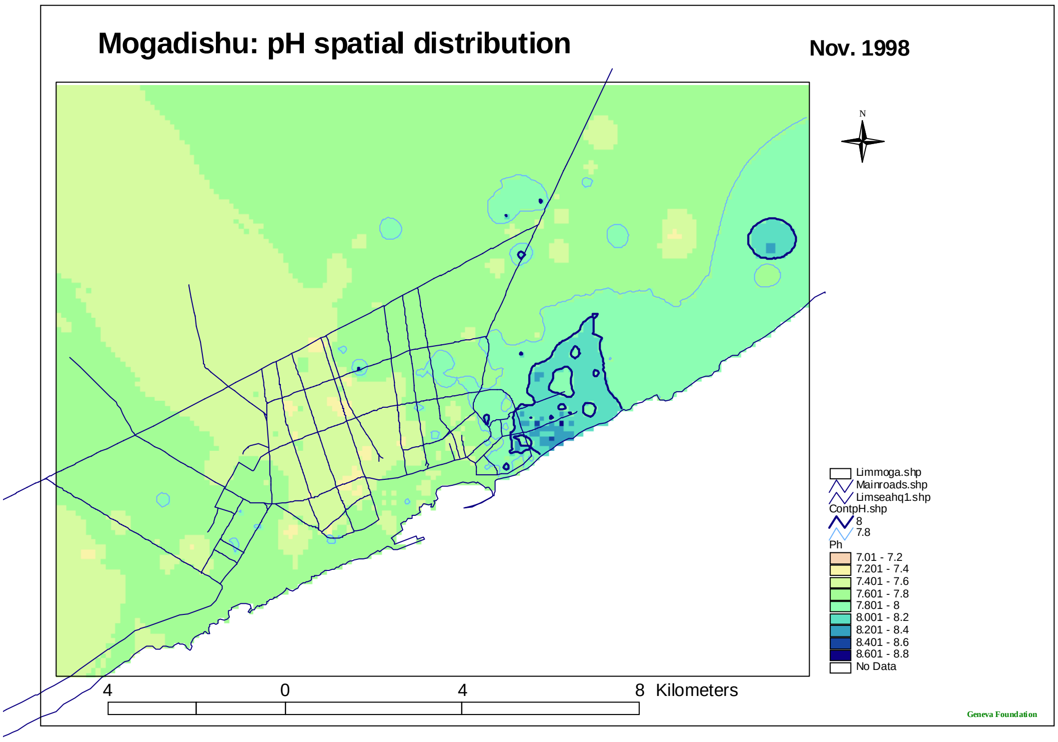
The next figure shows the spatial distribution of the pH of the groundwater. A significant increase of the pH can be observed in the water of the wells located east of the town, with a well delimited area where values reach 8.5. The reasons for such an increase are not evident and may be explained by a different geological formation or by a higher intrusion of brackish water, which has a higher pH. But at these pH values disinfection with chlorine is less efficient, as the proportion of the oxidizing agent HOCl (hypochlorite acid) compared to the dissociated form, is low and contact times must be longer for a proper effect.



Discussion

Evolution of the indicators, and relationships among them and with the other parameters

The spatial distribution of the different chemical indicators is of paramount importance for any planned intervention in the water supply field. Salinity is of course the leading parameter and this study gives an idea of the areas where it may be

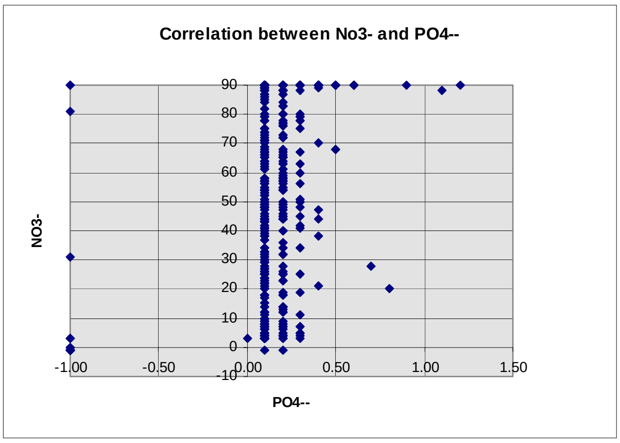


worthwhile to dig a new well or to improve the protection of existing ones. We have seen that most of the wells located close to the seashore are in poorer condition than those used to sell water to water vendors, their electrical conductivity, i.e the salinity, is also higher and also the levels of NO3- exceeds the

accepted WHO concentrations guidelines. The same can be outlined for NH4+ and PO4-- even if their levels are of less significance.

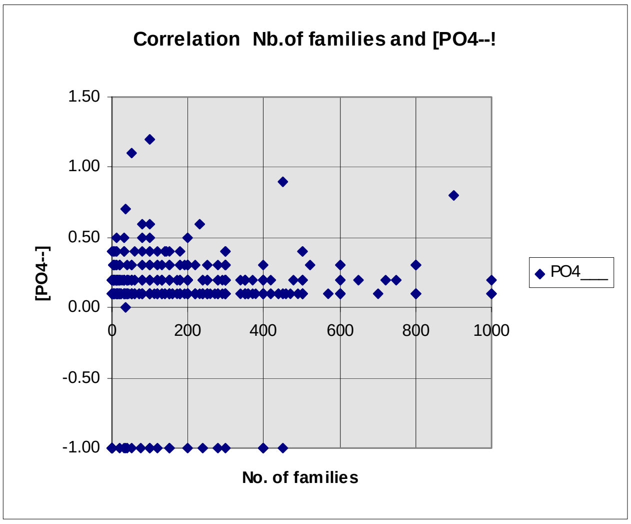
Although some rough conclusions can be drawn from the percentage of wells in varying condition and from the types of wells, the relationship between the chemical parameters chosen as indicators is less easy to highlight. It has been shown that the contamination of the wells, assessed by the number of faecal coliforms, is clearly correlated to the proximity of latrines or to poor maintenance. Hazard indexes were assigned to several well identified problems, such as, proximity of a latrine, poor drainage, poor lining, poor headworks, etc. [29].

In the previous chapters we have used a anking index from 1 to 5 to describe the general condition of each well. We have shown that the less equipped wells are also those which are in the worst condition, but the aim of the whole study was to find out if the different chemical indicators chosen would allow one to quantify a degree of contamination and, even more importantly, to establish a correlation between the levels of the indicators in the groundwater and the type of problems responsible for them. Unfortunately, it was not possible to establish a more precise ranking index as this would have implied a longer survey time for each well, difficult to implement in the present volatile situation. Moreover, this can be carried out only



by well-trained surveyors, capable of identifying with precision the specific problems and of setting up a suitable ranking index. However, a few specific factors which are quite easy to assess have been added, such as the presence of an apron, headwall, cover, and these may help to improve our understanding of the possible causes leading to a contamination of the water of a given well.

The problem here arises from the fact that many parameters change simultaneously. The depth of the wells increases, their location for a given depth is different, the numbers of people supplied may have an influence on the quality of the water, as the amounts abstracted are higher. Simple relationships may be made evident by plotting one parameter against the other, which means plotting the E.C. versus the depths of the wells, or the nitrates versus the concentrations of ammonium. The shape and distribution of the points on the graphs may give an indication of a given relationship. Studies carried out in urban groundwater in the city of Lucknow (India) have shown that a positive correlation can be observed between nitrate and chloride and that conclusions can be drawn from these results as to origin and fate of the nitrogen, leached into the groundwater from domestic effluents [30].



A similar approach was applied to our data. The next figures show some of these graphs where several parameters were tested versus the chemical indicators chosen and the indicators among themselves. Wells without chemical values are indicated as -1.The number of families is representative of the quantities pumped from every well. In the case of a positive correlation, an indication can be obtained of the proportion of families drinking water with a high nitrate content, making it possible to draw conclusions in terms of public health as to the importance of the quality of the water. In fact, a low negative correlation is observed, the wells supplying a large number of families have a lower nitrate content than those supplying a small numer of families. It happens that those supplying a small number of families are also located in the suburbs close to the seashore. They are therefore of lower total depth and, being closer to the sea, have a higher salinity. From the data it is not possible to differentiate between the water used as drinking water and that used for other domestic needs. It is also not possible to have a precise idea of the amounts drawn from each well, as surveyors could not spend too much time on one specific location. The number of families is obtained from interviews and the number of m3/day pumped from a given well is estimated from the number of families, assuming a mean number of 5 persons per family and a mean consumption of 20 liters/p/day. This is of course a rough estimation, even if it is based on several surveys carried out by different organizations.

The water from the wells with a high nitrate level is also quite saline and people may not drink it, the salinity having a protective effect for high nitrate levels, as has been observed in other contexts, such as in the southern areas of the Gaza strip [31]. For the other indicators, PO4-- and NH4+ the correlation is even less evident, if not inexistent. One of the problems in this kind of analysis is due to the fact that many measures are close to the limit of detection and, in the case of nitrates, over the upper limit of detection. A selection can be made but it is difficult to avoid bias. The last graph shows that there is no relation at all between NO3- and PO4--. The limits of these modes of representation are quite obvious and other methods had to be used.

Statistical analyses and correlations.

Table III gives the correlation coefficients computed for all the parameters versus the others using classic statistical methods. In this particular case, the different statistical formulas available in EXCEL have been used and applied to the database. Positive correlation coefficients are comprised between 0.0 and 1.0. The highest value means a perfect correlation and the lowest no direct relationship at all. Inverse correlations are given as negative values. The coefficients have been computed for the totality of the data (n=459) Coefficients higher than 0.40 have been highlighted in different colours. For all the wells the values comprised between 0.40 and 0.50 are highlighted in yellow, those between 0.50 and 0.60 in orange and finally those higher than 0.6, indicating a strong correlation, are in red .

Here again the results must be taken with precaution. Several cells in the table show a strong correlation. For instance, if we consider the correlation between the NO3- levels and the condition of the wells, the coefficient indicates that the levels of nitrates vary in inverse proportion to the index of well conditions, which means that nitrates are low when the condition of the well is high. To measure the correlation between the nitrates and the different types of wells a filter should be applied to compute a new value for the correlation coefficient between the hand-dug wells, for instance, and the nitrates. The value obtained for the totality of the wells would probably decrease, showing a high influence of the HD category (code 1) or, reciprocally, a high weighting of the motorized wells, for which the proportion of the wells in the high ranking categories (good and very good) are high. We know that most of the wells with a high nitrate level are those which have a low condition index, but in this case we would also expect a high coefficient for the HD category. Unfortunately, this is not possible with the present data as we know that the detection level of nitrate is limited to 90 mg/l and that a large proportion of the HD wells is in a very poor or poor condition. This means that for this category and and the parameter NO3-, the correlation cannot be shown even if there is one. The correlation coefficient between NO3- and the type of wells is -0.34, which means that there is a relationship between the two parameters, but that different effects may certainly play a role. What is interesting is the important negative correlation between the NO3- and the water layer, which is in this case the height of the water in the well. A straightforward interpretation may be related to a smaller dilution factor for the wells with a small volume, where a little amount of NO3- reaching the well leads to quite a high concentration. The latter is probably the true reason, because we know that shallow wells are those in the worst condition and those most prone to contamination.

The interpretation is becoming too biased and unfortunately the criteria used are not sufficiently precise to screen the different contributions, and this may not be possible without careful supervision of the surveyors. Unfortunately, this was not possible at the time of the study.

Table III
Correlation coefficients between the different parameters. All the wells of the screened database are taken into account (n= 459). Significant correlation is highlighted in color, from yellow to red.

	NO3-	NH4+	PO4-	pH	Type w	Nb. fam	E.C.	Water h.	Cover	apron	H.wall	Cond.
NO3-	1,00	0,01	0,17	0,08	-0,34	-0,35	0,23	-0,41	-0,27	-0,10	-0,11	-0,46
NH4+	0,01	1,00	0,17	-0,02	-0,13	-0,02	0,12	-0,09	-0,15	-0,19	-0,14	-0,09
PO4--	0,17	0,17	1,00	-0,05	-0,20	0,04	0,12	-0,15	-0,08	-0,05	-0,04	-0,15
pH	0,08	-0,02	-0,05	1,00	-0,27	-0,38	-0,03	-0,19	-0,30	-0,23	-0,21	-0,29
Typewell	-0,34	-0,13	-0,20	-0,27	1,00	0,42	-0,26	0,42	0,57	0,23	0,25	0,62
Nb. famil	-0,35	-0,02	0,04	0,38	0,42	1,00	-0,18	0,43	0,38	0,16	0,15	0,43
E.C.	0,23	0,12	0,12	-0,03	-0,26	-0,18	1,00	-0,26	-0,14	-0,06	-0,04	-0,25
Water h.	-0,41	-0,09	-0,15	-0,19	0,42	0,43	-0,26	1,00	0,28	0,12	0,14	0,39
Cover	-0,27	-0,15	-0,08	-0,30	0,57	0,38	-0,14	0,28	1,00	0,42	0,48	0,58
Apron	-0,10	-0,19	-0,05	-0,23	0,23	0,16	-0,06	0,12	0,42	1,00	0,79	0,28
Headwal	-0,11	-0,14	-0,04	-0,21	0,25	0,15	-0,04	0,14	0,48	0,79	1,00	0,35
Cond..co	-0,46	-0,09	-0,15	-0,29	0,62	0,43	-0,25	0,39	0,58	0,28	0,35	1,00

General discussion

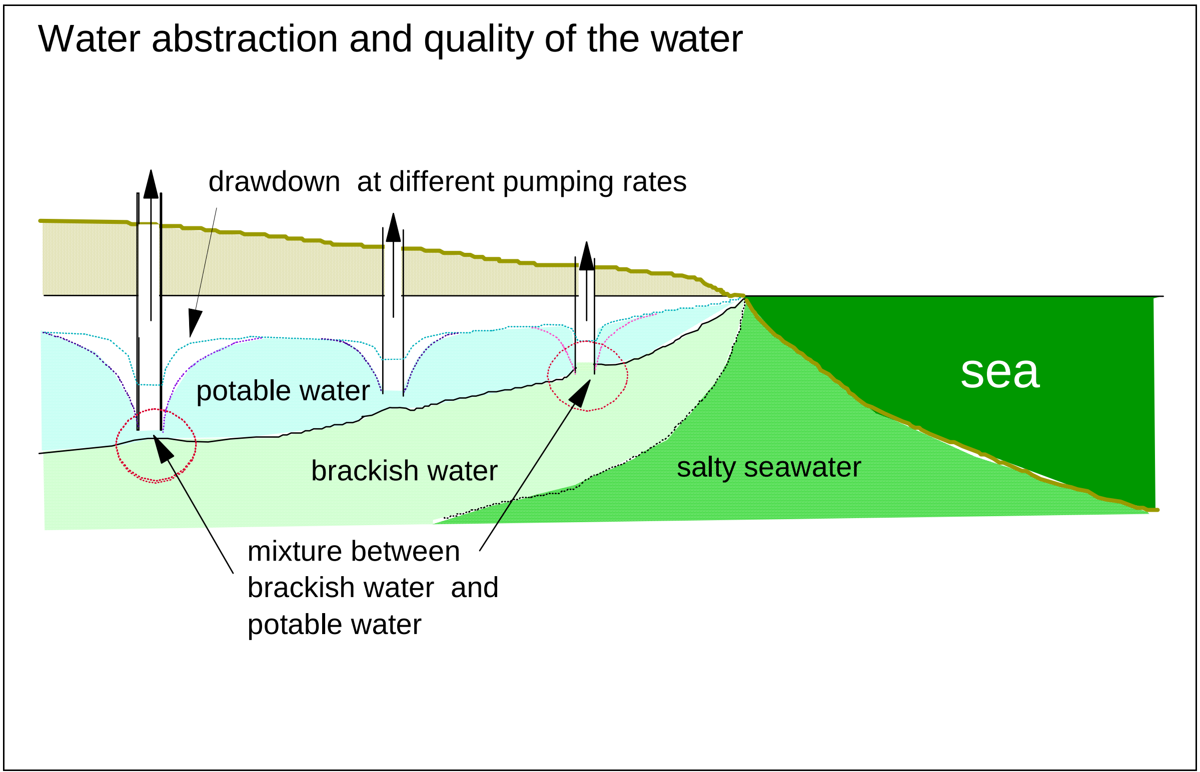
The civil war and the rapid increase in population have created enormous environmental problems and have put unprecedented pressure on the groundwater resources of the towns of Mogadishu and Kismayo.

We will discuss here the situation of Mogadishu but the problems can be easily extrapolated to the more southerly town, even if for the latter it is not clear, at least to the author, from where the recharge of the aquifer is occurring. For the capital, several studies have been carried out to find a suitable location for the new well fields and therefore a lot more is known. During the different studies carried out before the civil war it has been established that there exists almost everywhere along the coast a limestone basement, originating from coral reef, which has an eroded and slightly karstified surface, with horizontal and vertical variations. This limestone is covered by white sand which can extend several kilometers inland [32].

A continuous water table exists along the coast and all the wells tap water from this aquifer. These wells are dug in beach sand, in coral limestone and in sandstone, depending at which distance they are located. Some hand-dug wells can reach depths of 70 meters or more, but the majority are in fact open dug wells and their depth does not generally exceed 20-30 m. In most cases, the water table is only a few meters above sea level, with a gentle slope from the Shabelle aquifer toward the sea. As in all the coastal area, the fresh groundwater lens floats on more salty water, which is more dense.

Many parameters may contribute to modifying the quality of the groundwater: yearly droughts or heavy floods due to abnormal rainfalls, as was the case from the end of 1997 to the early months of 1998, the intensity of the exploitation of each well, the distance from the sea, the depth and penetration of the well into the aquifer, the lythological characteristics of the aquifer, the extent of sea intrusion, tidal effects, [33] and, last but not least, the type of equipment and protection, and the distance from a pollution source, which is in Mogadishu mainly due to domestic effluents. Other not well-known factors also have an influence, such as the tidal movements, particularly on the groundwater of wells located close to the seashore. All these factors are interrelated and it is quite difficult to separate one from the others. The following figure shows schematically what may happen in these wells, where the salinity may change according to the quantity of water that is withdrawn. If the well penetrates slightly into the more saline layer, some mixing may occur as the abstraction continues, and the global salinity may increase.

This is why all the wells have a quite different salinity. Previous studies have shown that the movement of the saline/fresh water wedge of the underground aquifer of the town has been considerable, progressing inland from 1970 to 1978 and again up to the end of 1997. In this study we have been able to compute more precisely the position of the different salinity boundaries, using surface analysis software, which allows one to compute the isoconductivity boundaries and therefore to map the spatial distribution of the water salinity of the different wells.



But the main objective of the study was to monitor the effects of the 1997/98 floods on the saline/fresh water interface and to measure a few chemical parameters used as possible indicators of water contamination, with the aim of trying to establish a relationship between the levels observed and the general conditions of the wells and of their surroundings.

We were able to show that the floods had a tremendous influence on the recharge of the aquifer and that the saline wedge has been pushed back to its 1980 level, with a subsequent improvement of the water quality, raising the level of the water table in almost all the areas of the town. The precise position of the salinity boundaries, expressed as conductivity values, was again computed using interpolation techniques, making it possible to map the areas at risk, located between the chosen boundaries, where the salinity is most likely to change during the recurrent drought periods or when important floods take place. The computed boundaries must be considered as extreme ones, as floods such as those of 1997/98 are not likely to occur often, the last of such a magnitude having been observed in 1961.

Chemical indicators

The concentrations of the chosen indicators have also been measured in almost all the wells (n= 459) and plotted on the map. Their spatial distribution has been calculated and areas of contamination plotted for NO_3^-, NH_4^+ and PO_4^{-2}. A few other parameters have also been mapped, for instance pH. Others, like temperature, the number of families supplied, the depth of the wells, the thickness of the water layer, the temperature of the water, the general conditions of the wells expressed in a ranking index, the type of protection, the type of well, the suburbs, etc., are listed in the database and can be consulted with the use of simple GIS software incorporated in a CD-ROM.

If the areas of contamination were mapped, only global trends relating the indicator chemicals with the condition of the wells could be established. Specific reasons explaining the evolution of the concentration of the different chemicals, such as the presence of an apron, poor sealing of the wells, the lack of covers, etc. could not be established and correlations were not evident. These relationships remain to be studied.

Nevertheless it was possible to show that NO3- may be used as an indicator for potential domestic pollution, as it has been in other contexts. It was possible to show that this effect is pronounced where the wells are quite shallow, even if for operational reasons linked mainly to security, values exceeding 90 mg/l could not be discriminated. Crude correlations were observed with the poor condition of the wells but it was not possible to distinguish between direct contamination by surface water as a result of poor sanitary completion of the dug wells, and unsanitary conditions around the wells, or by leachate infiltration through the ground from on-site sanitation facilities.

If both causes may be retained, it is quite possible that infiltration from leachates originating from latrines or septic tanks effluents may play a inportant role in areas where nitrates are high, i.e. more than 90 mg/l, where the salinity also increases. We are dealing here with densly populated areas and the methods of sewage disposal may contaminate the underground water where wells are shallow and where the natural mechanism of elimination is not able to reduce the contaminants. Studies in Dhaka have shown that although the constitution of the aquifer was in principle sufficient to eliminate most microorganisms through natural processes, the high population density within the peri-urban areas increased the risks of pollution by reducing the separation between on-site sanitation systems and water supply sources [34]. The mean density is lower in our case, close to 100 (800'000 inhabitants for 800 ha, or more) compared to the figure for the informal settlements of the suburbs studied, close to 600, but we do not know is the density of the most densly populated area of Mogadishu, which may be higher.

The origin of the contamination by nitrates is normally determined by measuring the ratio between NO3- and Cl- (chloride), which is 2 : 1 in excreta. In natural water this ratio changes to 1:2. The measurement of these ratios should in principle indicate the percentage of nitrogen being leached into the water table, since chloride is a conservative ion and is therefore not retarded or degraded during the transport. Unfortunately this distinction cannot be made here as chloride is present in the wells and we do not know which proportion of it is due to leachates and which to sea water infiltration or weathering from saline deposits.
One way to make the distinction would be to measure another conservative ion, such as Br- (bromide) and compare the ratios.

However, we know that organic nitrogen is oxidized to nitrate via ammonium. Our study shows that ammonium is low, less than 0.5 mg/l and increases only in a few “islands” and close to the sea, where the nitrates are also high, more than 90 mg/l. This oxidation reaction may occur during the infiltration process and we would then expect lower amounts of NH4+ where the wells are deeper. And this is the case, as we measure almost everywhere else levels below 0.2 mg/l, which is also the detection limit of the instrument.

Comparison with faecal coliform counts may allow a distinction. But if the presence of E.coli indicates the presence of faecal contamination, its absence does not prove the absence of such contamination, as its survival in the unsaturated zone may not be guaranteed, depending on the length of the flow path and its consequent possible attenuation [35].

References

ANNEXE I
Brief description of the database

Fields	Description
APRON	presence or absence of an apron: 1/0
CONDITION	Describes the general condition of the well
CONDITION CODE	1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good
COVER	Presence or absence of a cover: 1/0
DEPTH	Total depth in meters from the ground
DIAM	Diameter of the well in meters
E_C_	Electrical conductivity of the water in microSiemens/cm or in milliSiemens/cm.
FPOS	Allows to select the wells not precisely located from those located on the map 1/0
FPOS3	Selects the wells with a value for the chemical indicators used The total number of wells selected in this database is 459.

HWALL	Presence or absence of a headwall: 1/0
ID	Number of entries in the database
ID1	Identifaction number of each well, from 1 to 702
LOCATION	Name of the well or name of the owner.
M3_DAY	Quantity of water estimated from the number of family supplied by each well (20 l/p/day), indicative value, not measured.
MAPREF	Identification of each well per suburb ex KA 203, AZ23,..
NBFAMILIES	Number of families supplied by a given well:1 family: 5 people
NH4+	Concentration of ammonium in mg of NH4+/l.
NO_DISTRICT	Id Number for the wells of each suburbs/districts of the town
NO3-	Concentration in mg/l of NO3-.
NO3-TEXTE	Concentration of NO3- in mg/l.
PH	pH of the water sampled
PO4--	Concentration of PO4-- in mg/l
SOURCETHM	Name of the suburbs/districts ABDUL AZIZ, KARAAN, etc.
TDS	Total dissolved solids in mg/l calculated from E.C.
TEMP	Temperature of the water
TYPE	Type of well HD= hand-dug, HDA= Hand-dug for animals, HDAL = hand-dug animal lift, HDP= hand-dug and pumpother than hand-pump,HDHP = hand-dug and hand-pump,
HDMP=	hand-dug and motorized pump, BH = borehole,
BHP =	borehole with pump.
WATER LEVEL	Level of the water from the ground in meters.

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