

Hydrosalinity and environmental land degradation assessment of the East Nile Delta region, Egypt

Mohamed O. Arnous¹ · Ahmed E. El-Rayes¹ · David R. Green²

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Abstract Environmental land degradation is a major impediment to the utilization of land in many arid and semi-arid regions of the World and is a major issue in the East Nile Delta (END), Egypt. Waterlogging and salt-affected soil problems have serious implications for irrigated areas leading to socio-economic and agricultural development problems. In the present study, timely and accurate detection of land degradation through remote sensing and hydrosalinity indicators, along with their characteristics and severity classification in a GIS environment, has been undertaken to provide, determine, assess and map reliable geo-information of environmental land degradation. This research deals with an assessment of hydrosalinity and environmental land degradation based on some new, but simple and practical, approaches for assessing salinity and spread of land degradation through digital image processing, geo-statistics and geochemistry. This analysis utilises Landsat 8, ASTER GDEM data, hydrochemical and statistical analyses using a GIS, together with other field collected data sets for the same date of May 2014. The hydrosalinity mapping and the statistical data analysis of TDS, major ions, groundwater grouping and hydrochemical facies and also water table maps between 1994 and 2014 reveals that the main sources of groundwater recharge and water bodies are mostly attributed to the continuous seepage from newly cultivated lands. The new flow

regime is the main contributing factor to the rising water level, water salinity and waterlogging problems. Moreover, the spatial distribution of major ion content could be attributed to the leaching of aquifer materials along the flow path (Na, Ca, and Cl), the study area affected by agricultural pollution (Mg and SO₄) and the leaching process which acts on the easily soluble evaporate-rich fluvio-marine sediments of a shallow aquifer (NO₃ and PO₄). The spatial distribution maps of the physico-chemical properties of soil such as EC, pH, SAR, Na, Cl, SO₄ and Ca are compared with remote sensing salinity indices and then integrated to classify and map the salinity and salt-affected soil by using GIS tools. These indicate that increases in soil salinity levels pose a serious threat to sustainable agricultural developments that requires special attention to maintain an appropriate soil–water plant relationship by providing an adequate drainage system. The identification of land degradation mitigation measures requires thorough knowledge of the ground and surface water, human activities, and the salinity dynamics of the study area.

Keywords Hydrogeochemistry · Remote sensing · GIS · Spatial mapping · Geo-statistics

Introduction

Today, environmental land degradation is widespread throughout the World particularly in arid, semi-arid and some sub-humid regions and is one of the most common and serious environmental problems in the world. The problem of salinity and alkalinity increases every year as a result of secondary salinization, especially in the areas that have poor quality groundwater, irrigated land and those facing anthropological activities. Soil and water resources of dry lands are limited and poorly distributed. Growing demands for water and food

✉ Mohamed O. Arnous
arnous_72@yahoo.com; mohamed.arnous@science.suez.edu.eg;
m.arnous@abdn.ac.uk

¹ Geology Department, Faculty of Science, Suez Canal University, 41522 Ismailia, Egypt

² AICSM, Department of Geography and Environment, School of Geosciences, College of Physical Sciences, University of Aberdeen, AB24 3UF Scotland, UK

production have led to large-scale reclamation projects in the surroundings of inhabited desert areas, which are endowed by groundwater resources reserves (Bastawesy et al. 2013). Waterlogging and salinization are the twin evils of irrigated agricultural land due to severe environmental impact hazards widespread over the World particularly in arid and semi-arid regions. It is also considered as being ecologically dangerous, because it suppresses the growth of many agricultural plants and decreases agricultural productivity. Good quality land resources of water and soil are limited in arid and semi-arid regions. The increased salinization of groundwater and soils in the recent decades is considered to be a major problem of agricultural sustainability in Egypt and is thought to be a result of the Nile's weak demineralization of the soil due to the absence of flooding. In addition, the irrigation system was converted from seasonal to yearly after the construction of the High Dam (Abu-Ata 1997 and Khedr 1998). It is also facilitated by the introduction of a 12 month irrigation schedule without a corresponding drainage system, leading to the absorption and accumulation of salts in quantities toxic for plants. The lands of agricultural sustainable development needs to monitor, assess and maintain of the main degraded resources to provide food for a burgeoning global population that is expected to increase by another 2.25 billion people before levelling off at around 9.25 billion by 2050 (Bouwer 2000; Kleyer et al. 2003; United Nations 2008; De Fraiture and Wichelns 2010; Singh et al. 2012; Singh and Panda 2012; Arnous and Green 2015). In Egypt, the Nile Delta, along with its fringes, covers an area of 22,000 km² (EGSA 1997). It is occupied by the highest populated governorates in Egypt. About 60 % of Egypt's population lives in the Nile Delta region (Sherif and Al-Rashed 2001). Egypt is suffering from limited agricultural land and high demographic pressure on agricultural area. 97 % of Egypt is covered by desert and is therefore dependent on the Nile River for its existence. Only 5 % of the land area in Egypt is actually occupied and less than 4 % of the land is suitable for agriculture. Egypt's arable and permanent crop land in 1993 (2.8 million hectares) was the same as in 1974–76 and less than that in 1969–71 (FAO 1995). The area of land per capital has fallen from 0.2 ha in 1907–0.032 ha at the beginning of the year 2014 due to the population increase from 21 million in 1907–86 million in 2014 but the increase in agricultural land is very limited. Agriculture activities are predominant in the region (around 63 % of the total agricultural land) due to the nature of the soil and an irrigation system in place (Dawoud 2004).

Salinization is a worldwide problem in poorly drained irrigated lands that use a large amount of irrigation water. In addition due to threatened the sustainable development of any country. More than 76 million hectares of soil globally are affected by salinization (Eger et al. 1996; Mohamed et al. 2011; Mensah and FitzGibbon 2013). From the hydrosalinity and land degradation point of view, the risk of salinity is directly related to the quantity of salts dissolved in the

irrigation water. All irrigation water contains potentially harmful salts and nearly all the dissolved salts are left in the soil after the applied water is lost by evaporation from the soil or through transpiration by the plants. Unless the salts are leached from the root zone, sooner or later they will accumulate in quantities which will partially or entirely prevent the growth of most crops. The FAO (1990) reported that about 20–30 million hectares worldwide are severely affected by salinity and an additional 60–80 million hectares are affected to some extent which due to soil salinization is spreading at rate of up 2 million hectares per year. In Egypt, the total cultivated area of the Nile delta is 1741753 hectares representing 55.5 % of the cultivated land in Egypt. Salinization, waterlogging, soil compaction, alkalization have particularly been identified as one of the main threatened land degradation and water quality problems in the East Nile Delta (END) area (El-Gabaly 1972; Gad and Abdel Samei 1998; Wahab et al. 2010; Mansour 2012; Shalaby et al. 2012; Arnous and Green 2015). Land degradation was identified by several authors (FAO/UNEP 1978; Waren and Agnew 1988; Ayoub 1991; Wim and El-Hadji 2002) as the process which lowers the current and / or the potential capability of soil to produce goods or services. It can also be defined as a decline in soil quality caused through its misuse by humans (Lai and Stewart 1990). In the present study, the hydrosalinity dynamics refer to variations in water volumes and inorganic salt concentrations, masses and rates of mobilization. These dynamics may occur either in the surface water, groundwater, precipitation or soil (Bugan 2014).

The total cultivated area of the Nile Delta is 4, 354, 382 feddans, representing 55.5 % of the cultivated area of Egypt, compared with 3,353,909 feddans in the Nile Valley, which represents 32.3 % of the total cultivated area. The deltaic lands, worldwide, could be considered as problematic lands regarding their fine texture, poor drainage, as well as the intrusion of sea water into the ground water table. Therefore, these soils are threatened by land degradation processes more than any other alluvial soils. Land degradation processes are clearly observed also in different regions under the arid and semi-arid climatic conditions. The Nile Delta is one of these regions which is threatened by water logging, soil compaction, salinization and alkalization (Gad and Abdel Samei 1998; Arnous and Green 2015).

Many researchers have studied these problems from different perspectives using different methodologies, following different objectives focusing on either surface or groundwater and, consequently, have arrived at different findings. However, they all confirmed that significant groundwater salinization has affected the Nile Delta and this is likely to worsen rapidly in the future. The current study observes that the extensive seepage from canals and the reckless wastage of water in drains add to the groundwater. Improper alignment of canals has obstructed the natural drainage in many cases.

Both of these processes have led to the development of waterlogged conditions and subsequently salinization and / or alkalization. From the hydrosalinity point of view, the water transportation from outside the natural hydrological cycle causes the dual hazards of waterlogging and soil salinization (Singh 2010). Heuperman et al. (2002) stated that, there is more than 33 % of the World's irrigated land is affected by secondary salinization and / or waterlogging. The freshwater resources and land degradation of the East Nile Delta region (END) are experiencing increasing pressure as a result of increased human activities such as agricultural and economic development, and population increase. Moreover, the threatening impacts of climate change like sea level rise and water intrusion are expected to intensify the problem, particularly in the END region. Salt water intrusion is due to human activities, and may be compounded by relative sea level rise associated with global climate change (Juman and Ramsewak 2013). In addition, there are also significant water quality challenges in investigated area. Abbas and Khan (2007) observed that the water scarcity, especially in restricted irrigation supplies in supply channels, may be due to persistent drought, the re-use of poor quality groundwater for irrigation, and the failure of the tile drainage system and will probably disturb the water ecosystem as the risks of further environmental land degradation increase in the area. The main contributors to water quality problems in END area are urban development, industrial activities, agriculture activities (El Shamy and Geriesh 1992; Geriesh 1994; El-Rayes and Geriesh 2003; Geriesh 2004; Geriesh et al. 2008; Arnous and El-Rayes 2013; Ghodeif et al. 2013; Mabrouk et al. 2013; Arnous and Green 2015).

Waterlogging, high salinity levels and poor drainage in agricultural lands are believed to be the primary reasons for the collapse of many early civilizations, their infrastructure, and the loss of a large amount of fresh water through evaporation and pollution due to inappropriate land-use planning practices. Today, waterlogging is an important form of land degradation in the Nile Delta and is caused by unscientific management of soil, water, and agricultural crops within areas of irrigated land. Waterlogging and salinization go hand-in-hand, and have become major threats in some locations in the East Nile Delta (END) where agricultural land has become totally barren, and in some others, the soil has become saline. The prevailing hydrogeological conditions in association with poor land-use planning and the role of geological and geo-environmental factors determines the strategy of land reclamation and sustainable development and are the most likely causes of this problem. All of these problems will be observed and reported through field investigations and the use of enhanced satellite imagery. The waterlogged and salt-affected areas will be defined, eliminated and assessed using digital image processing and GIS tools. The present study aims to apply hydrogeochemistry, remote sensing (RS) and GIS tools

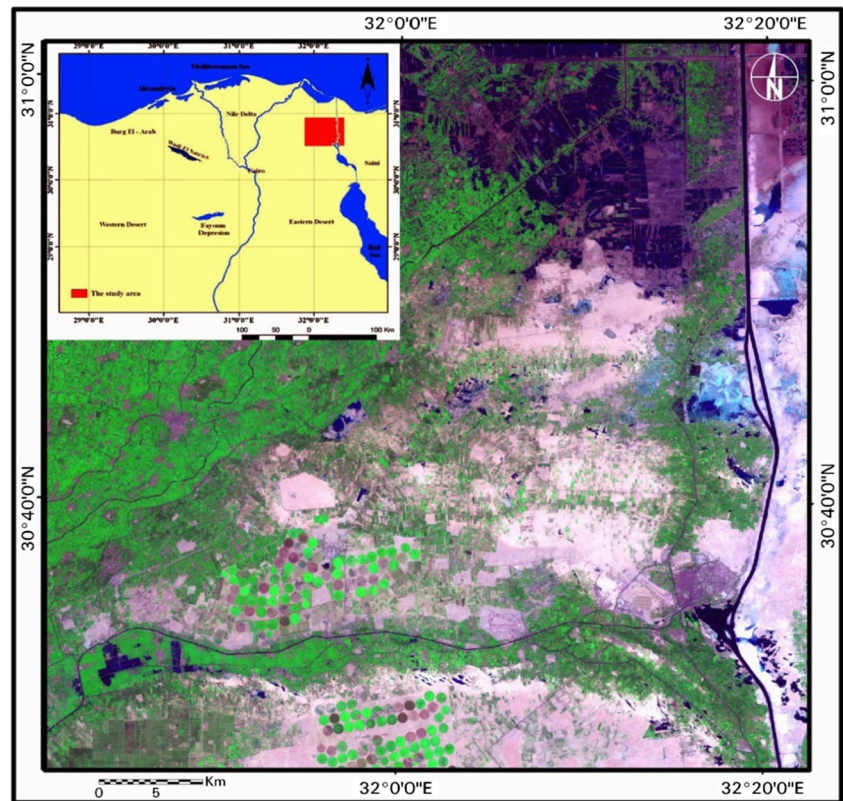
to assess, and map the hydrosalinity and environmental land degradation status, especially around the areas of the land reclamation projects in the desert fringe and coastal zone in the Eastern Nile Delta (END) region.

Study area

The END region is one of the most promising sustainable development areas in Egypt. It is characterized by a prominent watershed having abundant water resources. Furthermore, it is important as an essential development axis for the people of the heavily populated regions of the Nile Delta and Valley. The END area is presently undergoing rapid environmental degradation. Most serious are the combined effects of natural causes and human influence factors, such as land subsidence, rising sea level, due to global warming, irrigation, and damming. This results in, among other changes, sea water intrusion into the Nile Delta's water table and coastal erosion (Stanley and Warne 1993; Nosair 2011). In addition, the salinization has increased substantially since closure of Aswan High Dam in 1964, reducing the agricultural productivity (Biswas 1993) and altering the chemistry of the delta's lagoon and lake waters (Kerambrun 1986). Solving the problems of salinization, waterlogging and land degradation in the arid regions, in for example the END area in Egypt, depends more in understanding the natural setting more and mainly focusing on the natural reaction to local community activities.

The investigated area of the END covers an area of about 2425 km² located in the northeastern part of Egypt, approximately between the latitudes 30° 27' 18"–30° 55' 10" N and longitudes 31° 40' 42"–32° 20' 54" E (Fig. 1). It is bounded in the North by the Mediterranean Sea and Lake Manzala, and in the south by the desert rolling plains and foot hills of tertiary and cretaceous structural ridges varying in altitudes between 200 and 800 m asl. On the west it is bounded by Damietta Nile Branch while, the Suez Canal represents its current eastern boundary. The eastern Nile Delta Flank constitutes about 1 % of the Egyptian land that is totally covered by Quaternary deposits of silt, clay and sands with thickness varying between 200 m at the south and 700 m at the north. The flood plain fans out with a gentle slope of an order of 0.3 m/km and then at a very low gradient to the north through a distance of about 160 km. Lake Manzala and its surroundings are characterized by wet lands connected via narrow link with the Mediterranean Sea. The topography of the END area is characterized by low relief, and its surface slopes gently towards the north direction, while it takes a rolling shape towards the south direction, where the land rises up to a moderately elevated plateau with elevations range between 5 and 100 m. The geomorphology of the END consists of two deltaic plains: the modern deltaic plain comprises the main portion of the fertile and cultivated lands; and the old deltaic plain

Fig. 1 Location map of the East Nile Delta (END) study area



that stretches to the east and south of the modern flood plain. Some depressions are encountered such as Wadi El-Tumilat to the south and the Asthmus depression to the east. Sea level rise has its own bearing on coastal recession and hydro-environmental degradation of the northern parts of the study area. ASTER GDEM of the study area shows that the elevations at the END area decrease in the northward direction, and it ranges between less than 2 m at the north and about 98 m at the south (Fig. 2). The climate in END region is hot, dry and rainless in the summer and mild with some showers in winter. Mean monthly temperature ranges from about 12 °C in winter to 29 °C in summer. Average annual rainfall is ranging between 20 and 100 mm. The daily evaporation varies from approximately 1.5 mm in December to 7.5 mm in July and the evaporation from open water is about 1600 mm/year (Egyptian Meteorological 2006 and Nosair 2011)

Materials and methods

Remote sensing and GIS

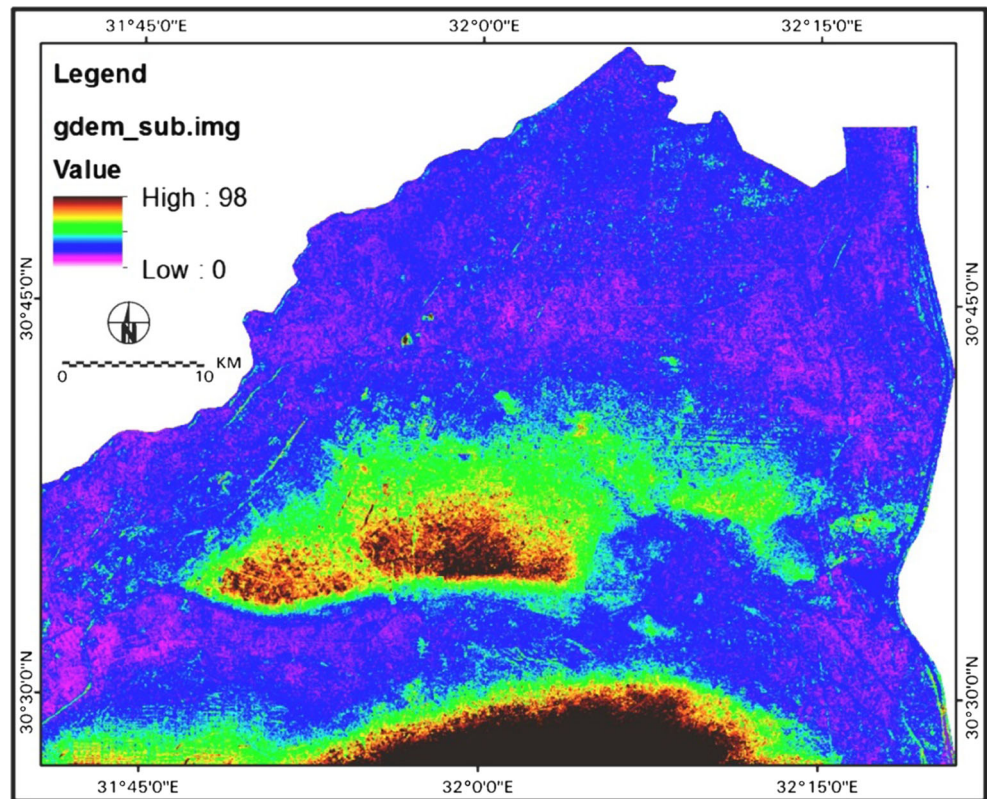
RS and GIS tools play important roles in the spatial integration of various data sets including geological maps, Landsat 8 images, ASTER GDEMs, and soil and hydrogeochemical data. These was applied to show the distribution and intensities of soil salinization and land degradation relative to the

hydrogeological, landforms and human activities elements of the study area by using ERDAS Imagine, ENVI and ESRI ArcGIS software.

Landsat eight Operational Land Imager (OLI) data of the study area were processed for waterlogging and land degradation mapping. A single Landsat OLI scene (Path 176, Row 39, date May, 2014) with nine spectral bands, of 185×185 km covering the investigated area, was geometrically and radiometrically corrected using the flash technique. The OLI is represented in the UTM projection with an output pixel size of 30 m. The panchromatic band of the OLI is digitally processed and merged with an output pixel size of 15 m using topographic maps of scales 1:50,000, 1:100,000 and the geological map of CONOCO (EGPC/CONOCO 1987) as reference maps. False colour composite (FCC) images (7, 5, 3 in RGB), principal component analysis (PCA) images, salinity index (SI), normalized water difference Index (NDWI) and normalized differential vegetation Index (NDVI) indices ratio images and classification techniques were applied to detect and assess the waterlogged areas, saline soil discrimination, water canals and drains network as well as revealed the land use/land cover in the study area.

In addition, the ASTER GDEM of the study area was used to carry out terrain analyses to assess the landforms, elevations, slope and slope aspect in order to integrated with all data extracted from the enhanced satellite data, hydrogeochemical and soil analyses data that are collected from the field work.

Fig. 2 Aster GDEM showing the elevation values of END area



Toward this end, spatial analyses and digital mapping of the geographical database by GIS tools were used to analyse and assess the hydrosalinity and land degradation conditions of the END area.

Soil and water sampling

The fieldwork included carrying out fieldtrips during May 2014 to verify the enhanced satellite image that was acquired on May 2014 and to assess the causes of the hydrosalinity and land degradation by waterlogging and salinization. During the fieldtrips, a reconnaissance traverse was made to establish the relationship between enhanced image features and different categories of the salt-affected soils and waterlogging and at the observation sites within the hot spot area. Terrain conditions, hydrogeological conditions, physiography, soil properties land use/land cover, surface drainage, groundwater table were also observed and mentioned. Water samples for a 68 surface and groundwater points were collected. Furthermore, water analysis sample data collected by Nosair (2011) and Mansour (2012) were also used. These samples provided data for Ismailia, Port Said Canals, irrigation drains, water logging ponds, dug holes and shallow hand pumps and were used to investigate and assess the hydrosalinity of the END area. Furthermore, a number of thirty-four (34) saturated soil samples were collected for each variation in the soil classes and near to the hot spots of water

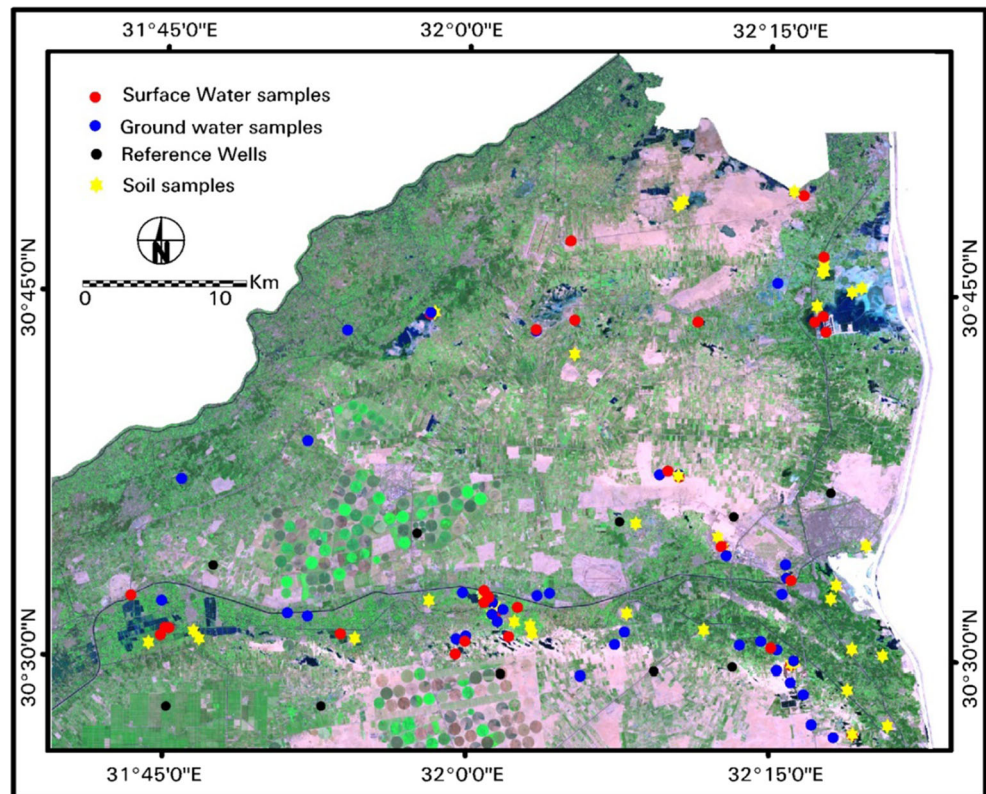
logged sites (Fig. 3). The in-situ salinity and pH values were measured directly in the field by using EC / pH Hanna pocket meter (Hanna Instruments, Woonsocket, Rhode Island, USA).

Hydrogeochemical methods

The most abundant dissolved constituents measured were the major ions (Bartos and Ogle 2002), which can be both positively charged (cations) and negatively charged (anions). The most abundant cations present in water are calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K); while the most abundant anions are bicarbonate (HCO_3^-), chloride (Cl), sulphate (SO_4), nitrates (N- NO_3) and phosphate (PO_4).

Thirty eight (38) well waters and thirty (30) surface water samples around the known water logged bodies and saline soil sites of the study area are sampled using a non-metallic thief-type sampler and chemically analysed for major and some trace metal contents. The dry, clean polyethylene bottles were rinsed three times with the water to be sampled. Two samples were taken from each site: a 500 ml unfiltered sample; for major ion determinations, and a 100 ml sample which was filtered and acidified with HNO_3 to a pH value ≤ 2 and used for trace element determinations. All samples were analyzed using the standard methods described by APHA (1989). Determination of the major constituents were performed by using several determinative methods: HCO_3^- , Cl^- , Ca^{2+} and

Fig. 3 Sample location map of the investigated study area



Mg^{2+} titrimetric, Na^+ and K^+ flame photometric and SO_4^{2-} colorimetric.

Trace element analyses including Zn, Ni, Pb, Co, Cu and Cd were performed with atomic absorption spectrophotometer (Perkin Elmer), Detection limits are 1.5 $\mu g/l$ Zn, 6 $\mu g/l$ Ni, 5 $\mu g/l$ Pb, 15 $\mu g/l$ Co, 9 $\mu g/l$ Cu, and 0.8 $\mu g/l$ Cd. All detection limits are based on a 98 % confidence level.

The ionic composition of water is used to classify it into ionic types based on the dominant dissolved cation and anion, expressed in milliequivalents per litre (meq/l). A milliequivalent (meq) is a measurement of the molar concentration of the ion, normalized by the ionic charge. Cation and anion concentrations (in meq/l) for each ground-water sample are plotted on Schoeller diagram (Schoeller 1935). Trace and major elements are represented as element distribution contour maps using ESRI ArcGIS and Golden Software's SURFER™ software.

Soil analyses

In the present study, two types of data have been used for assessing the salt affected soil hazard and degradation over the study area such as enhanced RS and collected field data. Field verification was carried out to represent the different soil salinity values. Thirty four (34) saturated soil samples were collected for each variation in the soil classes and near to the hot spots of water logged sites that are extracted from the

enhanced OLI images. The soil laboratory chemical analyses such as Electric Conductivity (EC), pH, Sodium Absorption Ratio (SAR), Total dissolved solids (TDS), soluble cations and anions were carried out soil samples using the soil survey laboratory methods manual (USDA 2004) and Saxena (1990). SAR and sodium percentage (% Na) was calculated according to (USDA 1954) formulae. The results of these analyses have been compiled in the GIS geographical database and then integrated into the attribute tables of the digital soil maps (Pavasovic 1993; Dinh 2001; Shalaby et al. 2012).

Statistical analysis of data

Statistical analyses were applied to the hydrogeochemical water and soil analyses data of the END area using STATISTICA software. The statistical analyses included *R*-mode and *Q*-mode cluster analysis based on the complete linkage method, correlation coefficients, principal components and factor analysis.

Cluster analysis is the name given to an assortment of techniques designed to perform classification by assigning observations to groups so each is more-or-less homogeneous and distinct from other groups (Davis 1986). As an exploratory technique with graphic output, cluster analysis does not require many of the assumptions that other statistical methods do, except that the data is heterogeneous. It provides an easily understood graphic display (dendrogram), and is a method used frequently in the geological sciences to help classify or

group samples/variables of a data set (Harbuaugh and Marreium 1968). It helps to identify natural groupings for samples (*Q*-mode) or variables (*R*-mode), and in turn, reduces the size of the samples/variables into smaller numbers of groups.

For the *Q*-mode analysis of the geochemical data collected, the Cosine Theta Similarity Coefficient was used. Cosine Theta expresses the similarity between samples by treating each as a vector defined in *p*-dimensional variable space, and calculates the cosine of the angle between the two vectors. It is sensitive only to the relative proportions of the variables, and not to their absolute magnitudes. This makes it a very good method for this dataset, because it is the grouping of samples according to variables that is of interest, not the relative chemical distribution amongst the samples.

For the *R*-mode analysis, the Product-moment Correlation Coefficient was chosen in order to be consistent with later *R*-mode factor analysis in which the Correlation Coefficient is considered the standard method in similarity matrix calculation. Before the similarity coefficient matrix was calculated, a percent transformation was completed for each sample in order to avoid the influence of the magnitude of a particular variable.

Results and discussion

Digital image processing and GIS for land degradation

The application of image enhancement techniques sought to improve the potential to interpret the image by increasing the apparent distinction between the land-use and land-cover classes in the OLI image. The enhancement of the RS data is more timely and quicker than ground methods and provides better spatial distribution coverages particularly when integrated with GIS tools (Rao et al. 1998; Qadir et al. 2008; Arnous et al. 2011; Arnous and Green 2011; Dehin and Lounis 2012; Arnous and Sultan 2014; El-Rayes et al. 2014 and Arnous and Green 2015). Salt-affected and waterlogged areas can be delineated and mapped both directly based on the reflectance from bare soil, or from the salt crust, and indirectly from vegetation cover and health status (Abbas and Khan 2007; Arnous and Green 2015). In addition, saline soils with visible salt efflorescence on the surface are easier to map using the enhanced RS data as strongly saline soils. Furthermore, vigorous growth and the type of vegetation are easily recognized and can be used to identify the extent of salinization.

In the current study, information is presented on the nature, extent and spatial distribution of waterlogged and salt-affected soils, derived from the enhanced OLI Landsat image and based on salinity indices from band combinations, PCA and classification techniques used to search for the occurrence pattern of waterlogging and salt-affect soil areas. The PCA

and the salinity indices were found to be promising techniques to assess the saline soil, waterlogging and environmental land degradation (Figs. 4 and 5).

The delineation of waterlogged and salt-affect areas made depend on image photointerpretation elements, namely tone, colour, texture, shape, pattern, and published soil survey reports and maps. As well as the association, the waterlogged area and salt affected soils were characterized and classified under different categories. Waterlogged areas appear very clearly in a dark blue to bluish black tone or bluish black to light bluish tone and various shades of a blue colour, and are confined to local depressions on either side of canal courses and low angled slopes. Salt-affected soils could be identified by their dull-to bright-white and cyan colour, whereas saline soils with patchy crops appeared in a dull white to cyan tone with cyan mottling. The main obstacle in the reclamation of salt-affected areas from RS data lies in distinguishing salt' and urban classes. To overcome this problem one can use up-to-date topographic maps to obtain information about the settlement/urban area boundaries and exclusion after vectorizing from the calculation process of surface changes when monitoring salt-affected areas (Arnous and Green 2015).

The results of RS analyses of the study area indicate that there is a positive relationship between the agricultural and reclaimed lands and waterlogged areas. In addition, it reveals a large scale spread of waterlogging and salinization in the newly reclaimed project lands especially at El-Huseinia, New Salhyia, El-Mullak and Sarabium areas. At some places in the study area, there are small pockets of salt- affected soils that have developed on account of rising ground water, owing to the introduction of canal irrigation. Furthermore, patches with severe salinity and alkalinity problems do show a characteristic spectral response pattern. In addition, some soils do not exhibit any characteristic features such as salt efflorescence on the surface due to prevailing hydrologic conditions, especially along the El Salhyia road and along the Suez Canal. This means that the irrigation and cultivation processes can be considered as the most important water sources creating waterlogging problems, particularly at sites having a subsurface clay layer and where there are low lying landforms in the study area (Fig. 6). In addition, using the supervised maximum likelihood algorithm classification for land-use analysis of the study area provided an overall accuracy of more than 90 %, and in which, the bare soil, salt-affected soils and the human activities were discriminated (Fig. 7). For the delineation of the salt-affected spread areas, particular in the arid and semi-arid regions in the World, many digital image processing and GIS techniques have been applied in previous studies such as those by Nagarajan et al. (1993), Sharma et al. (1996), Metternichit and Zinck (1997), Ayars and Tanji (1999), Khan et al. (2005), Kaul and Ingle (2011), Arnous and Green (2011) and Arnous and Green (2015). The sites of salt-affected areas that have a relatively high reflectance

Fig. 4 Enhanced false colour contrast stretching image (b7, b5 and b3 in RGB) of END

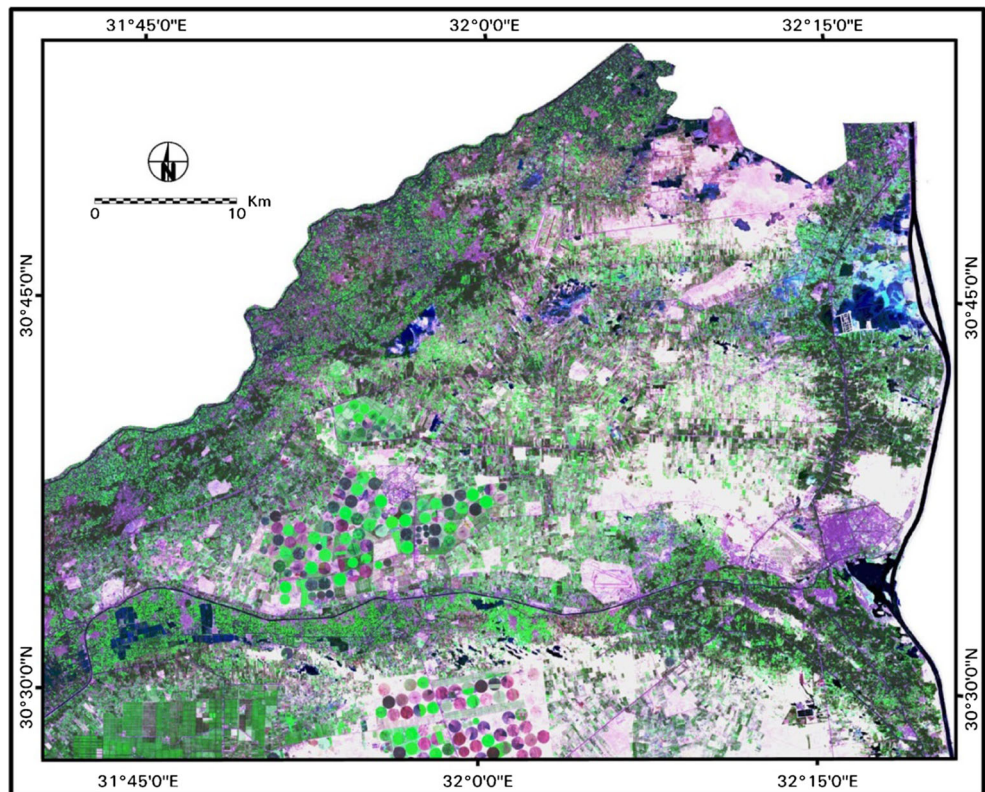


Fig. 5 Enhanced PCA OLI image (PC3, PC2 and PC1 in RGB) of END

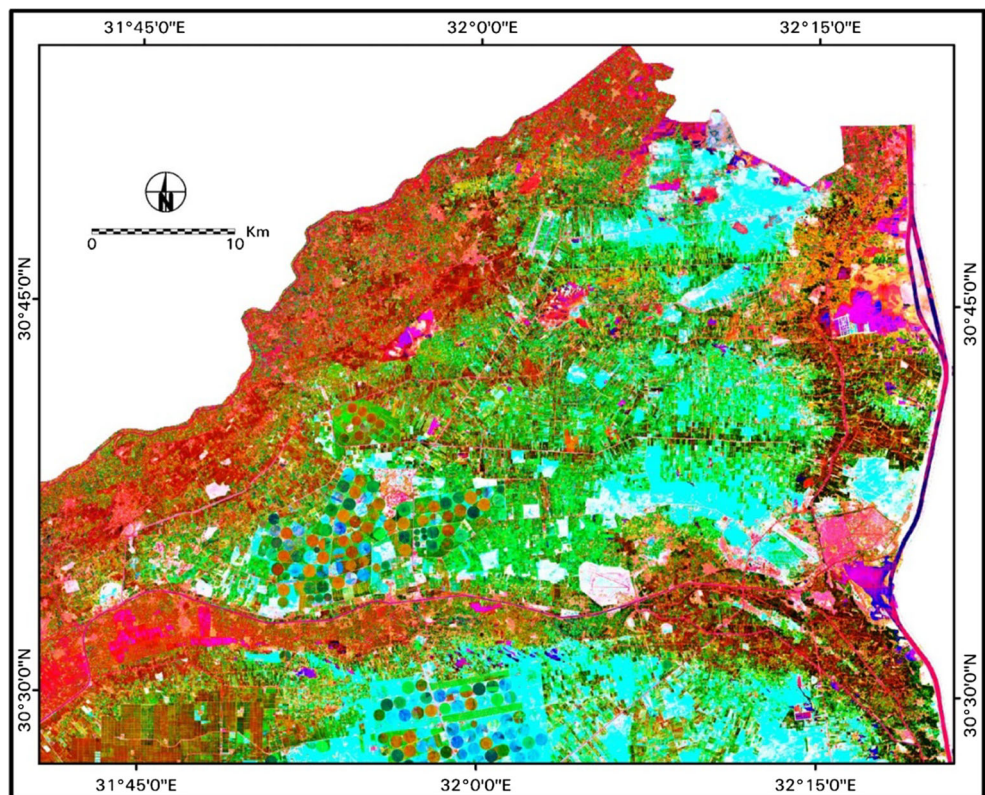


Fig. 6 Spatial distribution of the salt-affected and waterlogged areas of END; delineated from the enhanced satellite images

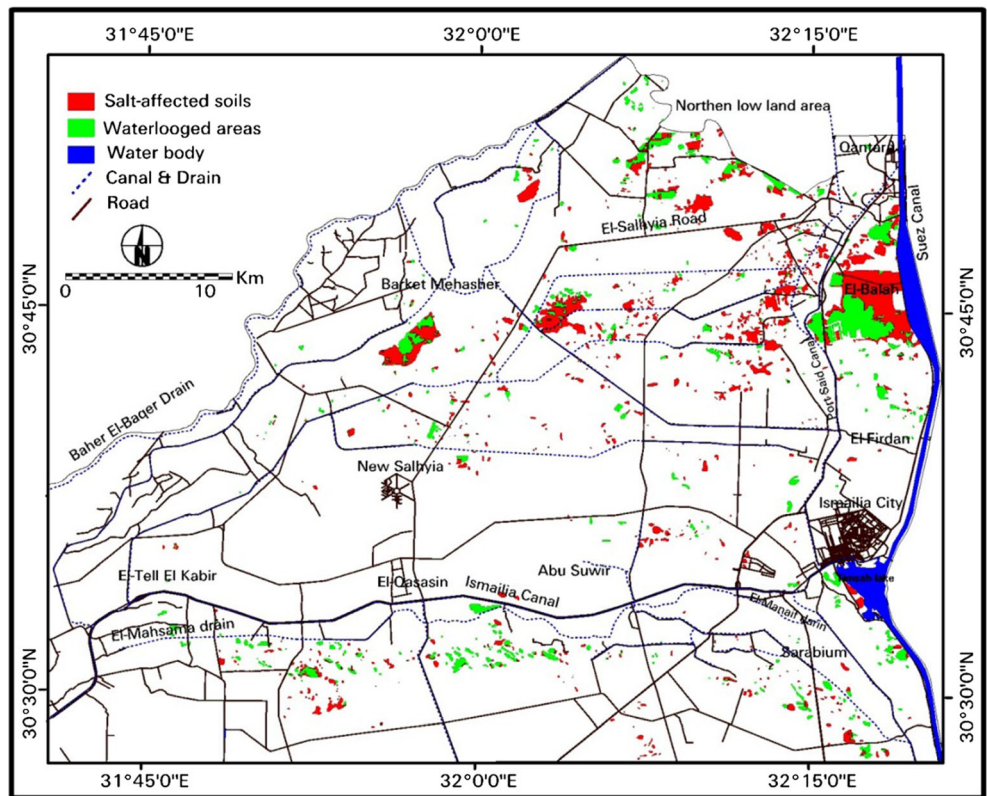
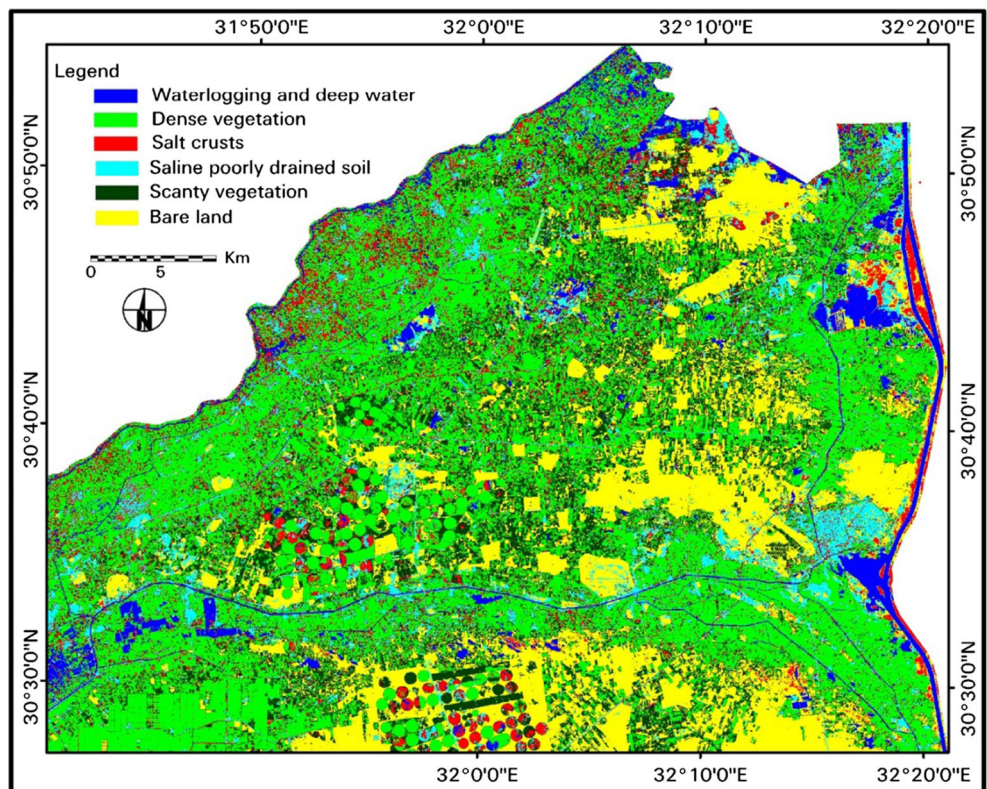


Fig. 7 Supervised image classification map of the study area



coefficient in the spectral bands of the Landsat 8 image data were picked out from the enhanced satellite images taking into account all surface information. The results showed that the spectral response pattern of salt-affected lands is higher than the other classes in all bands in all images whereas vegetation reflectance maximum in NIR range (Band 5). This response for saline soils is extremely valuable as it helps the discrimination and eliminate of salt-affected soils from normal soils and vegetation (Fig. 6).

Based on the image interpretation land degradation is a major impediment to sustainable development in the study area that has been the consequence of both naturally occurring phenomena due to primary salinity and / or sodicity, and human activities that are causing secondary salinity and / or sodicity. The RS data and GIS results agree with the results of Kaiser et al. (2013). These results indicate that there are some factors that affect the END area and lead to environmental land degradation; including topographic and surface elevation; drainage pattern and water flow direction; an excess of irrigation water and the deficiencies of the drainage system. In addition, there is the presence of impermeable clay lenses near the surface at less than 1 m depth. The current study reveals that extensive seepage from canals and the reckless wastage of water in drains adds to the groundwater. Furthermore, the improper alignment of canals has obstructed the natural drainage in many cases. Both of these processes have led to the development of waterlogged conditions and subsequently salinization and / or alkalization.

According to field verification of the enhanced OLI data that was interpreted the environmental land degradation in the END lands is predicted to become more serious and extensive environmental problems will arise in the next few years where the soil salinization and waterlogging are predominant forms of land degradation, especially in the low-lying lands. Furthermore, many infrastructures are drowning under waterlogging including cultivated land, houses, roads, electricity towers and industrial zones. In addition, the agricultural land has become totally barren and in some others, the soil has turned salty.

Origin of waterlogging and soil salinization

Development of waterlogging is an inevitable consequence of the introduction of irrigation without providing an adequate drainage system. Over-irrigation by canal water, along with inadequate water management practices has further aggravated the situation which culminates in waterlogging. Generally, the intensive irrigation of the cropland under an arid climate is the main reason for soil salinization and water logging that is due to the land degradation. In irrigated areas, farmers may not be able to control irrigation, which usually results in excess water being added to the groundwater. Continued irrigation with excess water leads to a rising groundwater table (Bouwer

et al. 1990). Waterlogging in low-lying areas is produced by seepage of water from irrigated uplands and from canal system (Chitale 1991). In the END region, seepage from irrigation practices and seepage from the Ismailia Canal and its branches are the main causes of waterlogging. The overall seepage at the END area causes a rise in groundwater level at a rate ranging from 3 to 8 cm/year (Mansour 2012). The groundwater level and its flow pattern along the END have been dramatically changed during the period from 1994 to 2014 (Figs. 8 and 9). Generally, the water table of END region has been raised by up to a half meter within 10 years. The main sources of groundwater recharge and waterlogging bodies are mostly attributed to the continuous seepage from the newly cultivated lands at El-Salhyia plain to the north of Wadi El-Tumilat and El-Shabab & El-Mullak projects to the south (Fig. 9).

The old flow direction had regular trends mainly toward the Northwest and, to lesser extent, toward the East via El-Manzala Lake and Suez Canal Navigation route (Fig. 8). Recently, these trends have changed because of the new sources of recharge, to be directed mainly via W. El-Tumilat lowland (from both its northern and southern flanks) and to the local depressions along END region (Fig. 9). The new flow regime is the most contributing factor of rising the water level and producing the waterlogging problem along the END.

Water chemistry

A number of thirty eight (38) groundwater samples and thirty (30) surface water samples (canals and water logging pools) are collected from END region (Fig. 3) and subjected to chemical analysis for major and some trace metal contents (Tables 1 and 2). The analytical data are statistically treated in order to be grouped and classified. The following is a detail discussion of the results obtained.

Water salinity distribution

Salinity distribution of shallow groundwater in END region has a wide range and varies between 230 and 7710 mg/l (Table 1). Groundwater salinity in END is mainly controlled by the length of flow path, depth to water and water-rock interaction. Groundwater near the recharge areas at the beginning of flow path has lower salinity than at the end of flow path.

Figure 10 shows that the groundwater salinity in END is gradually increases along the NE flow path (Figs. 9 and 10). Some anomalous salinity values are recently recorded at the southern lowlands of W. El-Tumilat due to a change in flow direction as a result of new sources of recharge (Fig. 10).

Depth to groundwater plays an important role in water salinity near the discharge zones, where the water table is extremely shallow or exposed at the ground surface. In such a case, the groundwater is subjected to evaporation leading to

Fig. 8 Showing the spatial distribution of the groundwater table map of 1994

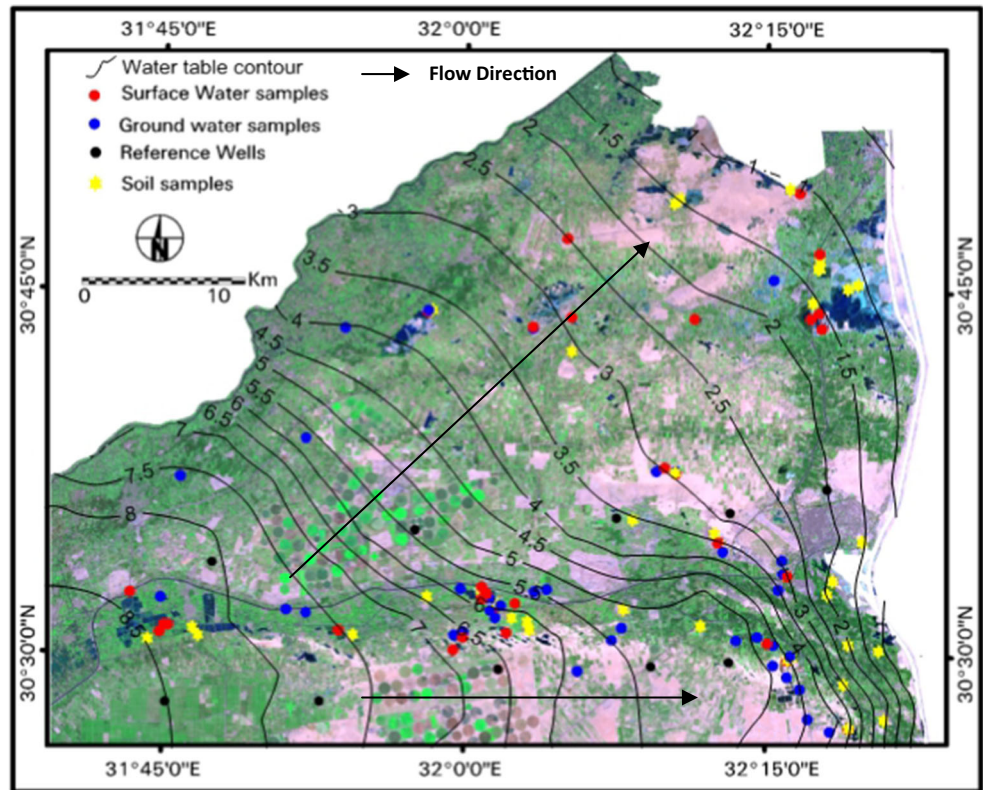


Fig. 9 Showing the spatial distribution of the groundwater table map of 2014

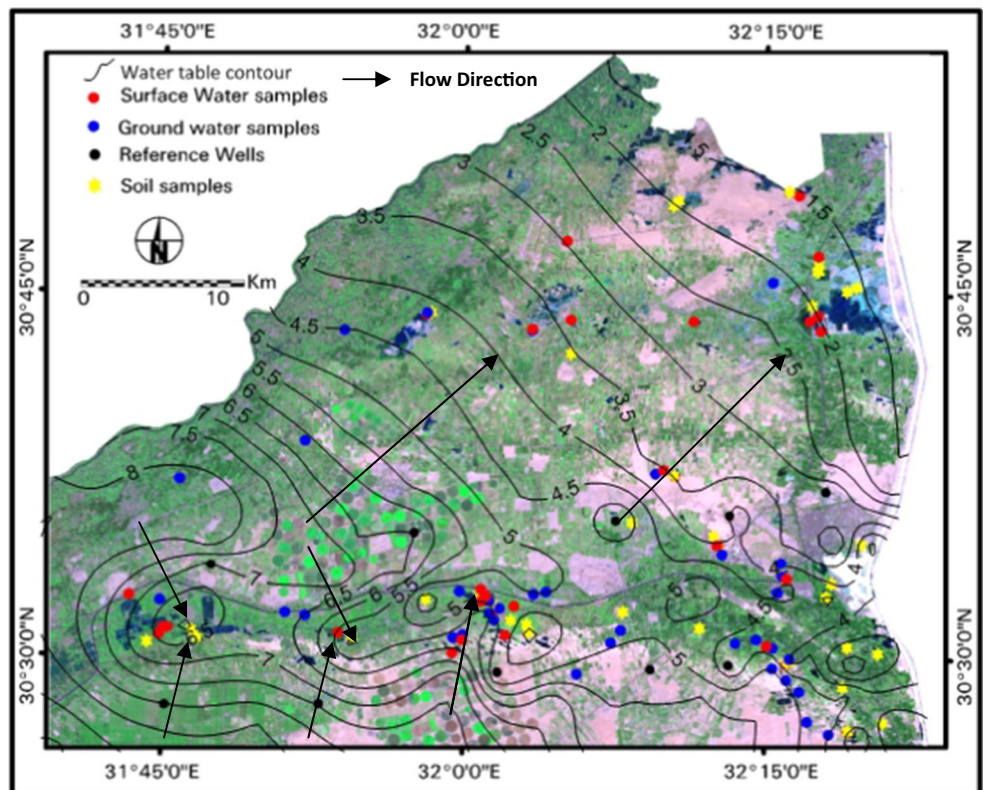


Table 1 Hydrochemical analyses of groundwater of END region

Sample No.	pH	EC	TDS	TH	Unit	Ca	Mg	Na	HCO ₃	SO ₄	Cl	N-NO ₃	PO ₄	Ion Relativity
1	7.2	2430	1580	110	mg/l	16	17	284	671	288	269	11	6.2	Na>Mg>Ca
					Meq/l	0.8	1	22	11	6	8			HCO ₃ >Cl>SO ₄
2	7.2	4080	2652	180	mg/l	28	26	677	336	336	727	10	14.8	Na>Mg>Ca
					Meq/l	1.4	2.2	29.4	5.5	7.0	20.5			Cl>SO ₄ >HCO ₄
3	7.25	5180	3367	530	mg/l	140	43	636	207	552	826	9	14.8	Na>Ca>Mg
					Meq/l	7.0	3.6	27.7	3.4	11.5	23.3			Cl>SO ₄ >HCO ₄
4	6.68	3460	2249	320	mg/l	56	43	378	256	240	482	6	6.2	Na>Mg>Ca
					Meq/l	2.8	3.6	16.4	4.2	5.0	13.6			Cl>SO ₄ >HCO ₄
5	6.37	757	492	240	mg/l	56	28	44	220	96	50	10	9.9	Ca>Mg>Na
					Meq/l	2.8	2.3	1.9	3.6	2.0	1.4			HCO ₃ >SO ₄ >Cl
6	8.25	850	724	N.D	mg/l	22	20	165	315	80	109	N.D	N.D	Na>Mg>Ca
					Meq/l	1.1	1.7	7.2	5.2	1.7	3.1			HCO ₃ >Cl>SO ₄
7	7.64	2140	1444	N.D	mg/l	143	30	320	311	310	430	N.D	N.D	Na>Ca>Mg
					Meq/l	7.2	2.5	13.9	5.1	6.5	12.1			Cl>SO ₄ >HCO ₄
8	7.56	960	646	N.D	mg/l	75	23	80	285	52	123	N.D	N.D	Ca>Na>Mg
					Meq/l	3.7	1.8	3.5	4.7	1.1	3.5			HCO ₃ >Cl>SO ₄
9	7.36	16000	6594	N.D	mg/l	900	65	1432	103	193	3845	N.D	N.D	Na>Ca>Mg
					Meq/l	44.9	5.4	62.3	1.7	4.0	108.5			Cl>SO ₄ >HCO ₄
10	N.D	551	358	N.D	mg/l	48	5	50	293	47	60	5	0.6	Ca>Na>Mg
					Meq/l	2.4	0.4	2.2	4.8	1.0	1.7			HCO ₃ >Cl>SO ₄
11	N.D	390	254	N.D	mg/l	40	10	30	226	30	40	10	0.9	Ca>Na>Mg
					Meq/l	2.0	0.8	1.3	3.7	0.6	1.1			HCO ₃ >Cl>SO ₄
12	N.D	8460	5499	N.D	mg/l	20	72	2788	1762	200	1974	23	1.2	Na>Mg>Ca
					Meq/l	1.0	5.9	121.3	28.9	4.2	55.7			Cl>HCO ₃ >SO ₄
13	N.D	1330	865	N.D	mg/l	96	14	195	348	74	215	5	0.7	Na>Ca>Mg
					Meq/l	4.8	1.2	8.5	5.7	1.5	6.1			Cl>HCO ₃ >SO ₄
14	N.D	680	442	N.D	mg/l	48	7	78	165	98	125	27	0.2	Na>Ca>Mg
					Meq/l	2.4	0.6	3.4	2.7	2.0	3.5			Cl>HCO ₃ >SO ₄
15	N.D	1450	942.5	N.D	mg/l	24	7	399	244	160	405	31	0.1	Na>Ca>Mg
					Meq/l	1.2	0.6	17.4	4.0	3.3	11.4			Cl>HCO ₃ >SO ₄
16	N.D	3410	2217	N.D	mg/l	40	5	1722	390	92	770	4	0.3	Na>Ca>Mg
					Meq/l	2.0	0.4	74.9	6.4	1.9	21.7			Cl>HCO ₃ >SO ₄
17	N.D	1031	670	N.D	mg/l	61	30	33	120	75	53	8	1.1	Ca>Mg>Na
					Meq/l	3.0	2.5	1.4	2.0	1.6	1.5			HCO ₃ >SO ₄ >Cl
18	N.D	1446	940	N.D	mg/l	24	15	240	231	300	98	22	0.6	Na>Ca>Mg
					Meq/l	1.2	1.2	10.4	3.8	6.3	2.8			SO ₄ >HCO ₃ >Cl
19	N.D	554	360	N.D	mg/l	91	41	220	260	360	360	42	0.8	Na>Ca>Mg
					Meq/l	4.5	3.4	9.6	4.3	7.5	10.2			Cl>SO ₄ >HCO ₄
20	N.D	477	310	N.D	mg/l	75	32	212	230	220	340	12	1.3	Na>Ca>Mg
					Meq/l	3.7	2.6	9.2	3.8	4.6	9.6			Cl>SO ₄ >HCO ₄
21	N.D	1735	1128	N.D	mg/l	80	31	232	316	218	248	4	0.1	Na>Ca>Mg
					Meq/l	4.0	2.6	10.1	5.2	4.5	7.0			Cl>HCO ₃ >SO ₄
22	N.D	4558	2963	N.D	mg/l	176	70	730	427	760	794	12	0.7	Na>Ca>Mg
					Meq/l	8.8	5.8	31.8	7.0	15.8	22.4			Cl>SO ₄ >HCO ₄
23	N.D	2555	1661	N.D	mg/l	32	7	483	610	192	336	2	0.8	Na>Ca>Mg
					Meq/l	1.6	0.6	21.0	10.0	4.0	9.5			HCO ₃ >Cl>SO ₄
24	N.D	7294	4741	N.D	mg/l	232	94	1432	280	800	1861	9	1.8	Na>Ca>Mg
					Meq/l	11.6	7.7	62.3	4.6	16.7	52.5			Cl>SO ₄ >HCO ₄
25	N.D	2320	1508	N.D	mg/l	32	23	415	634	162	248	3	0.5	Na>Mg>Ca

Table 1 (continued)

Sample No.	pH	EC	TDS	TH	Unit	Ca	Mg	Na	HCO ₃	SO ₄	Cl	N-NO ₃	PO ₄	Ion Relativity
26	N.D	5409	3516	N.D	Meq/l	1.6	1.9	18.1	10.4	3.4	7.0			HCO ₃ >Cl>SO ₄
					mg/l	128	91	1015	222	680	1408	12	0.6	Na>Mg>Ca
27	N.D	1731	1125	N.D	Meq/l	6.4	7.5	44.2	3.6	14.2	39.7			Cl>SO ₄ >HCO ₄
					mg/l	30	6	321	210	270	254	34	1.9	Na>Ca>Mg
28	N.D	2251	1463	N.D	Meq/l	1.5	0.5	14.0	3.4	5.6	7.2			Cl>SO ₄ >HCO ₄
					mg/l	44	10	432	216	348	392	21	1.2	Na>Ca>Mg
29	N.D	9538	6200	N.D	Meq/l	2.2	0.8	18.8	3.5	7.3	11.1			Cl>HCO ₃ >SO ₄
					mg/l	238	116	1790	206	1209	2428	8	0.6	Na>Ca>Mg
30	N.D	11815	7680	N.D	Meq/l	11.9	9.5	77.9	3.4	25.2	68.5			Cl>SO ₄ >HCO ₄
					mg/l	238	162	2112	128	3652	1412	2	0.8	Na>Mg>Ca
31	N.D	3572	2322	N.D	Meq/l	11.9	13.3	91.9	2.1	76.0	39.8			SO ₄ >Cl>HCO ₃
					mg/l	104	46	826	246	638	965	16	1.0	Na>Ca>Mg
32	N.D	11857	7707	N.D	Meq/l	5.2	3.8	35.9	4.0	13.3	27.2			Cl>SO ₄ >HCO ₄
					mg/l	420	432	1494	540	3045	1764	7	0.5	Na>Mg>Ca
33	N.D	8831	5740	N.D	Meq/l	21.0	35.5	65.0	8.9	63.4	49.8			SO ₄ >Cl>HCO ₃
					mg/l	388	73	1876	128	1966	2348	8	0.5	Na>Ca>Mg
34	N.D	3000	1950	N.D	Meq/l	19.4	6.0	81.6	2.1	40.9	66.2			Cl>SO ₄ >HCO ₄
					mg/l	36	24	618	342	320	586	15	1.3	Na>Mg>Ca
35	N.D	365	237	N.D	Meq/l	1.8	2.0	26.9	5.6	6.7	16.5			Cl>SO ₄ >HCO ₄
					mg/l	8	21	31	61	53	53	2	0.9	Mg>Na>Ca
36	N.D	471	306	N.D	Meq/l	0.4	1.7	1.4	1.0	1.1	1.5			Cl>SO ₄ >HCO ₄
					mg/l	26	18	40	68	72	80	2	0.3	Na>Mg>Ca
37	N.D	3840	2496	N.D	Meq/l	1.3	1.5	1.8	1.1	1.5	2.3			Cl>SO ₄ >HCO ₄
					mg/l	84	60	690	183	264	1106	19	0.8	Na>Mg>Ca
38	N.D	1979	1286	N.D	Meq/l	4.2	4.9	30.0	3.0	5.5	31.2			Cl>SO ₄ >HCO ₄
					mg/l	56	38	330	198	162	497	3	1.3	Na>Mg>Ca
					Meq/l	2.8	3.2	14.4	3.3	3.4	14.0			Cl>SO ₄ >HCO ₄

N.D Not detected

increase the water salinity. These conditions are observed along the northern and eastern zones of the mapped area (Fig. 10).

The eastern lowland is covered by fluvio-marine deposits, rich in evaporite minerals (mainly gypsum). Groundwater in these zones easily dissolves these minerals and gains higher salinity. The salinity distribution map shows the ever highest salinity values at these zones along the eastern lowlands (Fig. 10).

Major ion distribution

The major ion contents in groundwater of END region are represented as iso-concentration contour maps (Fig. 11). The spatial distributions of Na, Ca and Cl contents identical and following the groundwater flow direction (Figs. 9 and 11). This could be attributed to leaching of the aquifer materials along the flow path, where the groundwater tends to have a chemical type of sea water (Cl-Na type) (Chebotarev 1955).

Mg and SO₄ are distributed with different patterns, where they are distributed around the newly reclaimed lands and increase away along the flow path to the eastern discharge area (Fig. 11). This pattern may attributed to the excessive usage of pesticides rich in Mg and SO₄ during the cultivation of the reclaiming desert lands. This is confirmed by the similarity of NO₃ and PO₄ distributions, resulting from fertilizer practice, with Mg and SO₄ distributions (Fig. 11).

Groundwater grouping

Factor and cluster analyses have been applied to the hydrochemical data obtained from the END region. Factor analysis (Fig. 12) shows that the ion distributions of the END groundwater are controlled by two factors. The first one characterizes the agricultural pollution which is indicated by the predominance of NO₃, PO₄ and HCO₃ ions (Fig. 12a). The second factor characterizes the leaching process which acts on the easily soluble evaporate-rich fluvio-marine

Table 2 Trace metal contents in groundwater of END region

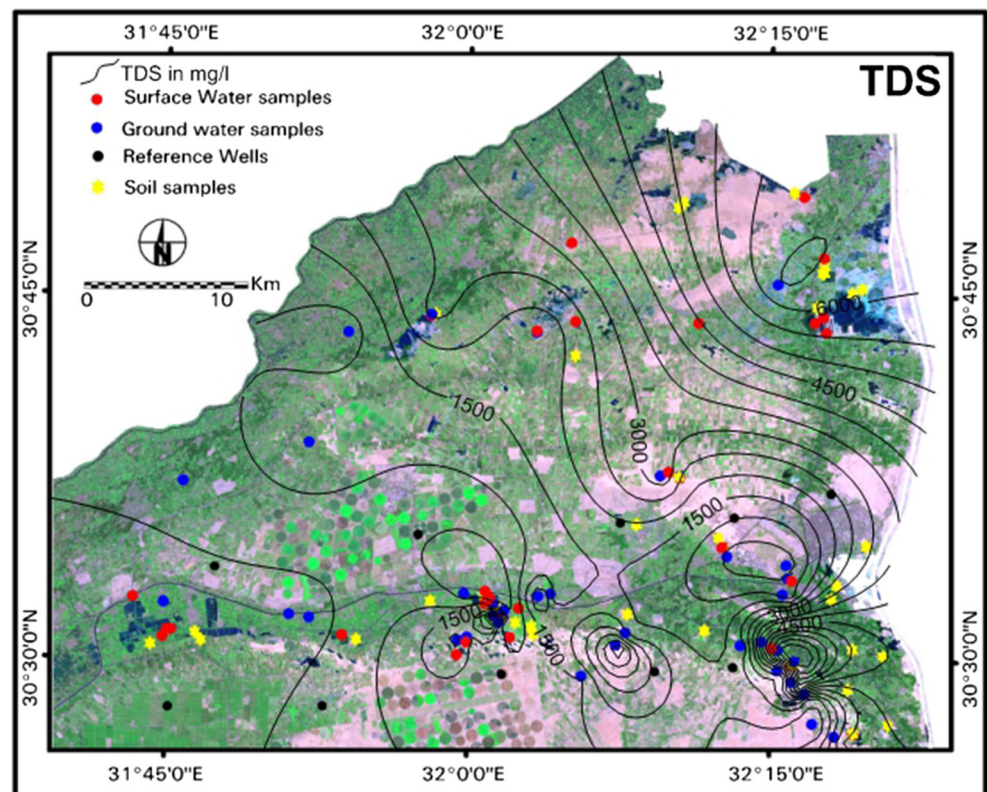
Sample No.	Pb ($\mu\text{g/l}$)	Cu ($\mu\text{g/l}$)	Co ($\mu\text{g/l}$)	Ni ($\mu\text{g/l}$)	Zn ($\mu\text{g/l}$)	Cd ($\mu\text{g/l}$)
1	20.9	24.3	N.D	58.6	55.5	3
2	7.9	25.8	18	20.2	55.5	2.3
3	37.1	30.3	10.3	14.1	28.5	4.1
4	8.3	30.4	23.7	26.4	22.3	2.8
5	22.2	5.2	15.7	18.4	20.9	3.4
6	40	4	9	22.6	23.7	0.1
7	16.4	7.9	10.1	32.8	24.5	0.4
8	9.7	8.2	14.6	23.7	19.9	1.1
9	6.8	11	19.8	18	24.1	5.7
10	20.6	11.8	0.3	3.5	14.5	2.9
11	57.7	19.6	24.8	9.7	28.6	2.5
12	25.5	18.9	18.5	5.7	41.2	3.7
13	10.9	25	22.7	10.2	19.4	1.6
14	14	29	14.1	15.6	19.9	3.6
15	20.3	22.1	22.1	17.2	28.6	2.5
16	13.8	23.8	16.8	15.6	23.8	5.3
17	46.3	19.5	12.9	17.9	39.5	2.3
18	2.3	16.4	20.3	17.7	35.5	2.2
19	28.4	13.8	17.6	14	29.5	2.9

N.D Not detected

sediments of the shallow aquifer at the END region (Fig. 12a). The leaching process produces a highly saline water (high TDS) richen in Na, Mg, Ca, SO_4 and Cl. The cluster analysis

grouped the groundwater of END region into two main groups with the same distribution of ion contents, exactly as the factor analysis did (Fig. 12b).

Fig. 10 Iso-salinity spatial distribution map of the investigated area



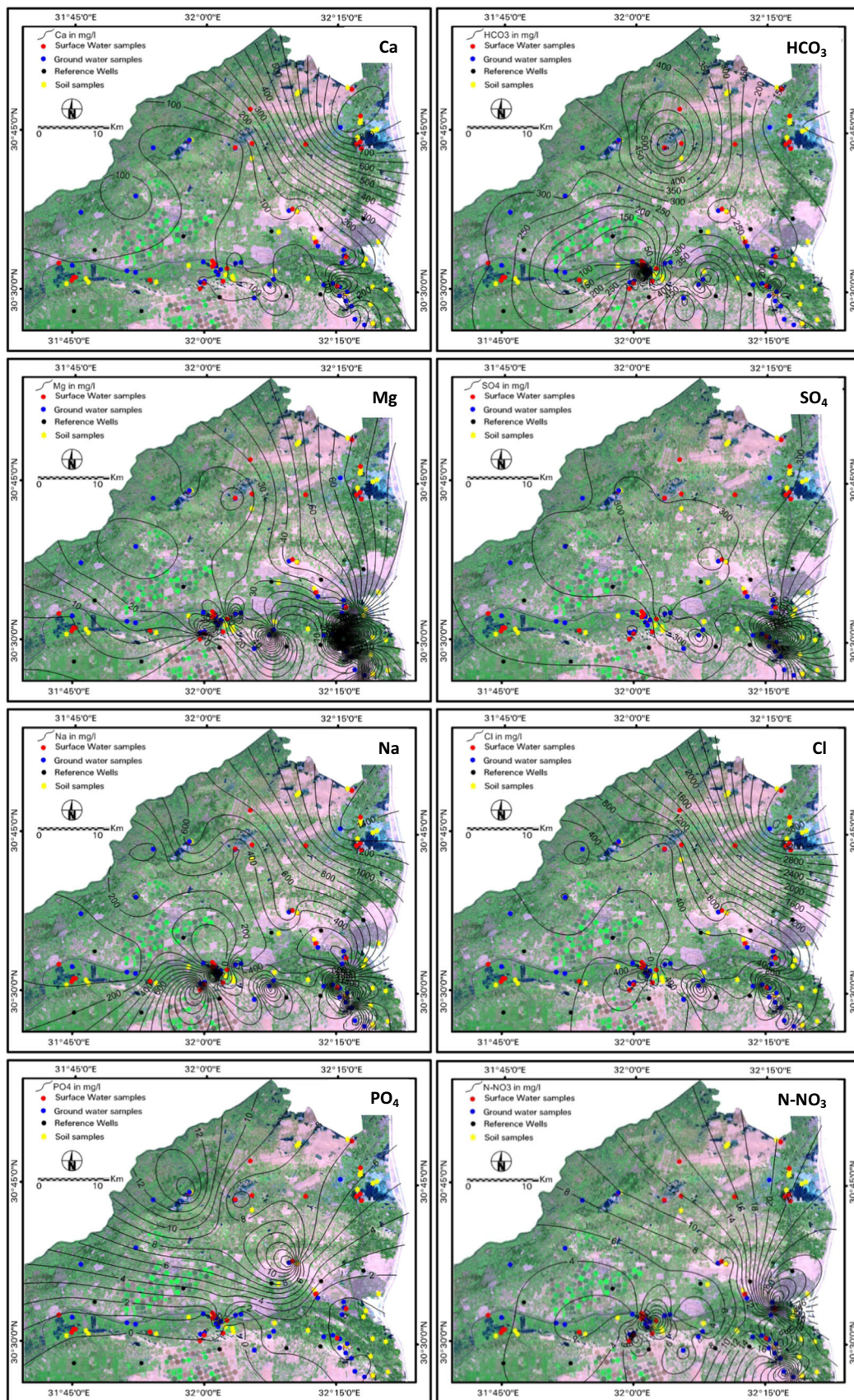


Fig. 11 Major ion distributions in groundwater of END region

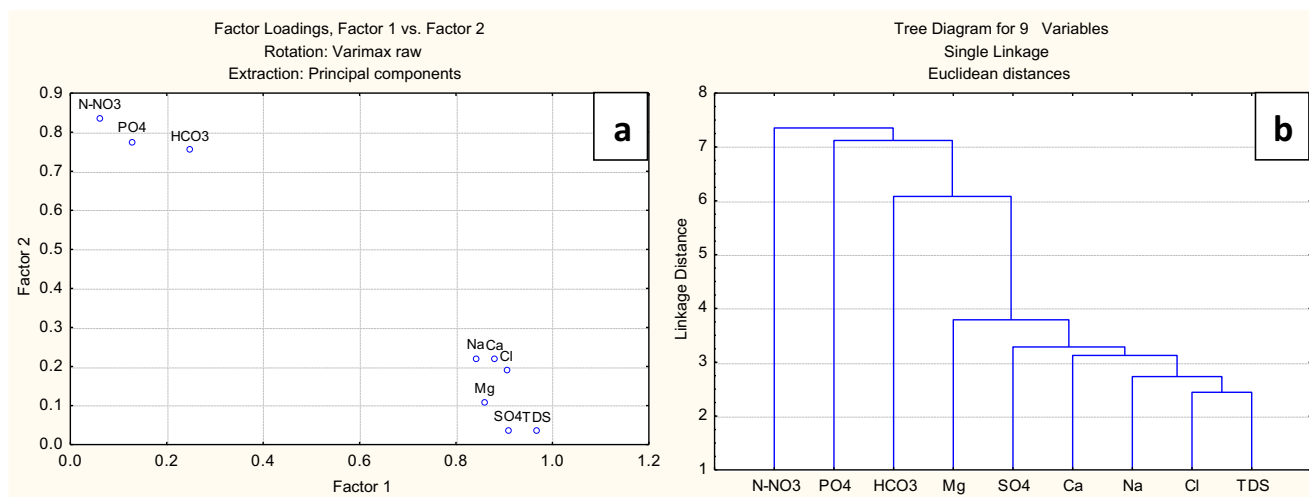


Fig. 12 Factors plot a and Cluster dendrogram b of ion distributions in groundwater of END region

Hydrochemical facies

Cl-Na chemical type is the most dominant for groundwater of END region (Fig. 13). Cl is mainly derived from the marine evaporates by leaching process or it could be resulted by evaporation process. The ion relativity in groundwater of the study area is mainly arranged as $Cl > SO_4 > HCO_3$ & $Na > Ca > Mg$. The richness of groundwater by $Ca > Mg$ may attributed to the cation exchange process acting on clay surfaces, where adsorbed Na is exchanged with dissolved Ca in water. This process is followed by flushing of the adsorbed Ca by recharged water resulting in dominating Ca over Mg.

Soil salinity

Where groundwater quality is poor, soil salinity changes are soon observed. As such, waterlogging and soil salinity have emerged as major problems in irrigated areas

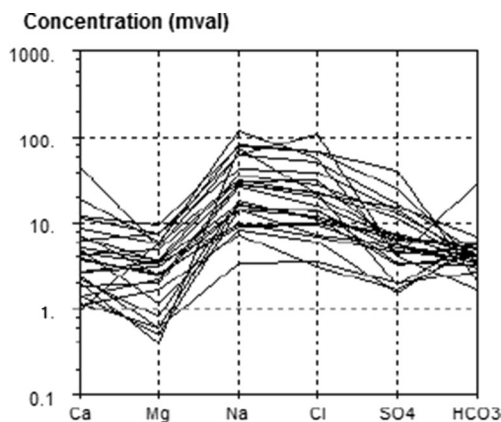


Fig. 13 Scheoller diagram showing the Cl-Na chemical type of groundwater in END region

which affects the agricultural productivity and sometimes becomes too severe such that it becomes imperative to take the land out of crop production (Choubey et al. 2009).

The salinization of land resources in the study area has been the consequence of both naturally occurring phenomena that is due to primary salinity and / or sodicity, and human activities that are causing secondary salinity and / or sodicity. The results obtained indicate that the END area is affected by water logging and soil salinization (Fig. 14). These environmental problems are widely evident throughout the END area especially over the last three decades, whereas many agricultural and land reclamation projects have been carried out such as in El-Huseinia, Salhyia and El-Mullak, El-Manaif areas, and implementing different industrial activities and construction new cities as well.

Physico-chemical properties and soil salinity mapping

The physico-chemical results of soil analyses indicate that these problematic soils required special attention to maintain a satisfactory soil-water-plant relationship by providing an adequate drainage system which may ultimately enhance the sustainable development of the agricultural activities. Some of physico-chemical properties (pH, EC, TDS and SAR) of soil samples from the END area indicate alkaline nature of soil that having range from 7.74 to 9.45. TDS values of the soil extract were found to vary from 575 to 59200 mg/l, showing higher concentration of salts in the root zone due to low food, fodder and fiber production. SAR varied from 0.61 to 2231. The mean values of pH (8.52) and EC (23.21 dSm^{-1}) show that the END soils fall under the saline-alkali group, and that soil particles remain flocculated.

The salinity indices were applied and the images obtained were compared with the ground verification data. The salinity

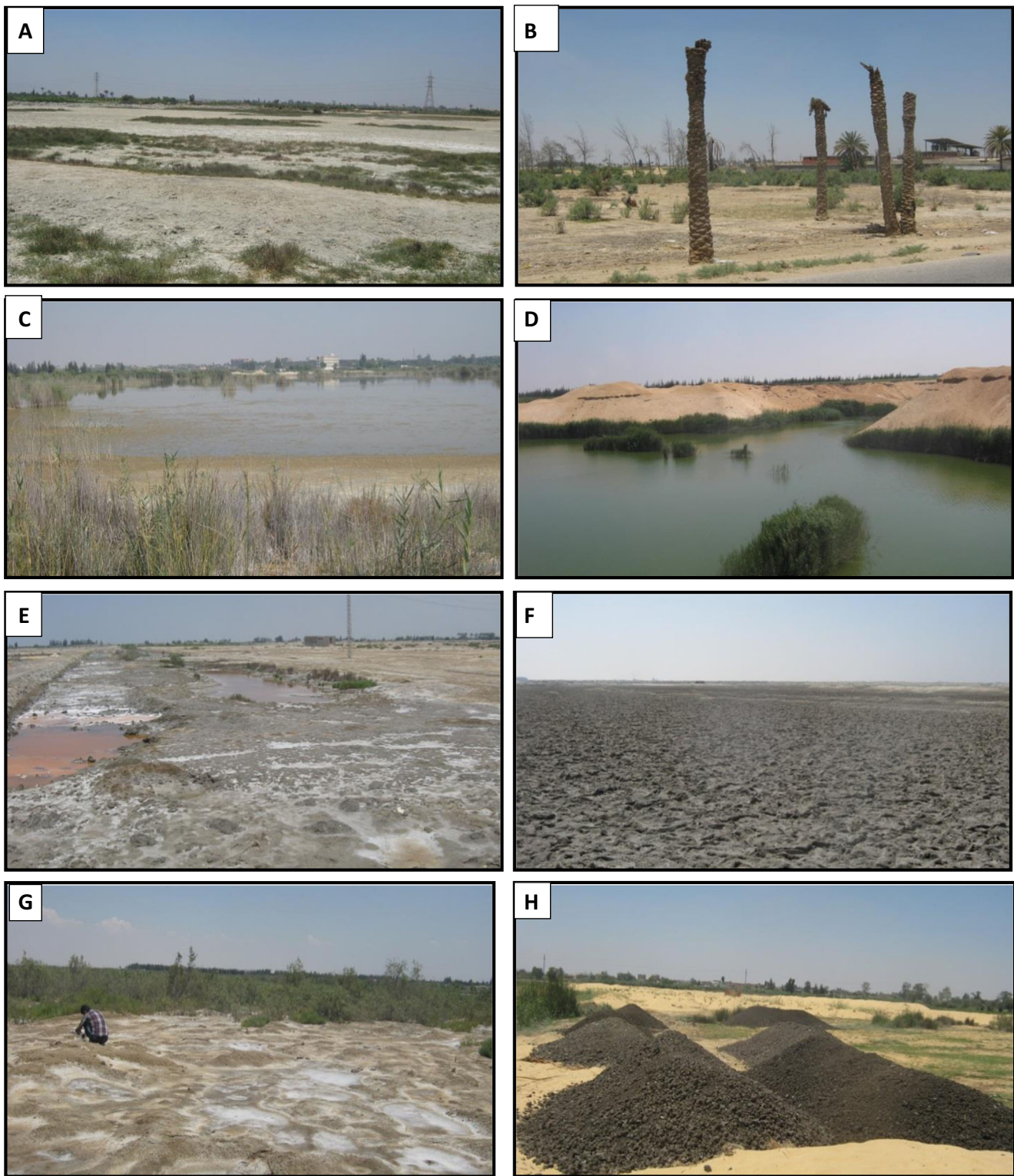


Fig. 14 Reflecting the indicators of land degradation due to the waterlogging, salinization and human activities (*a & b*) Soil salinization and land degradation by water logged and showing tree decline, sheet erosion and salt encrustation areas, (*c & d*) Drowning of some buildings

in the water logged and the waterlogged area in the low land form areas (*e, f, & g*) showing natural reed vegetation, vegetation zoning, vegetation death and small bare (*h*) showing the human activates to overcome the land degradation

index exhibits the highest correlation between observed and predicated EC data. To validate the predicted data, the

correlation between the measured salinity indicator data and the predicated values was applied. The results of the salinity

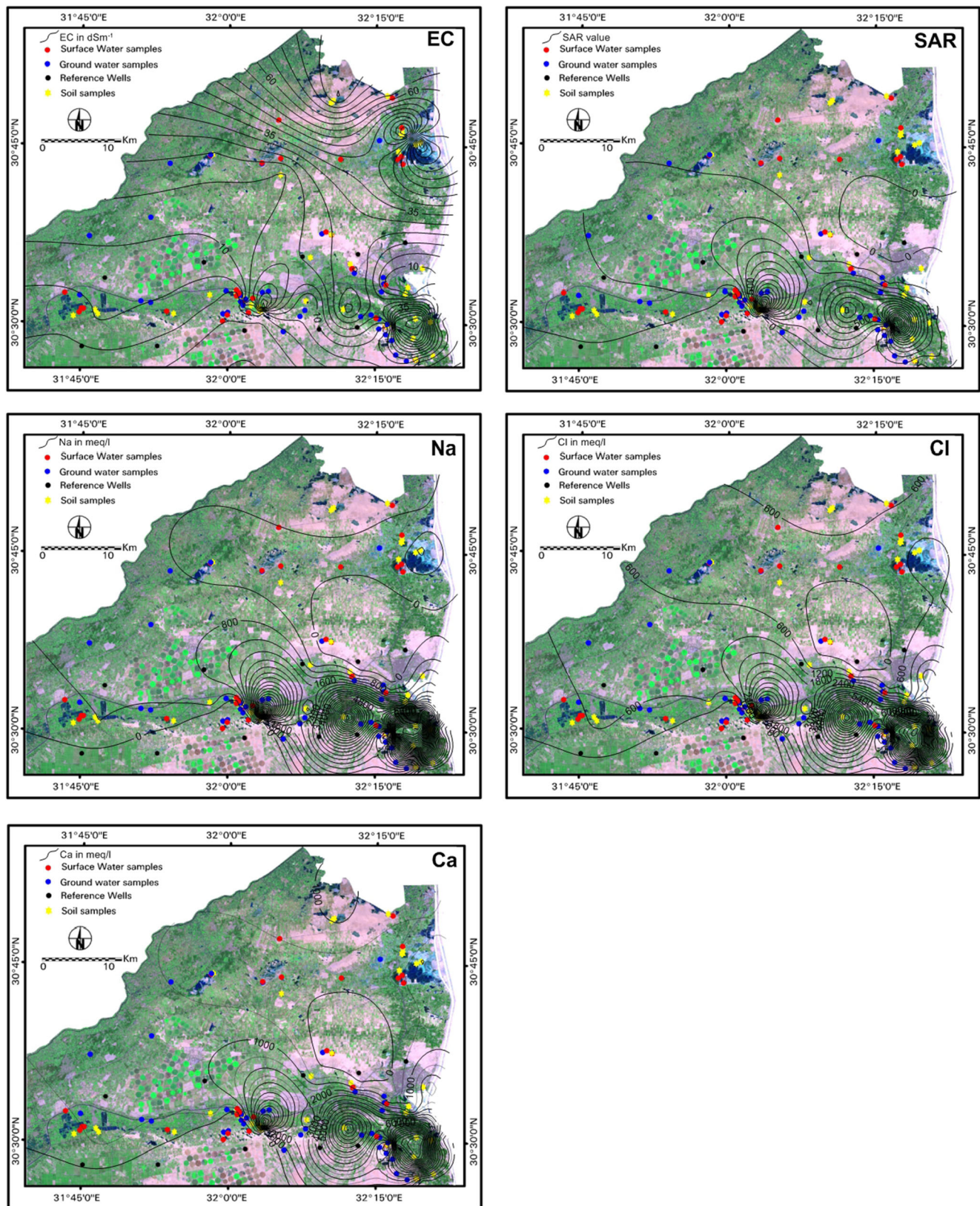


Fig. 15 Spatial distribution of main indicators to salinity and sodicity problems in the study area

are highly correlated with band4, band3, band2 of the OLI satellite image with EC, SAR, Na, Cl, SO₄ and Ca. The spatial

distribution of the important indicators for the soil salinity in the study area (Fig. 15) show that; there is a good correlation

Table 3 Soil salinity classes and their areas (GARPAD, 1984)

Ec		Area	
Class type	Ec (mS/cm)	Km ²	%
Slightly affected	4–8	658.461	27.20
Moderately affected	8–16	513.653	21.20
Strongly affected	16–32	622.914	25.70
Very strongly affected	32–64	476.452	19.70
Abnormally affected	>64	149.575	6.20
Total			100

between EC, Cl, and Na concentrations and also the soil salinity map could be used as a good indicator of Cl and Na contents. Moreover, this map shows that there is accumulation of gypsum in some irrigated and non-irrigated areas particularly around west Ismailia city, such as El-Salhyia and El-Balah areas respectively.

As salts build up in the soil, or the period of waterlogging increases, the composition of plant changes and vigor is reduced and surface conditions deteriorate (Fig. 14). These changes can be classified according to severity. Therefore, soil salinization classes take account of the landscape features and are ranked in terms of soil salinity (EC). According to GARPAD 1984 the EC ranges, the soil salinity of END area are classified (Table 3). The resulting map was categorized into five distinct classes of saline soils; slightly affected,

moderately affected, and strongly affected, very strongly affected and Abnormally affected (Fig. 16). As shown by the acreage of the soil salinity, about 90 % of the total area shows a strong salt accumulation; therefore, leaching is very important for improving the soil drain ability and land reclamation plan of the area under investigation.

Moreover, soil alkalinity causes severe soil permeability problems as well as toxicity from Na. Highly exchangeable Na induces the dispersion of clay fractions, and so the soil structure is degraded and the soil permeability is reduced considerably. Based on the analysis with ESRI ArcGIS, the EC and SAR values that are collected from ground truth data, the salt affected soils were classified into four classes (Table 4) according to USDA 1954 and Ghassemi et al. 1995. Both of EC and SAR coverages were combined together in a mathematical manipulation using GIS to assess various levels of salinity and sodicity in END area. The probability density and the occurrence pattern of salt-affected soils of the study area are represented in Fig. 17. In order to undertake optimal use of these lands and to prevent further degradation, and also mitigation measurements need to be made such as drains which should be desilted frequently and kept free from aquatic vegetation, and the use of the ideal quantity of irrigation water should also be performed. Moreover, there must be conjunctive use of groundwater and canal water in areas where the quality of water is poor. Lining of canals and drains should be assumed to reduce seepage losses. Finally, salt resistance crop

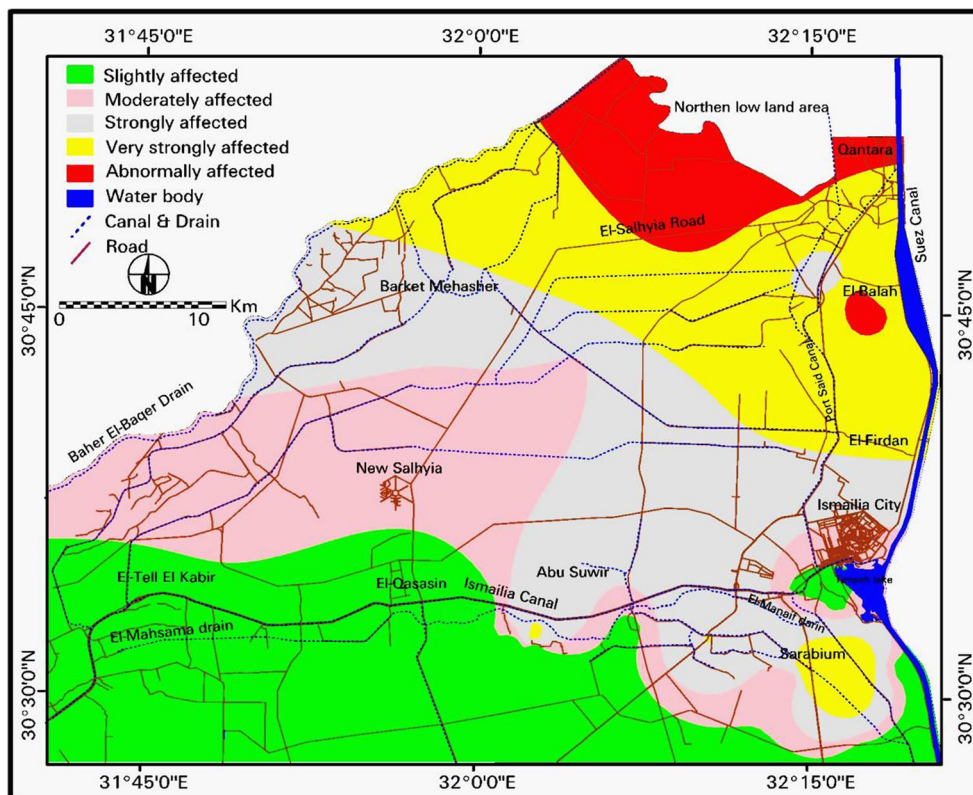
Fig. 16 Classified soil salinity spatial distribution map of the investigated area

Table 4 Classification of soil salinity and salt-affected soil

Soil salinity (Ghassemi, 1995)			Salt-affected soils (USDA 1954)		
Class type	Ec (dS/m)	Description	Class	Ec (dS/m)	SAR (meq/l)
Salt free	Ec<4	No visible salts on the soil surface	Salt free	<4	<13
Slightly saline	4<Ec<8	Visible salts on the soil surface	Saline-nonsodic	>4	<13
Moderately saline	8<Ec<15	Salts are fairly visible on the soil surface	Saline-sodic	>4	>13
Strongly saline	Ec>15	Soil surface is fluffy; salts are fairly and soil supports indigenous vegetation	Nonsaline-sodic	<4	>13

and / or horticultural plantation types should be raised in the study area.

Conclusions

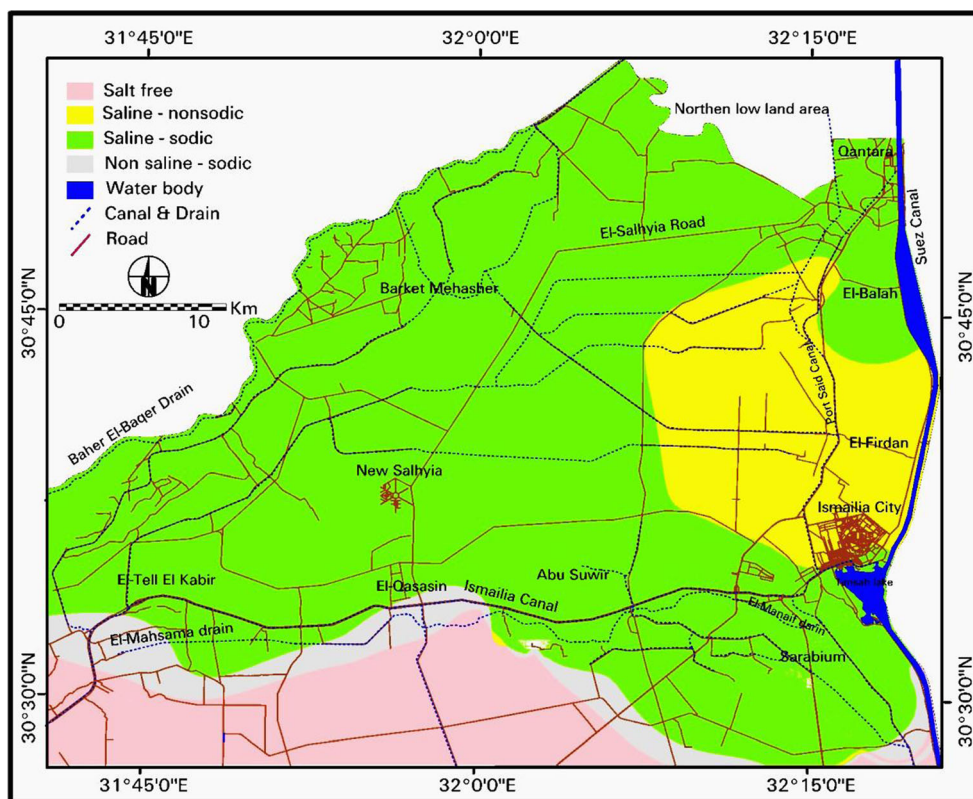
The problem of salinity and alkalinity increases every year as the result of secondary salinization especially in areas that have poor quality groundwater, irrigated lands and face more anthropological activities. In the present study, RS Landsat 8 and field data collection and analysis were acquired at the same time in May 2014 to assess the present status of the hydrosalinity, land degradation and land-use-land-cover activities.

According to field verification of the interpreted enhanced RS data; hydrogeological conditions, hydrogeochemical and soil data analyses and interpretation in the present study, it is concluded that the environmental land degradation in the

END lands is predicted to become more serious and there will be extensive environmental hazard problems in the next few years where the soil salinization and waterlogging are predominant forms of land degradation going hand-in-hand especially in irrigated agricultural and the low lying lands.

The current study has suggested some new but simple and practical approaches for assessing salinity and waterlogging through the digital image processing of RS data, GIS, geo-statistical and hydrogeochemistry analyses tools. The false colour composite, principal components analysis and image classification, in addition to salinity indices techniques, are useful and successfully reveal most of the waterlogging and salinity hazard problems sites through mapping. The hydrosalinity mapping and the statistical data analysis of TDS, major ions, groundwater grouping and hydrochemical facies and also water table maps of the study area have revealed that the seepage from irrigation practices and from the Ismailia Canal and its

Fig. 17 Classified salt-affected spatial distribution map of the investigated area



branches are the main causes of waterlogging. The groundwater level and its flow pattern along the END have been dramatically changed during the period 1994–2014. Generally, the water table of END region has been raised up to a half meter within 10 years timespan. The main sources of groundwater recharge and waterlogging bodies are mostly attributed to the continuous seepage from the newly cultivated lands at El-Sallyia plain to the north of Wadi El-Tumilat and El-Shabab & El-Mullak projects to the south. Groundwater salinity in the END is mainly controlled by the length of flow path, depth of water and water-rock interaction. Groundwater near the recharge areas at the beginning of flow path has lower salinity than that at the end of flow path. Some anomalous salinity values were recently recorded at the southern lowlands of W. El-Tumilat due to a change in flow direction as a result of new sources of recharge. Moreover, the spatial distribution of major ion contents could be attributed to leaching of the aquifer materials along the flow path (Na, Ca, and Cl), the study area affect by agricultural pollution (Mg and SO₄) and the leaching process which acting on the easily soluble evaporate-rich fluvio-marine sediments of shallow aquifer (NO₃ and PO₄).

The spatial distribution maps of the physic-chemical properties of soil such as EC, pH, SAR, Na, Cl, SO₄ and Ca were compared with remote sensing salinity indices and then integrated to classify and map the salinity and salt-affected soil by using GIS tools. This indicates that increases in soil salinity levels pose a threat to sustainable agricultural developments and it will take many years to reclaim. Special attention is required to maintain appropriate soil–water plant relationship by providing an adequate drainage system. There is a good correlation between EC, Cl, and Na concentrations and also the soil salinity map can be used as a good indicator of Cl and Na contents. Moreover, this map showed that there is an accumulation of gypsum in some irrigated and non-irrigated areas particularly around west Ismailia city. The resulting salinity soil map is classified into five distinct classes of saline soils; slightly affected, moderately affected, strongly affected, very strongly affected and abnormally affected saline soils.

The current study shows that extensive seepage from canals and reckless wastage of water in drains, add to groundwater. Improper alignment of canals has obstructed the natural drainage in many cases. Both of these processes have led to the development of waterlogged conditions and subsequently salinization and / or alkalization and due to many problems to the agriculture sustainable developments of the END region. It is concluded that the identification of land degradation mitigation measures requires thorough knowledge of the ground and surface water, human activities and salinity dynamics of the study area. In order to do optimal use of these land and to prevent further degradation, and also mitigation measurement need to be engaged such as drains should be desilted frequently and kept free from aquatic vegetation, use of the ideal quantity of irrigation water should be performed. Moreover, there

must be conjunctive use of groundwater and canal water in areas where the quality of water is poor. Lining of canals and drains should be assumed to reduce seepage losses. Finally, salt resistant crops and / or horticultural plantation types should be raised in the study area.

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References

- Abbas A, Khan S (2007) Using remote sensing technology for appraisal of irrigated soil salinity. In: Oxley L., Kulasiri D (eds) MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, pp. 2632–2638
- Abu-Ata AA (1997) The conversion of basin irrigation to perennial systems in Egypt. In: Worthington EB (ed) Arid land irrigation in developing countries: environmental problems and effects. Pergamon Press, Oxford, pp 99–105
- APHA (1989) Standard methods for the examination of water and wastewater, 17th edn. American Public Health Association, Washington DC, 1268 p
- Amous MO, Aboulela HA, Green DR (2011) Geo-environmental hazards assessment of the north western Gulf of Suez. *Egypt J Coast Conserv* 15(1):37–50. doi:10.1007/s11852-010-0118-z
- Amous MO, El-Rayes AE (2013) An integrated GIS and hydrochemical approach to assess groundwater contamination in West Ismailia area, Egypt. *Arab J Geosci* 6(8):2829–2842. doi:10.1007/s12517-012-0555-0
- Amous MO, Green DR (2015) Monitoring and assessing waterlogged and salt-affected areas in the Eastern Nile Delta region, Egypt, using remotely sensed multi-temporal data and GIS. *J Coast Conserv.* 19(3):369–391. doi:10.1007/s11852-015-0397-5
- Amous MO, Green DR (2011) GIS and remote sensing as tools for conducting geo-hazards risk assessment along Gulf of Aqaba coastal zone, Egypt. *J Coast Conserv* 15(4):457–475. doi:10.1007/s11852-010-0136-x
- Amous MO, Sultan YM (2014) Geospatial technology and structural analysis for geological mapping and tectonic evolution of Feiran–Solaf metamorphic complex, South Sinai, Egypt. *Arab J Geosci* 7: 3023–3049. doi:10.1007/s12517-013-0959-5
- Ayars JE, Tanji KK (1999) Effects of drainage on water quality in arid and semiarid lands. In: Skaggs RW, van Schilfgaarde J (eds) *Agricultural Drainage*. ASA-CSSA-SSSA, Madison, WI, USA, pp 831–867
- Ayoub AT (1991) An assessment of human induced soil degradation in Africa. U. N. environmental program, Nairobi, Kenya, 2nd Conf. of the African Soil Sci. Soc., 4 – 10 Nov., Cairo, Egypt
- Bartos TT, Ogle KM (2002) *Water Quality and Environmental Isotopic Analyses of Ground-Water Samples Collected from the Wasatch and Fort Union Formations in Areas of Coalbed Methane Development-Implications to Recharge and Ground-Water Flow, Eastern Powder River Basin*. Department of the Interior, U.S. Geological Survey, Water-Resources Investigations, Wyoming, p 96, Report 02–4045
- Bastawesy M, Ali RR, Al Harbi K, Faid A (2013) Impact of geomorphology and soil management on the development of waterlogging in closed drainage basins of Egypt and Saudi Arabia. *Environ Earth Sci* 68:1271–1283
- Biswas A (1993) Management of international waters: problems and perspective. *Water Resour Dev* 9(2):167–188

- Bouwer H, Dedric AR, Jaynes DB (1990) Irrigation management for ground water quality protection. *Irrigation Drainage Syst* 4:375–383
- Bouwer H (2000) Integrated water mangment: emerging issues and challenges. *Agric Water Manag* 45:217–228
- Bugan RD (2014) Modeling and regulating hydrosalinity dynamics in the sandspruit river catchment (Western Cape). Unpublished Ph.D. thesis, Faculty of Agrisciences at Stellenbosch University, 216 p
- Chebotarev II (1955) Metamorphism of natural waters in the crust of weathering. *Geochim Cosmochim Acta* 8:22–48, 137–170, 198–212
- Chitale MA (1991) Environmental management in water resources project – Indain experiences of irrigation power project. *J Indian Water Resour Soc* 1(2):56–59
- Choubey VK, Singh O, Srivastava SL (2009) Study of hydrological soil properties of salt affected areas around Gohana, Sonipat district, Haryana. *e-J Earth Sci India* 2(III):211–223
- Davis JC (1986) *Statistics and Data Analysis in Geology* (2nd ed). John Wiley & Sons, New York, 646p
- Dawoud AM (2004) Design of national groundwater quality monitoring network in Egypt. *J Environ Monit Assess* 96:99–118
- De Fraiture C, Wichelns D (2010) Satisfying future water demands for agriculture. *Agric Water Manag* 97:502–511
- Dehin A, Lounis M (2012) Remote sensing techniques for salt affected soil mapping: application to the Oran region of Algeria. *Procedia Eng* 33:188–189
- Dinh NQ (2001) Cave database development, Spatial analysis and 3D visualization with GIS, Case study in Son La (Vietnam). Master dissertation, Free University Brussels, 114 p
- Eger H, Fleischhauer E, Hebel A, Sombroek WG (1996) Taking action for sustainable land-use - results from 4th ISCO conference in Bonn, Germany. *Ambio* 25:480–483
- EGSA (1997) Egyptian general survey and mining: topographical map cover Nile delta. Scale 1:2 000 000
- Egyptian Meteorological Authority (2006) *Climatic Atlas of Egypt*. Published., Arab Republic of Egypt, Ministry of Transportation and communications
- El Shamy IZ, Geriess MH (1992) Hydrogeochemical studies of West Ismailia area. *Egypt Egypt J Geol* 36(1–2):17–31
- El-Gabaly MM (1972) Reclamation and management of salt affected soils. *Int. Symp. On development in the field of salt affected soils*, Cairo, Egypt, pp 401–434
- El-Rayess AE, Geriess MH (2003) Reasons of groundwater logging around Sarabiuem Waste water treatment Plant, Ismailia, Egypt. *Proc. 3rd Inter. Conf. groundwater level control inside urbanized areas*. Mansoura University, Egypt, pp 123–136
- El-Rayess AE, Arnous MO, Aboulela HA (2014) Hydrogeochemical and seismological exploration for geothermal resources in South Sinai, Egypt utilizing GIS and remote sensing. *Arab J Geosci*. doi:10.1007/s12517-014-1667-5
- EGPC /CONOCO (1987) Geological map of Egypt, scale 1:500,000, NH 36 NW-Cairo, Egypt. The Egyptian General Petroleum Corporation, Cairo
- FAO (1995) *Irrigation in Africa in figures*. FAO Water Reports / Rapports sur l'eau ISBN 1020–1203
- FAO/UNEP (1978) *Methodology for assessing soil degradation*. Rome, Italy, pp. 25–27
- FOA (1990) An international action program on water and sustainable agriculture development, a strategy for the implementation of the Mar del Plata action plan of the 1990s. Rome, Italy
- Gad A, Abdel Samei AG (1998) Study on desertification of irrigated arable lands in Egypt, – Salinization – accepted in *Egyptian Journal of soil science.*, ref 9/98, V. 2000
- GARPAD, (General Authority for Rehabilitation Projects and Agricultural Development) (1984) Feasibility study of the North Hussinia valley & South Port Said agricultural development project. Unpublished internal report by JICA submitted to General Authority for Rehabilitation Projects and Agricultural Development. Ministry of Agricultural and Land Reclamation, Cairo, Egypt
- Geriess MH (1994) Hydrogeological and hydrogeochemical evaluation of groundwater resources in Suez canal region. Unpublished Ph.D. thesis, Fac. Sci., Suez Canal Univ., Ismailia, Egypt
- Geriess MH (2004) Land degradation and soil salinization due to water logging in the newly reclaimed areas, East of Bitter Lakes, Sini Peninsula, Egypt. 7th Conference on Geology of Sinai Development, Ismailia, pp 23–40
- Geriess MH, Balke KD, El-Rayess AE (2008) Problems of drinking water treatment along Ismailia canal province, Egypt. *Int Biomed Biotechnol Sci* 9(3):232–242, Zhejiang Univ., press, China
- Ghassemi F, Jakeman A, Nix H (1995) *Salinisation of Land and Water Resources: Humans Causes, Extent, Management and Case Studies*. University of New South Wales Press Ltd., Sydney, Australia, 562 pp
- Ghodeif KO, Arnous MO, Geriess MH (2013) Define a protected buffer zone for ismailia canal, Egypt using geographic information systems. *Arab J Geosci* 6(1):43–53. doi:10.1007/s12517-011-0326-3
- Harbuaugh JW, Marreium DF (1968) *Computer application in stratigraphic analysis*. John Wiley & Sons, New York, 282 p
- Heuperman AF, Kapoor AS, Denecke HW (2002) *Biodrainage – principals, experiences and applications*. Knowledge Synthesis Report No. 6. International Programme for technology and research in irrigation and drainage. IPTRID Secretariat, food and agriculture organization of the United Nations, Rome, p 79
- Juman RA, Ramsewak D (2013) Land cover changes in the Caroni Swamp Ramsar Site, Trinidad (1942 and 2007): implications for management. *J Coast Conserv* 17:133–141. doi:10.1007/s11852-012-0225-0
- Kaiser MF, El-Rayess A, Ghodeif K, Geriess B (2013) GIS data integration to manage waterlogging problem on the eastern Nile delta of Egypt. *Int J Geosci* 4:680–687
- Kaul HA, Ingle ST (2011) Severity classification of waterlogged areas in irrigation projects of Jalgaon district, Maharashtra. *J Appl Technol Environ Sanit* 1(3):221–232
- Kerambrun P (1986) Coastal lagoons along the southern Mediterranean coast (Algeria, Egypt, Libya, Morocco, Tunisia) description and bibliography. UNESCO reports in Marine Science. UNESCO Paris 34:184
- Khan NM, Rastoskuev VV, Sato Y, Shiozawa S (2005) Assessment of hydrosaline land degradation by using a simple approach of remote sensing indicators. *Agric Water Manag* 77:96–109
- Khedr AA (1998) Vegetation zonation and management in the damietta estuary of the river Nile. *J Coast Conserv* 4:79–89
- Kleyer M, Feddersen H, Bockholt R (2003) Secondary succession on a high salt marsh at different grazing intensities. *J Coast Conserv* 9: 123–134
- Lai R, Stewart BA (1990) *Advances in soil science, soil degradation*. Springer Verlag, New York, 349 p
- Mabrouk MB, Jonoski A, Solomatine D, Uhlenbrook S (2013) A review of seawater intrusion in the Nile Delta groundwater system – the basis for assessing impacts due to climate changes and water resources development. *Hydrol Earth Syst Sci Discuss* 10:10873–10911
- Mansour BM (2012) Management of groundwater logging problems along Wadi El-Tumilat, Eastern Nile Delta using mathematical modeling and GIS techniques. M.Sc. thesis, Fac. Science, Suez Canal Univ., Ismailia, Egypt. 220p
- Mensah KO, FitzGibbon J (2013) Responsiveness of Ada sea defence project to salt water intrusion associated with sea level rise. *J Coast Conserv* 17:75–84. doi:10.1007/s11852-012-0219-y
- Metternicht G, Zinck JA (1997) Spatial discrimination of salt- and sodium-affected soil surfaces. *Int J Remote Sens* 18(12):2571–2586

- Mohamed ES, Morgun EG, Goma Bothina SM (2011) Assessment of soil salinity in the Eastern Nile Delta (EGYPT) using geoinformation techniques. *Moscow Univ Soil Sci Bull* 66(1):11–14
- Nagarajan R, Marathe T, Collins WG (1993) Identification of flood prone regions of Tapti river using temporal remotely sensed data. *Int J Remote Sens* 14:1297–1303
- Nosair AM (2011) Climatic changes and their impacts on groundwater occurrence in the northern part of east Nile Delta, Egypt. Unpublished M.Sc. Thesis, Zagazig Uni., Egypt
- Pavasovic K (1993) Land suitability models. Workshop on Geographic Information Systems in Integrated Coastal Management, Alexandria
- Qadir M, Qureshi AS, Cheraghi AM (2008) Extent and characterization of salt-affected soils in Iran and strategies for their amelioration and management. *Land Degrad Dev* 19:214–277
- Rao BRM, Dwivedi RS, Sermvas K, Khan QI, Ramana KV, Thammappa SS, Fyze MA (1998) An inventory of salt-affected soils and waterlogged areas in the Nagarjunsagar canal command area of southern India, using space – borne multispectral data. *Land Degrad Dev* 9: 357–367
- Saxena MM (1990) Environmental analysis: Water, Soil and Air, 2nd edn. Argo Botanical Publishers, Bikaner, India, 186 p
- Schoeller H (1935) Utilite de la notion des exchanges de bases pour le comparaison des eaux souterraines. *Fr Soc Geol Co R Sommaire et Bull Ser S* 5:651–657
- Shalaby A, Ali RR, Gad A (2012) Landdegradation monitoring in the Nile Delta of Egypt, using Remote Sensing and GIS. *Int J Basic Appl Sci* 1(4):283–294
- Sharma PK, Chopra R, Verma VK, Thomas A (1996) Flood mangment using remote sensing technology: The Punjab (India) experience. *Int J Remote Sens* 17:3511–3521
- Sherif MM, Al-Rashed MF (2001) Vertical and horizontal simulation of seawater intrusions in the Nile delta aquifer, first international conference on saltwater intrusion and coastal aquifers monitoring, modeling and management. Essaouira, Morocco, April 23.25, 2001, pp. 1–12
- Singh A (2010) Decision support for on farm water management and long-term agricultural sustainability in a semi-arid region of India. *J Hydrol* 391:63–76
- Singh A, Panda SN (2012) Effect of saline irrigation water on mustard (*Brassica Juncea*) crop yield and soil salinity in a semi-arid area of North India. *Exp Agric* 48:99–110
- Singh A, Panda SN, Flugel W, Krause P (2012) Waterlogging and farmland salinization: causes and remedial measures in an irrigated semi-arid region of India. *Irrig Drain*. doi:10.1002/ird.651
- Stanley DJ, Warne AG (1993) Nile delta: recent geological evolution and human impact. *260(5108)*: 628–634
- United Nations (2008) World population prospects: 2008. Revision population database online (<http://www.un.org/esa/population/unpop.htm>)
- USDA (2004) Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42, Version 4. USDA-NRCS, Lincoln, p 700
- USDA (1954) Diagnosis and improvement of saline and alkali soils. U.S., GPO, Washington, D. C, Handbook No. 60
- Wahab MA, Rasheed MA, Youssef RA (2010) Degradation hazard assessment of some soils north Nile Delta, Egypt. *J Am Sci* 6(6):156–161
- Waren A, Agnew C (1988) An assessment of desertification and land degradation in arid and semi-arid areas. International Institute for Environment and Development, London, p 50, IIED Paper No. 2
- Wim G, El-Hadji M (2002) Causes, general extent and physical consequence of land degradation in arid, semi-arid and dry sub-humid areas. Forest Conservation and Natural Resources, Forest Dept., FAO, Rome