Dynamics of groundwater use in the central part of the Nile Delta

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List of Abbreviations

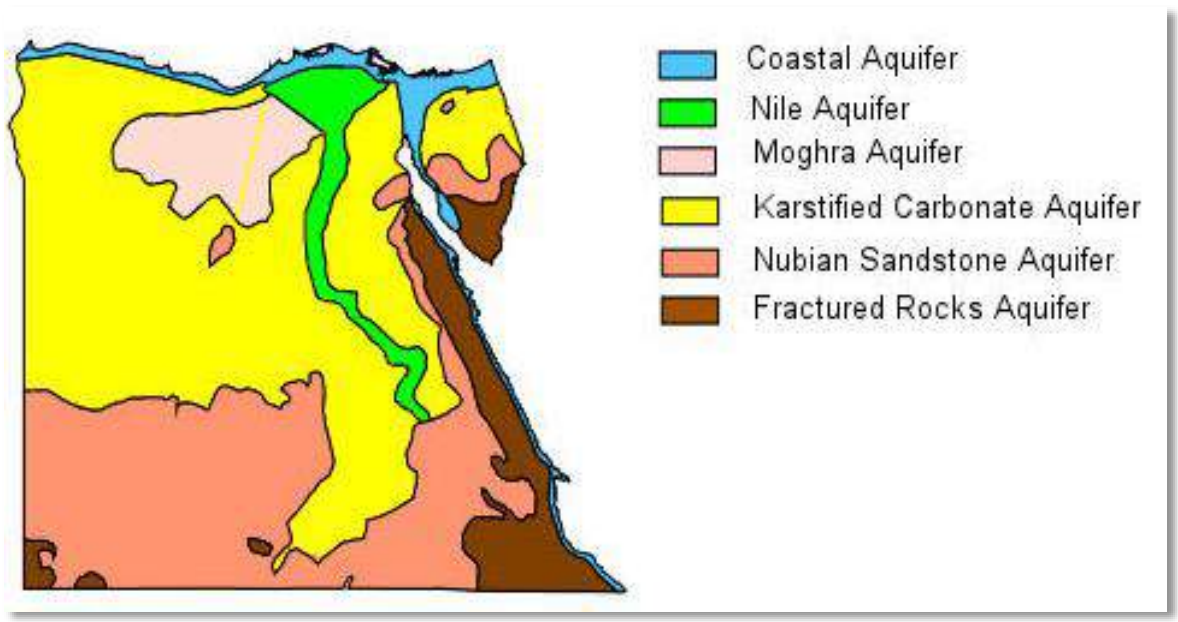
DRI	Drainage Research Institute
EGP	Egyptian Pounds
FAO	Food and Agriculture Organization of the United Nations
Feddan	Unit of land (0.42 hectares)
Gannabia	parallel branch canal
GWS	Ground Water Sector
Mesqa	Tertiary Canal
MWRI	Ministry of Water Resources and Irrigation
RIGW	Research Institute for Ground Water
Saqia	Persian Water Wheel

1 Introduction

The increasing demand for water resources along with the degradation of water quality due to urbanization in the Nile Delta have put enormous pressure on water resources management. The Nile delta aquifer is one of the largest aquifers in Egypt, recharged mainly from the irrigation network that feeds from the Nile river branches (Figure 1). The National Water Resources Plan for Egypt 2017 indicated that the abstraction from the Nile Delta aquifer already exceeds its safe yield (MWRI, 2005). However, accurate data about current groundwater abstraction levels in the Nile Delta is lacking and there are ample contradictions regarding the total irrigated area with groundwater in the published data (El-Agha et al. 2015).

An explanatory study carried out by El-Agha et al. (2015) shed light on the dynamics of groundwater use expansion in the central part of the Nile Delta and discussed its drivers, the social arrangements around investments in wells and their management as well as economic aspects. A focus area in the central Nile Delta was selected in this study to further examine this phenomenon and better understand the impact of well development on irrigation management as a whole, estimate the variability of well density over the study area, measure groundwater salinity to observe its spatial variability, and discuss legal issues concerning its regulation.

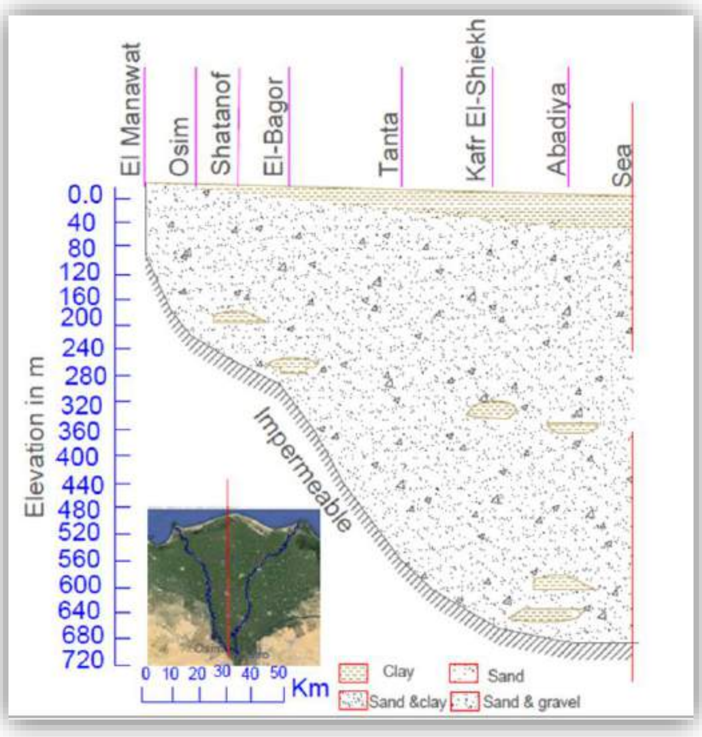
Figure 1. Groundwater Aquifers in Egypt (RIGW, 2003)



2 The Nile Delta Aquifer

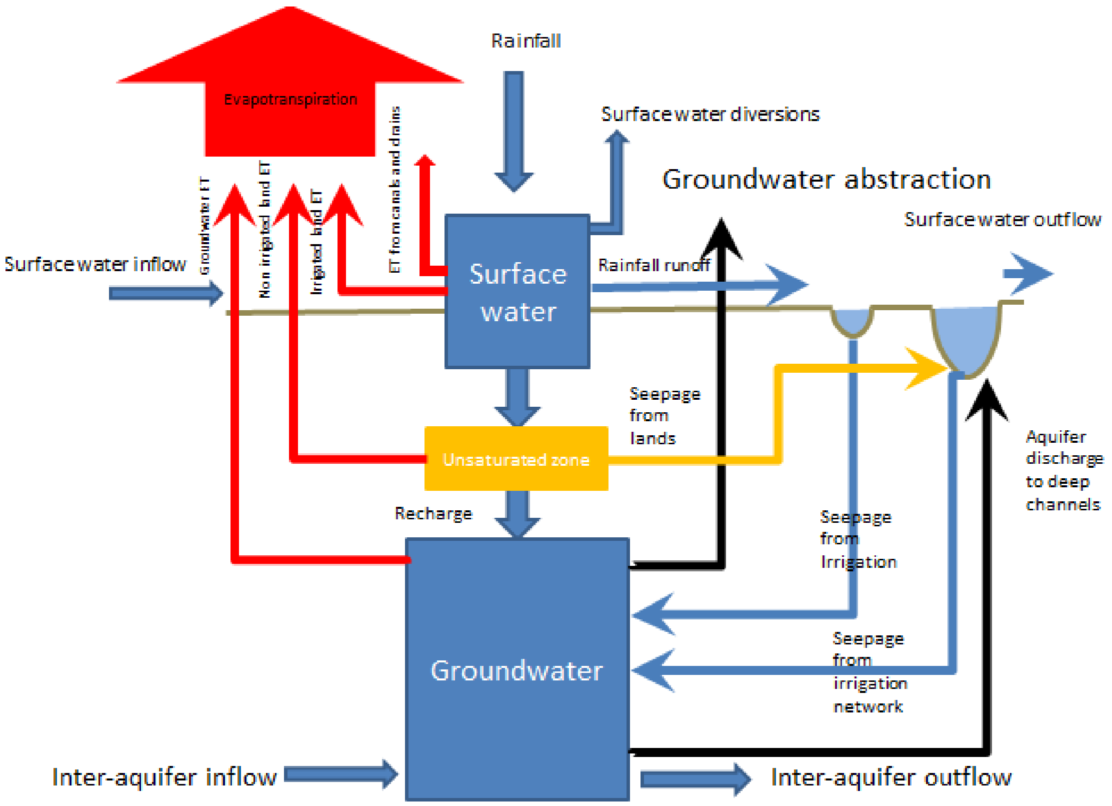
The capacity of the Nile Delta aquifer is estimated to be 500 Bm^3 (Sherif, 1999). The aquifer is considered semi-confined as the top of the aquifer is covered by a thin clay layer which varies in characteristics spatially across the Nile Delta, varying in thickness and disappearing in some places (Mabrouk et al., 2013). The clay layer varies from 5 m in the south to 20 m in the middle and reaches 50 m in the North of the Nile Delta (Figure 2). The saturated thickness of the aquifer varies from 200 m in the southern parts to about 1000 m in the northern parts (RIGW, 1992). The depth to the groundwater table in the Nile Delta ranges between 1–2 m in the North, 3–4 m in the middle and 5 m in the South (Mabrouk et al., 2013). The ground elevation ranges between about 18 m above mean sea level (AMSL) in the south at Qanater El-Khairia to about 5 m (AMSL) near Tanta sloping down very gently in a northward direction by an average value of 1 m/10 Km (Saleh, 1980). Furthermore, the Nile Delta slopes from east to west, making the Damietta branch 2 meters higher than the Rosetta branch (Abu Al-Izz, 1971).

Figure 2. Vertical Cross Section of the Middle Nile Delta (after Sherif, 2003)



Deep percolation from excess irrigation water and seepage from the river branches, canals and drainage systems in southern and middle parts of the Nile Delta are recharging the aquifer due to the thinner clay layer (Figure 3) (Kashif, 1982; Diab and Saleh, 1981). Also, some parts of the Nile branches recharge the aquifer while other parts capture groundwater when the level of the aquifer is higher than the surface water level (Attia, 1954; Farid, 1980 and FAO, 2013).

Figure 3. Diagram of recharge and discharge elements of the aquifer (modified from AWR, 2007)



The hydraulic parameters used in several research studies are based on average values for the whole Nile Delta. Downward leakage due to water applied for irrigation and canal infiltration towards the aquifer has been estimated between 0.25 and 0.80 mm/day in the central and southern parts of the Delta (RIGW, 1980; DRI, 1989). Also, average rainfall estimates vary from 25 mm/year in the south and central part of the Delta to 200 mm/year in the North Western part (RIGW, 1992). Groundwater modeling studies neglect recharge from rainfall (Mabrouk et al, 2013) as it is very small compared to the recharge rate, which was estimated in 2006 at 6.78 Bm^3 (FAO, 2013). Additionally, there is no data available for the inter-aquifer inflow from the valley part of the Nile aquifer.

Groundwater discharge from the aquifer takes place in the Nile Delta through: land drainage; evaporation; evapotranspiration; inter-aquifer flow of groundwater; seepage from the aquifer to irrigation network; and direct groundwater abstraction through wells. In the Northern part of the Nile Delta much groundwater is discharged into the drainage system with values ranging between 0.2 and 0.9 mm/day (DRI, 1989). The total evapotranspiration rate of the Nile Delta, using both the irrigation inflow and the aquifer storage was estimated by Mabrouk et al. (2013) at 2,000 mm/yr. Outflow of the Nile Delta aquifer also occurs towards the Moghra aquifer along the fringes of the western Nile Delta, with a transfer estimated by RIGW/IWACO (1990) between 50 and 100 Mm^3/year.

3 Case study in the central part of the Nile Delta

The command area of El-Qassed canal, which runs from the centre to the north of the Nile Delta, was selected to investigate the use and development of groundwater by farmers (Figure 5). El-Qassed canal is one of the main canals fed by the Bahr Shebin canal and serves an area of about 100,000 feddan (40,000 ha). It is a canal with enduring management problems, especially during the summer season (Figure 4). It crosses two directorates in the center of the delta towards the North (El-Gharbiya and Kafr El-Sheikh). Two regulators control its discharge, one at the head and the other (Sorad regulator) at the boundary between the two directorates.

The command area of El-Qassed canal is intersected by two main roads, a railway and also urban areas which hinder the flow of water in many sub-branches and mesqas. Many farmers indicated water access problem for irrigation due to the informal disposal of the villages' waste, the blocking of pipes passing under the roads and railway, and the improper maintenance of canals and mesqas (Figure 4).

Crops cultivated are onion, berseem (alfalfa), wheat and sugar beet in winter, while in summer rice (most of the time), maize, and pumpkin seeds. Widespread use of wells (private and collective) was observed, especially in the summer season. In the studied area, farmers ensure their water supply at peak periods by digging wells (individually or collectively (even more so those only depending on cash crops like onion and fruit trees) (El-Agha et al., 2015). Wells were found in different locations on the fields: along main and secondary drains; in the middle of the farm plots; along tertiary canals (*mesqas*); at the same location as the old *saqia* (water wheel).

Studied drilled wells have different depths, ranging from 55 to 92 m. Wells are drilled by small private contractors until they reach the sand- gravel layer that holds the water (as stated by the contractor). Groundwater is found at depths varying from 4 to 15 m. The average diameter of the pipes used for casing is 8 inches (most of the time plastic pipes), costing on average 11,180 LE (1,400 USD). Farmers operate their wells using three main types of energy source: 1) movable suction diesel pumps; 2) electric pumps (although they are very rare); 3) tractors operating the suction pump through either an axis connected to the tractor engine or a belt connected to the rotor of the tractor (El-Agha et al. 2015).

Figure 4. Deterioration of irrigation channels and water quality

Mesqa feeding from Seberbay canal

Drain in Qutor district

Figure 5. Map of El-Qassed Canal and command area

4 Density of wells in the study area

A survey was carried out (July 2014 to August 2015) using a GPS photographic camera in order to establish the number and locations of the groundwater wells in El-Qassed command area. The total number of wells observed, photographed and documented during the study was about 1,815, as shown in Figure 6. A density analysis using Kernel Method in ARCGIS was done to produce a density map for the wells. The highest well density was found after the roads as shown in Figure 7., where 57 wells per square kilometer have been drilled (1 well/4 feddan).

As the semi-structured interviews conducted to complement the density study showed, the branch canals feeding from El-Qassed canal cross under the two main roads as underground pipes. The lack of maintenance and breaking of these pipes causes water supply problems to the areas downstream of these crossings. After the road crossing, 12 farmers interviewed relied between 70 and 100 percent on wells for irrigation during the summer season. The density map presented here confirms that areas with high concentration of wells (and potentially with higher groundwater abstraction levels) are located on the eastern side of the roads.

As described by El-Agha et al. (2015), the amount of water that farmers use from wells to irrigate depends on the availability of surface water in the canals. Many interviewees stated that they first run their pumps using surface water from the canal and only when there is no water do they start to operate the wells. Some farmers also operate their pumps using both canal water and the well in order to improve the quality of water for irrigation. As also shown by El-Agha et al. (2015), farmers supplement their irrigation needs with groundwater during times of water shortage. Farmers irrigate from wells mostly at the beginning of summer season during June and July (Figure 8 and Figure 9). During winter, the frequency of irrigation varies from no use at all to 100 percent depending on the availability of water and the location of the land plot along the canal. During interviews, farmers indicated a drawdown in groundwater levels and a decrease of the amount of groundwater that can be pumped from wells when all farmers irrigate at the same time, in June and July. Also, the interviews documented some cases where farmers (upstream and therefore closer to the intake of the system) use their wells only in winter, as the water level in the surface water canals increases during the summer in order to accommodate for the summer irrigation needs in the downstream Kafr El-Sheikh area.

Based on these patterns and dynamics, it is possible to establish that the use of groundwater in the central part of the Nile Delta is spontaneous and doesn’t follow a specific pattern of resource use or management. It is a response to varying surface water availability in the canals. Whenever there is water in the canals farmers use it and whenever it is lacking, they supplement their irrigation needs from wells.

Figure 6. Spatial distribution of drilled wells in El-Qassed command area

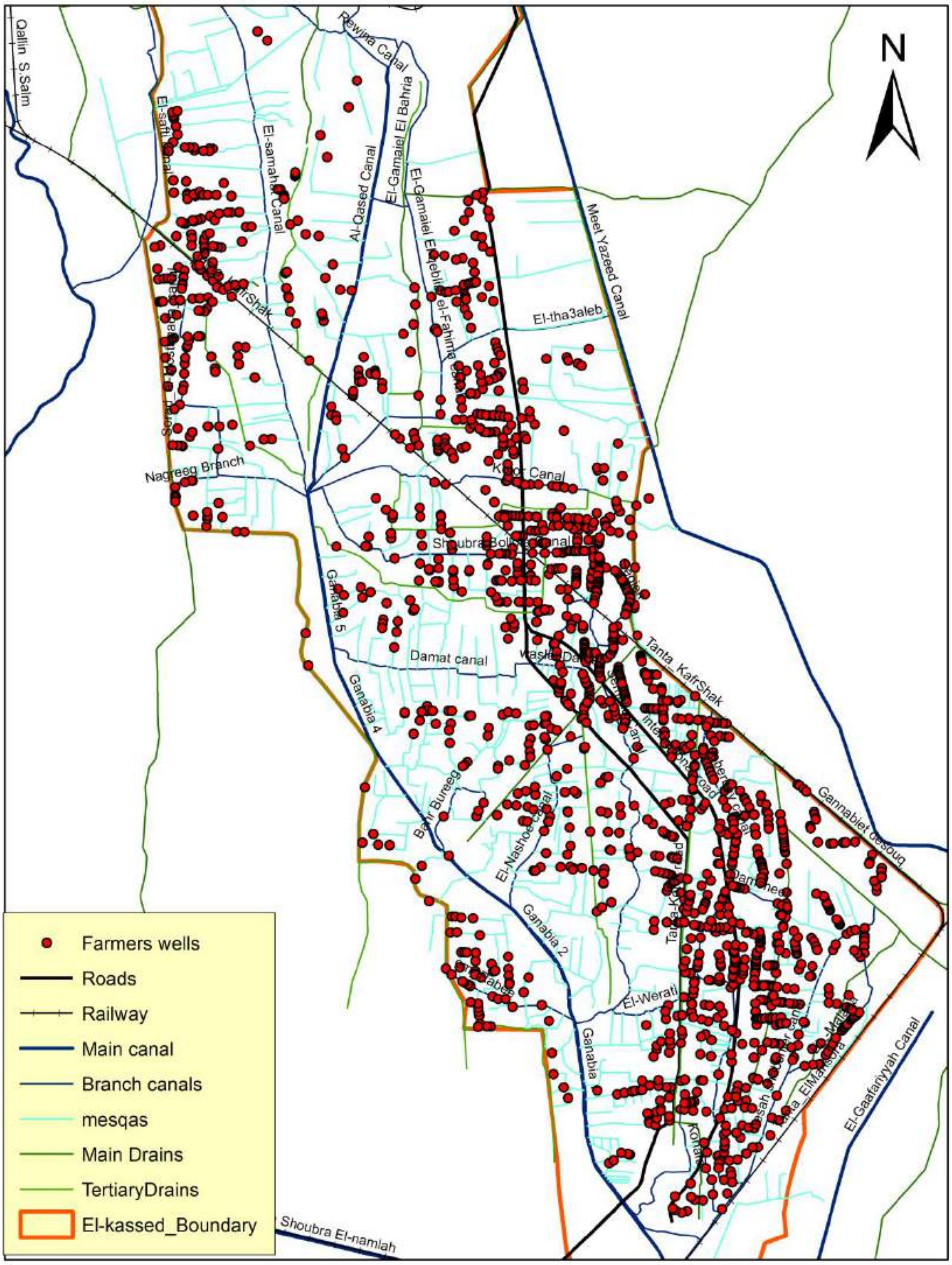


Figure 7. Density of drilled wells by farmers in the study area

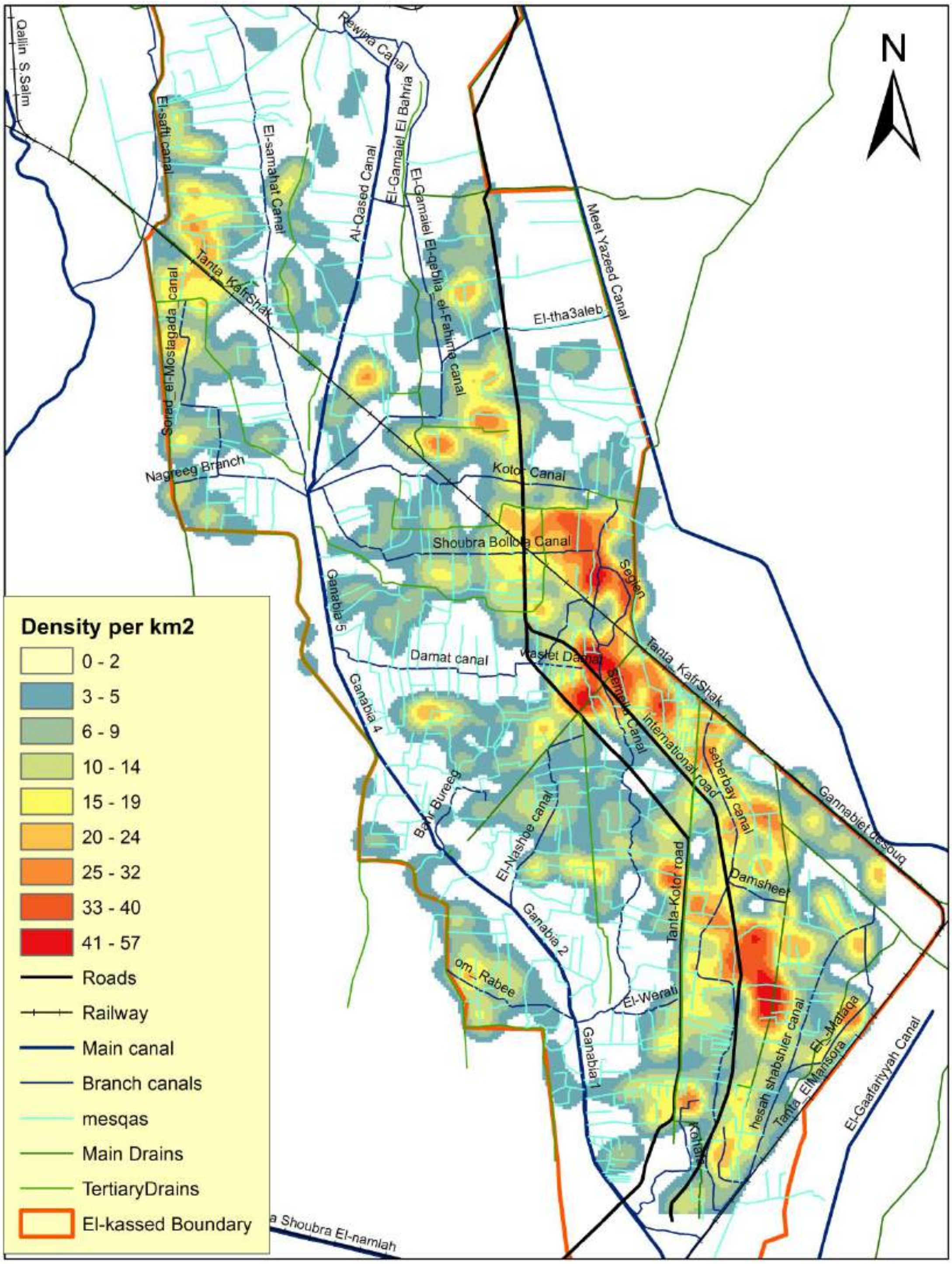


Figure 8. Farmer responses to the percentage of water use for irrigation from wells in the summer

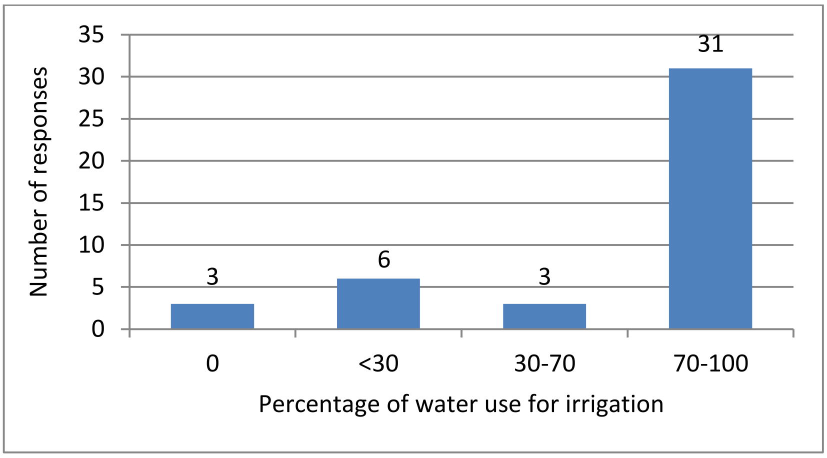
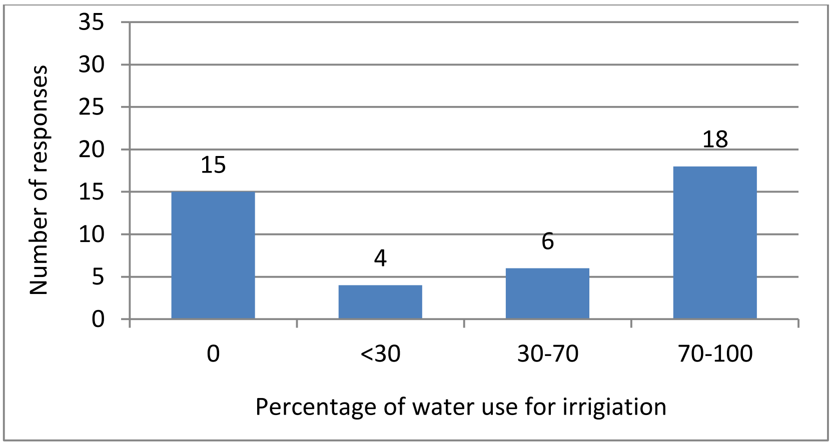


Figure 9. Farmer responses to the percentage of water use for irrigation from wells in winter



5 Variability of groundwater salinity in the study area

The Nile Delta aquifer is one of the few cases where seawater migrates inland more than 100 km from the shoreline (Sherif et al, 2012), intruding the aquifer water at a depth of 175-225 m (Laeven, 1991). Farid (1985) presented a simplified cross section of the Middle Nile Delta aquifer showing the interface between saline and fresh groundwater with isosalinity lines ranging from 1,000 ppm to 35,000 ppm.[1] The study area of El-Qassed canal is located between the transition zone and the freshwater zone (Tanta- Kafr El-Sheikh) (Figure 10).

The annual salinity of the aquifer analyzed by Morsy (2009) between years 1980 and 2008 indicate a gradual movement of the fresh groundwater (indicated by the salinity isoline of 1,000 ppm) northward in the central part of the Delta (Figure 11). More recent data and studies are needed however to assess the variation of salinity isolines across the delta with the explosion of well

[1] Note that: 1 mS/cm = 1000 µS/cm= 1dS/m= 1 mmhos/cm= 640 mg/L=640 ppm, TDS (in ppm or mg/L) ≃640 X ECw in dS/m or mmhos/cm.

drilling during the last 15 years and the potential risk of further sea-water intrusion given the increase in groundwater abstraction and the possible destabilization of the water budget in the Delta.

Figure 10. Schematic presentation of a cross section in the middle Nile Delta aquifer (Farid, 1985)

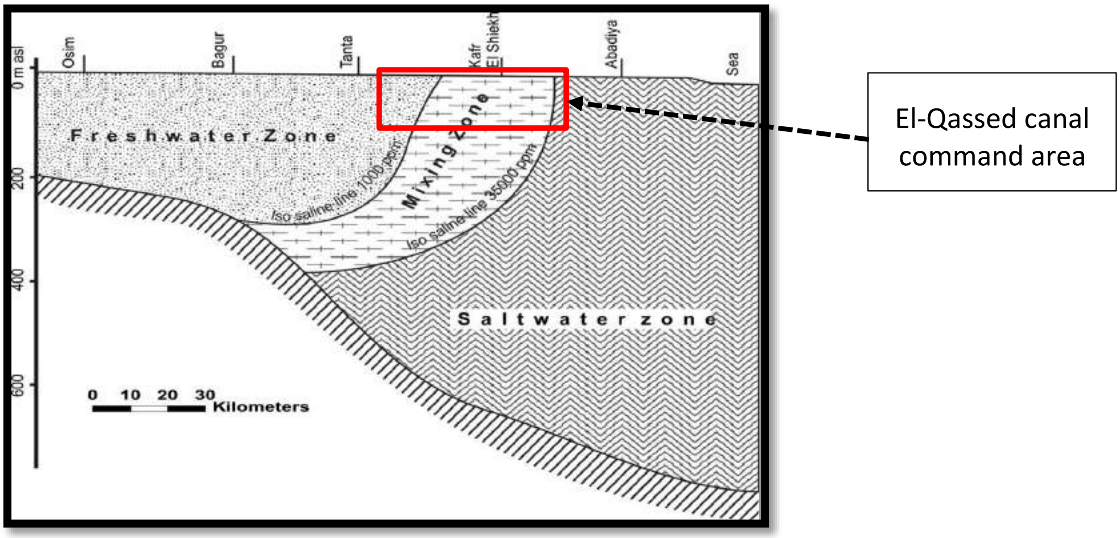
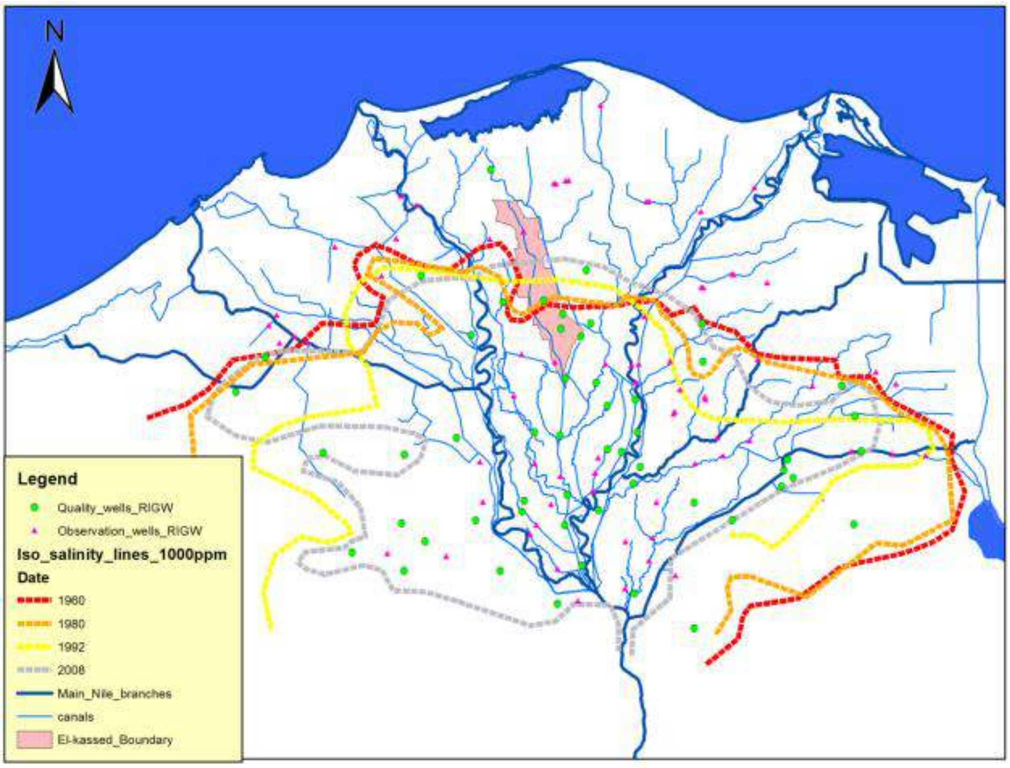


Figure 11. Comparing isosalinity lines 1000 ppm for years 1960, 1980, 1992 and 2008 (after Morsy, 2009)



We can observe that on the right and left sides of the Delta salinity has progressed inland since pre-high Aswan dam times (1960), which reflects the fact that the natural flood had clear effect on the infiltration of surface water to the aquifer. It is not fully clear why a distinct pattern is observed in the central part of the Delta and whether these isosalinity lines have been drawn based on the same set of observation wells.

El-Agha et al. (2015) emphasized the need for recent data to assess the impact of decreasing water supply and increasing groundwater pumping on groundwater salinity levels, as concentrated pumping in some areas can cause up-coning and localized higher salinity. In order to establish some preliminary results regarding the variation of salinity in the Delta influenced by groundwater abstraction, water quality parameters were measured for 60 wells to assess salinity variations across the studied area. Ranges for electrical conductivity (EC) varied substantially, from 485 to 2,836 µmhos, even within a rather limited distance between wells (Figure 12). The measurements were done when the wells were being operated by farmers and with well depth variation (30 to 95 m) as shown in Figure 13.

Groundwater salinity is affected by local variables such as soil type, density of wells, intensity of groundwater use, as well as infiltration of pollutants. Further research with monitoring of groundwater quality parameters to study the temporal variability of groundwater salinity is required. During the interviews, some farmers mentioned a deterioration of water quality in some domestic wells used for drinking water in the area (specifically Qutor). Most of the wells with low groundwater salinity (485- 721 µmhos) are located on the left-hand side of the road, in areas of lower well density. However, no correlation was found between either the depth of the well and increases of salinity levels or the year of drilling, on the one hand, and the salinity of the water pumped from the well, on the other. Further studies are needed to define the impact of the aquifer heterogeneity on the salinity of the groundwater.

Figure 12. Spatial distribution of groundwater salinity

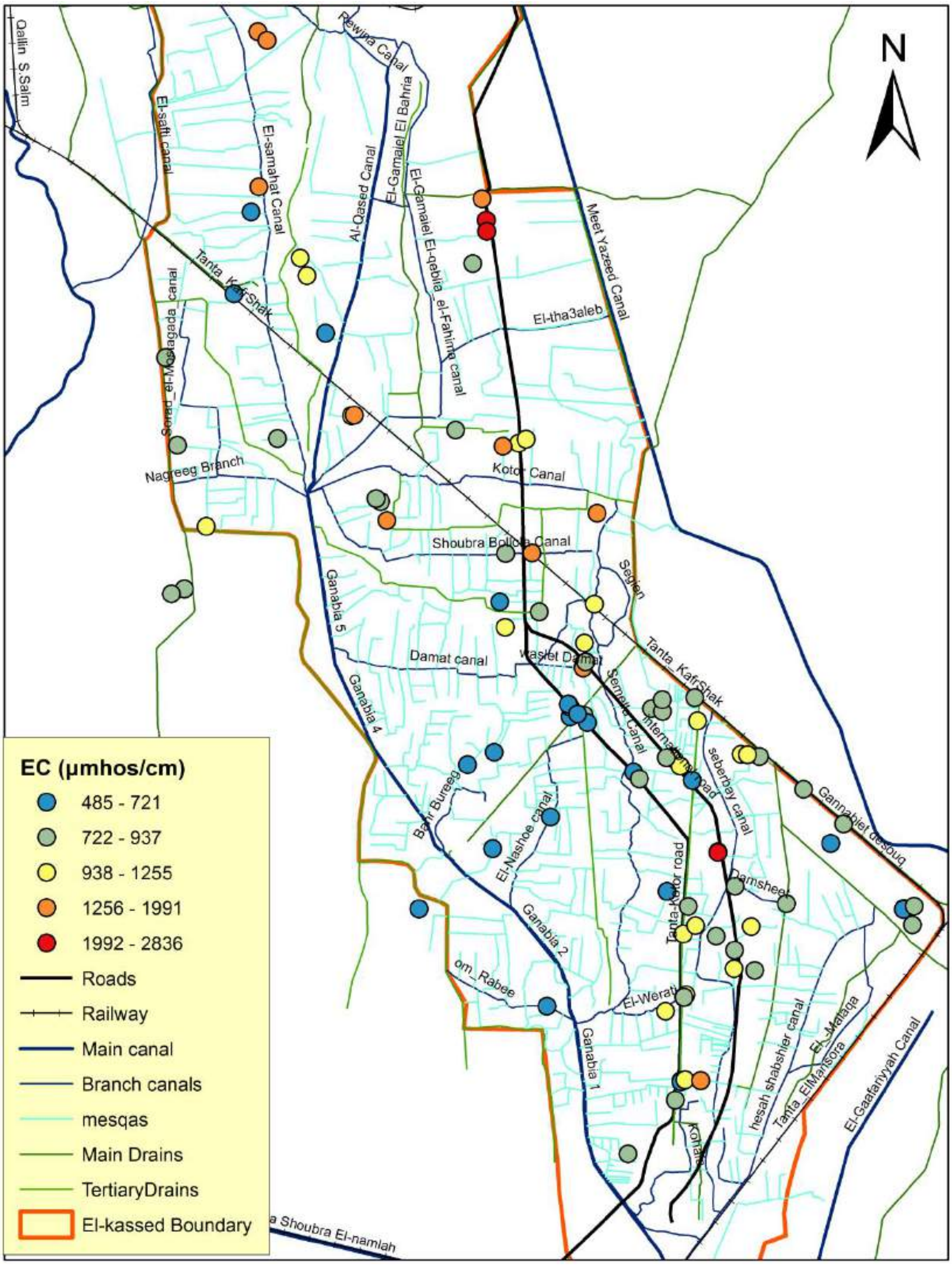
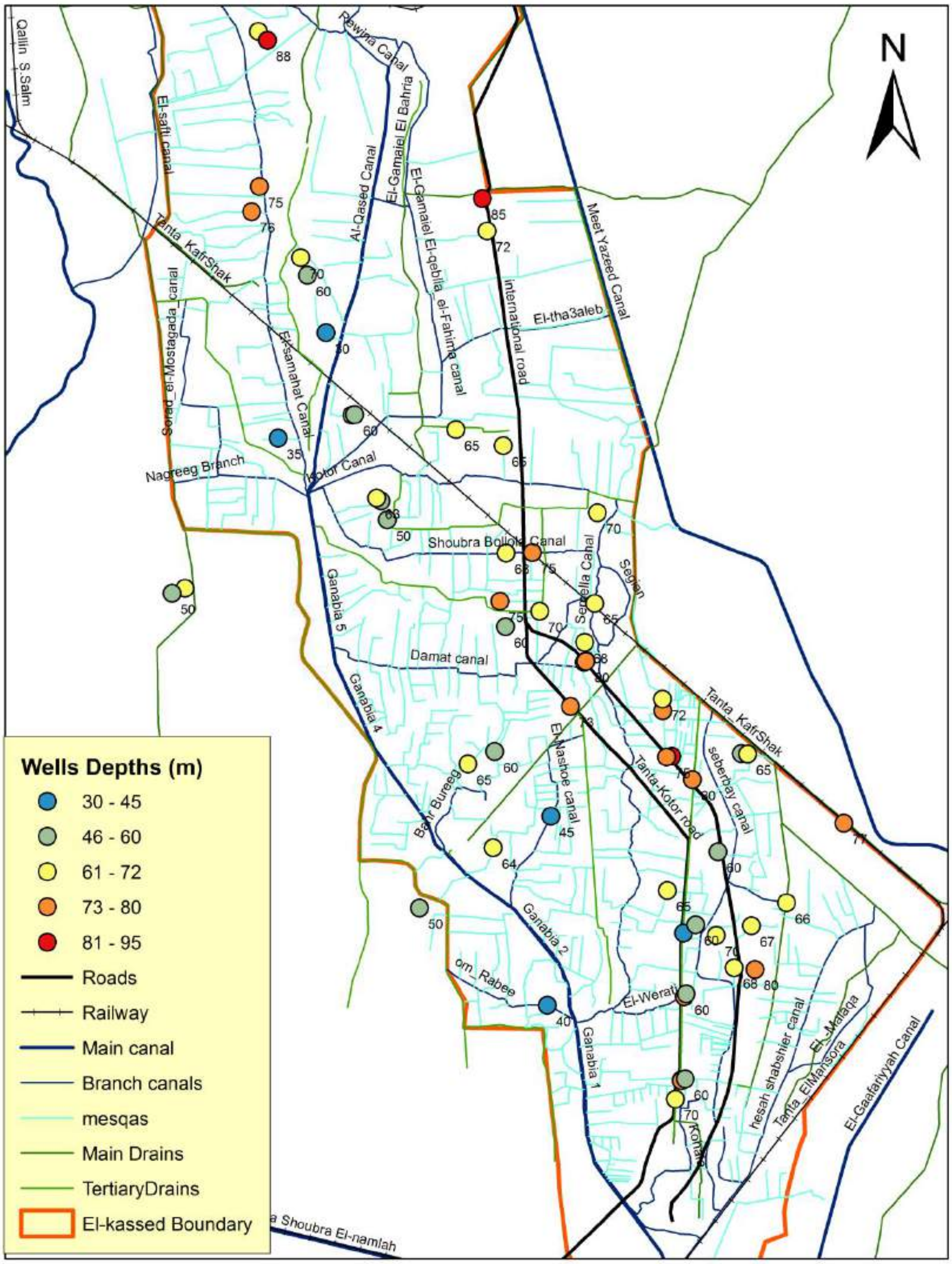


Figure 13. Depths of surveyed wells



6 Conjunctive use and irrigation water supply

The use of groundwater in the central part of the Nile Delta is subject to the inadequate and/or untimely supply of surface water due to different reasons described by El-Agha et al. (2015) and recalled above. Proper management of irrigation water supply can control farmers' groundwater overexploitation and avoid possible adverse impacts. A potential way to do so is through the conjunctive management of surface and groundwater, an attempt to optimize the operation of surface water allocation and groundwater use to increase agriculture production (Tod, 1959; Bredehoeft and Young, 1983).

As things stand in the Nile Delta in Egypt, the management and planning of surface water and groundwater is performed separately by two sectors in the Ministry of Water Resources and Irrigation (MWRI). The irrigation sector is responsible for the distribution and planning of surface water while the groundwater sector is responsible for planning and monitoring groundwater use. However, since surface and groundwater are tightly intertwined, as one recharges the other, any surface water reduction results in a reduction in groundwater recharge rates to the aquifer. On the other hand, farmers will also tend to use more groundwater to compensate for the lack of surface water in the canals, one thing adding to the other. But in practice groundwater development is not managed and farmers respond directly to water shortages.

El-Qassed main canal receives an average annual supply of 3.3 BCM distributed following a rotation between the 16 branch canals and 6 Gannabia (parallel canals). A review of 12 years (2008 to 2014) of El-Qassed discharges official records showed a slight decrease in the amounts of water supplied (from 3,436 MCM discharged in 2003 to 3,009 MCM in 2014) (Figure 14). The analysis and comparison of the monthly variation for these 12 years shows significant decreases in the summer months, especially in the year 2014 (Figure 15). During an interview, the Manager of water distribution in El-Gharbia directorate corroborated this and stated that farmers had complained of water supply problems that year. Therefore, it appears that reduction and supply and expansion of groundwater use are dynamically linked: the expansion of groundwater use in the area is observed by managers and ministry officials who therefore consider that supply to this area can be curtailed to deal with water shortages during peak time, since farmers can resort to wells. This however has the potential to further foster well drilling and groundwater abstraction, since farmers will respond to this reduced supply by further groundwater abstraction. This situation is not uncommon in large-scale gravity irrigation schemes, with managers first 'allocating scarcity' (reducing supply) to areas that have alternative resources. A similar situation can be found in the very downstream part of Meet Yazid main canal, which has access to drainage water by gravity and has seen its share of fresh water dramatically curtailed (IWMI and WMRI 2013).

Figure 14. Total annual discharges of El-Qassed Canal for twelve years (according to MWRI records)

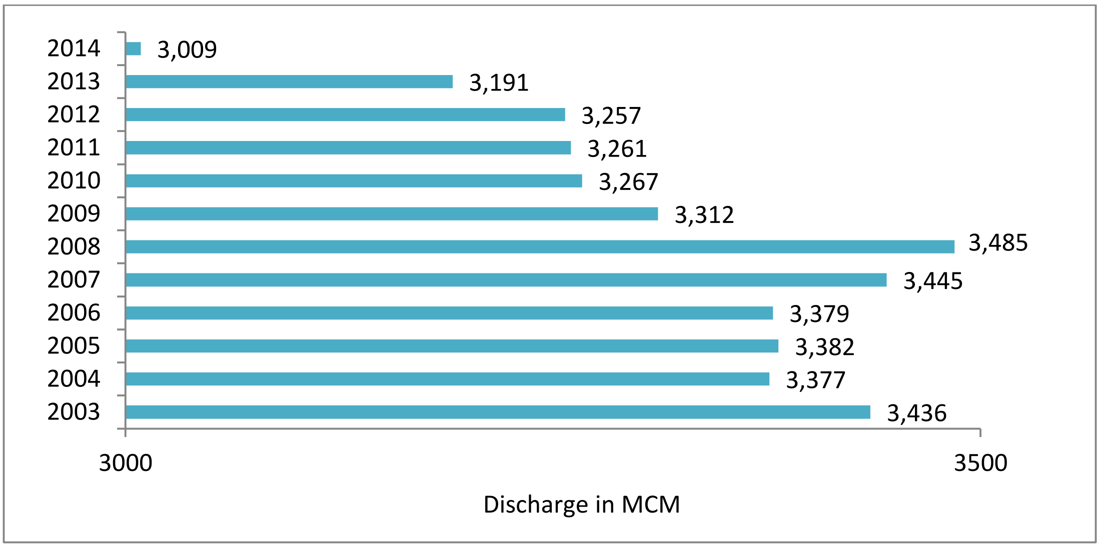
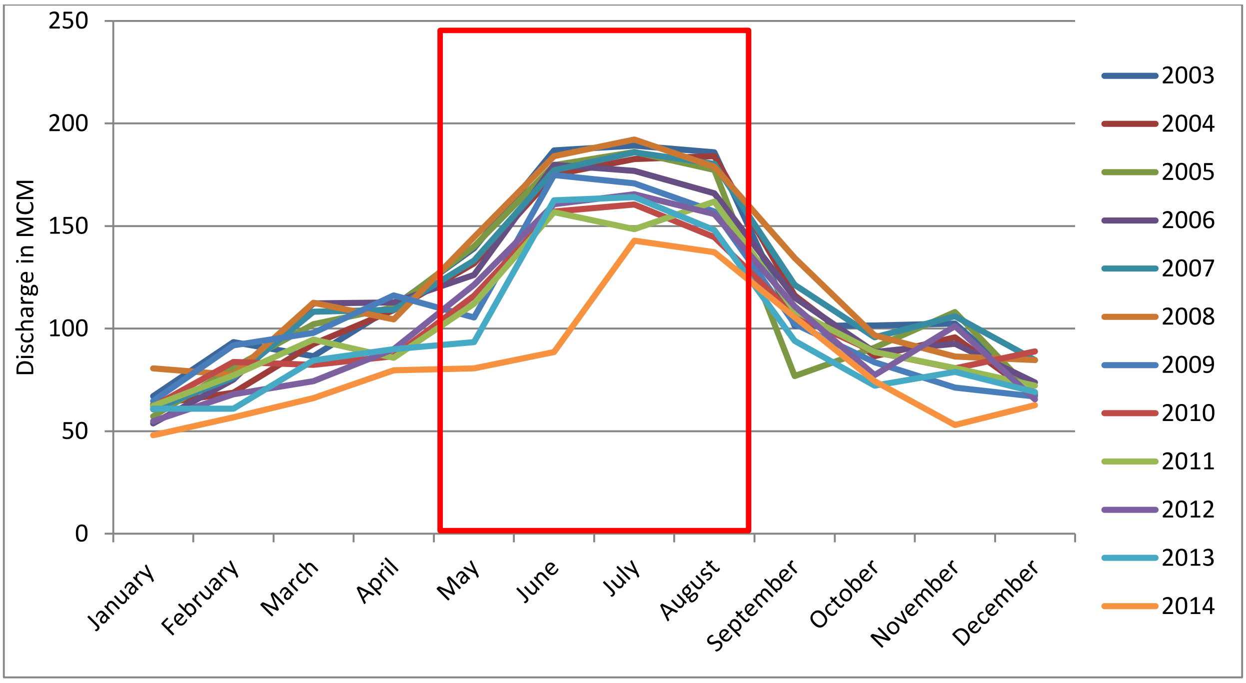


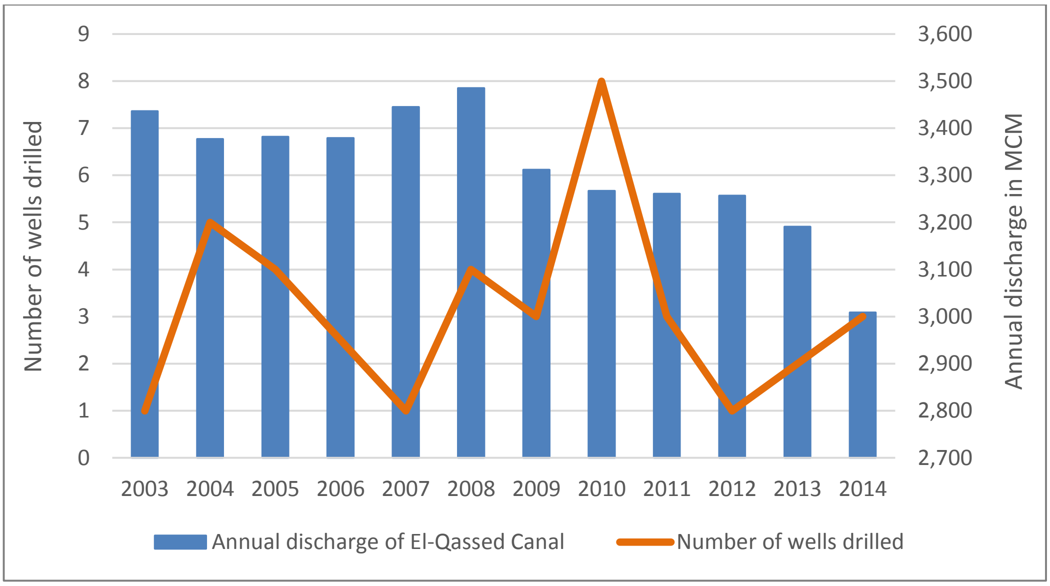
Figure 15. Monthly variations of discharges at the head of El-Qassed canal (according to MWRI records)



The government itself has already made use of groundwater for irrigation in the Nile Delta. The state drilled seven public wells to supplement irrigation water demand with groundwater in the sub-branches of El-Qassed canal (Segien, Bahr Burieg, Smella, Damat, Waslet Damat and Seberbay canals) according to MWRI records. These wells were placed in small pump houses and were operated by the ministry, directly pumping water into the (downstream) reach of canals affected by shortages. Several of those wells observed in the area were not functioning (and the pump house had sometimes been destroyed). Farmers reported failed attempts by the ministry to hand over the operation and maintenance (and associated costs) to farmers.

As explained earlier, farmers' groundwater use is spontaneous and without any regulations or control regarding the amount abstracted, the drilling depth or the distance between wells. Given the lack of rules, adverse effects could arise very soon. Following this scenario, a coordinated and planned management of both surface and groundwater is needed to optimize the efficient use of the resource and prevent its degradation.

Figure 16. Number of wells drilled (sample) and annual discharge of the El-Qassed Canal



7 Legal situation of wells

Like in most countries in the MENA region, the drilling of wells and the use of groundwater are associated with permits and licenses. In Egypt the MWRI, which has been made responsible for groundwater issues in the whole country in 1996, regulates groundwater use and quality through the Law 12-1984 on Irrigation and Law 48 -1982 regarding the protection of the Nile River and waterways from pollution.

Section 4 of the executive regulations of Law 12-1984 states:

> *"Article 18: The state authorities, local departments, other governmental or non-governmental authorities or individuals shall not be allowed to authorize or carry out digging groundwater wells whether deep or surface in all the lands of the Republic except via a license from the Ministry of Irrigation and in conformity with the stipulations set by the Ministry".*

In order to obtain a license for drilling a well, the following procedures are defined by the law:

> *"Article 25: Applications for obtaining a license for digging the wells in the lands of the Delta and the Nile Valley stated in clause (a) of article (17) shall be presented to the provincial Irrigation Engineer in whose area of competence the proposed well is located.*

The application form should bear the official stamps and include the data required, with the following documents enclosed:

1- Name and address of the license applicant.

2- Location of the proposed well on a survey map with a scale 1/2500 of three copies.

3- A copy of all the studies, analyses and designs related to the well if there is any.

4- Purpose of the use of the well's water.

5- Area to be irrigated by the well's water if the purpose of the well is irrigation.

6- Title deeds of the land utilizing the well or a certified statement from the agricultural cooperative society that proves his ownership of that land or a resolution for allotment of the land to be irrigated.

7- Paying a temporary insurance amounting to 200 pounds (two hundred pounds).

8- The well's owner should provide the irrigation district that the well follows with the results of water analyses and layers of the authorized well after completion of digging. In case of lack of the owner's commitment, the insurance stated in item 7 of the same article shall not be paid back to the owner."

The Irrigation Directorate will then review the drilling request, establishes whether it is needed, and send the documents to the RIGW which will carry out a detailed study of the suitability of the location for the well, and establish the discharge available to use as well as the technical provisions and specifications that should be followed by the user. Without the agreement of the RIGW, the Irrigation Directorate cannot allow the drilling of any well. The licence granted to the user should not exceed three years and it should be renewed at least two months before the expiry date of the licence. Also, to protect groundwater from contamination, Law 48-1982 prohibits the discharge of any liquid waste in the water ways or recharge it into the groundwater.

The very burdensome process described above readily explains why none of the farmers interviewed in the surveyed wells (60 wells) had obtained a license from the MWRI to drill the well. Some of the interviewed farmers did not even know about the procedures for getting a license. One striking observation is the absence of distinction between wells to be drilled in the Delta and wells drilled to exploit deep (and often fossil) desert aquifers.

The realization by MWRI that Egypt needed a new groundwater law with provisions for more effective controls of groundwater development has prompted several attempts at drafting a revised groundwater law, to address well licencing; the registration of drilling contractors; monitoring and protection of groundwater abstraction; identification of violations and applied penalties (El Arabi, 2012).[2]

The proposed draft law (still to be approved) recognized the public property of groundwater under the control and supervision of the MWRI which would regulate the utilization and secure the development and preservation of groundwater resources. Also, the new law would restrict the digging of new wells to the contactors registered with the MWRI and lay penalties not exceeding

[2] The draft of the new groundwater law includes 35 Articles under 6 sections as follows: Part 1: Definitions and general provisions; Part 2: Licenses of the new wells; Part 3: The violating wells; Part 4: Amendment of the licenses for the existing wells; Part 5: Supervision and control of the groundwater wells and protecting them from pollution; Part 6: punitive measures.

10,000 EGP (1,200 USD) for any violation. The licence should be renewed every three years. The Ministry also has the right to refuse the issuing of a licence and amend the design of a well according to the potential of the underground reservoir in the area.

Private companies, investors, and land owners in development and land reclamation projects are required to setup control wells at their own expense. Part 6 of the proposed new law identifies punishments in cases of violation, entitling the police to take action against the violator in addition to penalties not exceeding 25,000 EGP (3,100 USD) . The owner of the well has to install a meter to measure groundwater use and if it is not installed or remains unrepaired for more than a week and without informing the Ministry, the well owner would be subject to a fine of 5,000 EGP (620 USD). The new proposed law put penalties at not less than 20,000 EGP and not more than 50,000 EGP (2,500 and 6,200 USD respectively) for protecting the groundwater from pollution.

Procedural violations of well drilling in the central Delta as shown in this study are ubiquitous and famers have no motivation to register their wells and go through such complicated procedures and also have to pay for registering their wells. These farmers already suffer from water supply shortages and abstracting water from wells is twice as expensive as abstracting water from canals (El-Agha et al. 2015). Therefore applying the law as it is remains difficult due to social and economic reasons. A simplification of procedures and removal of costs would encourage the registration of wells, something that is needed in order to be able to monitor the impact of groundwater-fed irrigation on the quantity and quality of the groundwater.

8 Conclusion

Egypt has six groundwater aquifers and the Nile Aquifer (Delta and Valley) is considered an important source of groundwater abstraction as it represents 87 percent of the total groundwater abstraction in the country (MWRI, 2005). The use of groundwater in the southern part of the Nile Delta is strategic, adding flexibility and increasing the supply of water to farmers during peak irrigation times. However, adverse impacts stemming from a lack of control of groundwater abstraction could quickly arise. Possible negative impacts could be the drop of the dynamic water table level under 10 m (which would require further investment and technology called adjustment to continue accessing water) and the increasing salinity levels and abstraction costs associated with the drop of the water table. A potentially more devastating impact for the whole Nile Delta, still to be evaluated, is the increase in sea water intrusion due to the increase in groundwater abstraction levels and the shift inland of the isolines across the delta. This could potentially affect food production (as some crops are not suitable for certain concentrations of saline water) but also individual and municipal wells used for domestic use.

To overcome these possible impacts a proper management of both groundwater and surface water is required. Groundwater abstraction in the Middle Delta is strongly linked to inadequate and/or untimely availability of surface water in the canals (with different factors causing this). These wells are in general only used intermittently and it is not always easy to assess the frequency of use by farmers. Farmers mostly use these wells during summer (June and July), the beginning of rice cultivation. It has also been observed that managers have already started to take groundwater abstraction into consideration for surface water allocation by reducing the amount of surface water supplied to areas known to have developed conjunctive use of surface and groundwater. This however can drive farmers to increasingly drill wells and rely on groundwater (depending on the time of the year this surface water reduction is done).

With regards to groundwater quality, the values of groundwater salinity measured show large spatial variability (locally and regionally), contrasting with the homogenous data and neat salinity isolines usually exhibited in groundwater salinity maps for the Nile Delta. Further research is required to monitor the temporal and spatial variability of groundwater salinity and its impact on domestic wells for drinking supply and on agriculture production. Also, an in-depth study needs to be undertaken in order to assess the risk of sea water intrusion in to the Delta caused by the potential increase of groundwater abstraction and reduced Nile River flows in the Delta. This phenomenon could have serious repercussions for the Delta ecosystem and the livelihoods depending on the fine balance between fresh and saline water.

The legal situation of the wells surveyed in the study area expresses the barriers that famers face to register their wells. All farmers using groundwater from the surveyed wells had not obtained permits from the MWRI to drill their wells and some of them did not even know the procedures for getting these licenses. In order to monitor groundwater use in the central part of the Nile Delta, there is a paramount need to encourage farmers to register their wells. The new law should differentiate between renewable and non-renewable groundwater use and between wells drilled already in new and old lands. Moreover, barriers concerning registration time, costs and the period granted for permit renewal should be lessened to enable farmers to register their wells. Surveys by field staff using smart phones with GPS should also be undertaken in order to complement the information and data on groundwater used by the MWRI.

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