The Gaza strip:
the state of the water supply after the 2008 – 2009 war

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Images : CMWU

Occasional paper no. 10

June 2010

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Introduction

In a former paper [1] published on the aftermath of the war, the number of buildings completely destroyed was estimated to be of about 2500 and it was estimated that about 20000 buildings were severely or partially damaged. Collateral damage to the electricity network, to the water storage and distribution systems connecting the buildings was also foreseen as well as the possible damage to the sewage network systems.

Data on specific damage on the electrical network were not yet available but were likely to be important, owing to the above mentioned numbers of buildings affected by the IDF military operation. Damage to the electricity network has been probably easy to spot with distribution cables, poles, transformers and other fittings destroyed. Even if precise data are not available, the interventions, whenever possible, have certainly been important.

On the contrary, possible leaks of toxic substances used in the step-down transformers into the ground and finally to the water table, leading to potential health risks for the whole population of the strip, were considered more difficult to evaluate and would have need specific assessments.

As far as water is concerned, emergency assessments were carried out by CMWU teams immediately after the cessation of the hostilities and even during the war, and detailed reports on the damage to the water infrastructure, have been issued end of January 2009, whenever possible. According to this first damage assessment, 11 municipal wells have been affected, with 3 completely destroyed and the remaining only partially damaged, depriving about 50000 people from their normal access to water. 4 main reservoirs have also been hit, with one almost totally destroyed.

Not surprisingly the distribution network has also been affected, with damage to the primary and secondary networks easy to spot, leading to a precise list of pipes of different diameter to be replaced or repaired. The complete list of pipes to be replaced or to be repaired is listed in the CMWU report, which outlined an amount of about 6 M USD for the immediate emergency intervention[2].

CMWU emergency teams were at work immediately and where possible, repairs carried out. House connections and tertiary networks could only be estimated, but with about 2660 buildings severely hit by the shelling (UNEP[3]), the damage has certainly been important, representing a large part of the reconstruction effort to be carried out.

New distribution lines had to be laid to bypass the rubbles and to reconnect, wherever possible, the buildings still prone to be used. The numbers are impressive: 840 HH have had their water supply totally damaged, 5200 roof water tanks have been lost and about 2335 have suffered some damage and were in need of repair.

As outlined in our previous paper, interventions on the tertiary network are more difficult to assess, as leeks are not immediately visible, but they are likely to be important. CMWU engineers have given a high importance to this budget line (1 M USD), even if precise information could not yet be available, particularly in the Rafah governorate, where the use of vibration bombs has been wide, in order to destroy the smuggling tunnels, used to supply

[1] P.G.Nembrini, A. Moreau, The Gaza strip: the last ghetto: an organized deprivation and a denied urban development, January 2009, www.thirstycitiesinwar.com.
[2] CMWU, Damage Assessment Report, Water and wastewater infrastructure and facilities, Gaza 27 Dec 2008-19 Jan. 2009, January 2009, personal communication.
[3] UNEP, Environmental assessment of the Gaza strip following the escalation of the hostilities in December 2008-January 2009, September 2009, www.unep.org

essential goods not allowed to entry into the strip by the COGAT[4] authorizing entity [5](see also Haaretz[6]).

Post-conflict damage assessment have been carried out by several INGO and, as quoted, by UNEP. The last assessment, published end of September 2009 was carried out in April 2009 and reports about damage likely to occur to the environment[7].

Data on the number of buildings completely or severely destroyed have been compiled using high resolution satellite images acquired before, during and after the conflict. Damage was recorded by type and the estimated occurrence reported by governorate. As it easy to see, Gaza North, Gaza and Rafah have born the brunt of the shelling, with Khan Younis and the Middle governorate showing a lower number of impacts, targeting specific locations close to the border.

Some areas, East of Jabalia and West of Beit lahia in the North and the area along the Gaza Egyptian border have been severely hit and it is likely that they will be almost impossible to rebuild in the near future, as the amount of rubbles is huge and the number of poorly secured buildings is close to 100 %. Owing to the extension of the damage and to the impossibility to live in such areas, it was considered that nothing would be done to try to restore any essential service in these highly affected areas until they would be cleaned and prepared for any possible new development, implying a new layout of the water and the electricity networks, as wells as any other services.

In this paper we will try to analyze the impact of the “Cast lead” war on the water supply of the Gaza strip using data gathered from the CMWU during the 2009 year. The evolution of the water quality will also be analyzed by comparing data collected in 2004 with those obtained recently, bearing in mind that damage to waste water conveying pipelines has been important but also taking into account new developments in the waste water treatment infrastructure, implemented before the onset of the war and partially completed during 2009 and beginning of 2010.

Over-pumping has been the major cause of the depletion of the water table observed under Rafah/Khan Younis and under Gaza city, as documented during the studies carried out in the framework of the CAMP project, in 2000, when also the evolution of the salt intrusion has been measured. To which extent the increased pumping has also induced an inward movement of the saline wedge remains also to be analyzed.

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[4] GOGAT Coordinator for Government Activities in the Territories
[5] Gisha, Restriction on the transfer of goods to Gaza:Obstruction and Obfuscation, January 2010, www. gisha.org.
[6] Yotam Feldman and Uri Blau, "Gaza Bonanza", Haaretz, October 15, 2009
[7] Environmental Assessment of the Gaza strip, following the escalation of the hostilities in December 2008 - January 2009, UNEP September 2009. uneppub@unep.org or www.unep.org

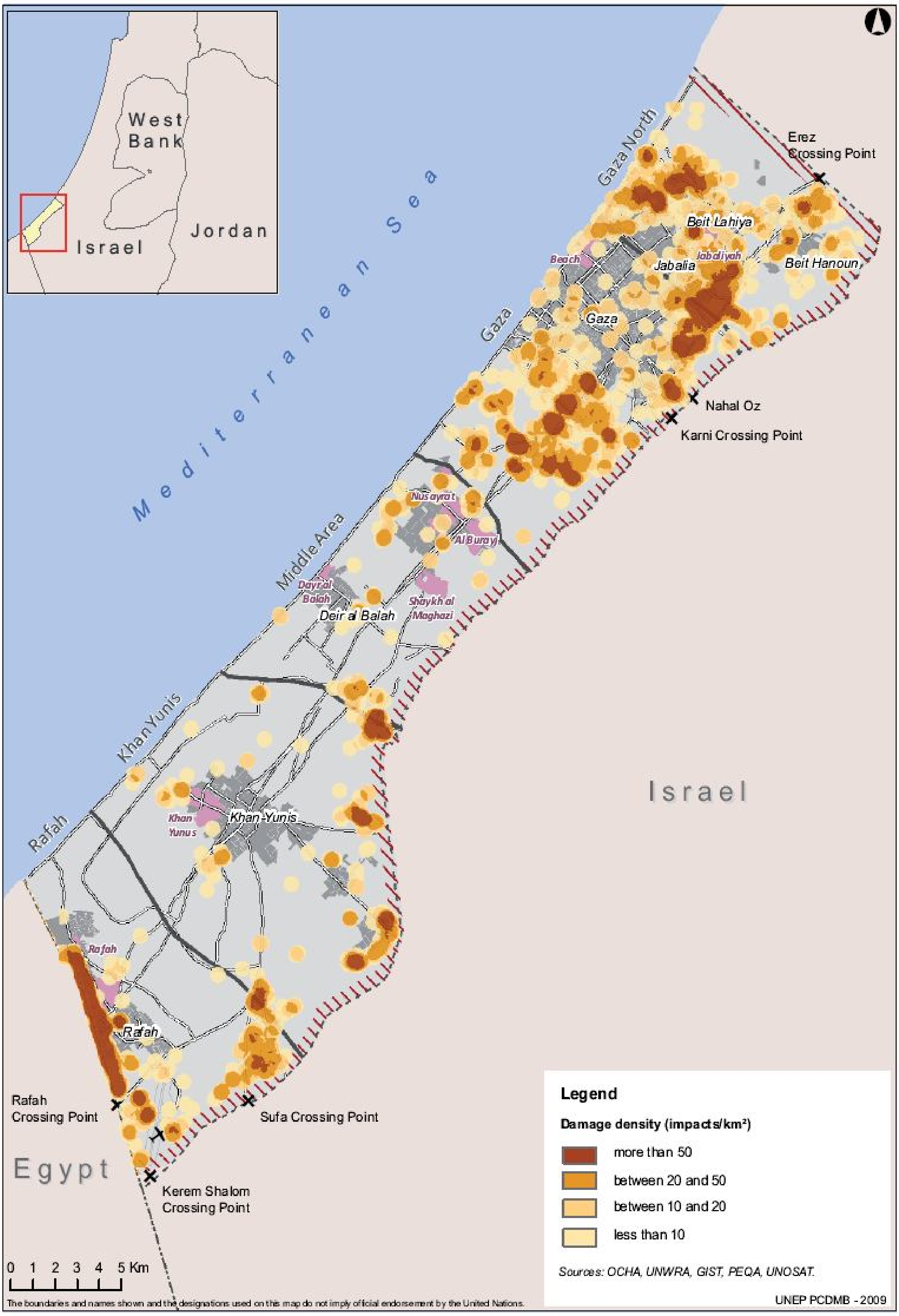

Figure 1 Damaged analysis map (source UNOSAT/UNEP)

Evolution of the water table

The important quantities of water abstracted to meet the demand of an increased population have put the aquifer under stress already since the late nineties. A comprehensive study, carried out with funding from the United States Agency for International Development (USAID) and the Palestinian Water Authority (PWA), led to the CAMP project or IAMP (Integrated Coastal Aquifer Management Plan) aimed to provide planning guidelines for water supply and usage through 2020. A particular concern was the overexploitation of the coastal aquifer, resulting in continuous lowering of regional water levels and to a gradual worsening of the water quality. Several specific studies have also been conducted to understand the behavior of the aquifer and particularly to study the extent of seawater intrusion and up-coning of deep fossil brines. According to the model developed for the Gaza strip[8] the implementation of the IAMP would have beneficial impacts on the Gaza coastal aquifer, predicting that seawater intrusion and up-coning could be significantly reduced or stabilized over the next 20 years. The model predicted an improvement of the water table depressions under the southern part of the Strip and the disappearance of the depression under the city of Gaza around 2010 but only if several steps were taken to improve the management of the whole aquifer, namely:

- Reduction of agricultural pumping from 90 Mm3/y to 16 Mm3/y
- Improved management of municipal supplies with new wells and better management of the existing ones. The demand was expected to grow to 127 Mm3/y in 2020.
- Recharge of significant quantities of treated effluent to the aquifer system
- Significant contribution of the production of water through desalination units, most likely a large scale RO integrated to the municipal supply (60 Mm3/y) with subsequent increase in return flows
- Return flows from wastewater and municipal water supply distribution networks (76 Mm3/y by 2020)
- Artificial recharge basins up to 35 Mm3/y.
- Return flows from irrigation (25% of 63 Mm3/y by year 2020)

Following the implementation of the IAMP, the anticipated improvement in ground levels were outlined in 5 years increments to 2020. It was foreseen that the observed levels below mSWL observed under Rafah/khan Younis and under Gaza city, would progressively disappear and shift to positive values, above mSWL already before 2010.

However, since then, there were quite drastic changes: all the Israeli settlements have been dismantled, following the unilateral pullout of the Israeli Army in August 2005, and open hostilities between the ruling entities in the Gaza strip and the Israeli Defense Forces have reached war proportions, at two times, in 2006 during the “Summer rains” operation and culminating end of 2008/beginning of 2009 with the “Cast Lead” incursion, when more than 1500 civilians have lost their lives and more than 5000 have been wounded, with systematic wanton destructions of the infrastructure in specifically areas targeted.

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[8] Moe H., Hossain R., Fitzgerald R., Banna M., Mushtaha A., Yaqubi A., Application of a 3-Dimensional Coupled Flow and Transport Model in the Gaza Strip. First International Conference on Saltwater Intrusion and Coastal Aquifers-Monitoring, Modeling and Management, Essaouira, Morocco, April 23-25, 2001.

The prevailing situation existing during the first decade of the 21st century were clearly not conducive for a "dedicated data collection, requiring the installation of observation wells, the implementation of systematic sampling programs and careful study of the major factors that influence the ground water regime in the Gaza strip" as outlined in the steps to be taken in the framework of the IAMP in order to reach the modeled behavior.

The large scale RO desalination plant is still at the planning stage, the infiltration of water to recharge the aquifer has not been implemented as all the water has been devoted to match the increased demand, and the infiltration of treated waste water is at its beginning, with water qualities at the outflow still largely over the accepted level of 20 mg/l of BOD5. However, a few projects have been completed, in Rafah and in Khan Younis, to improve the treatment of the waste water, which collection has also improved or will improve with the different projects carried out to collect the waste water and to channel them to the waste water treatment stations, which capacity has also been increased. The lagoons were built to improve the treatment but no infiltration has been planned, the water being discharged to a seawater outfall. It may be possible, if the treatment process is efficient, to reclaim some of this water for irrigation, decreasing the burden of the water abstracted for agriculture purposes.

But the main monitored cause has been the increased pumping from the municipal wells.

According to Qahman[9], the amounts pumped from municipal wells (domestic use) were estimated to be close to 40 Mm3/y in 1996 (about 110'000 m3/day) with about 80 Mm3/y from agricultural wells and an estimated 10 Mm3/y for the Israeli settlements.

In 2007 the abstraction for domestic and industrial use were monitored at 83.5 Mm3/y (229'000 m3/day)[10] and the amounts abstracted for agricultural use again estimated to be close to 80 Mm3/day. The Israeli settlements were dismantled.

As a consequence the foreseen improvements have not been observed. The situation has even worsened, with levels of the water table below mswl (mean seawater levels) reaching -10 to -12 m under Rafah and Khan Younis and -6 m under Gaza city. If a porosity factor of 0.25 is considered, the depression under Rafah and Khan Younis corresponds to a loss of 8 Mm3/y, equivalent to about 22'000 m3/d, close to 10% of the total daily output for the entire strip.

It is difficult to appreciate the impact of the Israeli use of the water before it enters into the strip, either from underground flow or from the Wadi Gaza. What is evident is that an important amount of the water flowing into the Wadi Gaza is harnessed for irrigation purposes, reducing the flow rate of the wadi to a minimum during the dry seasons, and therefore its potential for the recharge of the aquifer, but also letting it flowing during the seasonal storms, with dramatic consequences for the downstream's riparians.

If the effects of the over-abstractions combined with the poor recharge can be observed almost in time, the longer term effects on the aquifer, like the likely inland shift of the saline wedge in the different sub-aquifers, due to seawater or brine intrusions, are less easy to monitor. 10 years after the first attempt to monitor the extent of the salt intrusion, the systematic study of the aquifer has to be carried out again, in order to appreciate the importance of its likely inland shift, and to appreciate the impact of any step undertaken to improve the management of the aquifer.

[9] Qahman K.A., Zhou Y. Monitoring of Seawater Intrusion in the Gaza strip, Palestine. First International Conference on Saltwater Intrusion and Coastal Aquifers-Monitoring, Modeling and Management, Essaouira, Morocco, April 23-25, 2001.
[10] Coastal Municipalities Water Utility, Water situation in the Gaza Strip, Year 2007/2008. October 2008. www.cmwu.ps

Municipal wells monthly production between 2008 and throughout 2009.

During a high intensity war as the one witnessed during the "Cast lead" operation, it is expected to observe a decrease in the monthly production recorded for the municipalities by CMWU. However, not all the municipalities have been similarly affected. According to the UNOSAT[11] figures reporting the number of craters per area the municipalities of Beit Lahia, Beit Hanoun, Jabalia and the Gaza city have been particularly targeted in the North and the Municipality of Rafah in the South. However, only about 10 municipal boreholes have undergone severe damage, as listed in the CMWU damage assessment, carried out during

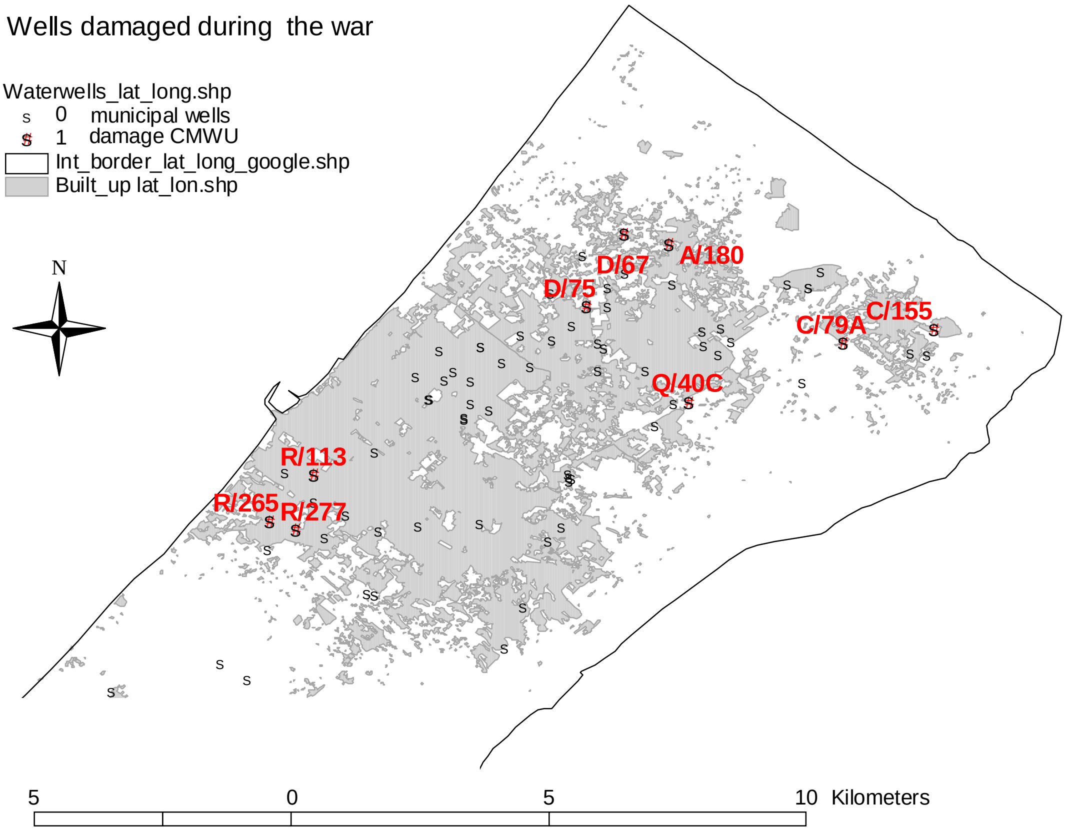


Figure 2 Wells which operation was severely or moderately affected by the shelling. In the Northern areas.

the hostilities and in the aftermath of the war. The effects of power cuts have been minimized by the installation of back-up electrical generators during the previous incursions[12], allowing the CMWU to operate the boreholes close to their normal schedules, when fuel was available and operators able to run the facilities. Fuel has been made available by different

[11] UNOSAT, UNEP report, op. cit.
[12] Summer Rains, June 2006

organisations which were able to overcome the restrictions imposed by the IDF on the delivery of fuel to the pumping stations[13].

Only 10 wells have been affected in the Northern areas, a few completely destroyed with the borehole damaged to an extent beyond any repair, other where the pumping premises have been severely damages and others more or less affected. The total output of these wells, based on their pumping capacity, was close to 900 m3/d, that is about 15000 m3/day taking into account their operation hours. This represents only a small part of the production of the wells delivering water into the network.

However, some localities, like Beit Hanoun may have been proportionally more affected. If the maintenance of the production is of paramount importance, other steps of the distribution are important too. In the Gaza strip, the unaccounted for water (losses, illegal connections, erroneous metering, etc.) are important, probably over 40%. If production can be quite easily recorded, UFW are in general computed from the volumes recorded by the installed meters or delivered to the customers by any other means, like water tankers, etc., compared to what is pumped into the network. In a war situation, where the number of leaks is increasing daily, where many roof and underground storage tanks have been damaged and where the people try to get water from any available source, the UFW are likely to increase dramatically.

Emergency teams may be quick to repair the leaks and to suppress the connections affected by the shelling, taking considerable risks, but despite that, the losses are enormous. Data are also difficult to collect, and in general a repair team is happy when it was able to fix a problem without sustaining any injury, and without loss of any materials. With luck, and commitment, data on the number of problems reported and of the interventions carried out by the teams are sometimes available. Unfortunately, in the present case they are not or , more likely , they were not been made available to the author.

Interventions can be divided into three categories:

- those affecting the primary network, which number is low and easy to spot if the pumping is maintained, but requiring heavy materials and spare parts
- those affecting the secondary network, more important in terms of number, less easy to observe but relatively easy to repair, provided that the necessary tools, fitting and pipes are available
- those affecting the tertiary network, which number is high, sometimes difficult to spot, and requiring a systematic cut off of the buildings until better information is available. Their repair may take months or even more.

Data on the production of the 18 municipalities, most only slightly affected, with the exception of Rafah, are shown in the following figures, compiled from metered volumes recorded by CMWU operators in the different pumping stations between November 2008 and December 2009, therefore covering the entire period of the war.

For these municipalities, if we look into the production figures the following conclusions can be drawn:

- The war operations did not affect significantly the production of water. There is a slight drop in, January 2009, but this can be explained by the difficulties in securing supply of fuel (diesel) and by the power outages. What is remarkable is that the CMWU operators were able to maintain such levels of production. In other contexts

[13] CMWU, op cit.

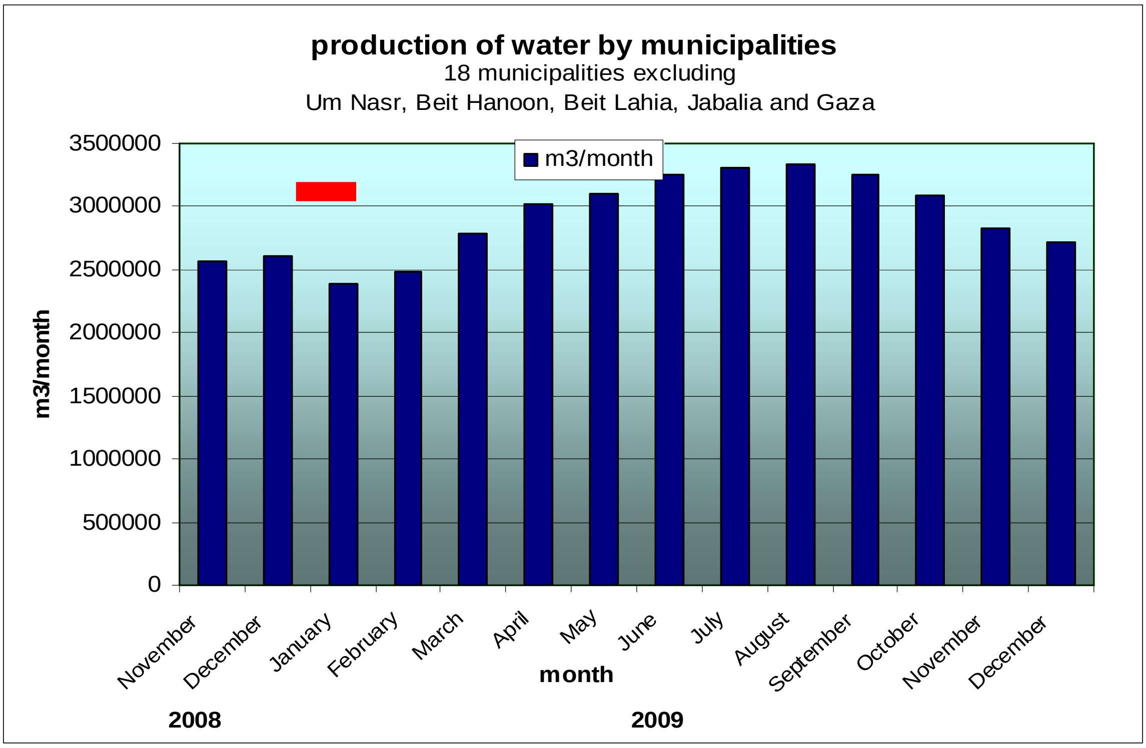
(Basrah 2002, etc. [14]) drops up to 50 % sometimes locally up to 100 % were observed, even if every system is particular. The situation of the Gaza strip particular too, as almost all the pumping stations can be operated with the use of back-up generators and the boreholes are relatively safe from shelling.

- The amount supplied from Mekorot to several municipalities have not been reduced during the hostilities, or just slightly, as it can be seen from the data compiled in the following table, obtained from CMWU[15].

Table I Amounts in m3/month supplied to different municipalities of the Gaza strip by Mekorot

Municipalities	January 2008 m3/month	December 2009 m3/month
Al Maghazi	1317	1000
Al Nuseirat	2670	2300
Al Burji	1956	1300
Al Zawaida	139	253
Bani suhalia	3250	4000
Total	8500	9000

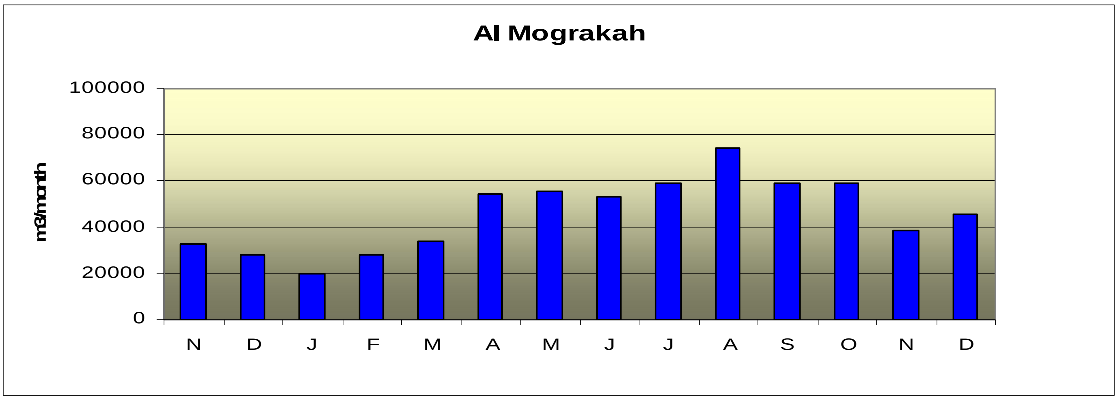
The total amounts produced by the 18 municipalities show the typical seasonal increase, with higher pumping during the summer months, when the demand for water is increasing. Interestingly, the amounts produced in December 2009 are slightly higher than those for December of the previous year, a trend that will be most probably observed in the coming



years.

Figure 3 Monthly production for the 18 municipalities of the middlle/southern governorates

[14] P.G. Nembrini, www.thirstycitiesinwar.com/...
[15]CMWU to Marwan Bardaweel, personal communication, March 2010.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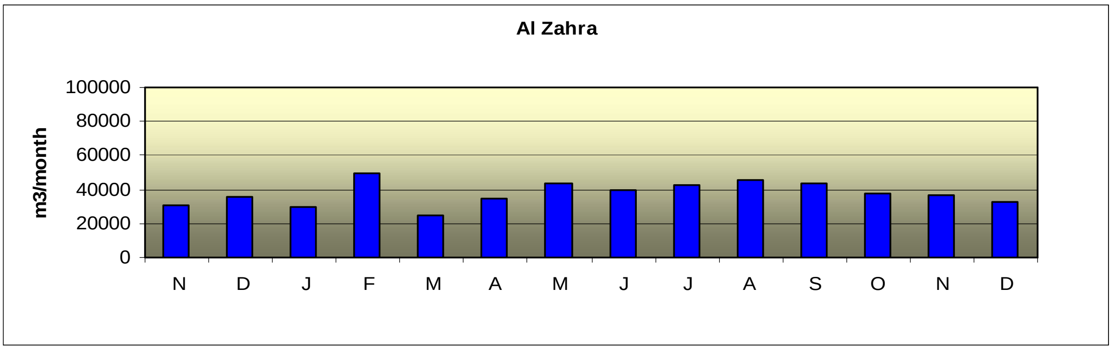
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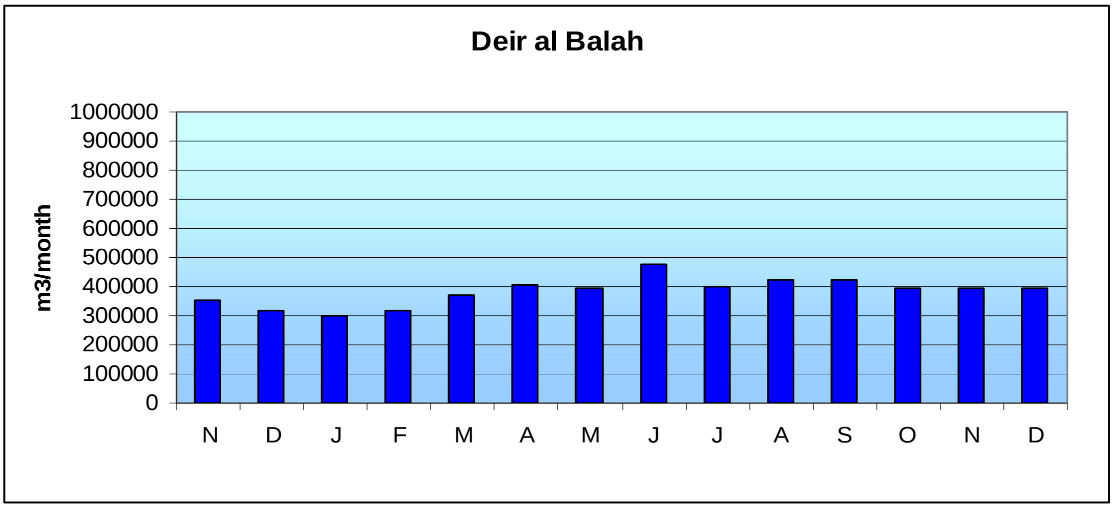
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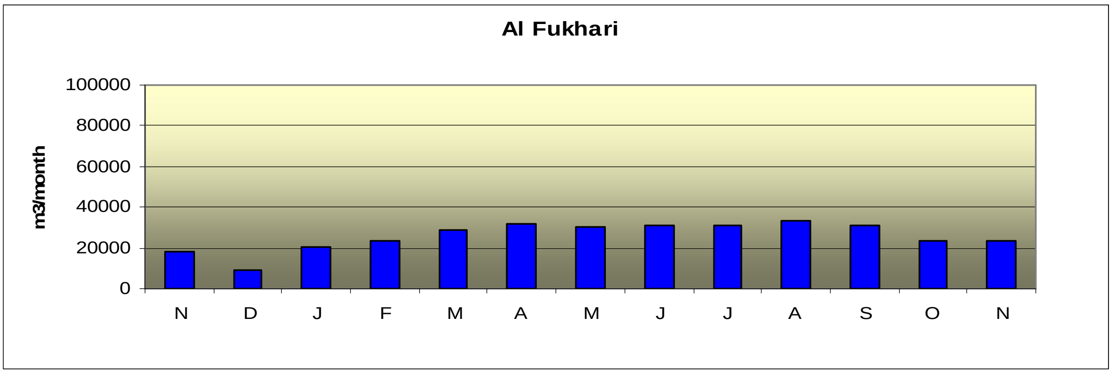
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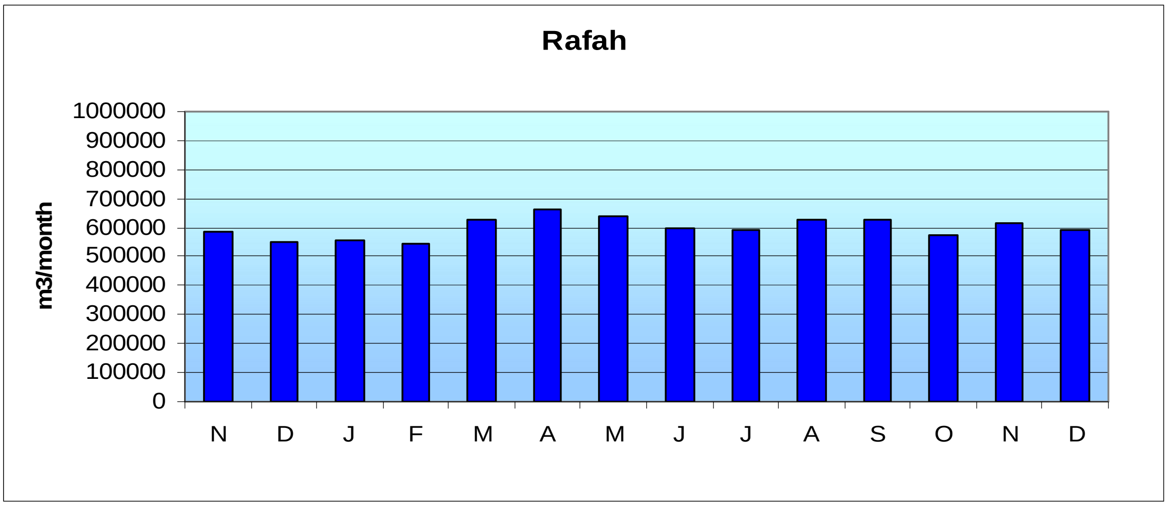
Figure 4 a, b Monthly production for different Middle and Southern Gaza strip municipalities (data



from CMWU). Note the different scales.

Figure 4 c. Monthly production for the municipality of Rafah**.**

The area of Rafah, close to the b order with Egypt has been heavily targeted in order to destroy the underground tunnels, used to smuggle goods into the Strip. If damage was important, as shown in the UNEP report, the monthly production figures have not been affected, the boreholes being located away from the border areas. It is not known how far the distribution networks have been affected by the vibration bombs allegedly used by the IDF during the Cast lead operation. It was foreseen that leaks would be on the increase, but precise data are not yet available.

Abstractions

In the meantime the abstractions seems to have increased from 2006, when the total amount computed from data compiled from the Master plans for the different governorates where close to 200'000 m3/day [16]. Output data for the different municipalities obtained from CMWU for November and December 2008 are slightly higher, at 210'745 m3/day and up to 221'969 m3/day for November.

Daily abstractions computed from pumping rates and pumping hours for 2008 are higher, close to 295'000 m3/day (n=143). The mean flow rate in m3 / hour for each well seems to be consistent from one dataset to another, with only slight variations from one year to another, which is probably linked to the fact that the vast majority of the wells are pumping directly into the network, a problem identified since a while but not yet solved.

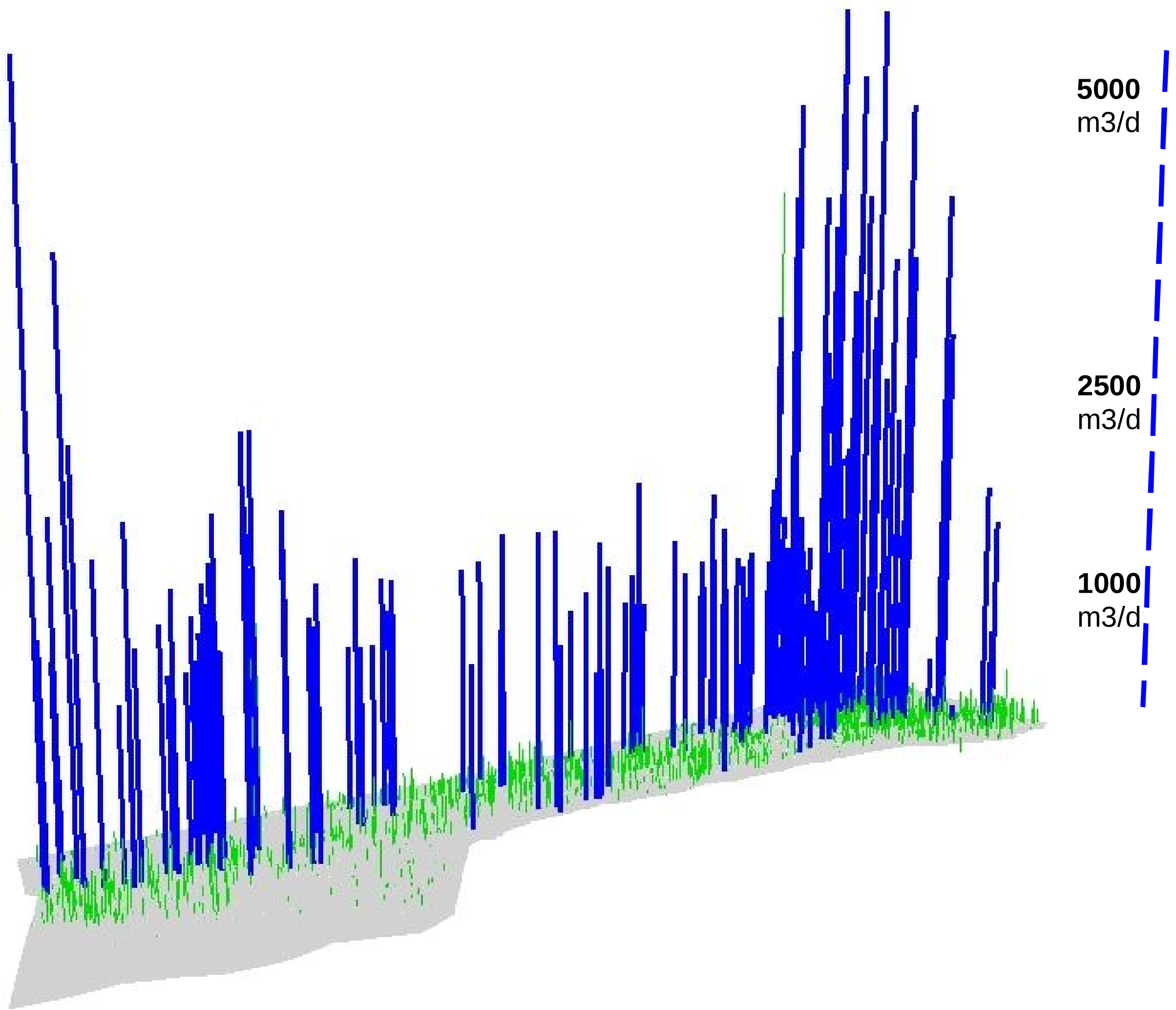


Figure 10 Relative proportion of outputs for municipal wells (blue) and agricultural wells (green) in m3/day (143 municipal wells and 1516 agricultural wells with output data over 2055 with coordinates).

[16] P.G. Nembrini, A. Moreau, The Gaza strip. The last ghetto: an organised deprivation and a denied urban development. Cities in war, thirsty cities, Occasional paper no. 9, January 2009. www.thirstycitiesinwar.com

Mean abstraction per agricultural well: 91 m3/day with a maximum of 506 m3/d. mean abstraction per municipal well: 2065 m3/d with a maximum of 5760 m3/d.

However, pumping hours for many wells had to be set to 24 h and this is increasing the output, which is likely to be just above 200'000 m3/day and most probably reaching 250'000 during the summer, when consumption is boosted by the high temperatures.

If we add to these abstractions the amounts abstracted from agricultural wells, computed to be close to 135'000 m3/day for 1483 wells and estimated to be close to 187'000 m3/day for the 2055 wells for which data have been recorded, if the mean value of 91 m3/ well per day is used.
It has been suggested that the number of agricultural wells may be even higher, up to 4000, but data on their location, equipment, outputs, etc. are not known and the only available figures are those obtained from ARIJ[17]. Their importance must be monitored as they contribute significantly to the abstractions, with high proportions of water lost in the watering process and not returned to the underground.

In the southern part of the strip these depressions may act initially as traps for dissolved chemicals entering the strip from the east. But unfortunately the water is then distributed through the network without treatment and will finally reach all the parts of the strip, where it will infiltrate directly or via the infiltration basins, built to remove pathogens from the waste water. As such they may have some usefulness in the south, where they may protect the water pumped from the wells closer to the shores, where the water table is fairly thick, particularly if the concerned wells are used to supply desalination units handling brackish water, provided that the brines are disposed into the sea. In the northern areas however they represent a threat for the whole water table, due to possible seawater intrusion, which is likely to occur by up-coning.

In fact, what is happening in the southern areas is what Weinthal[18] et al. have outlined in their article: the solution would be to pump water where it enters the strip, remove the chemicals, mainly chloride, using reverse osmosis or any other desalination methods and distribute the treated water within the strip, where, when disposed, it will infiltrate the ground. This will, in the long term, improve the chemical composition of the water. However, this requires energy, and the present situation is not conducive for such an approach, neither is the proposed location of the pumping station and of the treatment station outlined in Weinthal's paper, to be located within Israel. Given the current stall in the negotiations between the two parties this is not likely to happen, unless major political breakthroughs are going to take place.

Drilling for new municipal wells is still ongoing in order to cope with the increased demand, but also to better manage the aquifer, with less deeper wells, less output and shorter daily pumping.

Agricultural wells

Data on agricultural wells have been collected in 2000[19]. Recent data on agricultural wells are lacking. The available Master plans are not considering these wells but are mainly focusing on how to increase the daily amounts to be made available to the present and future population from the municipal wells. Only estimated of their present total abstractions are

[17] ARIJ, Applied Research Institute of Jerusalem, J.Isaac, personal communication. Data from, Ministry of Agriculture, 1998.
[18] Weinthal et al., Op. cit.
[19] USAID report

available, with an annual withdrawal of about 80 Mm3 (about 220’000 m3/d). Only part of the water abstracted is returned to the aquifer. Its importance is difficult to appreciate. For the municipal wells all the proposals have been focusing to reach 150 l/p/d, by drilling new wells in specific locations and eventually decrease the output of some of the existing ones, mainly to avoid possible up-coning due to high draw-downs. For the agricultural wells the matter is made more complex, depending on the techniques used for irrigation, which, when

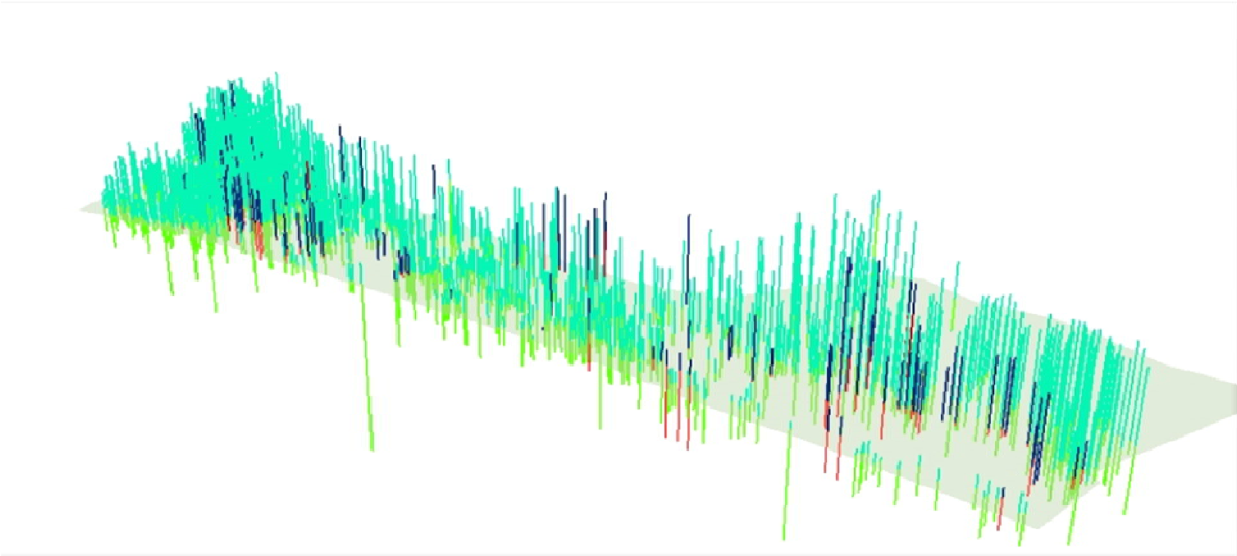


Figure 11 3D representation of the Gaza strip wells. Agricultural wells (1999, n=1296 (out of 2046)) and municipal wells (2008, n= 143). Elevation above mswl and depth of the wells for the agricultural ones (green bars below the surface) and elevation above mswl for the municipal wells with depth to water level when available (red bars). Deep agricultural wells are piezometers. Surface transparency 50%. Vertical exaggeration: meters x 0.0002.

traditional, may result in 60-70 % of the water lost, mainly through evaporation. Some water is used by the crops, a large quantity is lost due to evaporation and only some is trickling down to recharge the aquifer. The global effect of the number of new wells and of the agricultural ones on the water table has received little attention, despite the ascertained yearly decrease of the level of the aquifer, reaching 30-40 cm/year.

Comprehensive data on all the agricultural wells are not recent and there is a need to carry out an inception study allowing comparing with previous reports, compiled in 2000. In the next figure we have represented the available data for the entire strip.

Elevation of the wells above m seawater level, total depth of the wells and depths to water can be used to have an idea of the level of the groundwater. A large part of them have been dug by hand and therefore will draw water from the surface of the water table and can be easily used to monitor the evolution of the level of the water table, as they are not or less affected by drawdown problems, like for the boreholes in general.

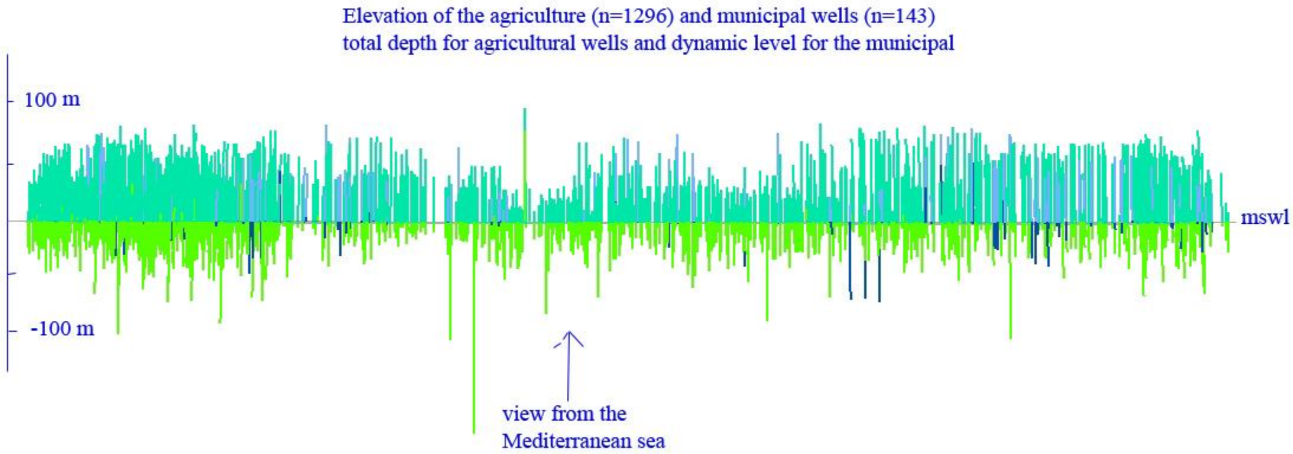


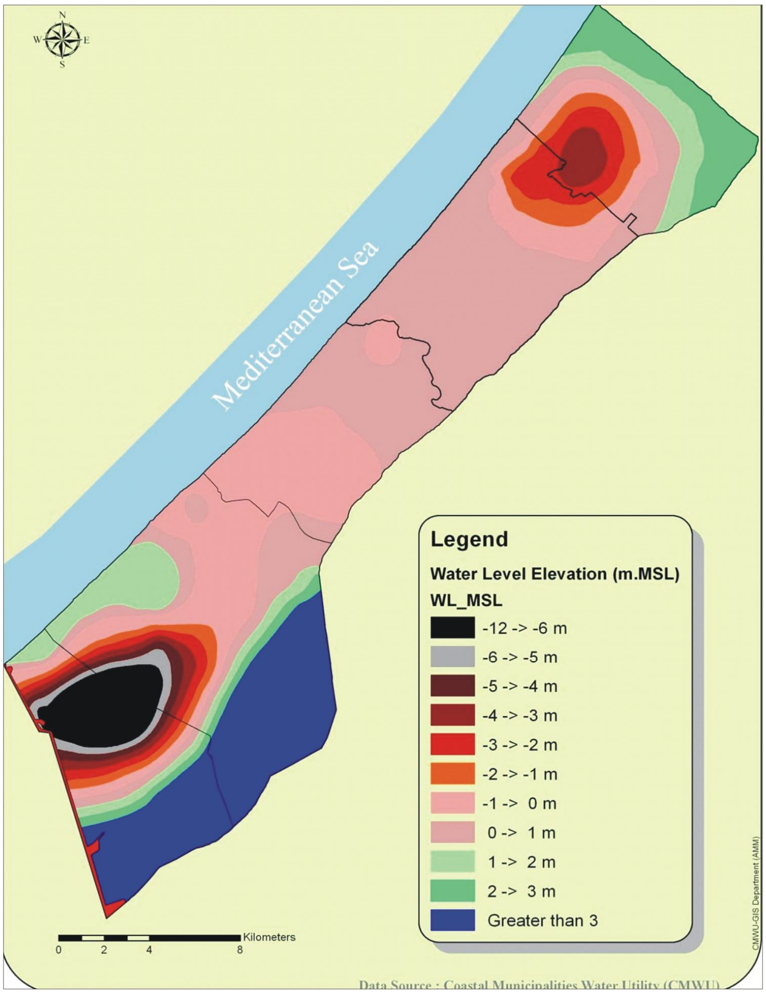
Figure 12 Vertical representation of the magnitude of the wells elevation and depths for agricultural wells and municipal wells (partially masked) front view from the Mediterranean sea. Deep wells are piezometers.

It is important, in times of overharvesting and falling water levels, and possible increased inland shift of the saline intrusion, to appreciate which wells will be affected and how. As most of the agricultural wells are sunk into the upper aquifer (Sub aquifer A) they will be affected by the water table depressions, but less from the possible inland movement of the saline wedge.

Depletion of the water table

In the Gaza strip underground water flows from South-East toward North-West. The major recharge is occurring from rainfall spread from the western coast to the Mount Hebron ridge, with a large part of the recharging surface located in Israeli territory (Weinthal &Vengosh). The thickness of the water table may reach 120-150 m at its western bounds but may be as low as a few tenths of meters on its Eastern limit[20].

The data compiled from existing studies, outlined in the previous papers, showed important depressions the water table in two areas of the strip, located under the built up areas of Gaza North and in the southern area of Rafah and Khan Younis, already reported in the study carried out by CAMP in his 2004's final report, due to high abstractions. Depletions down to about 3 meters below mean sea water level (mswl) were recorded. Their importance was foreseen to increase in the following years, at a pace of about 0.4m/year, leading to a more important depression, particularly if the current pumping rates for the municipal wells would not change.



Data from CMWU for 2008 show where these depressions have been observed and their importance. In the southern areas, mean levels of the water table reach -10 m below mswl (mean sea water level), as it shown in the following figure, courtesy from CMWU.

According to these data the depletion cone recorded in the Northern area has only slightly changed, reaching -4 m below mswl, remaining of the same order of magnitude than what was observed during the CAMP study.

Figure 13 Water level elevation in m MSWL (source CMWU)

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20 Vengosh, A., A.J. Spivack, Y. Artzi, and A. Ayalon. 1999.Boron, strontium, and oxygen isotopic and geochemical constraints for the origin of salinity in groundwater from the Mediterranean coast of Israel. Water Resources Research 35, no. 6: 1877–1894.

Salt intrusion

It is likely that the boundary and the magnitude of the depression showed in the above figure have been recorded from existing piezometers or from levels taken from open agricultural wells. Data on municipal wells, in general drilled to deeper depths, do also show the same parameters, like altitude above mean seawater level, total depth, the depth to water from the surface of the well and a few other parameters like pumping yield in m3/h, the daily hours of operation of the borehole and the concentrations of chloride and nitrate.

Comprehensive data for 47 wells located in the Gaza governorate have been listed in a Master thesis published in 2009 [21]. They have been compiled in ARCGIS and represented using the 3D analyst extension. Several views are shown in the next figures, observed from the seashore and from the North.

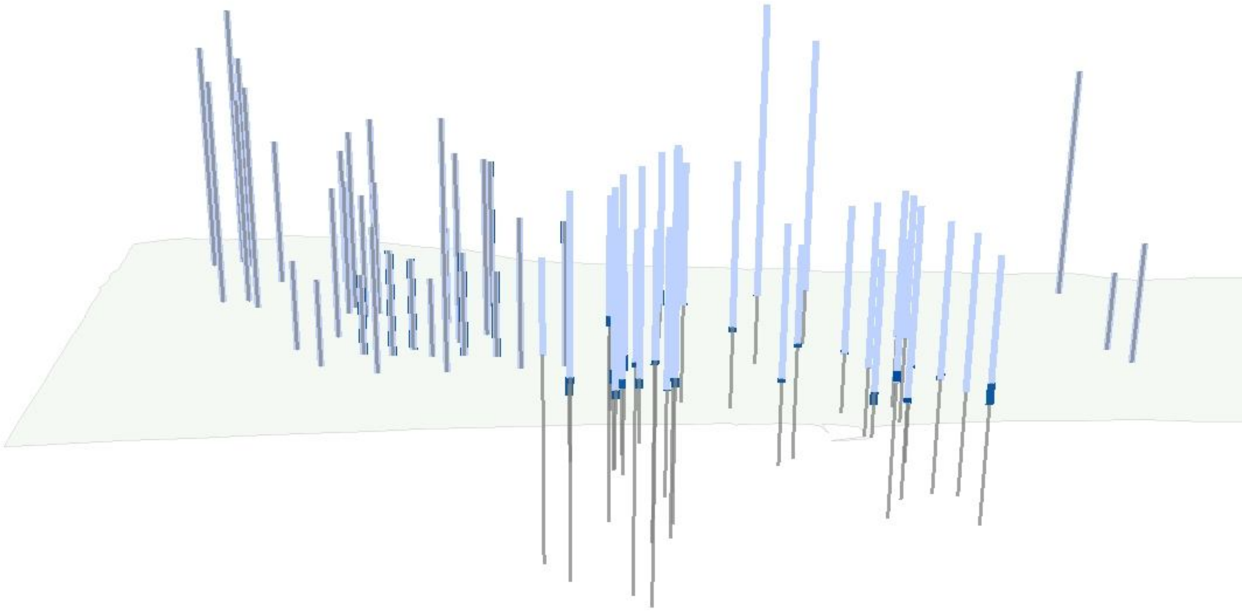

Figure 14 View (from the seashore) of the Gaza governorate municipal wells. Only the total depths (grey lines) below mSWL are shown (altitude - total depth) The large blue lines are the depths to the water.Verticvasl exageration x 0.0005

Only a few wells of the Gaza governorate reach depths close to 60 m below mSWL.the majority is drilled down to – 25 to -35 m, still harvesting water from the upper aquifer, as the majority of the agricultural ones do. From previous studies using TBEM (Time bound electrical measurement) [22], [23] the salt intrusion at a cross section in Jabalia, has been recorded to reach 1000 m inland in the subaquifer B1 and to about 2000 m inland in the lower subaquifer C, with the upper subaquifer A1 not affected. As such, only the wells drilled at about -60 m below the mSWL may be affected by the possible inland shift of the saline wedge, the first clayish/loam formation acting as a protection against salinisation for the less deep drilled wells, and of course, for the majority of the agricultural wells too.

[21] Tarazi G. M., Delineation of Wellhead Protection Plans for Municipal Supply Wells in Gaza Governorate, The Islamic University - Gaza – Palestine 2009 – Thesis no. 1430
[22] Moe H. et al., op. cit
[23] Qahman K. A. , op. cit

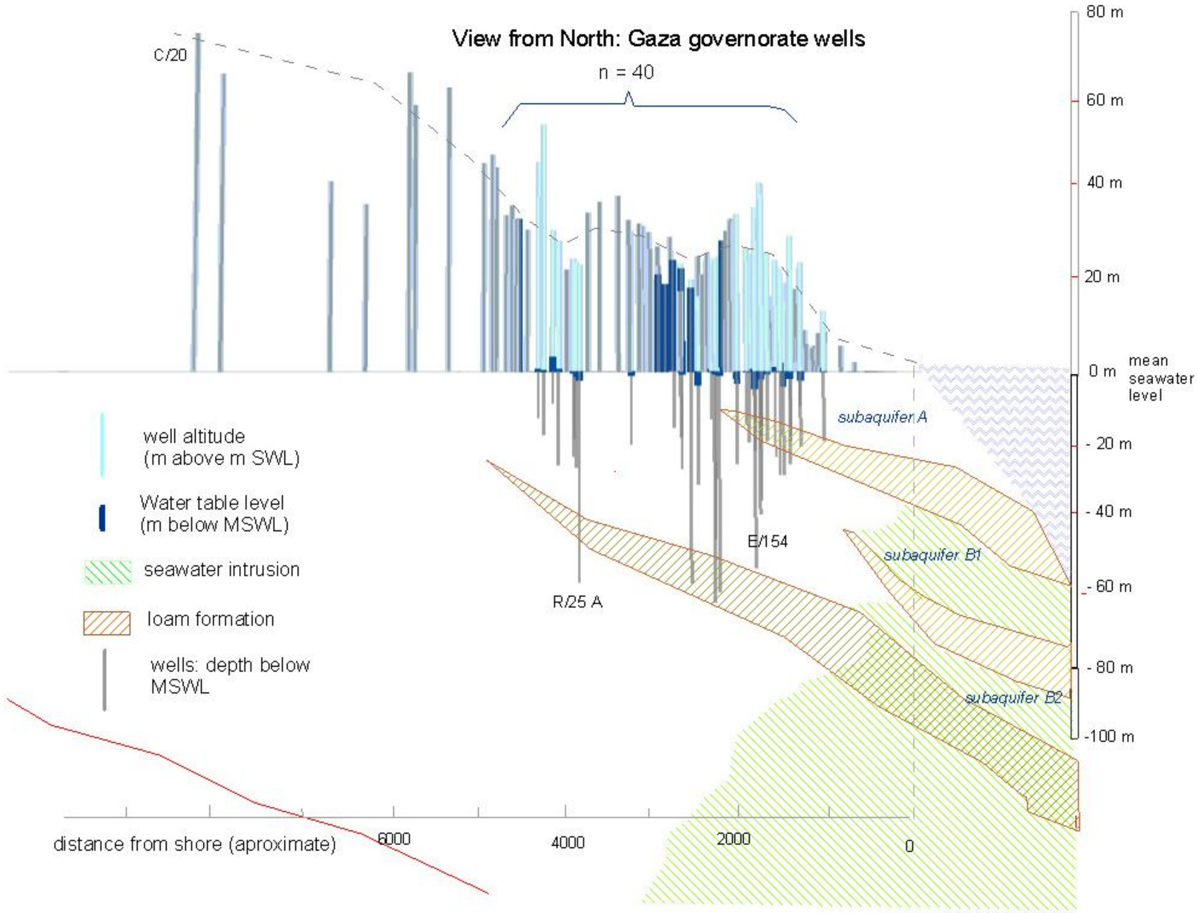

Figure 15 ARGIS 3.2 spatial analyst section view from the North of the wells of the Governorate of Gaza. The depths of the wells are those of the governorate. Other wells (Ex: Northern governorate) may be represented in the view but without depth parameters. The location of the loam formation (aquitard) and the approximate seawater intrusion have been adapted from ref. 5 (Moe et al.). Hydrographic behaviour is approximate. Wells parameters are from reference 15 (Tarazi g. M.)

However, the thickness of the aquifer is quite important and the boundaries between the saline water zone and the fresh water zone seem to reach levels close to -50 m below mswl at a distance of about 800 m from the shore, according to the figure cropped from Ginzburg et al. derived from electrical resistivity studies carried out across the aquifer [24].

In the Southern area of the Strip the closest well to the shore is P/139, located at about 850 m from the sea. Its depth to water is at about -25 m b SWL, according to the CMWU data, and its chloride concentration is low, close to 250 mg/

[24] A. Ginzburg, A. Levanon, Determination of a salt water interface by electric resistivity depth soundings, Hydrological Sciences-Bulletin- des Sciences Hydrologiques, XXI, 4 12/1976

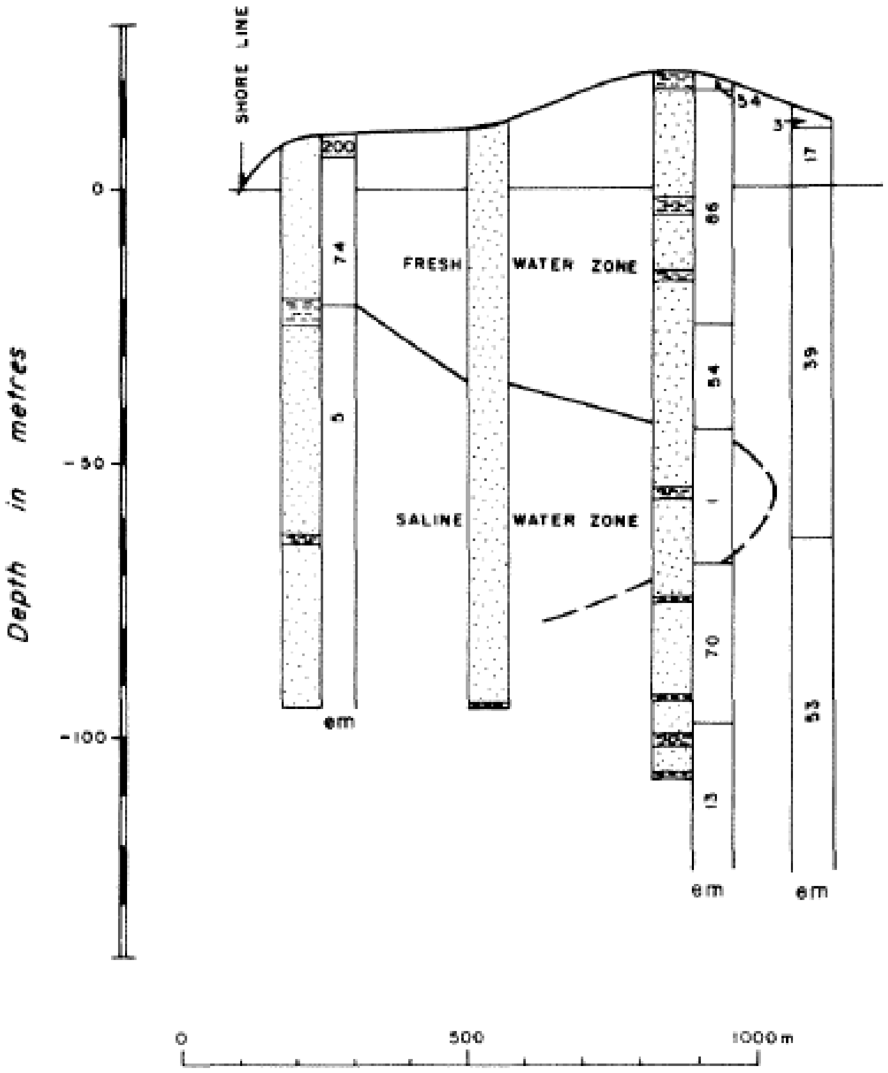

Figure 16 Geo-electrical survey and saline / freshwater wedge 's behavior across the aquifer (source: Ginzburg et all.)

According to the data from Ginzburg, the saline interface wedge is located at about -50 m at about 1000 m from the shore. The hourly abstraction, close to 70 m3/h, being relatively low, the consequences for this well may not be important, as the under-laying saline water may still be quite deep, limiting the salt intrusion into the aquifer from possible up-coning only to speculations.

The saline intrusion seems to be contained below the first "aquitard", according to measurements carried out during the CAMP project. The position and the thickness of the "aquitards are shown schematically in the next figure, adapted from reference 4, showing the altitude and total depth of the agricultural wells, viewed from the South. Only a few piezometers are sunk deeper and may reach the lower subaquifers.

More precise data on the position of the wedge are available from studies carried out in 2000 .[25] . If a salt intrusion has been modeled in the Northern areas, the available data do not allow gaining precise figures for the middle and southern areas. The position of the saline wedge in the upper aquifer is difficult to appreciate. It is likely that it is still contained by the first clay formation.

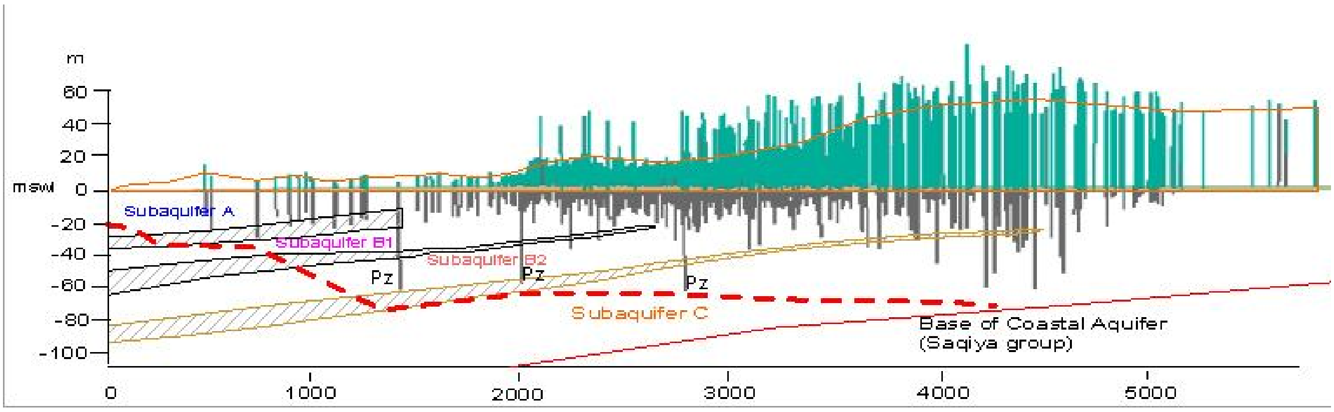

Figure 17 ARCGIS[R] 3.2 3D analyst. View of the agricultural wells from the south (Egyptian border). The depth of the green bar is the depth of the well in meters. A vertical exaggeration factor (x 0.0004) has been used to allow for a better visualization. Deep agricultural wells are piezometers. Aquitards and saline wedge are adapted from reference 4 and 5.

The lack of boreholes in the Eastern side does not allow for a strict interpretation, but former data show that the water table is high above mswl in these areas, as wells as chloride levels.

Interpolation of data from the municipal wells seem to show that local depressions may also occur for specific boreholes, where the depletion cones are most likely affected by particular high abstractions, leading to important draw-downs.

However, as outlined previously, a salt intrusion is not likely to occur, particularly away from the shore, where the soft water table is considered to be thicker, even if it cannot be totally ruled out, as some up-coning may occur in some specific wells, where high abstractions and consequent high draw-downs may take place, particularly if the seawater – brackish water wedge is positioned relatively high. However in that case we would observe salinity levels higher than those presently observed. It is more likely that any increase of the chemical concentrations of pollutants of concern, like Cl_, and NO3_ may be due to an increased flow of water already charged with high concentrations of Cl-, flowing toward these depressions enhanced by the resulting increase of the hydraulic gradient.

It appears that the depressions under Gaza city and in the southern part are not homogenous as reported but may be locally affected by the high abstractions, leading to depletion cones reaching lower levels that those recorded for the water table.

[25] Qamah K.A, Zhou, OP. cit.

Evolution of the chloride and the nitrate concentrations in the pumped water.

Chloride

As outlined in a previous paper, the chloride concentrations in some parts of the areas are on increase, particularly in the south. Data from CMWU collected in January 2008 on municipal wells have been analyzed and the results are presented in the next figure, where the spatial distribution of the Cl_ concentrations in the water, have been plotted, together with the built up areas (in grey).

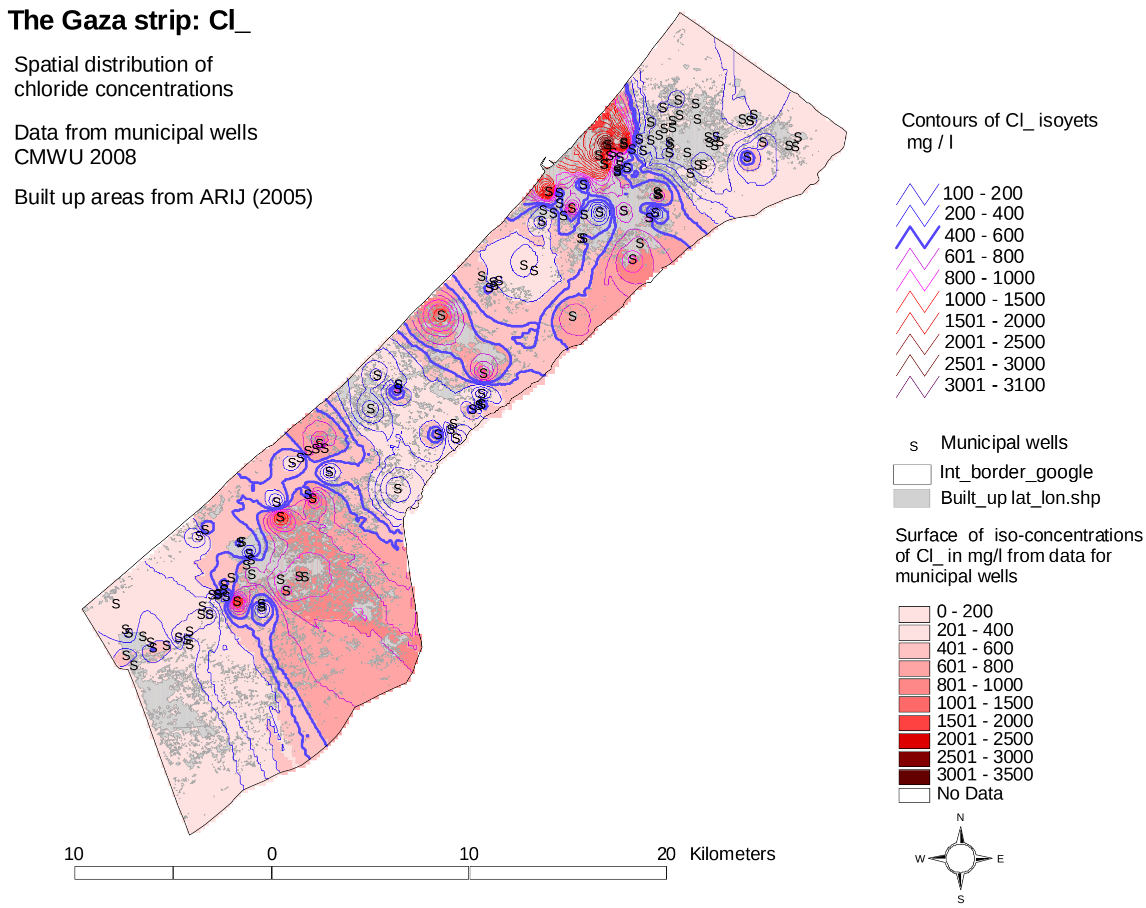

Figure 18 Spatial distribution of Cl_ concentrations obtained by interpolation of municipal data (n=143) collected in January 2008 by CMWU.

Isohyets (surfaces of equal range concentrations) as well as the contours computed from the surface boundaries do show that the underground water is reaching the strip already enriched with chloride, mainly in two “corridors” in the southern part of the strip, at the Khan Younis level and in the northern part at the southern Gaza built-up area. When a similar approach is including the agricultural wells, the behavior of water with high Cl_ concentrations, up to 1000 mg/l, is also observed in the very southern part

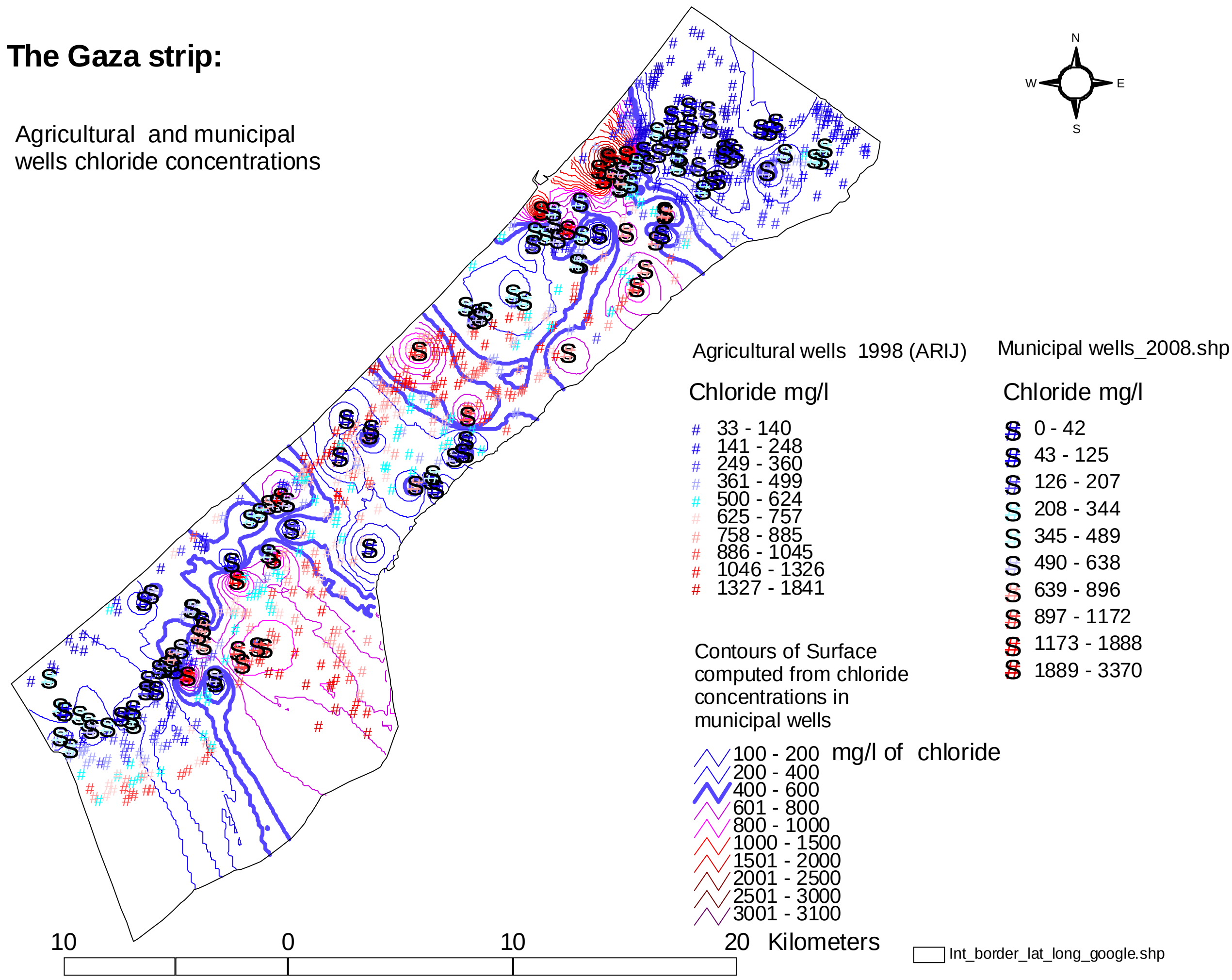

Figure 19 Spatial distribution of Cl_ concentrations in municipal wells (large dots) and in agricultural wells (small dots, n=643, data from 1998). The 400-600 mg/l boundary is computed from data of municipal wells and is shown in blue (thick line).

of the strip. The relative better situation of this area shown in the above figure is only due to lack of any municipal well to be included in the interpolation. Unfortunately the data of the agricultural wells are quite old, back to end of the nineties. It is likely that any new collection campaigns would show that the situation has not improved for these wells too.

It is possible that the preferential flows throughout the strip are due to different gradients created by the depressions cones, at least in the Eastern-central part of the strip. In the North-West and in the Central-West areas the high Cl_ levels may be due to over-abstractions, with possible up-coning of brackish water, even if in the latter area the continuum of the high concentrations from East to West may also call for a preferential flow from the East. Comparison of data collected by CMWU in 2004 and in 2008 show that the concentration of Cl_ is increasing significantly in a number of wells (E154, R162D, R162EA, R112) but their location does not coincide with the lowest depressions levels and other factors may have to be explored.

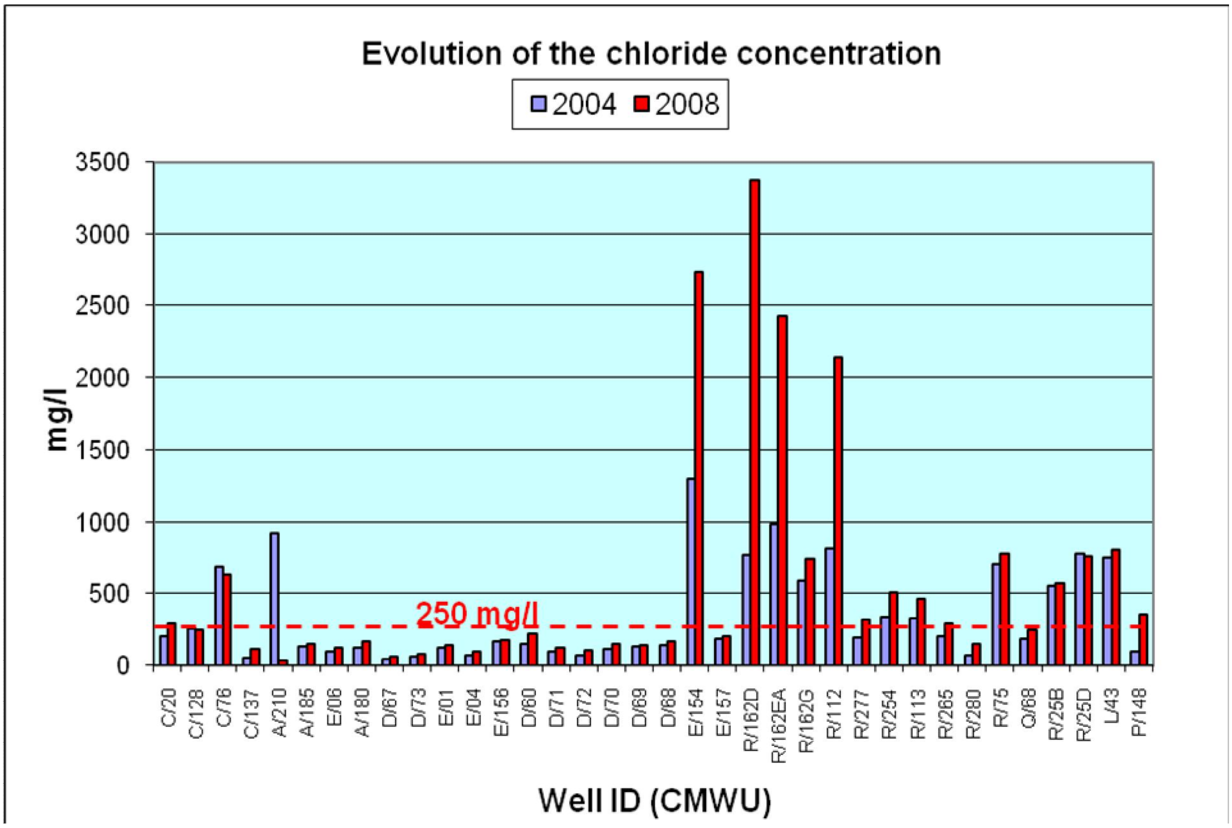

Figure 20 Comparison of chloride (Cl-) concentrations in municipal wells between 2003 (Shomar) and 2008 (CMWU) for 36 wells, located in different governorates.

Are these wells located where RO are operated and where brines are discharged, reaching the abstraction area of the pumps? As a matter of facts, the comparison carried out among 36 wells, for which data could be matched, shows that the levels of chloride have remained fairly constant, with the exception for the wells listed above, which may tap into the layers where salt intrusion has occurred. .

If the most recent data (2008) are used, 87 wells out of 143 have values exceeding the 250 mg/l guideline value of the WHO. 33 have levels between 250 and 500 mg/l, but 55 do exceed the concentration of 500 mg/l, limit set by the PWA as a temporary one, applicable until 2015 for the Gaza strip and for the other Palestinian territories. It is expected that the Cl- will then decrease due to the effects of the quality of the water produced by the planned RO treatment station.

Nitrate

The spatial distribution of nitrate is shown in the next figure. As for chloride, isohyets have been computed from data collected by CMWU in January 2008. Previous studies have attributed the origin of the high nitrate levels to the use of fertilizers or manure by the farmers and by the discharge of waste water into the ground from cesspits, septic tanks, or by sewage systems not connected to any waste water treatment plant and simply by-passed during the frequent power cuts or when the loads were too important. This has led to high levels of nitrate in several areas, where levels as high as 400 mg/l have recorded, posing a potential threat to the inhabitants, particularly to the young infants (blue babies)[26].

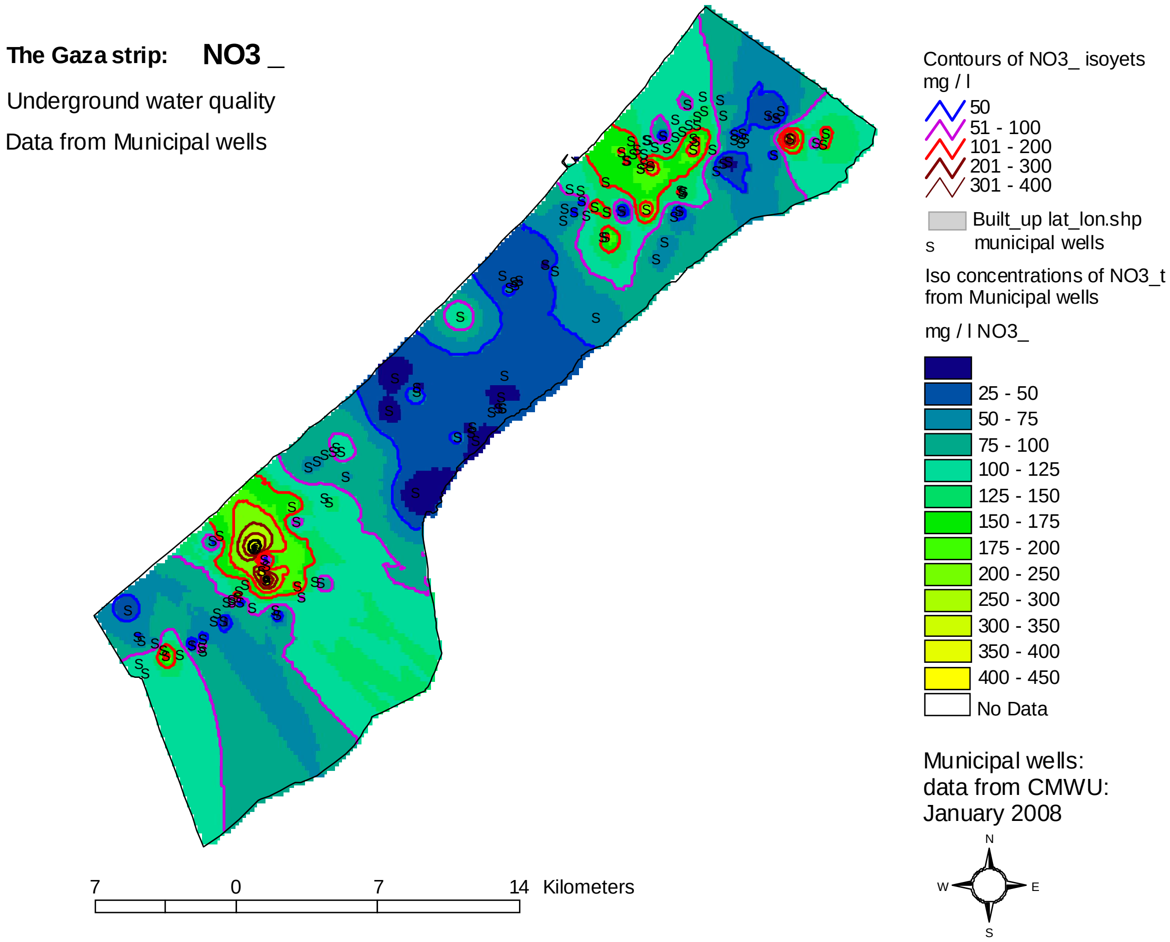

Figure 21 Spatial distribution of NO3_ concentrations obtained by interpolation of municipal data (n=143) collected in January 2008 by CMWU.

These spots of high concentrations are located under the built up areas of Gaza, Beit Hanoun, Khan Younis and Rafah and coincide with part of the depressions. However, if we compare the data compiled by CMWU in 2004 with those of 2008 for the same wells, a stabilization of the nitrate concentrations can be observed. Moreover, a slight decrease in

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[26] B.Shomar, Water and wastewater in the Gaza strip: environmentally as hot as political, Z.Geol.Wiss., Berlin **35** (2007), 3; 165-176.

about 24 wells over 36 is recorded. As shown in the following graph only 7 wells over 36 have concentrations below 50 mg/l, but half of the analyzed ones have concentrations below 100 mg/l. Unfortunately only 36 wells that could be matched and the comparison should be carried out for all the wells. If we analyze the recent data (CMWU 2008) 39 wells over 143 are below the guideline value of 50 mg/l for drinking water, 37 are between 50 and 100 mg/l, 66 are exceeding the 100 mg/l concentration and out of those over 100 mg/l, 15 have nitrate levels above 200 mg/l. As the origin of the nitrate is mainly from human waste and manure the stabilization trend of the levels of nitrate is probably linked with a better connection of the outflows to the waste water treatment plants and to an accumulation into the “collection traps” where the water table level is far below the mean seawater level or to a decreased use of fertilizers by the farmers, due to the prevailing closures problems.

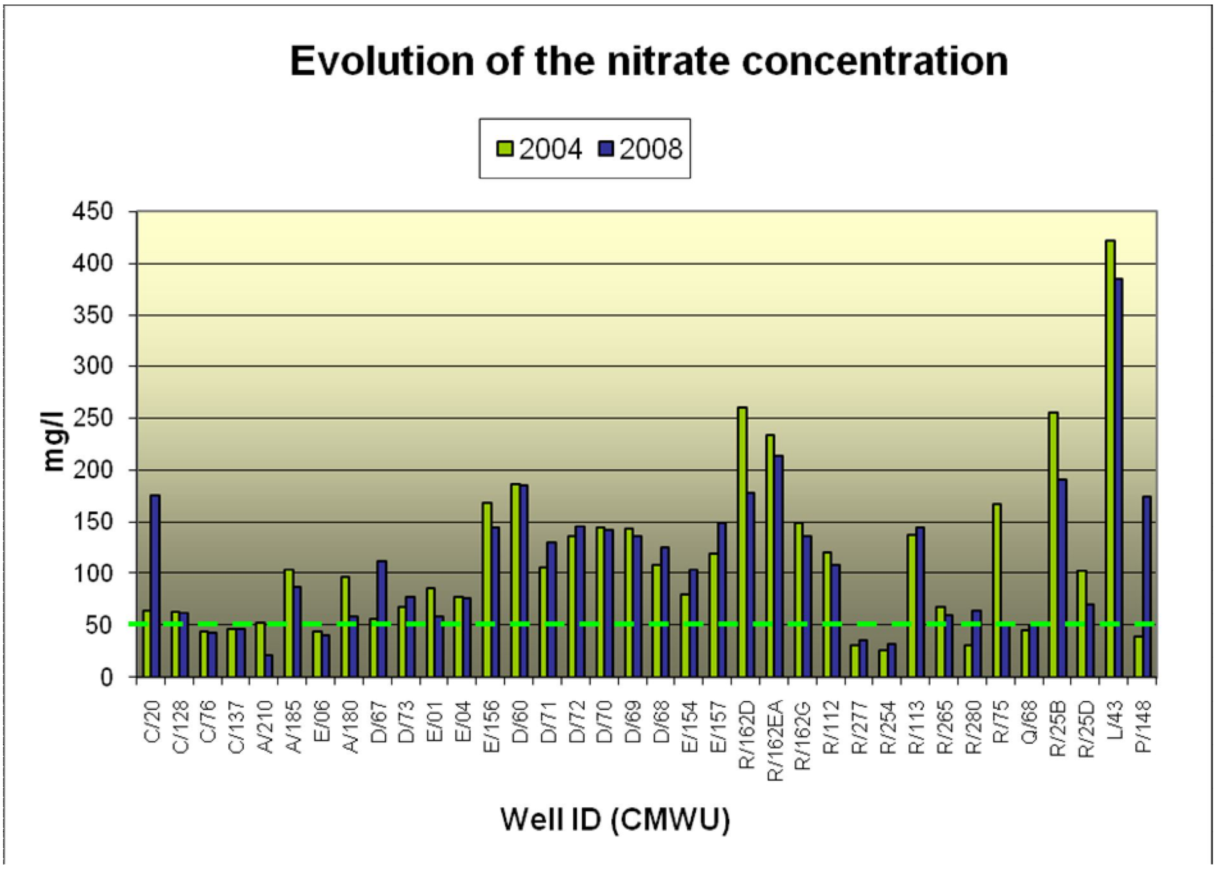

Figure 22 Comparison of nitrate concentrations in municipal wells between 2003 (Shomar) and 2008 (CMWU) for 24 wells, located in different governorates.

The high hydraulic conductivity of the saturated aquifer, between 20 and 80 $m.d^{-1}$, is conducive for a rapid mixing of the dissolved chemicals, particularly if the hydraulic gradient is increased by the over-abstractions, and nitrate is no exception. In absence of specific treatment processes, the observed stabilization of the nitrate concentrations may be only temporary and the trend will be reversed when the use of fertilizers will increase again, when consequent quantities will be allowed to enter the strip. The nitrate originated by the domestic outflows is not likely to decrease even if better collection and treatment have now been implemented. The concentration of nitrate will continue to increase where the depressions are observed and as water will be pumped into the network from the few wells abstracting water from these spots, it will end up again into the underground water in a continuous cycle. Unfortunately, if specific treatment to remove nitrate do exist, their application to the strip is likely not to be foreseen for the near future.

Quite astonishing, in the areas surrounding the Wadi Gaza, the quality of the water abstracted form the boreholes and from the agricultural wells is much better than elsewhere, for chloride and for nitrate. This can be linked with the recharge effect of the “wadi”, when water flows through the riverbed or to an underground flow due to some infiltration which will occur during the rainy season, when the flow can reach storm flood proportions.

Groundwater flow and recharge from the Wadi.

As pointed out by many authors[27], [28] the ground water flows from Israel into the Gaza strip. The aquifer, considered as a continuum, is recharged by rainfall and by the Wadi Gaza, when water flows through it. Data on isotopic composition suggest that the underground water of the eastern area of the Gaza strip is identical to the underground water of the Israeli territories. Saline water is emerging from the underlying Eocene “aquitard” and flows toward the Gaza strip, its flow being enhanced by the increasingly important gradient resulting from the over-pumping in the Strip.

As a consequence the salinity of the water has increased regularly and if the present trend is maintained, it may be, in a few years, unsuitable for human consumption and even for irrigated agriculture.

Israel is using the underground water for irrigation purposes and pumps an estimated 6 -10 Mm3/year of saline underground water, with concentrations of Cl- reported to be > 1000 mg/l[29]. It has been suggested that Israel should pump even more water from an increased number of wells located close to the eastern side of the Strip, in order to decrease the flow of chloride toward the strip. This water should then be treated and delivered to the strip, to facilitate the reduction of pumping on the Palestinian side. This will also reduce the present depressions and consequently the flow of the underground water induced by the present increasingly high hydraulic gradients.

The quality of the water abstracted from the underground on the Israeli side is not available. If it is likely that the water pumped from deep boreholes may show high level of chloride it is also possible that over-pumping is inducing up-flow of the high saline brines located in the deeper layers of the aquifer, which will then flow toward the Gaza strip.

The arguments about the lack of precise provisions for underground trans-boundary flows expressed in their paper are pertinent and the “do not harm” policy, which would justify an increased pumping on the Israeli side to reduce the quantities of chloride flowing into the strip are laudable, but they should also be applied to the surface water and in particular to the flow of water in the Wadi Gaza, which has been almost completely diverted by the Israeli.

Dams and storage reservoirs have been built to take advantage of the high flows during the rainy season, storing water for irrigation practices. As a result the flow of the “wadi” in Gaza is barely observable throughout the year but can reach storm flows proportions during a few

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[27] Weinthal et al. , The Water crisis in the Gaza strip: Prospects for Resolutions, Ground water 43, no. 5: 653 – 660.
[28] Moe, op. cit.
[29] Weinthal et al. Op. cit.

days of heavy rainfall. Water is than left to flow free over the dams causing floods and damage in the strip, but, before, the storage reservoirs have to be filled up.

Peak flows recorded at the Salah al Deen bridge in Gaza, during this year storm flood on 18-20 of January, were up to 500 m3/s, with an estimates 13-15 MCM total flow during the event[30], flowing directly to the sea, but also causing severe damage in the areas downstream the bridge. Part of this water is infiltrated into the ground but it is almost impossible to evaluate at which proportion.

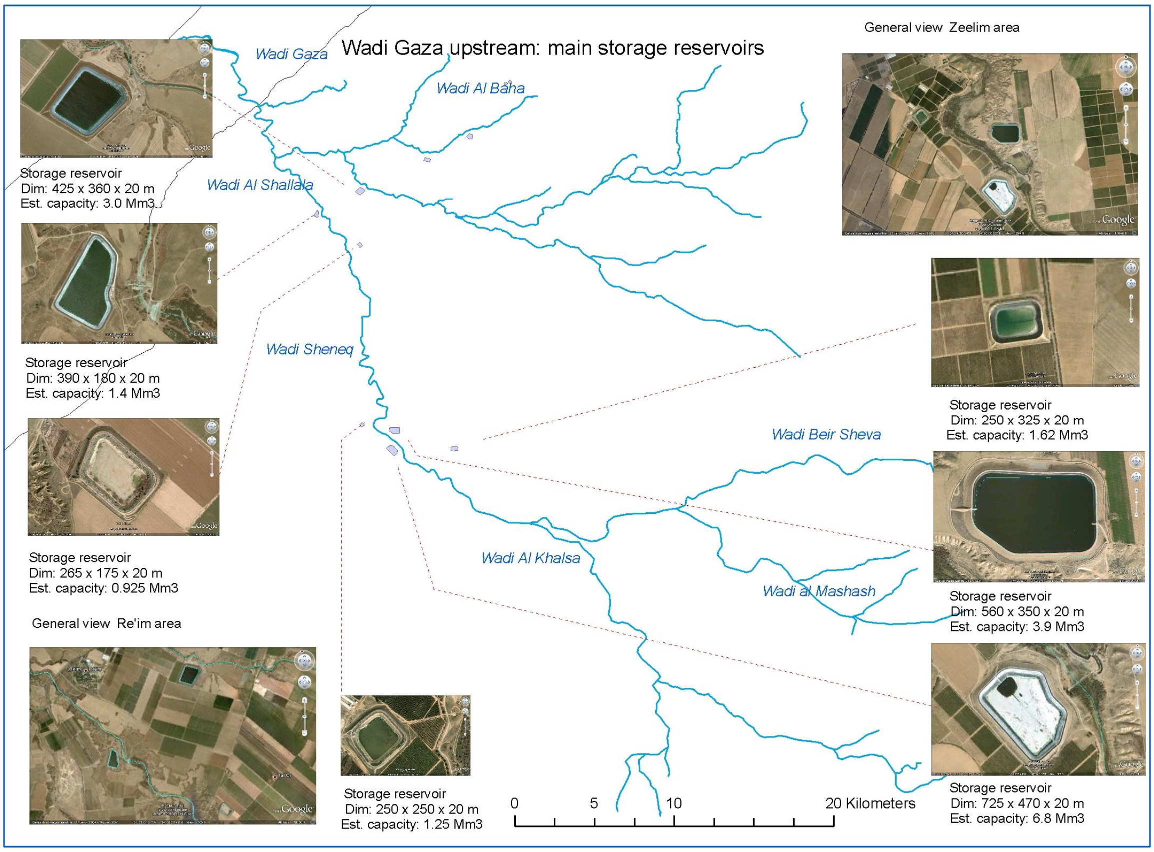

Figure 23 Wadi Gaza and tributaries. Digitized from Google earth [R] Location and image of the main storage reservoirs and estimated capacity.

On the Israeli side, large storage reservoirs have been built to take advantage of the better quality of the water of the Wadi. The above figure shows their location and gives an estimation of their capacities. Their lengths and widths have been obtained from Google Earth [R] and to compute their capacity a mean depth about 20 m has been used. Using these data a total storage capacity of about 17 MCM is obtained. Even if a figure of 10 m for the depth of these reservoirs is used, the amounts are important, of the same order of magnitude than the amounts reported to be pumped from the aquifer. It is not known how these reservoirs are managed, but it is likely that they are filled up when water is available, during the rainy season, when the flow of water is important.

Are the Israeli applying the "do not harm" policy, claimed for the underground water? The obligation of not to cause significant harm between upstream and downstream users should be considered in view of all the trans-boundary stream and not restricting it to underground water only. Is Israel withdrawing a reasonable amount of water from the aquifer or is the

[30] ICRC, personal communication.

pumping increasing the up-flow of saline water from the lower layers of the aquifer? What is the effect of the dams on the recharge of the aquifer and how this recharge is affecting the water quality pumped from the boreholes should also be analyzed.
Quality data from the water abstracted from the boreholes around the Wadi in Gaza show that the levels of chloride are lower than elsewhere. This seems to indicate that some recharge is occurring when there is water flowing through the riverbed. The same should occur on the Israeli side and all the boreholes drilled in the vicinity of the different wadis, when not immediately beside, should pump water of better quality, far better than what is claimed by the quoted authors.

In principle, the International law for the protection of surface waters shared by two of more states should be applied and in particular“ the obligation not to cause significant harm, the duty of equitable and reasonable use, the obligation of prior notification, and the duty to negotiate” should be applied to the “wadi” waters too.

The lack of storage reservoirs on the Gaza side is of course an easy way to avoid to consider the problem. The Israeli will argue that the water they are presently harvesting would anyway be lost for the Palestinians and in they are certainly doing what is necessary to maintain a reasonable recharge of the aquifer on their side, as they are likely to claim.

But on the Palestinian side, it is also easy to argue that they have not been allowed to consider the construction of any reservoirs or storage system, due to the restrictions imposed on Gaza by the COGAT, and would they build some, they would be filled up only in special events, occurring once or twice in a decade, when the Israelis let the water go to avoid problems on their side.

Possible solution?

The present use of the aquifer will inevitably lead to a deterioration of the water quality, under way since the nineties. The measures undertaken recently have certainly slowed down the process, but the foreseen increase of the population and the possible restart of the agricultural production may give another boost in the wrong direction, even if the planned waste water treatment stations and the decentralized water desalination units will eventually be commissioned. The problem will always be the cost of the energy and already at present power is a problem within the strip. Only Israel is in a position to produce water from seawater at a reasonable cost. Of the different options explored and studied , the cheapest and most efficient solution will be the delivery of drinking water from Israel at an unbeatable cost, far below what would be achievable by any Gaza alone solutions.
The low mineralized water supplied and then discharged into the aquifer will at least maintain the present situation and most probably would improve the level of the chloride and possibly that of the nitrate presently recorded in the groundwater.
Progressively, pumping from the aquifer for drinking water will be reduced and restricted to the desalination units already operational. If the flow of chloride from the eastern side cannot be stopped, it can be reduced with the decrease of the hydraulic gradient as well as the risk of any salt intrusion. Only water for agricultural purposes will still abstracted from the aquifer, but the total amounts are half of what is presently retrieved and spread more homogenously within the strip.
This option has a political cost and, as in many other areas, only political solutions will help to solve the dire problems of the coastal aquifer. The need for cooperative management schemes including all the stakeholders is more than urgent. But are the parties involved ready for it?