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# Agro-ecological analysis through the application of geomatics techniques. The case of wheat (*Triticum aestivum* L.) production in El Fayoum Region, Egypt.

**Doctoral Thesis**

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# Abstract

Egypt is one of the biggest importer for wheat, worldwide. Thus, many national plans have been conducted aiming at increasing wheat production and reducing the gap between production and consumption. Agro-ecological research at multiple scale and field experiments are therefore needed to study and assess the land suitability for wheat cultivation and the effect of various production constraints on wheat production.

El Fayoum Governorate, as one of the main wheat production regions in Egypt, was selected as a case study in the current research. With the overall aim of monitoring and improving the understanding of past and actual constrains of wheat production in the area, a multiple scale approach (field, local, regional scale) was designed, integrating field agronomic surveys, geostatistics, and remote sensing.

At field level, an experiment was carried out to assess the effect of soil salinity on wheat production, as soil salinity is the major problem threatening the agricultural production in the area. The experimental work was carried out to cover several locations with different salinity levels and where different wheat varieties were planted. Moreover, soil salinity monitoring during the last five years was performed. More specifically, the field experiment was performed in 3 different geographical locations with different electric conductivity levels. The first two locations successfully produced wheat, while the third location did not. The main logical justification related to the third location is the very high existing level of electric conductivity (16.5 dS $m^{-1}$). The achieved results confirmed that salinity has a strong effect on wheat production, as the location characterized by 4.6 dS $m^{-1}$ gave a mean production of 8.1 t/ha, while the location with 8.64 dS $m^{-1}$ gave a mean harvest of 4.9 t/ha. In addition, the 1000-grain weight was 58.4 g in the location with 4.6 dS $m^{-1}$, and 53.2 g for the location with 8.64 dS $m^{-1}$.

At local scale, soil salinity monitoring was applied at Sinnuris District comparing the soil samples collected in the framework of this study in 2014 with available soil salinity data collected in 2009. Geo-statistical Kriging technique was utilized in order to produce the soil salinity map for Sinnuris District for the periods 2009 and 2014. Then, a detailed comparison between recent and older map was performed. The results show a significant improvement in soil salinity, with an increase of the area of low electric conductivity (i.e. $< 2$ dS $m^{-1}$) from 1.28 ha in 2009, to 9119.16 ha in 2014. This impressive result could be related to the construction of a new sub-surface drainage system in the area, which started in 2007, and demonstrate the effectiveness of water management policies in Sinnuris District.

Land use/ land cover change analysis was performed to provide a general overview of the landscape dynamics in the El Fayoum region over the last thirty years, with a specific focus on urban expansion, land reclamation, and agricultural transition processes. To meet this task, a set of Landsat TM/OLI multispectral images acquired in 1984, 1998, and 2013 were classified using supervised techniques and maps of the main land covers (i.e. agricultural area, orchards, bare soil, desert, water bodies, urban areas) were generated. The classification accuracy has been evaluated by means of ground truth GPS data collected in the field. Finally, post-classification change detection analysis has been applied to identify the main changes occurred in the study area during the considered time frame. Classification accuracy for all the images was satisfactory (overall accuracy > 90%, K > 0.9). Regarding land cover changes, the results indicate that during the 1984-1998 period the rapid population growth has led to a strong expansion of urban areas (+21%) and a concurrent expansion of agricultural lands (+36%) at the expenses of orchards, but also of deserts and bare lands, thanks to relevant land reclamation projects. Between 1998 and 2013, the trend of urban expansion continued steeply (+50%), but a dramatic decline in agricultural (-16%) and orchard (-41%) areas occurred, accompanied also by an increase in bare soils (+57%). This trends suggest possible overexploitation and depletion of the soil resources in the area, with consequent decrease of land productivity and soil degradation processes leading to serious loss of agricultural production potential. Land reclamation projects seem not always effective in a long term perspective, as many reclaimed lands were re-converted into bare soils after few years. Given the strong soil salinization problems reported in the study area, more efficient irrigation and water management strategies are deemed fundamental to reverse this trend.

The results of this study demonstrate how an integrated analysis of traditional agronomic field experimental data and modern technologies such as remote sensing and geographic information systems can be a powerful tool for multiple-scale analysis of complex agricultural landscapes such as the El Fayoum region. Current general trends of urban expansion and loss in land production in the area calls for immediate intervention by policy makers, preferentially to improve water and irrigation management rather than reclaiming new land. An efficient implementation of water drainage system project in the Sinnuris District lead to a strong improvement of soil quality reducing salinity in a short time. Given the strong effect on wheat production of soil salinity, further agronomic experimentation for identifying salt-tolerant wheat varieties could also greatly contribute to wheat production increase in the region.

# General introduction

Food security is a non-dispensable policy objective not just for Egypt but also for many countries. However, food self-sufficiency may not be a policy objective of many countries such as industrial countries that can always achieve food's security through imports. Food self-sufficiency is declared in several Egyptian policy documents as "an important policy objective." It is declared that it should be reached throughout vertical expansion i.e., higher yield per hectare in the current lands and horizontal expansion i.e., new lands. Nevertheless, up till now it is not defined to which degree should Egypt be self-sufficient (a degree of 100% is not achievable). Thus the food self-sufficiency degree can be one of the socio-political attributes for evaluating of water demand management strategies. An approximate of 4% only of Egypt's total area can be considered as an agricultural land. This area has one of the highest inhabitation densities all over the world. The remaining 96% of the land is arid desert. Stating so, the need for desert reclamation arise inevitable considering the continuous population increasing and the increased congestion in the long-settled lands in the Nile valley and the delta as well. The calculation of the trend and rate of land cover conversion is considered as a prerequisite for the development of a rational policy for the land use. The current degree of food self-sufficiency for certain subsistence crops (cereals) is around 50%. The gap between production-demand (50%) is covered via imports. The Egyptian government initiated plans to the adjusting of such situation via re-distributing the population via applying an efficient horizontal urban expansion along the desert areas, yet, near the fringes of the Nile delta. Such policy tries to minimize the pressure on the old and highly productive agricultural areas, reduce inhabitation density in the inhabited areas and reduce pollution resources via establishing industrial areas outside the Nile valley and its delta. Thus, calculation of the trend and the rate of land cover transitions are vital for the development planner in order to establish rational policy for land use.

Large portion of the reclaimed land for the Mubarak project is happened to be located on the western side of the Nile delta. It receives water throughout irrigation canals from the Nile. The count of inhabitants who are benefiting from this project is an approximate of 150,000 family members included. Based on the Ministry of Agriculture and Land Reclamation (MALR), 66% of the beneficiaries are unemployed graduates; 24% are former tenants; 7% are small farmers; and 3% fall into the classification ‘others’ (MALR, 2003.) The MALR, further, stated that the rational underlying this project is that graduate unemployment can be faced via give graduates reclaimed land. For global food security, it is important to ensure the stability of wheat production as well as to maintain wheat prices at an affordable level.

## Study objectives

Soil salinity one of the major and widespread problem limiting crop productivity in irrigated agriculture, especially in arid and semi-arid regions of Egypt. In addition, a major population surge was reported in the last years, leading to an increasing of urbanization rate which has caused a reduction of agricultural area; this trend seem to be stable in the future.

Given this premises, the general objective of this study is the integration of geomatics techniques (GIS and RS), modeling and classical cultural methods to improve land management with respect to salinity problem, by providing policy makers and land managers information about the status of land productivity and good practices related to wheat management.

The specific objectives can be summarized as follows:

1- Monitoring the impact of soil salinity on wheat crop yield by field agronomic trials;

2- Mapping soil salinity at local level from field soil information by means of geostatistical techniques to compare changes over time:

3- Mapping different land use/land cover classes using satellite remote sensing data;

4- Analyzing changes in the landscape over the last three decades to evaluate the dominant trends and drivers.

# Study Area

- **Location and climate:**

El Fayoum Governorate covers a circular depression in the Eocene Limestone plateau at the northern part of the Egyptian western desert. It is location about 90 Km to the south west of Cairo, between latitudes 29˚ 35' and 29˚ 05' N and longitudes 30˚ 20' and 31˚ 10' E. The studied area at Sinnuris District is located between latitudes 29˚ 20' and 29˚ 30' N and longitudes 30˚ 43' and 30˚ 56' E. El Fayoum area is characterized by a hot dry summer with scanty winter rainfall and bright sunshine throughout the year. Unless for the Nile River, the El Fayoum Depression would be just another unoccupied desert, similar to the adjacent Wadi El-Rayan. Except for some years of no rainfall at all and the ones with 44 mm rainfalls in one day, the average annual rainfall is 0.67 mm. The minimum average temperature in the rainless summer is 22 C, while the maximum one is 38 C or higher (up to 50 C.) The lowest average degrees, 20 C, occur in January usually. The evaporation rate varies from one month to another, ranging between 3.5 and 10 mm/day. The lowest values usually are being reported in (December and January), whereas the highest values are being recorded in (June and July.) Normally, the average annual evaporation is about 6.7 mm/day. The total surface area of the Governorate is approximately 6000 km2. The governorate is of a particular unique nature that differs from the Delta, Upper Egypt, and from other oasis as well. The differences are not limited to agriculture, it extend to geographical and topographical attributes such as the environment. The environment is a mixture of agricultural, desert, and coastal nature. In El Fayoum governorate, which is located at the northern part of the Egyptian western desert, the drainage water discharge had been gradually increased over the years resulting a rise in water level of Qaroun Lake to a critical level (43.79 m below main sea level).

- **Irrigation system**

El Fayoum governorate has a special irrigation system due to the nature of its land, which slopes downward regularly, from south to north for 67 meters along 35 km of distance towards Qaroun Lake, with a sloping average of 2 m/km. Thus, most of the governorate's land (93%) is currently being irrigated directly via waterfalls with openings and continuous irrigation around the clock. Water is being delivered to farmers via a rotating mechanism as it is shared by beneficiaries through irrigation canals letting water enter the fields of each farmer. The wastewater flows from south to north towards the slope where it pours into Qaroun and Wadi Al Rayan Lakes. Due to the special nature of El Fayoum, it is applicable to control the irrigation water coming from Youssef Sea to cover local needs. That should occur with the condition that the water level in Karoun Lake should not get too high in order to preserve the land bordering the Lake. Bahr Youssef is the main source of fresh water to El Fayoum. El Fayoum 's share of irrigation water amounts to approximately 2.5 billion cubic meters a year. Karoun Lake's surface area amounts to 55,000 feddans and Wadi Al Rayan Lake's surface area amounts to 35,000 feddans. Both are considered the main source of water drainage for the agricultural lands in the Governorate.

# Chapter I

## Effects Of Salinity On Wheat (*Triticum Aestivum* L.)

## 1.1 INTRODUCTION

### 1.1.1 OVERVIEW OF WHEAT CROP: ITS PRODUCTION AND STATUS

Estimates of wheat (*Triticum aestivum* L.) crops and their yields influence economies and food supplies all over the world, as wheat (*Triticum aestivum* L.) is one of the top global agricultural crops in terms of annual production. For global food security, it is important to ensure the stability of wheat production as well as to maintain wheat prices at an affordable level.

Wheat started to be cultivated around 10’000 years ago in the Euphrates Valley in present-day Iraq. Wheat is grown in every state in the world, and it is the most widely grown crop compared to corn and rice for its highly nutritious values: wheat is the most important source of proteins, thanks to its seeds, commonly called *kernel*. Wheat grain contains all essential nutrients. Indeed, its kernel contains about 12 percent water, including carbohydrates (65.2%), proteins (12.3%) containing adequate amounts of all essential amino acids (except lysine, tryptophan and methionine), lipid (2.6%), vitamins (such as vitamin C, vitamin E) and 9.7% total fibers (INRA, 2009). Wheat crop is also very useful in the production of many goods, such as straw particleboard that are used in wood production and in kitchen cabinets. Wheat can also be used to produce paper, milk replacer, medical swabs, charcoal and biodegradable plastic eating utensils.

The harvest of wheat happens every month of the year in different areas of the world, having both winter wheat and spring wheat. Winter wheat grows best in areas where the winters are not too cold, while wheat varieties that are planted in spring are called spring wheat (Robertson & Curtis, 1942) and (Kulp & Ponte, 2000). Wheat varieties are classified by grain hardness, the color of its kernels, and by planting time. Each class has its own uniform characteristics related to milling, baking, or other uses. There are more than 30’000 varieties of wheat, such as: hard red winter, hard red spring, soft red winter, durum, hard white, and soft white. Bread wheat represents more than 90% of total wheat production, although durum wheat is prevalent in specific regions. Numbers of factors are affecting the quality of a wheat yield, some of which are not controllable by humans while others are manageable. Some of these factors are: agro-climatic conditions, including temperatures and rainfall, insect pests, soil quality, disease, wheat varieties (wheat genetic potential), using technology delivery to breeders, agronomic practices; methods of irrigation, fertilizing, harvesting and sharing information (Carew *et al.,* 2009).

### 1.1.2 EFFECT OF SALINITY ON WHEAT

***Effect of Salinity on Wheat Growth***

Many crops show a reduced tolerance to salinity during seed germination, but greater tolerance during later growth stages and vice versa in other crops. Salinity affects both vegetative and reproductive development, which has profound implications depending on whether the harvested organ is a stem, leaf, root, shoot, fruit, fiber or grain. Salinity often reduces shoot growth more than root growth (Cramer *et al.,* 1990). While, it decreases the can the florets outcome quantity, it increases the sterility and the effective flowering time of and the overall maturity of wheat (Mass & Poss, 1989). Under saline conditions, the reduction in final leaf size is due not only to a shorter leaf length, but also to a narrower leaf. Wheat is moderately tolerant to salt with threshold without yield loss at 6 dS $m^{-1}$ and with yield 50% loss at 13 dS $m^{-1}$ (Mass & Hoffiman, 1977). The sequence and the order of the development stage define the wheat life cycle; accordingly salinity could significantly affect the development processes at a certain epoch. These sequence and developmental order have been categorized into three distinctive phases with the main characteristic of being continuous (Francois & Mass, 1994). The first phase covers the early growth stage. It occurs when both leaf and tiller buds are being produced in the axils of the leaves and spikelet primordial is initiated. The existence of high salinity levels would reduce the total number of leaves per culm, the number of tillers per plant, and the number of spikelet per spike (Mass & Grieve, 1990).

According to (Greenway & Munns, 1980) plant development can be prevented via salinity in three main forms:

(i) Reduction of water consumption via the elevated osmotic pressure.

(ii) Ion toxicity, which is most likely combined with sodium uptake or excessive chloride.

(iii) Reduction of Ca2+, NO3-, P, and K+ consumption as a result of the surplus in Na+ or CI-, which causes an imbalance of nutrient ion or the decrease of the internal distribution of any of the ions, mentioned earlier.

***Effect of salinity on physiological aspects***

According to the salt concentrations and salt tolerance of a certain plant, salinity can dramatically reduce the total content of chlorophyll and the level of reduction as well. Ashraf & McNeilly, (1988) mentioned that a higher tolerance for salt would lead to the increase of the chlorophyll content, while salt-sensitivity would lead to a reduction of overall content of chlorophyll. Velegaleti *et al*., (1990) stated that in salt-sensitive species, a dramatic reduction in chlorophyll could be associated with accumulation of Cl level.

The very obvious indirect effect on plant development caused by salinity is reduced availability of soil water. Soil water availability has an inverse relationship with salinity. Moreover, it is difficult to distinguish physiological reaction of soils with low water potential from those in react to salinity.

Generally, osmotic potential of soil decreases with the increase of salt percentages, which produces water stress and reduces plant consumption of required water for its growth, and decreases the leaf water potential accordingly (Munns, 1993). Such reduction in water potentials in leaf is associated with a reduction in the osmotic potential of leaf, which maintained its turgor pressure of the salinized plant (Tattini *et al.,* 1995). Hence, the turgor pressure in growing tissues is correlated with the growth of the cell, and it was founded that under saline conditions is the main reason for the inhibition of the expansion of the cells of the plant (Greenway & Munns, 1980). Furthermore, turgor presser decrease leads to stomatal conductance reduction.

***Effect of salinity on phenological aspects***

Salt accumulates till it reaches toxic levels in the leaves of salt-sensitive genotypes, where salt is not appropriately excluded from the transpiration stream. These levels cause injuries and succulence to new leaves, and the death of old ones (Munns & James, 2003). Accordingly, the total number of green healthy leaves is remarkably downsized. Also, acceleration in both seeds' production and flower initiation is noticed while reasonable counts of green leaves are left to provide the required photosynthesis (Mass & Poss, 1989) and (Munns & James, 2003). As a result, the salinity effects reduce the size and the count of the plant's seeds.

***Effect of salinity on wheat: Experiments worldwide***

A series of studies on wheat in the region were conducted to examine salinity's effect on different growth stages and on grain yield by countries' scientists, since the wheat is the most sensitive crop to salinity during the vegetation stage and less sensitive during flowering and grain filling stage (El-Hendawy *et al*., 2005).

Howladar & Dennett (2014) in Saudia Arabia; studied the effect of exogenous application, seed priming or foliar spraying of salicylic acid on Yecora Rojo and Paragon wheat cv. under two levels of NaCl-salinity, tap water (approximately 1 mM NaCl as control) and 100 mM NaCl. Results clarified that a significant reduction in green leaf number, tiller number, total fresh weight, total dry weight (leaf and stem of plant), yield and yield components of Yecora Rojo and Paragon wheat cv. under saline conditions without salicylic acid in both cultivars.

Abbas *et al*., (2013) in Pakistan; assessed the effect of two levels of salinity non-saline (0.33 dS $m^{-1}$ )and saline (15 dS $m^{-1}$ ) on yield components, ionic relations and grain quality using wheat genotype Pasban-90. Results showed that salinity resulted in a significant reduction of the yield components i.e. plant height, tillers $plant^{-1}$, spike length, spikelets per spike and grain weight $plant^{-1}$, maximum reduction was noted in case of number of tillers $plant^{-1}$, followed by grain weight $plant^{-1}$.

El-Lethy *et al*., (2013) in Egypt; studied the effect of salinity stress on two cultivars of wheat, one is sensitive (Gemiza 9) and the other cv. is tolerant (Sakha 93) by irrigation plants with tap water contain different salinity levels i.e. 40, 80, 120 mM NaCl and found that NaCl-stress triggered significant inhibitory effects on wheat plant growth i.e. plant length, fresh and dry weights, spike length, number of spikelets/spike, grains yield/plant and 1000 grains weight of both cultivars at all levels of NaCl-salinity, especially at 120 mM and sensitive cv. (Gemiza 9) of wheat.

Rawson *et al*., (2013) in Bangladesh; assessed 28 wheat selections (including Triticale) in variably saline fields. They found that plot grain yield was best correlated with salinity measured as an average of 0-90 cm deep soil cores extracted within a month of sowing. Yield declined linearly and sharply at approximately 14 $g/m^2$ (146 kg/ha) per dS $m^{-1}$.

Ali *et al*., (2012) in Pakistan; evaluated ninety eight hexaploid wheat inbreeds differing in geographic origin and belonging to six diverse adaptation groups were studied in control, EC-10 and EC-15 dS $m^{-1}$ treatments to evaluate variability for salt tolerance. Results showed that the set of 98-hexaploid wheat inbreeds were significantly different for the grains/spike, 100-grain weight and grain yield under control, 10 and 15 dS $m^{-1}$.

Arshad *et al.*, (2012) in Pakistan; evaluated the performance of different wheat genotypes against salinity at low and adequate calcium supply viz., $T_1$: non-saline with adequate $Ca^{2+}$, $T_2$: non-saline with low $Ca^{2+}$ (level of calcium was 1/4$^{th}$ of the adequate level), $T_3$: saline (125 mM NaCl) with adequate $Ca^{2+}$ and $T_4$: saline with low calcium. Results indicated that all the physical growth parameters including shoot length and shoot fresh weight were decreased significantly due to salinity and low calcium alone as well as in combination. Reduction was more pronounced under the combined stress of salinity and low calcium and different genotypes differed significantly in different stress treatments for shoot fresh weight.

Asgari *et al.*, (2012) in Iran; conducted pot study to the effect of different salinity levels, i.e. ECe=3 dS $m^{-1}$ (control), 8, 12 and 16 dS $m^{-1}$ on grain yield, yield components and leaf ion uptake of wheat cultivars, i.e. Tajan, Rasoul, Atrak and Kouhdasht. Results indicated that number of leaves per plant, number of tiller per plant, number of spikes per plant, spike length, number of spikelets per spike, thousand-grain weight, straw weight, harvest index, grain yield of all wheat genotypes significantly decreased with increasing salinity levels.

Bahkt *et al.*, (2012) in Pakistan; studied response of 6 wheat genotypes to induced salinity stress (0, 4, 6, 10 dS $m^{-1}$ ) and $CaCl_2$ (2:1 molar ratio) was introduced gradually after four weeks from emergence and observed that different salinity levels had a significant effect on number of spikes $plant^{-1}$, grains $spike^{-1}$ and 1000 grain weight, values of these traits were reduced with increased salinity level up to 10 dS $m^{-1}$ compared to untreated plants.

Kumar *et al.*, (2012) in India; a pot study was conducted to study the effect of different salinity levels EC 3, 6, 9 and 12 dS $m^{-1}$ in addition to control on eight wheat genotypes differing in their tolerance to salinity. Results indicated that salinity level >3 dS $m^{-1}$ showed a reduction in plant height, tiller production/plant, dry weight/plant, ear length, grain yield and straw yield/plant, biological yield, harvest index and test weight.

Asgari *et al*., (2011) in Iran; a pot study was conducted to study the effect of different salinity levels, i.e. ECe = 3 (control), 8, 12 and 16 dS $m^{-1}$ on wheat grain, yield components. Desired salinity levels were obtained by mixing adequate NaCl before filling the pots. Results clarified that grain yield/plant, 1000-grain weight, number of spikelets /spike, spike length, number of tillers/plant, number of spikes/plant, straw weight and Harvest index of all wheat genotypes decreased with increasing salinity levels.

Yadav *et al*., (2011) in India; studied the harmful effect of salinity on physiological, biochemical traits, growth and yield of wheat genotypes namely, Raj-3077, Raj-3765 (salt tolerant) and Raj-1482, PBW-502 (salt susceptible), were grown in cemented pots under different levels of salinity (0, 4.0, 6.0 and 8.0 dS $m^{-1}$ ) at 30, 60 Days after sowing and anthesis stage. Results revealed that salinity was found to decrease significantly the plant height, number of leaves, number of grains, total number of tillers/plant, 1000-grain weight, fresh, and dry weight, grain yield, and biological yield in all the genotypes.

Ranjbar *et al*., (2010) in Iran; evaluated of five salt-tolerant wheat varieties-Roshan, Kavir, Akbari, Bam and Sistan-along with two local wheat cultivars (Chamran and Verinak) for their mean productivity on salt-affected soils. Results indicated that among the genotypes, Sistan and Verinak produced the highest and lowest grain yield, respectively, regardless of the years. Salt-tolerant varieties produced more grain yield than the local varieties by 15%. Grain yields of salt-tolerant varieties were significantly correlated with number of kernel per spike and biological yield. Relationship of grain yield and some other traits such as number of spike and harvest index were not significant.

Shafi *et al*., (2010) in Pakistan; conducted a study to investigate the response of 11wheat genotypes to salinity stress at three different locations Yar Hussain, Baboo Dehari and Khitab Koroona in Pakistan. These locations had different salinity profile i.e., EC. ranged from 3-3.5, 4- 4.5 and 5-5.30 dS $m^{-1}$, respectively. Results indicated that biological and grain yield was more in treatments at Yar Hussain when compared with the other two locations Baboo Dehari and Khitab Koroona.

Zheng *et al*., (2010) in China; tested foliar application of $KNO_3$ on wheat in the heading stage to reduce salinity-induced injuries, produce high grain yield, and improve grain quality. Salt-resistant DK961 and salt-sensitive JN17 wheat cultivars under 0 or 100 mM–NaCl conditions were foliarly watered with distilled water or a 10 mM–$KNO_3$ solution. The four treatments included: $T_1$ ($CK_1$), 0 mM NaCl + distilled water; $T_2$, 0 mM NaCl + 10 mM $KNO_3$; $T_3$ ($CK_2$), 100 mM NaCl + distilled water; $T_4$, 100 mM NaCl + 10 mM $KNO_3$. Results indicated that salinity significantly reduced plant height and yield of both cultivars. DK961 yield decreased 22% in $T_3$ ($CK_2$) compared with $T_1$ ($CK_1$), while $T_4$ was only reduced 8% compared with $T_1$, JN17 yield declined 54% more in $T_3$ compared with $T_1$.

Abdel-Ghani (2009) in Jordan; conducted a pot experiment to determine the effects of salinity levels (control, 6, 12 and 18 dS $m^{-1}$ ) on germination, seedling growth, and some agronomic traits of nine wheat varieties. He found that the plant height, number of tillers per plant, number of seeds per spike, the 1000-kernel weight and grain yield were significantly reduced by increasing salinity level. Yield reduction in saline soil varied over varieties ranging from -

6.5 % to 28.1 %, 13.2–35.8 % and 19.7–54.4 % at 6, 12 and 18 dS $m^{-1}$ salinity levels, respectively.

Abdul-Qados (2009) in Egypt; investigated the effects of salinity on growth and yield of wheat cultivar (Sakha 61) by irrigation of plants with different salinity levels (0.00, 2000, 4000, 6000 and 8000 ppm) in a pot experiment. Results revealed that the lowest salinity level used (2000 ppm) induced significant increases all growth parameters compared with control plants while increasing salinity levels up to 8000 ppm resulted in gradual significant reduction in growth response of wheat plant (plant height and fresh and dry weight/plant). Concerning yield components of wheat, results showed the lowest salinity level used in this study 2000 ppm induced marked increase in all yield components (spike length, spike weight, spikelets number/spike, grains yield/plant, biological and straw yield/plant and harvest index) as compared with control.

Datta *et al*., (2009) in Bengal; studied the impact of salt stress under different salinity level (0, 25, 50, 75, 100, 125, 150 mM NaCl) on five varieties of wheat viz., HOW- 234, HD-2689, RAJ-4101, RAJ-4123, and HD-2045. The data showed that different level of salinity significantly affected the growth attributes by reducing shoot length for salinity below 125mM. Fresh weight and dry weight of shoot were reduced significantly with subsequent treatment. Regarding germination maximum germination was found in variety HD2689 in all the treatments and maximum inhibition was found to be in case of HOW234 variety at 150mM salinity level.

Katerji *et al*., (2009) in Italy; investigated durum wheat productivity in saline–drought environments under soil salinity levels 0.9, 5.8 and 8.9 dS $m^{-1}$ which represent S1 (control), S2 and S3. They found that a significant reduction in grain and straw yields in comparison with control treatment S1.

Zheng *et al*., (2009) in China; studied the grain yields and quality criteria of contrasting wheat cultivars, DK961 (salt-tolerant) and JN17 (salt-sensitive) in response to a series of salinity levels (0, 50, 100, 150 mM). Results showed that salinity led to a reduction in grain yields of both cultivars and 1000-grain weight of JN17 in each salinity treatment more than in the control.

Ruan *et al*., (2008) in Germany; studied two contrasting genotypes salt-tolerant genotype Kharchia and salt-sensitive genotype Sakha 61 of spring wheat were grown in a greenhouse under saline or non-saline conditions. Results refer that under saline conditions, the reductions in shoot dry weight, seed yield and seed number per plant for the salt-tolerant genotype Kharchia were of a greater magnitude in the treatments where only one or two tillers per plant were present compared with the untouched treatment, whereas the magnitude of this reduction in the salt-sensitive genotype Sakha 61 was decreased.

Saboora *et al.,* (2006) in Iran; evaluated nine wheat cultivars under six treatments of salinity including 0 (control), 75, 150, 225, 300, 375 mM NaCl. Results refer to salinity had considerable effect on the germination percentage, germination rate and total dry weight.

El-Hendawy *et al*., (2005) in Egypt; a pot study was conducted to study the effect of four salinity levels (control, 50, 100 and 150mM NaCl) on thirteen wheat genotypes, eight varieties (Sakha 8, Sakha 93, Sakha 61, Sakha 69, Giza 168, Sids 1, Sahel 1 and Gemmeza 7) were obtained from Egypt. Sakha 8 and Sakha 93 are usually cultivated in saline areas in Egypt. Of the remaining varieties, Thassos and Triso were from Germany, Westonia and

Drysdale were from Australia, and Kharchia was from India. Results showed that tiller number was affected more by salinity than leaf number at the vegetative stage. Salinity decreased dry weight per plant significantly at all growth stages. Spikelet number on the main stem decreased much more with salinity than spike length, grain number and 1000-grain weight at maturity. According to cluster analysis with multiple agronomic parameters at all growth stages, the Egyptian genotypes Sakha 8 and Sakha 93 and the Indian genotype Kharchia were ranked as the most tolerant to salinity.

Katerji *et al*., (2005) in Italy; tested the effect of salinity on grain quality of two durum wheat varieties differing in salt tolerance, salt tolerant variety Cham-1 and salt sensitive variety Haurani using fresh water and two saline waters. Results showed that the grain yield and 100-grain weight were higher for the salt tolerant variety Cham-1 than for the salt sensitive variety Haurani.

Akram *et al*., (2002) in Pakistan; investigated the effects of increased levels of NaCl salinity (2.5, 10, 15, 20 dS $m^{-1}$) on some yield components and their correlation with some growth parameters of salt tolerant (234/2), medium responsive (243/1) and sensitive (Fsd-83) accessions/varieties (Acc/Var) of wheat. Results showed that Salinity reduced spike length, number of spikelets per spike, number of grains per spikelet, 100-grain weight and grain yield per plant. The extent of reduction varied greatly with tolerance and salinity levels. The reduction entailed adverse effect on 100-grain weight and grain yield per plant. Significant correlation was found between shoot dry weight, leaf area and transpiration rate and the grain yield.

Javaidi *et al*., (2001) in Pakistan; conducted study to monitor the response of wheat var. Inqlap-91 to 1:1, 3:1 and 1:3 Ca/Na ratios, were developed under salinity levels of 6 and 12 dS $m^{-1}$ using salt mixture of NaCl, $Na_2SO_4$, $CaSO_4$, $CaCl_2$, $MgSO_4$ in the original soil having ECe of 2.4 dS $m^{-1}$. Results indicated that both Ca/Na ratios and salinity levels had a significant effect on spike length, seed index weight and grain yield while plant height was not significantly affected by salinity levels. Maximum values of these characteristics were recoded under ECe of 6 dS $m^{-1}$ with Ca/Na ratio of 3:1.

Maas et al., (1994) in USA; determined the effects of soil salinity on the occurrence and rate of tiller development and the incidence of tiller abortion in spring wheat cultivars Anza and Yecora Rojo using three salinity treatments were imposed by irrigating with waters containing equal weights of NaCl and $CaCl_2$ (electrical conductivities of 1,12 and 18 dS $m^{-1}$ ). Higher salinities reduced the percentage of tillers with spikes, but not as much as the reduction in tillers. Tiller and spike production per plant decreased about 0.13 to 0.15 organs for each unit increase in soil water salinity.

## 1.2 Theoretical Background

### 1.2.1 WHEAT PRODUCTION IN THE WORLD

***The status of wheat production in the world***

Depending on agro-climatic conditions, about 670 million tonnes are globally produced every year. Table 1 shows the Egyptian local production versus the global wheat yield beside the local and global harvested wheat areas. Growing world populations, increasing price of fertilizers and the negative effects of high temperature and drought on crop yield resulting from climate change caused instability in world wheat production and made particularly difficult to meet increasing global demand in the past 15 years (Butcher, 2013). The rate of increase in wheat production slowed down after 1960 to the early 1990s. Salinity is a major constraint to food production because it limits crop yield and restricts the use of land that was previously not cultivated: indeed, there is 7% of lands in the world affected by salinity

(Flowers *et al.*, 1997). The Wheat Initiative Report in May 2013 estimated that climate change in some areas of the world will cause losses up to 30% by 2050 and considering that global wheat mean yield increased at 1.1% from 2001 to 2010, there is a need for a second sustainable Green Revolution to increase global wheat production by 60% by 2050 (Wheat Initiative, 2013). Figure 1 and 2 show the four top producers in 2013 and the period from 1993 to 2013 respectively: China, India, United States of America, and the Russian Federation.

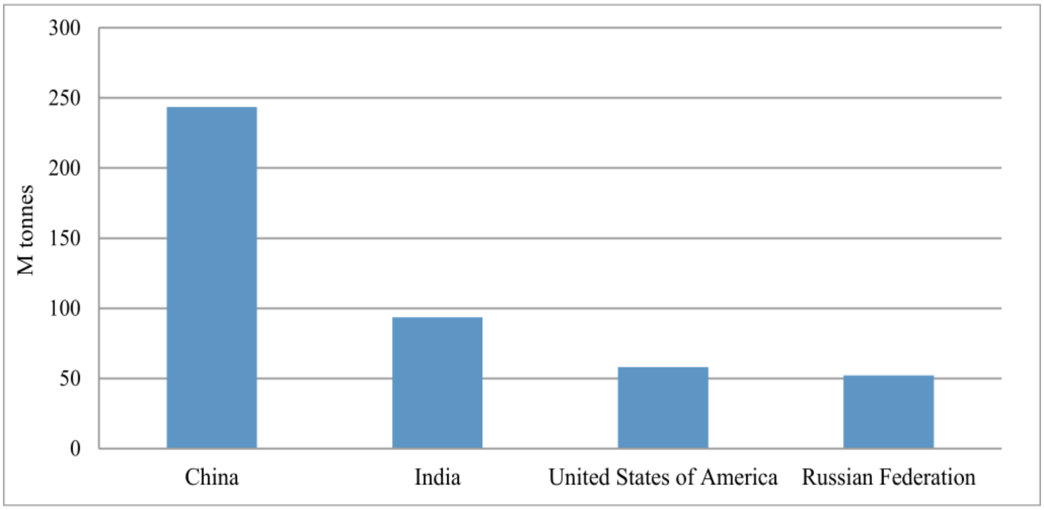



*Figure 1: The top 4 commodities country for wheat production in 2013.*

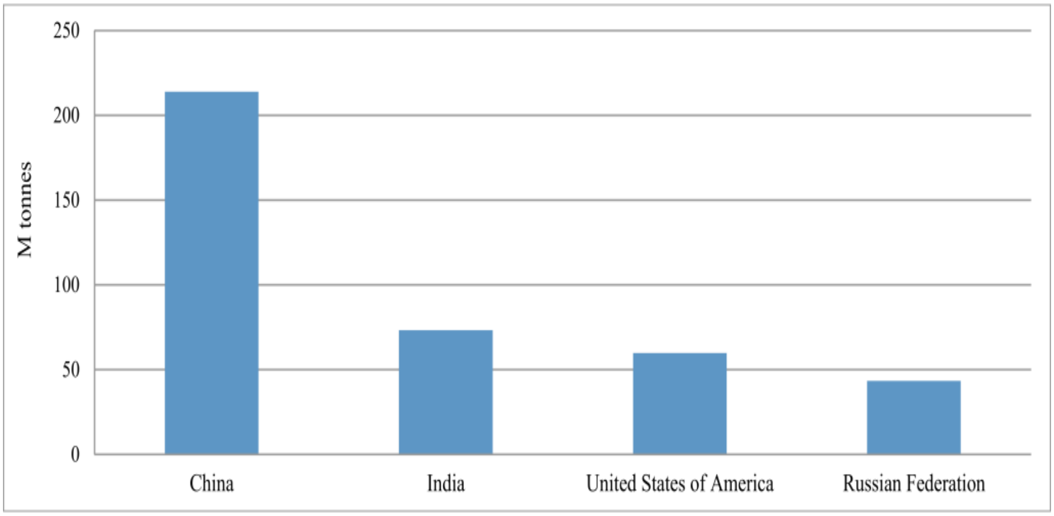



*Figure 2: The top 4 commodities country for wheat production from 1993 to 2013.*

*Table 1: Average data of area harvested, yield and wheat production in the world and Egypt for 1993 and 2013.*

| **Area harvested (ha)** | | | |
|---|---|---|---|
| | | Year | |
| | **Country** | **1993** | **2013** |
| | Egypt | 1.053.016 | 1.418.708 |
| | World + (Total) | 207.699.862 | 218.460.701 |
| **Yield (t/ha)** | | | |
| | | Year | |
| | **Country** | **1993** | **2013** |
| | Egypt | 6.5001 | 6.6682 |
| | World + (Total) | 2.6968 | 3.2646 |
| **Production (tonnes)** | | | |
| | **Country** | Year | |
| | | **1993** | **2013** |
| | Egypt | 6.844.692 | 9.460.200 |
| | World + (Total) | 560.128.836 | 713.182.914 |

### 1.2.2 WHEAT PRODUCTION IN EGYPT

***The importance and statues of wheat production in Egypt***

Egypt has experienced rapid development over the last two decades. The production of wheat has not been enough to meet the demand of food security to the growing population. Agriculture faces many challenges in Egypt, as a result of urban settlements onto old land that used to be cultivated due to population increase reported in (Table 2) and soil degradation with soil salinity being one of the main reasons of soil degradation (El Habbasha *et al.*, 2013). For these reasons agricultural production in Egypt has decreased over the years, and it is now important to reverse such trend - increasing the ratio of food production and land reclamation. Consequently, Figure 3 visually reports the Egyptian wheat production growth from the year 1993 to 2014 (USDA).

*Table 2: a- Average of population in Egypt (source of Central Agency for Public Mobilization and Statistics). b- Average of population in El Fayoum region.*

**( a )**

| Year | Population |
|---|---|
| **1937** | 15.920.694 |
| **1947** | 18.901.128 |
| **1966** | 29.846.809 |
| **1976** | 36.626.204 |
| **1986** | 48.254.238 |
| **1996** | 61.452.382 |
| **2014** | 87.494.586 |

**( b )**

| Year | Population |
|---|---|
| **1940** | 670000 |
| **1960** | 839000 |
| **1966** | 935000 |
| **1976** | 1142000 |
| **1996** | 1990000 |
| **2006** | 2512000 |
| **2007** | 2575000 |
| **2008** | 2646661 |
| **2009** | 2694000 |
| **2010** | 2756000 |
| **2011** | 2819000 |
| **2012** | 2884000 |
| **2013** | 3037620 |

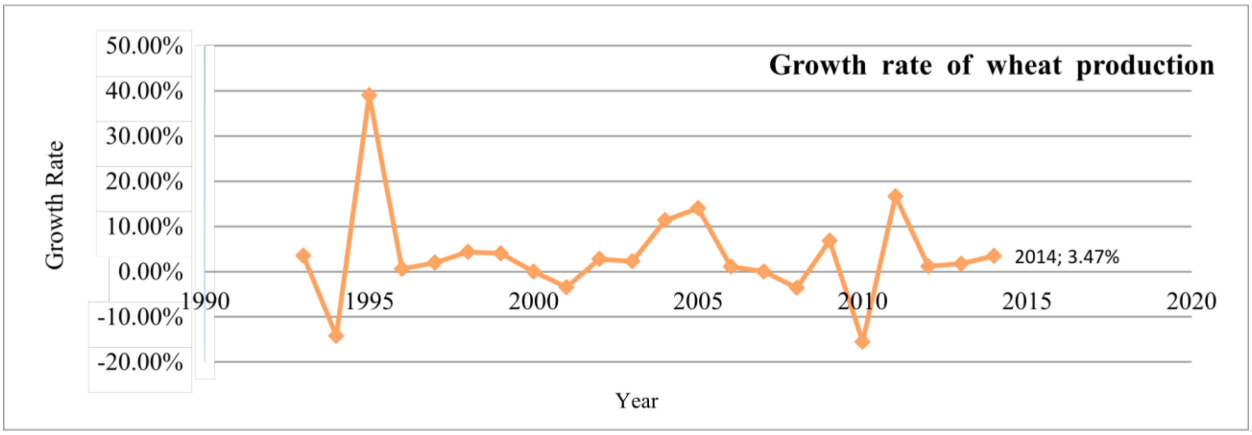



*Figure 3: **The average data of wheat production and the rate of the production in Egypt from 1993 to 2014.***

Egypt is the world's top wheat importer, shipping in Wheat imports for the 2014/15 marketing year are estimated at 10 million tonnes, about the same as the previous year and the average. "There is an urgent need to increase wheat productivity," stated (FAO, 2014) as a rapidly growing population under local climate and topographic conditions makes Egypt dependent on external supplies where according to (FAO Grains, 2013); Egypt imported about 5 million to 5.5 million tonnes in the year to June 30, 2014. The following Table 3 shows imported and exported tonnes of wheat from 2013 back to 1993: there was a 100-fold increase in imports 5.866.000 tonnes in 1993 and 10.500.000 tonnes in 2013 (USDA).

*Table 3: The average data of wheat imported and exported quantities from 1993 to 2013.*

| Year | Imported (t) | Exported (t) |
|---|---|---|
| **2013** | 10,500,000 | 200,000 |
| **2012** | 8,300,000 | 190,000 |
| **2011** | 11,650,000 | 232,000 |
| **2010** | 10,600,000 | 225,000 |
| **2009** | 10,500,000 | 175,000 |
| **2008** | 9,900,000 | 94,000 |
| **2007** | 7,700,000 | 43,000 |
| **2006** | 7,300,000 | 12,000 |
| **2005** | 7,771,000 | 10,000 |
| **2004** | 8,150,000 | 10,000 |
| **2003** | 7,295,000 | 10,000 |
| **2002** | 6,327,000 | 10,000 |
| **2001** | 6,944,000 | 11,000 |
| **2000** | 6,050,000 | --- |
| **1999** | 5,872,000 | --- |
| **1998** | 7,454,000 | --- |
| **1997** | 7,134,000 | 1,000 |
| **1996** | 6,893,000 | 3,000 |
| **1995** | 5,932,000 | 10,000 |
| **1994** | 5,856,000 | 3,000 |
| **1993** | 5,866,000 | 2,000 |

***Wheat production potential in Egypt***

Figure 4 represents the wheat production potential in Egypt. High production potential is present only along the valley of the Nile River and around its Delta.

There are four main classes of wheat production potential in Egypt:

- **Land with high potential** (P1): Located around the River Nile and in the central part of the Nile Delta. Some areas within the unit have been affected by localized salinity. One fifth of these soils has slight to medium surface salinity. In general these soils have a high potential (PI) for wheat, at high level of inputs.
- **Land with moderate potential** (P2): Located in stretches along the eastern and western flanks of the Nile Delta. Lands are potentially limited by stony and infertile soils, and the shape of these P2 occurs in the form of narrow strips along the margins of the Nile valley.
- **Land with low potential** (P3): Lands with limited potential because of saline and sodic soils. This class occurs as a narrow belt along the Mediterranean coast. The limited potential arises a result of the stony and the infertile soils. This P3 lands is located on the Upper Nile valley of Egypt.

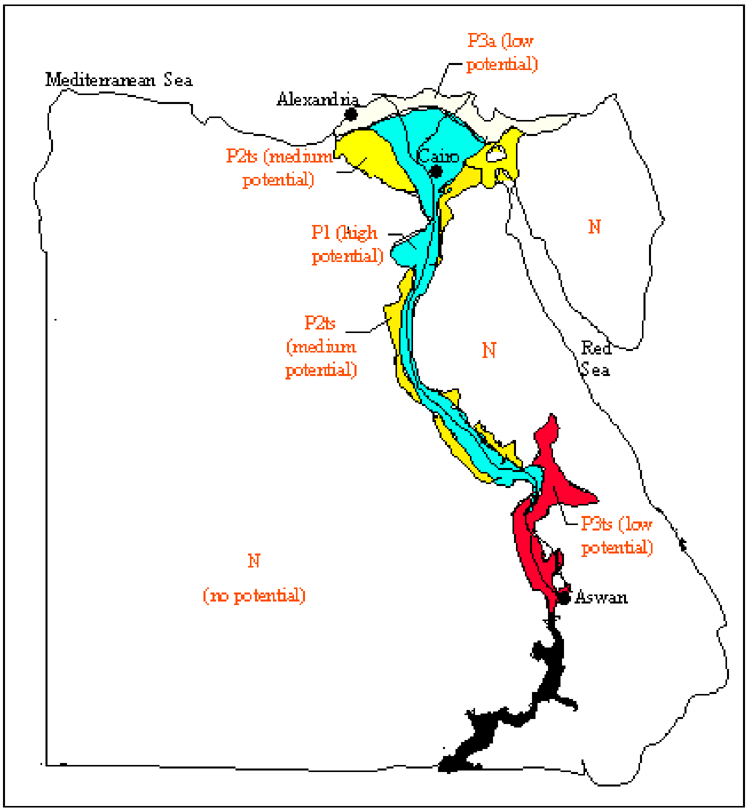


*Figure 4; Wheat production potential in Egypt (Source: http://www.fao.org/ag/agp/AGPC/doc/field/Wheat/africa/egypt/egyptagec.htm#map)*

- **Land with no potential** (N): This class covers all remaining land in Egypt that is neither irrigated nor likely to become so. Extension of irrigation is restricted due to unfavorable relief, poor soils conditions and lack of suitable irrigation water. This entire class has no potential for wheat production.

***Wheat production of El Fayoum region in Egypt***

The following Table 4 shows the average of yield of wheat (t/ha) and the harvested area (ha) in El Fayoum governorate, Egypt. El Fayoum governorate as a whole unit used to produce 6 t/ha until the year 2002 where the yield slightly increased. As shown in Figure 5 the highest yield ever experienced in El Fayoum occurred on the years 2011 – 2012 was 7.2 t/ha.

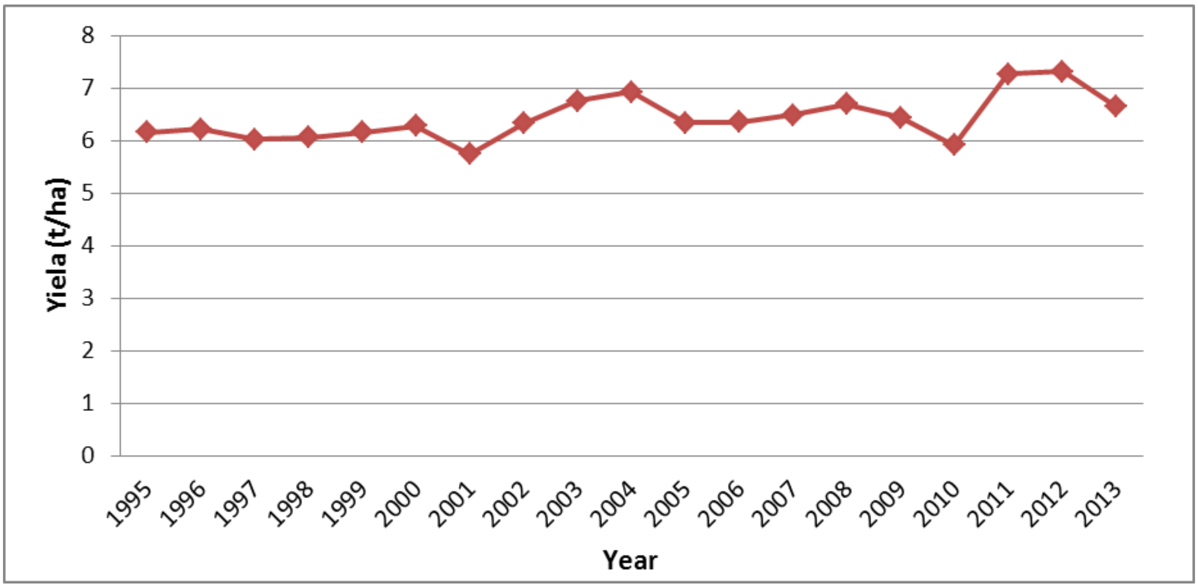



*Figure 5; The average wheat yield (t/ha) in El Fayoum governorate, Egypt.*

As shown in Figure 6 El Fayoum city fully exploited the available agricultural land of 11,000 ha till the year of 2004. After this year, a new reclamation policy was adapted after the loss of some agricultural land. This policy managed to alleviate the agricultural areas to 16,000 ha by the year 2013.

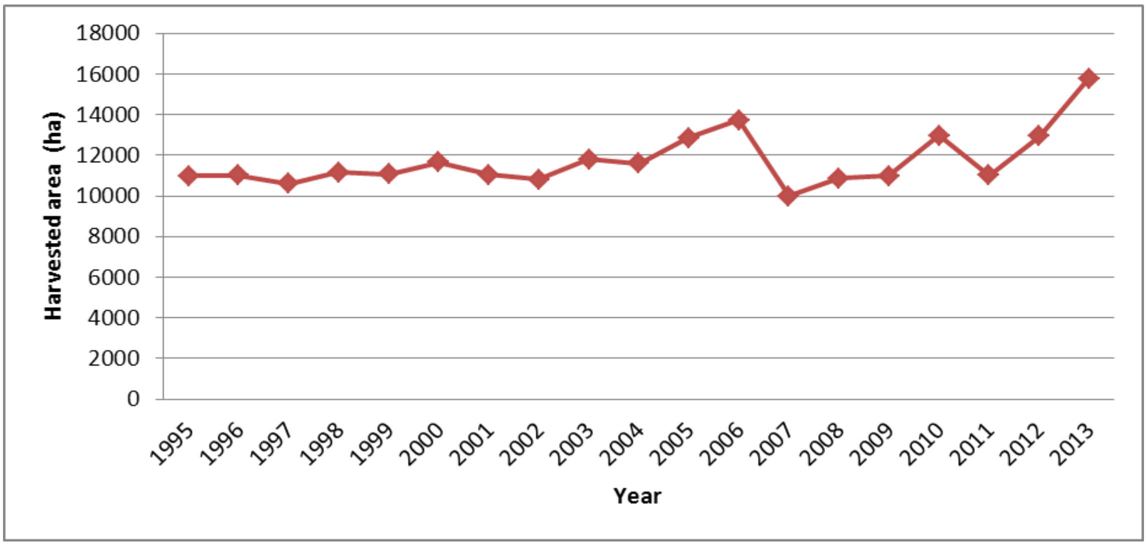



*Figure 6; The average harvested area (ha) in El Fayoum city, El Fayoum governorate, Egypt.*

On the one hand, Sinnuris used to have the same agricultural area of around 8,500 ha from 1995 to 2013 as shown in Figure 7.

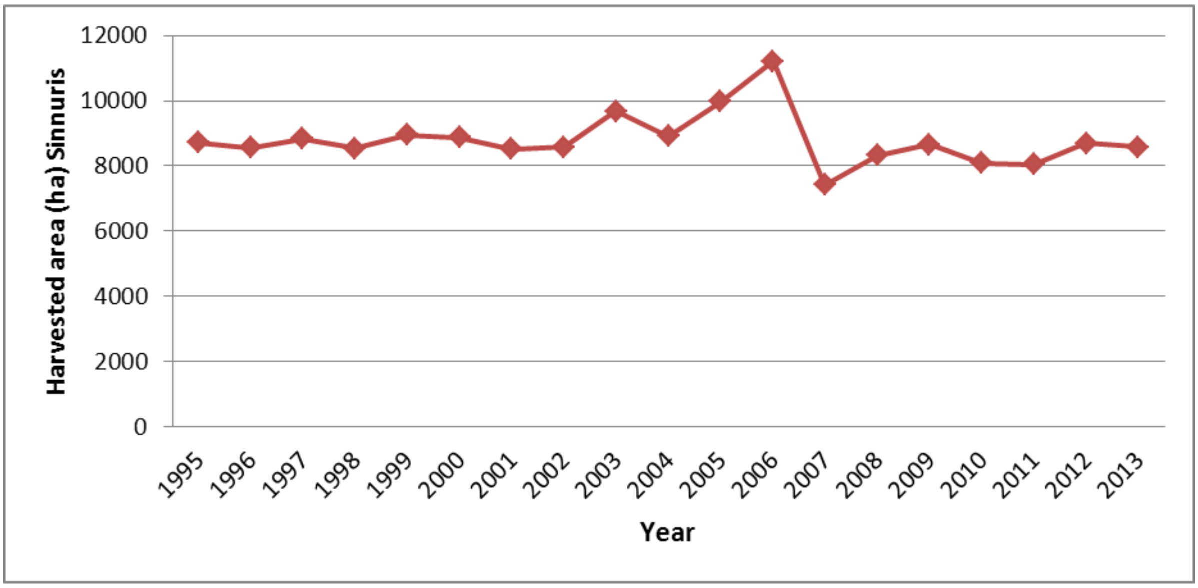



*Figure 7; The average harvested area (ha) in Sinnuris district, El Fayoum governorate, Egypt.*

One the other hand, Itsa (Figure 8) has a slightly increasing agricultural land from around 16,200 ha on 1995 to 21,000 ha on 2013.

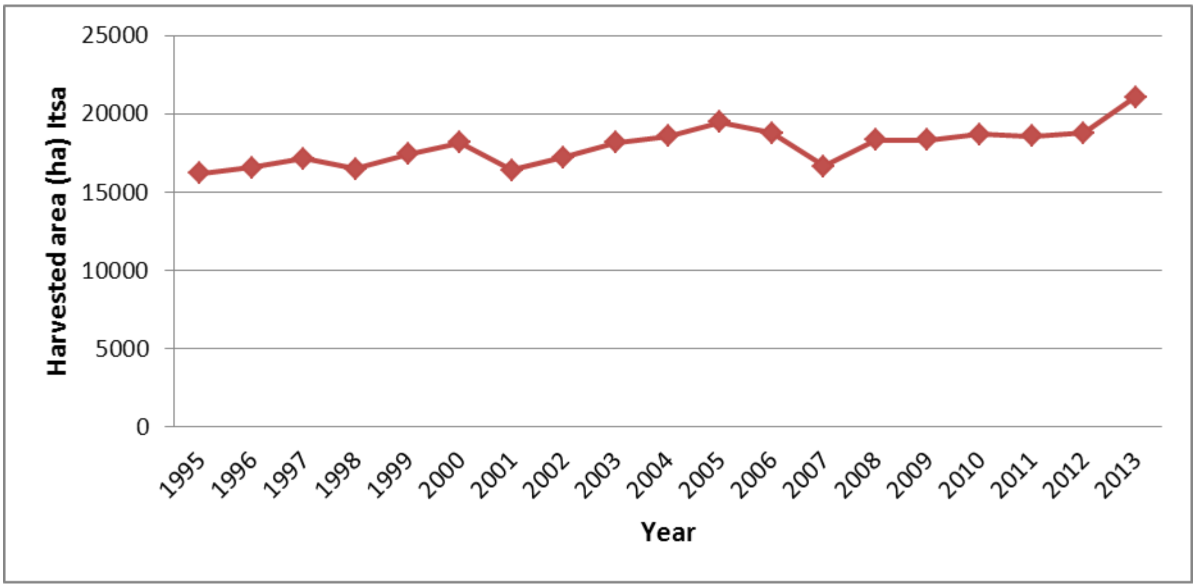



*Figure 8; The average harvested area (ha) in Itsa district, El Fayoum governorate, Egypt.*

Tamia's agricultural land (Figure 9) shows the same uprising trend that started with a value around 11,100 ha on 1996 to reach a value close to 17,000 ha by the year 2013.

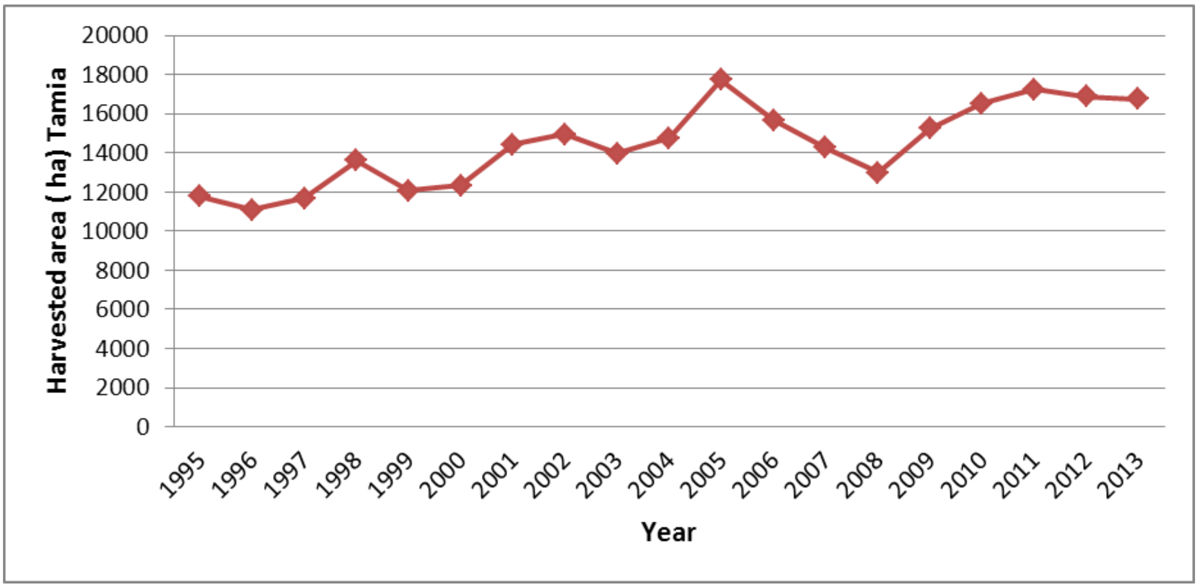



*Figure 9; The average harvested area (ha) in Tamia district, El Fayoum governorate, Egypt.*

As Itsa and Tamia, Abshway (Figure 10) and Youssef el sedik (Figure 11) shows slowly increasing agricultural lands with added values of 3,000 and 3,500 ha respectively between the years 1996 and 2013.

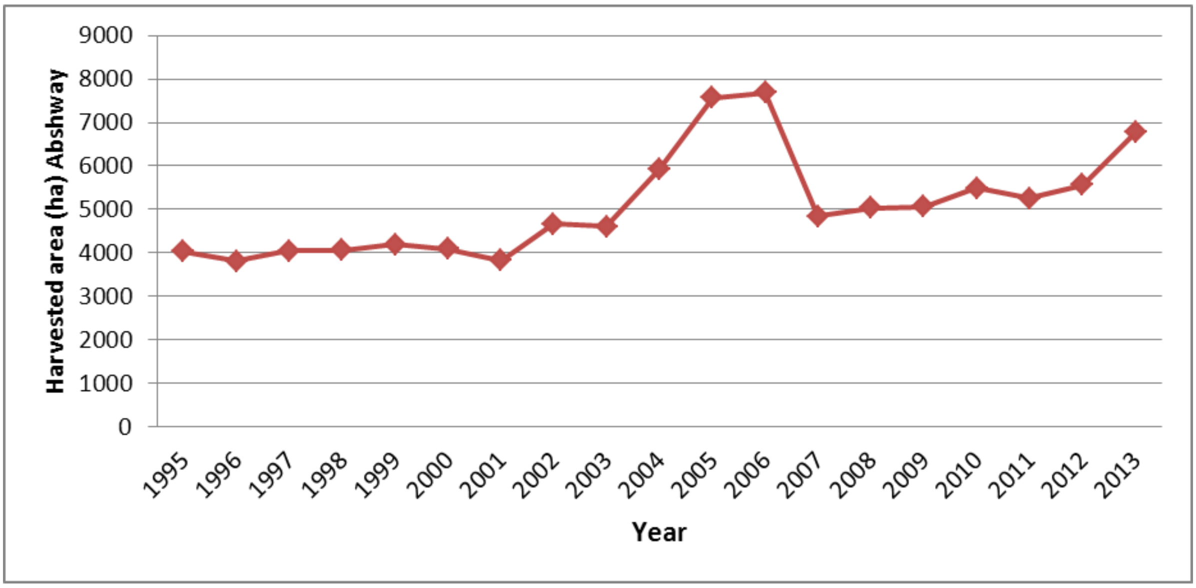



*Figure 10; The average harvested area (ha) in Abshway district, El Fayoum governorate, Egypt.*

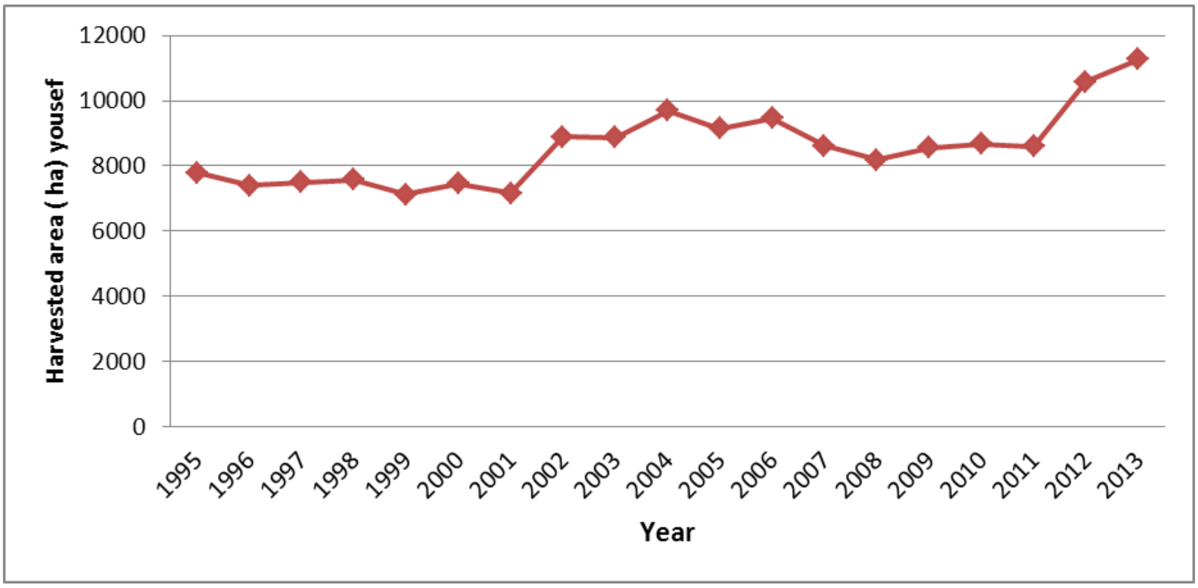



*Figure 11; The average harvested area (ha) in Youssef el sedik, El Fayoum governorate, Egypt.*

*Table 4;The average yield of wheat (t/ha) and the harvested area (ha) in El Fayoum governorate, Egypt.*

| Year | El Fayoum | | Senures | | Tamia | | Itsa | | Abshway | | Youssef el sedik | | Total of Governorate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area (ha) | Yield (t) | Area (ha) | Yield (t) | Area (ha) | Yield (t) | Area (ha) | Yield (t) | Area (ha) | Yield (t) | Area (ha) | Yield (t) | Area (ha) | Yield (t) |
| 1995 | 10988.88 | 6.24 | 8706.6 | 6.23 | 11777.22 | 6.18 | 16208.64 | 6.05 | 4038.72 | 6.25 | 7801.08 | 6.08 | 59521.14 | 6.15 |
| 1996 | 10997.28 | 6.3 | 8551.2 | 6.27 | 11076.66 | 6.24 | 16576.14 | 6.14 | 3814.02 | 6.15 | 7405.02 | 6.21 | 58420.32 | 6.22 |
| 1997 | 10596.6 | 6.04 | 8825.04 | 6.09 | 11665.5 | 6.02 | 17152.8 | 5.96 | 4049.22 | 6.17 | 7505.82 | 6.00 | 59790.78 | 6.02 |
| 1998 | 11150.58 | 5.9 | 8537.76 | 6.34 | 13611.78 | 6.05 | 16474.92 | 6.25 | 4060.98 | 5.9 | 7583.94 | 5.63 | 61419.96 | 6.06 |
| 1999 | 11058.6 | 6.43 | 8959.86 | 6.25 | 12059.04 | 6.06 | 17424.96 | 6.16 | 4189.08 | 5.92 | 7132.86 | 5.88 | 60824.40 | 6.15 |
| 2000 | 11656.26 | 6.51 | 8864.1 | 6.23 | 12323.64 | 6.29 | 18138.54 | 6.36 | 4096.26 | 5.96 | 7458.78 | 5.91 | 62537.58 | 6.28 |
| 2001 | 11052.3 | 5.55 | 8512.98 | 5.61 | 14413.56 | 5.80 | 16387.56 | 5.91 | 3819.48 | 5.98 | 7158.90 | 5.55 | 61344.78 | 5.74 |
| 2002 | 10806.18 | 6.60 | 8574.3 | 6.27 | 14936.04 | 6.22 | 17213.7 | 6.38 | 4672.92 | 6.18 | 8896.44 | 6.22 | 65099.58 | 6.33 |
| 2003 | 11810.4 | 7.15 | 9684.78 | 6.78 | 13979.7 | 6.60 | 18177.6 | 6.75 | 4609.5 | 6.58 | 8874.60 | 6.53 | 67136.58 | 6.75 |
| 2004 | 11602.08 | 7.36 | 8910.72 | 7.04 | 14756.28 | 6.77 | 18571.14 | 6.70 | 5914.02 | 7.00 | 9702.00 | 6.88 | 69456.24 | 6.92 |
| 2005 | 12840.66 | 6.9 | 9978.78 | 7.06 | 17730.3 | 6.17 | 19453.14 | 6.53 | 7570.5 | 6.40 | 9146.76 | 6.31 | 76720.14 | 6.34 |
| 2006 | 13718.04 | 6.64 | 11203.08 | 6.56 | 15657.18 | 6.1 | 18763.5 | 6.34 | 7686 | 6.26 | 9468.90 | 6.21 | 76496.7 | 6.35 |
| 2007 | 9981.3 | 6.56 | 7415.52 | 6.59 | 14253.96 | 6.55 | 16647.54 | 6.49 | 4844.28 | 6.35 | 8619.24 | 6.25 | 61761.84 | 6.48 |
| 2008 | 10873.38 | 6.52 | 8313.48 | 6.5 | 13000.26 | 6.39 | 18302.76 | 7.31 | 5032.86 | 6.43 | 8183.70 | 6.34 | 63706.44 | 6.69 |
| 2009 | 10987.2 | 6.58 | 8662.08 | 6.26 | 15256.08 | 6.44 | 18311.16 | 6.41 | 5058.9 | 6.43 | 8562.54 | 6.45 | 66837.96 | 6.43 |
| 2010 | 12972.12 | 6.04 | 8093.82 | 6.09 | 16520.28 | 5.81 | 18670.68 | 5.88 | 5490.66 | 5.80 | 8673.00 | 5.89 | 70420.56 | 5.91 |
| 2011 | 10998.96 | 7.42 | 8046.78 | 7.38 | 17252.34 | 7.16 | 18561.48 | 7.24 | 5250 | 7.17 | 8606.64 | 7.34 | 68716.2 | 7.27 |
| 2012 | 12943.98 | 7.44 | 8687.28 | 7.35 | 16872.66 | 7.24 | 18785.76 | 7.30 | 5559.54 | 7.23 | 10578.54 | 7.29 | 73427.76 | 7.31 |
| 2013 | 15764.28 | 6.71 | 8580.18 | 6.64 | 16766.4 | 6.57 | 21052.5 | 6.82 | 6773.76 | 6.36 | 11263.98 | 6.36 | 81881.10 | 6.64 |

## 1.3 Materials and Methods

The experiments carried out in this study deal with two bread wheat (*Triticum aestivum* L.) varieties (Sakha 93: salt-tolerant and Sids 12: salinity sensitive) response to different salinity levels under specific growing season, winter-spring, and semi-arid environmental conditions.

### 1.3.1 STUDY AREA

The study area is El Fayoum governorate (Figure 12), Egypt, which is described in details in chapter one.

*Figure 12; Aerial view for El Fayoum governorate, Egypt*

- **Experimental and Site Description**

The field experiment had been conducted in the period November 2013-April 201 and it was applied in three different sites. The experiment was carried out at the experimental farm of the faculty of Agriculture, El Fayoum University which is located at Deimo city, El Fayoum Governorate, Egypt. Deimo is located 6 km off El Fayoum with an altitude of 28 m above the sea level.

- **Plant materials**

Two Egyptian varieties of bread wheat (Triticum aestivum L.) were obtained from Egypt. Sakha 93 is usually cultivated in saline areas in Egypt while Sids 12 is sensitive to salinity. The main characteristics of Sakha 93 and other sensitive variety Sids 1 are summarized in (Table 5) **Errore. L'origine riferimento non è stata trovata.**.

The three experiments conducted on bread wheat (Triticum aestivum L.) varieties; (Sakha 93: salt-tolerant and Sids 12: salinity sensitive.) For crops, the experimental layout was a randomized block design with four replicates for each salinity level as illustrated in Figure 13. There were 8 plots for each experiment: with a size of (3.5*3m).

*Table 5; Characteristics of different Egyptian bread wheat, El Fayoum agricultural and land reclamation directorate*

| **Characteristics** | Sakha 93 | Sids 1 |
|---|---|---|
| **Cross Name** | SAKHA 92/TR810328 | HD21/PAVON ˝S ˝//1158.57/ MAYA7 4˝ S ˝ |
| **D F** | 90 Days | 100 Days |
| **D H** | 150 Days | 160 Days |
| **Spike Length** | ------- | 14 cm |
| **Plant height** | 95 cm | 110-115 cm |
| **Protein %** | 12% | 13.20% |
| **1000-grain weight** | 45 g | 44 g |
| **Grain yield (t/ha)** | 7.14 t/ha | 6.78 t/ha |

- **Experiment Locations**

Figure 13 represents the different locations as follows:

Location one; at 29$^{o}$ 17’ 27.61 N latitude, 30$^{o}$ 55’ 08.49 E longitude, while the altitude is 28 m above the sea level, and clay soil has electric conductivity (8.64 dS $m^{-1}$).

Location two; at $29^{o}$ 17' 40.74 N latitude, $30^{o}$ 54'59.41 E longitude, while the altitude is 28 m above the sea level, and clay soil has electric conductivity (4.6 dS $m^{-1}$).

Location three; at $29^{o}$ 17’ 44.70 N latitude, $30^{o}$ 54’55 E longitude, while the altitude is 28 m above the sea level, and clay soil has electric conductivity (16.5 dS $m^{-1}$).

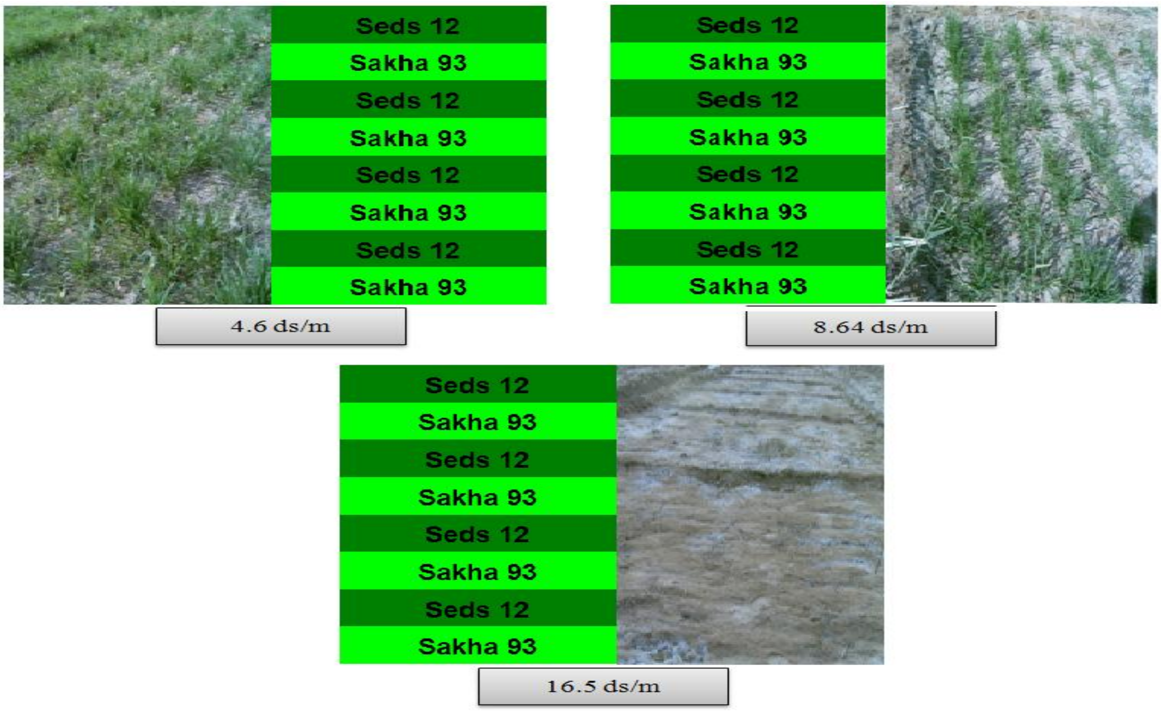
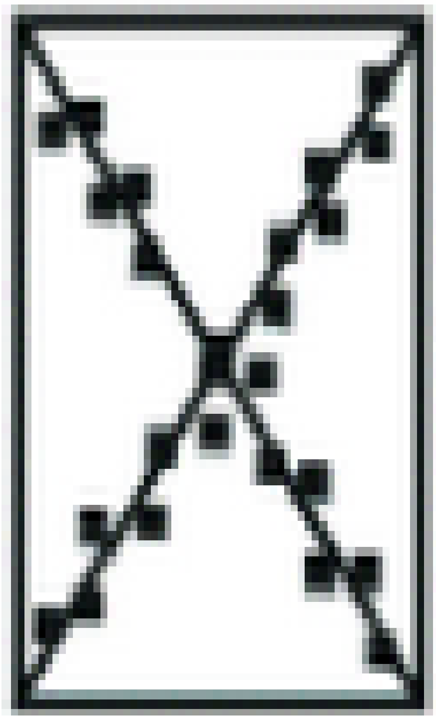



*Figure 13; Three experiments with 8 plots for each experiment*

### 1.3.2 AGRICULTURE PRACTICES

***Soil sampling method***

The samples were collected on a systematic way; the samples were located on X-shape (Figure 14-a) that forms the diagonals of the location. The probe used to collect the sample is shown in (Figure 14-b). The overall collected samples from a certain location were then mixed up forming 1 big sample that was used for lab analyses.



**a** **b**

*Figure 14; a- the shape of location diagonals and location of the samples, b- the probe used to collect the soil samples.*

➢ **Chemical analysis**

The measurements of these chemical properties were carried out using the techniques described by Page *et al*., (1982) as follow:

- Soil pH, was estimated in soil saturation paste using Beckman pH meter.
- Total soluble salts, the Electrical Conductivity (EC) was determined in the soil saturation paste extract solution by using the EC-meter.
- Soluble Cations; Ca++ and Mg++ were determined in the soil paste extract by titration.
- Soluble Anions, (i.e., CO3=, HCO3- and CL-) were determined in the soil paste extract by titration.

- Soluble sulfate was determined by the difference between total soluble cations and anions.
- Organic matter content was determined according to Walkly and Black's methods. The chemical analyses of the soil samples extracted from locations 1 and 2 are summarized in Table 6**Errore. L'origine riferimento non è stata trovata.** and Table 7, respectively.

*Table 6; some chemical characteristics of experimental soil at location 1*

| pH 1:2.5 | O.M % | EC ds $m^{-1}$ at 25°C | $Ca^{++}$ | $Na^{+}$ | $Mg^{++}$ mg/kg | $K^{+}$ mg/kg | $CO_3^{--}$ | $HCO_3^{-}$ | Cl | $So_4$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.71 | 1.36 | 8.64 | 33.4 | 65 | 8.4 | 1.4 | - | 4.2 | 50 | 53.8 |

*Table 7;  some chemical characteristics of experimental soil at location 2*

| pH 1:2.5 | O.M % | EC ds $m^{-1}$ at 25°C | $Ca^{++}$ | $Na^{+}$ | $Mg^{++}$ mg/kg | $K^{+}$ mg/kg | $CO_3^{--}$ | $HCO_3^{-}$ | Cl | $So_4$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.78 | 1.36 | 4.6 | 33.4 | 30 | 8.4 | 1.2 | - | 3.6 | 37 | 30.7 |

- **Physical analysis**

Mechanical analysis was carried out according to the international pipette method. Also, Calgon solution was used as a dispersing agent as described by Gee & Bauder (1986).

The summery of the physical and texture properties for the soil composition of locations 1 and 2 are summarized in Table 8 and Table 9 respectively.

*Table 8; texture class of soil at location 1*

| **Particle Size distribution %** | | | **Texture class** |
|---|---|---|---|
| **Sand** | **Silt** | **Clay** | |
| 28.4 | 12.3 | 59.3 | Clay |

*Table 9; texture class of soil at location 2*

| **Particle Size distribution %** | | | **Texture class** |
|---|---|---|---|
| **Sand** | **Silt** | **Clay** | |
| 31.8 | 11.4 | 56.8 | Clay |

***Fertilization strategies***

Urea was added at a rate of 120 and 140 kg ha-1 for clay soils, according to official release for Faculty of Agriculture, El Fayoum University, time of fertilizer application, following showed in Table 10 as follows:

*Table 10; time of fertilizer application*

| **Date of fertilization** | **For all location** |
|---|---|
| 16/12/2013 | 350 g/replicate |
| 04/01/2014 | 350 g/replicate |

***Irrigation treatments.***

Irrigation water was applied in the three locations as the same amount of control in the real field. The dates and amount of irrigation water are showed in the Table 11. Where Table 12 summarizes the growth stage at the specific time of irrigation rounds.

*Table 11; The dates of the irrigation*

| **Irrigation** (water as non-limiting factor) | Location 1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Location 3 (16.5 ds/m) |
|---|---|---|---|
| **Date of irrigation** | 26/11/2013 | 26/11/2013 | 26/11/2013 |
| | 16/12/2013 | 16/12/2013 | |
| | 04/01/2014 | 04/01/2014 | |
| | 06/02/2014 | 06/02/2014 | |
| | 02/03/2014 | 02/03/2014 | |
| | 23/03/2014 | 23/03/2014 | |

*Table 12; showed the time of irrigation with plant stage of BBCH*

| **Dates** | **(BBCH-scale)** | **Plant Stage** |
|---|---|---|
| 26-Nov | 0 | Initial |
| 16-Dec | 12 | |
| 04-Jan | 19 | Development |
| | 23 | |
| | 32 | |
| 06-Feb | 45 | Mid-season |
| 02-Mar | 71 | |
| | 75 | |

**Determinations:** At the end of the experiment, 24 April 2013, the harvesting processes have been started in terms of collecting the plant and shows the development stages from sowing to harvesting date (Table 13).

*Table 13; Shows the development stages from sowing to harvesting date*

| | **Location 1 (8.64 ds/m)** | **Location 2 (4.6 ds/m)** | **Location 3 (16.5 ds/m)** |
|---|---|---|---|
| Sowing date | 26/11/2013 | 26/11/2013 | 26/11/2013 |
| Emergence | 04/12/2013 | 03/12/2013 | nn |
| Leaves development (3 Leaves) | 20/12/2013 | 20/12/2013 | nn |
| Flowering | 19/02/2014 | 13/02/2014 | |
| Physiological Maturity | 11/04/2014 | 02/04/2014 | |
| Harvesting | 24/04/2014 | 24/04/2014 | |

### 1.3.3 THE STUDIED CHARACTERS

➢ **Sampling strategy**

The measurements were carried out at vegetation, reproductive, and grain maturity stages.

- Measurements at vegetation stage were conducted at 62 days after sowing (DAS).
- Measurements at reproductive stage were conducted at 90 days after sowing.
- Measurements at grain maturity stage were conducted at 149 days after sowing.

At the vegetation stage, on the 62$^{nd}$ day after sowing, ten plants from each replicate experimental unite were harvested and separated into leaves and stems, then plant materials were dried at 90 °c for 24 hours in order to determine DW.

- The characters, which were measured, were:
- Plant height (cm)
- Number of leaves (n)
- Dry weight of leaves (g)
- Dry weight of stem (g)
- Fresh weight of plant (g)
- Dry weight of plant (g).

At the vegetation stage, on the $90^{th}$ day, after sowing, ten plants from each replicate experimental unite were harvested and separated into leaves, stems and ears, then plant materials were dried at 90 °c for 24 hours in order to determine DW.

The characters, which were measured, were:

- Plant height (cm)
- Dry weight of plant (g)
- Fresh weight of ear (g)
- Dry weight of ear (g)
- Ear length (cm)
- Number of tillers (n)
- Number of leaves (n)
- Fresh weight of leaves (g)
- Dry weight of leaves (g)
- Fresh weight of stem (g)
- Dry weight of stem (g).

At the grain maturity stage, the harvest area was cut at ground level and bounded, then, one line was collected randomly from each replicate experimental unite, weight was recorded and the plant samples were oven dried. A sub-sample of ten stems was threshed separately. Straws and grains were saved for analysis using the standard equation to determine the average of the following characters:

- Plant height (cm)
- Ear length (cm)
- Number of Ears/plant (n)
- Number of Ears/m2 (n)
- Number of tillers/plant (n)
- Number of plants/m2 (n)
- Number of spikelets/ear (n)
- Weight of plants/m2 (g)
- Grain yield/plant (g)
- Weight of grains/ear (g)
- 1000-grain weight (g)
- Grain yield (t/ha) : Were calculated based on their determination per $m^2$
- Harvest index (%): According to Wallace *et al.*, (1972) It was expressed as follows:

Harvest index = (Economic yield / Total biological yield) * 100

### 1.3.4 STATISTICAL ANALYSIS:

- **Analysis of Variance Univariate**

The variables were tested with IBM SPSS 21© with a univariate model of ANOVA using the previously mentioned the two locations as a source of variations. The results showed high salinity (8.64 dS $m^{-1}$) and low salinity (4.6 dS $m^{-1}$) in the two bread wheat (*Triticum aestivum* L.) variety, Sids 12 and Sakha 93 respectively. The following section represents the table of Mean and ANOVA.

## 1.4 Results and discussion

The present study was carried out under Egyptian conditions in two experiment fields represent textured soils, i.e. clay soils and two different levels of salinity respectively referred as high salinity (8.64 dS $m^{-1}$) and low salinity (4.6 dS $m^{-1}$) and the two bread wheat (Triticum aestivum L.) varieties, respectively (Sakha 93: salt-tolerant and Sids 12: salinity sensitive).

Data released from this study will be discussed in the following chapter

### 1.4.1 FLOWERING TIME (DAY)

Results showed that decreased number of days from sowing to flowering in location 2 (4.6 dS $m^{-1}$) compared to location 1 (8.64 dS $m^{-1}$). This result was in line with that obtained by who recorded clear for genotype sown.

### 1.4.2 HARVEST INDEX %

Without statistical analysis, results with regarding harvest index showed that highest values of harvest index 31.30, 25.90 and 31.80% were recorded by location 2, Sids 12 and the combination of location 2 and Sids 12, respectively (Table 14).

*Table 14; Means of harvest index as affected by Level of electric conductivity, varieties and their interaction.*

| Harvest Index (%) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 19.9 | 31.8 | 25.9 |
| Sakha 93 | 18.3 | 30.7 | 24.5 |
| Mean | 19.1 | 31.3 | 25.2 |

### 1.4.3 MEANS OF YIELD AND ITS COMPONENTS AS AFFECTED BY SOIL SALINITY IN TERMS OF ELECTRIC CONDUCTIVITY, VARIETIES AND THEIR INTERACTION AT 62, 90 AND 149 DAYS AFTER SOWING.

Means of yield and its components as affected by soil salinity related to EC and varieties and their interaction are shown in Table 44, Table 45, and Table 46.

***Measurements at grain maturity stage were conducted at 149 days after sowing.***

- **Plant height (cm)**

Results showed in that the plant height at 149 DAS was not significantly (P < 0.05) influenced by varieties, locations and their interaction (Table 15 and Table 44). Average of plant height at 149 DAS for Sids12 was (86.80 cm) while (81.10 cm) for Sakha 93, while averages (82.80 and 85.10 cm) were recorded at location 1 and location 2, respectively. Location 2-x Sids12 interaction gave the highest plant (87.80 cm). On the other hand, plant height at harvest was significantly affected by salinity levels as reported by El-Lethy *et al.*, (2013).

*Table 15; Means of plant height as affected by Level of electric conductivity, varieties and their interaction.*

| Plant height (cm) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 85.8 | 87.8 | 86.8 |
| Sakha 93 | 79.7 | 82.5 | 81.1 |
| Mean | 82.8 | 85.1 | 83.9 |

- **Ear length (cm)**

Results in Table 16 and Table 44 clarified that insignificant difference for varieties, locations and their interaction when ear length concerned. While results of Asgari *et al.*, (2011) showed that ear length for all wheat genotypes in his study decreased with increasing salinity levels.

*Table 16; Means of ear length as affected by Level of electric conductivity, varieties and their interaction.*

| Ear length (cm) | | | |
|---|---|---|---|
| | EC | | |
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 10.0 | 11.3 | 10.7 |
| Sakha 93 | 10.8 | 10.8 | 10.8 |
| Mean | 10.4 | 11.1 | 10.7 |

- **Number of ear/ plant (n)**

The ANOVA indicated that no significant differences between number of ear/plant at 149 DAS due to varieties, locations and their interaction as revealed in Table 17 and Table 44. Asgari *et al.*, (2012) showed that the effect of salinity levels on number of ear/plant of all wheat genotypes was significantly decreased.

*Table 17; Means of number of ear/plant as affected by Level of electric conductivity, varieties and their interaction.*

| Number of ear/ plant (n) | | | |
|---|---|---|---|
| | EC | | |
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 4.0 | 3.6 | 3.8 |
| Sakha 93 | 4.3 | 4.5 | 4.4 |
| Mean | 4.1 | 4.0 | 4.1 |

- **Number of ears/m$^2$**

No significant differences due to varieties and interaction between varieties and locations for number of ears/m$^2$ at 149 DAS were observed. However, there was significant difference due to locations, the highest number of ears/m$^2$ (254.60) was obtained by location 2 (4.6 dS m$^{-1}$) compared to (201.20) for location 1 (8.64 dS m$^{-1}$) as showed in Table 18 and Table 44. This result of the effect of salinity on number of ears/ m$^2$ also was observed by Khan *et al.*, (2008).

*Table 18; Means of number of ears/m² as affected by Level of electric conductivity, varieties and their interaction.*

| Number of ears/m2 | | | |
|---|---|---|---|
| | EC | | |
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 213.4 | 250.6 | 232.0 |
| Sakha 93 | 189.0 | 258.6 | 223.8 |
| Mean | 201.2 | 254.6 | 227.9 |

- **Number of tillers/ plant**

Results in Table 19 and Table 44 illustrated that the varieties, locations and their interaction have no significant effects on number of tiller/plant at 149 DAS. Inverse result was reported by Howladar & Dennett (2014) that number of tillers/plant reduced significantly under saline conditions.

*Table 19; Means of number of tillers/plant as affected by Level of electric conductivity, varieties and their interaction.*

| Number of tillers/ plant | | | |
|---|---|---|---|
| | EC | | |
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 4.1 | 3.6 | 3.8 |
| Sakha 93 | 4.4 | 4.5 | 4.5 |
| Mean | 4.2 | 4.0 | 4.1 |

- **Number of plants/m²**

Number of plant/m² at 149 DAS was not significantly affected by varieties, locations and their interaction as showed in Table 20 and Table 44.

*Table 20; Means of number of plants/m² as affected by Level of electric conductivity, varieties and their interaction.*

| Number of plants/m2 | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 105.4 | 86.9 | 96.1 |
| Sakha 93 | 94.6 | 85.1 | 89.9 |
| Mean | 100.0 | 86.0 | 93.0 |

- **Number of spikelets/ear**

Results in Table 21 and Table 44 clarified that mean values of number of spikelets/ear at 149 DAS were not significantly influenced by varieties, locations and their interaction. While previous studies showed that number of spikelets/ear were significantly influenced by salinity levels (AKram *et al.*, 2002 and Asgari *et al.*, 2012).

*Table 21; Means of number of spikelets/ear as affected by Level of electric conductivity, varieties and their interaction.*

| Number of spiklets/ear | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 17.8 | 18.0 | 17.9 |
| Sakha 93 | 19.3 | 19.8 | 19.6 |
| Mean | 18.6 | 18.9 | 18.7 |

- **Weight of plants/m² (g)**

Data in Table 22 and Table 44 showed that the varieties as a main effect and the varieties x locations interaction were insignificantly effected on averages of weight of plants/m2 at 149 DAS. However, locations as a main effect were significantly ($P < 0.05$) influenced on this trait, where the heaviest weight of plants/m² (2602.90 g) was recorded at location 1 compared to (2207.1 g) at location 2. While Kumar *et al.*, (2012) revealed that salinity level >3 dS $m^{-1}$ showed a reduction in dry weight/plant.

*Table 22; Means of weight of plants/m² as affected by Level of electric conductivity, varieties and their interaction.*

| Weight of plants/m2 (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 2057.1 | 2565.7 | 2311.4 |
| Sakha 93 | 2357.1 | 2640.0 | 2498.6 |
| Mean | 2207.1 | 2602.9 | 2405.0 |

- **Grain yield/ plant (g)**

Mean values of grain yield/plant showed insignificant difference due to varieties, locations and their interaction. However, Abbas *et al.*, (2013) found that salinity resulted in a significant reduction of grain yield/plant as seen in Table 23 and Table 44.

*Table 23; Means of grain yield/plant as affected by Level of electric conductivity, varieties and their interaction.*

| Grain yield/ plant (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 8.2 | 10.9 | 9.6 |
| Sakha 93 | 10.1 | 12.1 | 11.1 |
| Mean | 9.1 | 11.5 | 10.3 |

- **Weight of grains/ear (g)**

Results presented in Table 24 and Table 44 revealed that weight of grains/ear was remarkably ($P < 0.05$) influenced by locations, the location 2 (4.6 dS $m^{-1}$) gave heaviest weight (2.9 g) exceeded that of location 1 (8.64 dS $m^{-1}$) which was (2.20 g). While the varieties main effect and the interaction between varieties and locations were not significantly influenced on this trail. These results are in line with Ali *et al.*, (2012).

*Table 24; Means of weight of grains/ear as affected by Level of electric conductivity, varieties and their interaction.*

| Weight of grains/ear (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 2.1 | 3.1 | 2.6 |
| Sakha 93 | 2.3 | 2.7 | 2.5 |
| Mean | 2.2 | 2.9 | 2.5 |

- **1000-grain weight (g)**

Results in Table 25 and Table 44 indicated that in case of 1000-grain weight, the interaction between varieties and locations showed a significant (P < 0.05) effect, the combination of location 2 with Sakha 93 registered higher average value (61.1g). Also, locations caused a significant (P < 0.05) effect on1000-grain weight which location 2 produced the heaviest 1000-grain weight (58.4g). This result is in agreement with those of Khan *et al.*, (2008) and Zheng *et al.*, (2009).

*Table 25; Means of 1000-grain weight as affected by Level of electric conductivity, varieties and their interaction.*

| 1000-grain weight (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 55.3 | 55.6 | 55.4 |
| Sakha 93 | 51.1 | 61.1 | 56.1 |
| Mean | 53.2 | 58.4 | 55.8 |

- **Grain yield (t/ha)**

Results in Table 26 and Table 44 showed that only locations as a main effect has showed a significant (P < 0.05) effect on grain yield (t/ha), where location 2 results in higher yield (8.1 t/h) over both varieties compared to (4.9 t/h) from location 1. This is in accordance with findings of Katerji *et al.,* (2009); Yadav *et al.,* (2011).

*Table 26; Means of grain yield (t/ha) as affected by Level of electric conductivity, varieties and their interaction.*

| Grain yield (t/ha) | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 4.8 | 8.1 | 6.5 |
| Sakha 93 | 5.0 | 8.1 | 6.5 |
| Mean | 4.9 | 8.1 | 6.5 |

***Measurements at reproductive stage were conducted at 90 days after sowing.***

- **Plant height (cm)**

Results in Table 27 and Table 45 revealed that while the interaction between varieties and locations and the varieties main effect were not significantly influenced, the plant height at 90 DAS was significantly ($P < 0.05$) influenced by the varieties. In particular, the plant height at 90 DAS is higher (74.40 cm) in the variety Sids 12 compared to (58.30 cm) the variety Sakha 93.

*Table 27: Means of harvest plant height as affected by Level of electric conductivity, varieties and their interaction.*

| Plant height (cm) | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 75.2 | 73.7 | 74.4 |
| Sakha 93 | 54.8 | 61.8 | 58.3 |
| Mean | 65.0 | 67.7 | 66.4 |

- **Dry weight of plant (g)**

Data in Table 28 and Table 45 revealed that there were insignificant differences due to varieties, locations and their interaction for plant weight DM at 90 DAS.

*Table 28; Means of dry weight of plant as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of plant (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 71.6 | 67.2 | 69.4 |
| Sakha 93 | 64.8 | 76.4 | 70.6 |
| Mean | 68.2 | 71.8 | 70.0 |

- **Fresh weight of ear (g)**

Data in Table 29 and Table 45 concerning fresh weight of ear at 90 DAS showed that there were no significant effects on this trait due to varieties, locations and their interaction.

*Table 29; Means of fresh weight of ear as affected by Level of electric conductivity, varieties and their interaction.*

| Fresh weight of ear (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 48.1 | 51.0 | 49.6 |
| Sakha 93 | 46.2 | 68.1 | 57.1 |
| Mean | 47.1 | 59.5 | 53.3 |

- **Dry weight of ear (g)**

As seen from Table 30 and Table 45 the varieties, locations and their interaction have no significant effect on dry weight of ear at 90 DAS.

*Table 30; Means of dry weight of ear as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of ear (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 EC) | Location 2 (4.6 EC) | **Mean** |
| Sids 12 | 15.9 | 16.8 | 16.3 |
| Sakha 93 | 14.4 | 21.3 | 17.9 |
| Mean | 15.2 | 19.0 | 17.1 |

- **Ear length (cm)**

The main effect of varieties and the interaction between varieties and locations were insignificant when ear length at 90 DAS was concerned. On the other hand, the ear length at 90 DAS was significantly influenced, the highest value (10.70 cm) of ear length was produced in location 2 compared to (9.30 cm) for location 1, as represented in Table 31 and Table 45.

*Table 31; Means of ear length as affected by Level of electric conductivity, varieties and their interaction.*

| Ear length (cm) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 9.5 | 10.9 | 10.2 |
| Sakha 93 | 9.1 | 10.5 | 9.8 |
| Mean | 9.3 | 10.7 | 10.0 |

- **Number of tillers (n)**

Mean values in Table 32 and Table 45 showed that the differences in number of tillers at 90 DAS due to varieties, locations and their interaction were not significant.

*Table 32; Means of number of tillers as affected by Level of electric conductivity, varieties and their interaction.*

| Number of tillers (n) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 2.7 | 2.1 | 2.4 |
| Sakha 93 | 3.0 | 3.0 | 3.0 |
| Mean | 2.8 | 2.5 | 2.7 |

- **Number of leaves (n)**

Data in Table 33 and Table 45 revealed that neither the interaction between varieties and locations nor and the main effect of locations have significant effects on the number of leaves at 90 DAS, while varieties caused a significant effect on this traits. Higher numbers of leaves

(6.00) were registered with Sids 12 compared to (4.90) with Sakha 93. These results are in line with Yadav *et al*., (2011).

*Table 33; Means of number of leaves as affected by Level of electric conductivity, varieties and their interaction.*

| Number of leaves (n) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 5.9 | 6.0 | 6.0 |
| Sakha 93 | 5.0 | 4.9 | 4.9 |
| Mean | 5.4 | 5.4 | 5.4 |

- **Fresh weight of leaves (g)**

Both varieties and locations as a main effects and their interaction have no significant effects on fresh weight of leaves at 90 DAS as represented in Table 34 and Table 45.

*Table 34; Means of fresh weight of leaves as affected by Level of electric conductivity, varieties and their interaction.*

| Fresh weight of leaves (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 60.1 | 50.0 | 55.1 |
| Sakha 93 | 66.3 | 61.2 | 63.7 |
| Mean | 63.2 | 55.6 | 59.4 |

- **Dry weight of leaves (g)**

Dry weight of leaves at 90 DAS was insignificantly influenced by varieties, locations and their interaction as showed in Table 35 and Table 45.

*Table 35; Means of dry weight of leaves as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of leaves (g) | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 15.3 | 12.6 | 14.0 |
| Sakha 93 | 14.3 | 15.0 | 14.6 |
| Mean | 14.8 | 13.8 | 14.3 |

- **Fresh weight of stem (g)**

Results in Table 36 and Table 45 showed that the effects of varieties and locations as a main effects and their interaction have no significant effect on fresh weight of stem at 90 DAS.

*Table 36; Means of fresh weight of stem affected by Level of electric conductivity, varieties and their interaction.*

| Fresh weight of stem (g) | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 152.0 | 131.1 | 141.6 |
| Sakha 93 | 153.1 | 154.9 | 154.0 |
| Mean | 152.6 | 143.0 | 147.8 |

- **Dry weight of stem (g)**

Results in Table 37 and Table 45 indicated that varieties and locations as a main effects and their interaction have no significant effects on dry weight of stem at 90 DAS.

*Table 37; Means of dry weight of stem as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of stem (g) | EC | | |
|---|---|---|---|
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 40.3 | 37.8 | 39.1 |
| Sakha 93 | 36.0 | 40.1 | 38.1 |
| Mean | 38.2 | 38.9 | 38.6 |

***Measurements at vegetation stage were conducted at 62 days after sowing.***

- **Plant height (cm)**

Neither the locations nor the interaction between varieties and locations were significantly influenced on plant height at 62 DAS. In contrast, the plant height at 62 DAS over locations was significantly (P<0.05) influenced by varieties. The tallest plant (30.00 cm) was observed in Sids 12 compared to (27.00 cm) in Sakha 93 as showed in Table 38 and Table 46. This is in agreement with the result of Khan *et al.,* (2008).

*Table 38; Means of plant height as affected by Level of electric conductivity, varieties and their interaction.*

| Plant height (cm) | | | |
|---|---|---|---|
| | EC | | |
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 28.8 | 31.3 | 30.0 |
| Sakha 93 | 26.5 | 27.5 | 27.0 |
| Mean | 27.6 | 29.4 | 28.5 |

- **Number of leaves (n)**

As showed in Table 39 and Table 46 either the locations or the interaction between varieties and locations have not significantly influenced the number of leaves at 62 DAS. In contrary, the number of leaves at 62 DAS cross-locations was significantly (P<0.05) affected by varieties. The variety sids 12 recorded highest number of leaves at 62 DAS (6.00) compared to (5.00) for Sakha 93. This may be due to the genetic diversity between the two genotypes under this study. Similar result was found by El-Hendawy *et al.,* (2005).

*Table 39; Means of number of leaves as affected by Level of electric conductivity, varieties and their interaction.*

| Number of leaves (n) | | | |
|---|---|---|---|
| | EC | | |
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 5.8 | 6.3 | 6.0 |
| Sakha 93 | 5.0 | 5.0 | 5.0 |
| Mean | 5.4 | 5.6 | 5.5 |

- **Dry weight of leaves (g)**

Data presented in Table 40 and Table 46 that the varieties and locations were significantly ($P<0.05$) effected on dry weight of leaves, but the varieties x locations interaction has no significantly influence on this trait. Dry weights of leaves at 62 DAS were the highest (4.10 and 4.20g) for the variety sids 12 and location 2 compared to the lowest mean values (3.60 and 3.50g) for Sakha 93 and location 1, respectively. Reduction dry weight of leaves at 62 DAS might be due to lower uptakes of water and nutrients from the growing media due to higher concentration of salts present in the root zone, which may causes imbalances in osmotic pressure. This agreement with Saqib *et al.,* (2006).

*Table 40; Means of dry weight of leaves as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of leaves (g) | | | |
|---|---|---|---|
| | EC | | |
| Variety | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | Mean |
| Sids 12 | 3.6 | 4.7 | 4.1 |
| Sakha 93 | 3.5 | 3.7 | 3.6 |
| Mean | 3.5 | 4.2 | 3.9 |

- **Dry weight of stem (g)**

While the varieties main effect and the interaction between varieties and locations have no significant influence on the dry weight of stem at 62 DAS, the locations main effect has significant ($P<0.05$) influence as showed in Table 41 and Table 46. Location 2 recorded the greatest mean value (6.50 g) compared to (5.20 g) for location 1. Reduction dry weight of stem at 62 DAS under salt stress might be due to reduced transport of essential nutrient to the stem. This result is in line with Shahzad *et al.*, (2006).

*Table 41; Means of dry weight of stem as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of stem (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 5.2 | 7.1 | 6.2 |
| Sakha 93 | 5.2 | 5.9 | 5.5 |
| Mean | 5.2 | 6.5 | 5.9 |

- **Fresh weight of plant (g)**

Although Results in Table 42 and Table 46 indicated that the interaction effect between varieties and locations was insignificant, the difference between varieties or locations was significant at ($P<0.05$). The highest fresh weights of plant (62.50 and 61.90 g) were produced by Sids 12 and location 2 compared to the lowest mean value (51.90 and 52.50g) by Sakha 93 and location 1, respectively. This result is supported by Sourour *et al.*, (2014).

*Table 42; Means of fresh weight of plant as affected by Level of electric conductivity, varieties and their interaction.*

| Fresh weight of plant (g) | EC | | |
|---|---|---|---|
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 56.3 | 68.8 | 62.5 |
| Sakha 93 | 48.8 | 55.0 | 51.9 |
| Mean | 52.5 | 61.9 | 57.2 |

- **Dry weight of plant (g)**

However, the interaction effect between varieties and locations was not significant on dry weight of plant at 62 DAS, the effect of varieties and locations were significant ($P<0.05$)

evident on this trait. Dry weight of plants at 62 DAS were higher (10.30 and 10.70 g) for variety sids 12 and location 2 compared to lower (9.10 and 8.70 g) for the variety Sakha 93 and location 1, respectively (Table 43 and Table 46). This is in accordance with Sourour *et al.*, (2014).

*Table 43; Means of dry weight of plant as affected by Level of electric conductivity, varieties and their interaction.*

| Dry weight of plant (g) | | | |
|---|---|---|---|
| | **EC** | | |
| **Variety** | Location1 (8.64 ds/m) | Location 2 (4.6 ds/m) | **Mean** |
| Sids 12 | 8.8 | 11.7 | 10.3 |
| Sakha 93 | 8.6 | 9.6 | 9.1 |
| Mean | 8.7 | 10.7 | 9.7 |

All vegetative growth traits at 62 DAS (i.e. plant height, number of leaves, dry weight of leaves and fresh and dry weight of plant) and at 90 DAS (i.e. plant height and number of leaves) were significantly influenced by verities. This may be due to the genetic diversity between the two genotypes under this study.

On the other side, locations main effect was significant on dry weights of leaves and stems and fresh and dry weight of plant at 62 DAS. This may be attributed to adverse effect of salinity on plant growth, and may be due to lower uptakes of water and nutrients from the soil due to higher concentration of salts present in the root zone, which may causes imbalances in osmotic pressure, thus the reduction in plant height Kumar *et al.*, (2012).

Furthermore, yield and yield components (number of ears/$m^2$, weight of plants/$m^2$, weight of grains/ear, 1000-grain weight and grain yield per ha at 149 DAS) of bread wheat were affected significantly by locations. This may be due to direct or indirect inhibit of salinity on cell division, cell enlargement, resulting in reduction of plant height, number of leaves, dry matter accumulation, leaf area, mobilization of nutrients from source to sink Kumar *et al.*, (2012). Another hypothesis might be due to the reduction in total biomass in the sensitive genotype (Sids 12) was probably due to the extra energy utilization for osmotic accumulation, which is much more ATP consuming for osmotic adjustment El-Hendawy *et al.,* (2005). In addition to salinity stress that may cause shortening the duration of spikelet differentiation, resulting in fewer spikelets per spike, thus reduction of weight of grains/ear, consequently, the reduction in the end grain yields / ha Akram *et al.,* (2002).

Results revealed that the interaction effect between varieties and locations has markedly affected 1000-grain weight. This may be indicated that the fact that tolerant genotype (Sakha 93) has a capability to better nutrient and water absorption that provide maximum leaf area that resulting in better accumulation of photo-assimilate in plant.

## 1.5 Conclusion

The field experiment was performed in 3 different geographical locations with different electric conductivity levels. The first two locations successfully produced wheat, while the third location did not. The main logical justification related to the third location is the very high existing level of electric conductivity (16.5 dS $m^{-1}$). The achieved results confirmed that salinity has a strong effect on wheat production, as the location characterized by 4.6 dS $m^{-1}$ gave a mean production of 8.1 t/ha, while the location with 8.64 dS $m^{-1}$ gave a mean harvest of 4.9 t/ha. In addition, the 1000-grain weight was 58.4 g in the location with 4.6 dS $m^{-1}$, and 53.2 g for the location with 8.64 dS $m^{-1}$.

The challenges for wheat breeders and growers aiming to meet the demand of a growing population with a changing diet are tremendous nowadays. By using advanced genetic techniques and a great deal of patience they have been able to constantly increase the yield potential of wheat cultivars. Nevertheless, we must improve our understanding of wheat breeding, and particularly of the physiological traits of wheat genotypes and their interactions with the environment, to improve wheat yield genetic potential towards increasing wheat production without agricultural expansion.

Based on the review carried out within the framework of this study, the most urgent goals we need to achieve are the following:

- Monitor wheat diseases and develop wheat varieties with durable resistance;
- Increase resource use efficiency and tolerance to abiotic stress;
- Improve the nutritional and processing quality and safety of wheat varieties;
- Tailor wheat varieties and types to diverse agro-systems and production systems;
- Have all breeders implement modern breeding methods;
- Develop Information Systems on wheat, providing easy access to data to all the stakeholders.

Particularly, an integrated *Wheat Information System* could provide to the international wheat research community an easy access to existing and future genetic, genomic, phenotypic and agronomic data as well as bioinformatics tools and services to visualize, analyze and connect the different types of data.

*Table 44; Means of yield and its components as affected by Level of electric conductivity, varieties and their interaction (DAS 149).*

| Treatments | Levels | Plant height ( cm ) | Ear length ( cm ) | Number of Ears/plant ( n ) | Number of Ears/m2 ( n ) | Number of tillers/plant ( n ) | Number of plants/m2 ( n ) | Number of spikelets/ear ( n ) | Weight of plants/m2 ( g ) | Grain yield/plant ( g ) | Weight of grains/ear ( g ) | 1000-grain weight (g) | Grain yield (t/ha ) | Grain yield ($g/m^2$) | Harvest index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Varieties (V) | $V_1$ | 86.8 | 10.7 | 3.8 | 232.0 | 3.8 | 96.1 | 17.9 | 2311.4 | 9.6 | 2.6 | 55.4 | 6.5 | 647.1 | 25.9 |
| | $V_2$ | 81.1 | 10.8 | 4.4 | 223.8 | 4.5 | 89.9 | 19.6 | 2498.6 | 11.1 | 2.5 | 56.1 | 6.5 | 654.9 | 24.5 |
| L.S. | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| Salinity (L) | $L_1$ | 82.8 | 10.4 | 4.1 | 201.2 | 4.2 | 100.0 | 18.6 | 2207.1 | 9.1 | 2.2 | 57.7 | 4.9 | 490.6 | 19.1 |
| | $L_2$ | 85.1 | 11.1 | 4.0 | 254.6 | 4.0 | 86.0 | 18.9 | 2602.9 | 11.5 | 2.9 | 58.4 | 8.1 | 811.4 | 31.3 |
| L.S. | | ns | ns | ns | * | ns | ns | ns | * | ns | * | * | * | * | |
| Interaction (V x L) | $V_1$ x $L_1$ | 85.8 | 10.0 | 4.0 | 213.4 | 4.1 | 105.4 | 17.8 | 2057.1 | 8.2 | 2.1 | 55.3 | 4.8 | 479.4 | 19.9 |
| | $V_1$ x $L_2$ | 87.8 | 11.3 | 3.6 | 250.6 | 3.6 | 86.9 | 18.0 | 2565.7 | 10.9 | 3.1 | 55.6 | 8.1 | 814.9 | 31.8 |
| | $V_2$ x $L_1$ | 79.7 | 10.8 | 4.3 | 189.0 | 4.4 | 94.6 | 19.3 | 2357.1 | 10.1 | 2.3 | 51.1 | 5.0 | 501.7 | 18.3 |
| | $V_2$ x$L_2$ | 82.5 | 10.8 | 4.5 | 258.6 | 4.5 | 85.1 | 19.8 | 2640.0 | 12.1 | 2.7 | 61.1 | 8.1 | 808.0 | 30.7 |
| L.S. | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | * | ns | ns | |

$V_1$ and $V_2$ represent wheat varieties Sids 12 and Sakha 93, respectively.
$L_1$ and $L_2$ represent 8.64 Ec and 4.6 Ec levels, respectively.
L.S., level of significance.
* P < 0.05
Non-significant (ns)

*Table 45; Means of yield and its components as affected by Level of electric conductivity, varieties and their interaction (DAS 90).*

| Treatments | Levels | Plant height (cm) | Dry weight of plant ( g ) | Fresh weight of ear ( g ) | Dry weight of ear ( g ) | Ear length ( cm) | Number of tillers ( n ) | Number of leaves ( n ) | Fresh weight of leaves ( g ) | Dry weight of leaves ( g ) | Fresh weight of stem ( g ) | Dry weight of stem (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Varieties (V) | $V_1$ | 74.4 | 69.4 | 49.6 | 16.3 | 10.2 | 2.4 | 6.0 | 55.1 | 14.0 | 141.6 | 39.1 |
| | $V_2$ | 58.3 | 70.6 | 57.1 | 17.9 | 9.8 | 3.0 | 4.9 | 63.7 | 14.6 | 154.0 | 38.1 |
| L.S. | | * | ns | ns | ns | ns | ns | * | ns | ns | ns | ns |
| Salinity (L) | $L_1$ | 65.0 | 68.2 | 47.1 | 15.2 | 9.3 | 2.8 | 5.4 | 63.2 | 14.8 | 152.6 | 38.2 |
| | $L_2$ | 67.7 | 71.8 | 59.5 | 19.0 | 10.7 | 2.5 | 5.4 | 55.6 | 13.8 | 143.0 | 38.9 |
| L.S. | | ns | ns | ns | ns | * | ns | ns | ns | ns | ns | ns |
| Interaction (V x L) | $V_1$ x $L_1$ | 75.2 | 71.6 | 48.1 | 15.9 | 9.5 | 2.7 | 5.9 | 60.1 | 15.3 | 152.0 | 40.3 |
| | $V_1$ x $L_2$ | 73.7 | 67.2 | 51.0 | 16.8 | 10.9 | 2.1 | 6.0 | 50.0 | 12.6 | 131.1 | 37.8 |
| | $V_2$ x $L_1$ | 54.8 | 64.8 | 46.2 | 14.4 | 9.1 | 3.0 | 5.0 | 66.3 | 14.3 | 153.1 | 36.0 |
| | $V_2$ x$L_2$ | 61.8 | 76.4 | 68.1 | 21.3 | 10.5 | 3.0 | 4.9 | 61.2 | 15.0 | 154.9 | 40.1 |
| L.S. | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |

$V_1$ and $V_2$ represent wheat varieties Sids 12 and Sakha 93, respectively.
$L_1$ and $L_2$ represent 8.64 Ec and 4.6 Ec levels, respectively.
L.S., level of significance.
* $P < 0.05$
Non-significant (ns)

*Table 46; Means of yield and its components as affected by Level of electric conductivity, varieties and their interaction (DAS 62).*

| Treatments | Levels | Plant height (cm) | Number of leaves ( n ) | Dry weight of leaves ( g ) | Dry weight of stem ( g ) | Fresh weight of plant ( g ) | Dry weight of plant ( g ) |
|---|---|---|---|---|---|---|---|
| Varieties (V) | $V_1$ | 30.0 | 6.0 | 4.1 | 6.2 | 62.5 | 10.3 |
| | $V_2$ | 27.0 | 5.0 | 3.6 | 5.5 | 51.9 | 9.1 |
| L.S. | | * | * | * | ns | * | * |
| Salinity (L) | $L_1$ | 27.6 | 5.4 | 3.5 | 5.2 | 52.5 | 8.7 |
| | $L_2$ | 29.4 | 5.6 | 4.2 | 6.5 | 61.9 | 10.7 |
| L.S. | | ns | ns | * | * | * | * |
| Interaction (V x L) | $V_1$ x $L_1$ | 28.8 | 5.8 | 3.6 | 5.2 | 56.3 | 8.8 |
| | $V_1$ x $L_2$ | 31.3 | 6.3 | 4.7 | 7.1 | 68.8 | 11.7 |
| | $V_2$ x $L_1$ | 26.5 | 5.0 | 3.5 | 5.2 | 48.8 | 8.6 |
| | $V_2$ x $L_2$ | 27.5 | 5.0 | 3.7 | 5.9 | 55.0 | 9.6 |
| L.S. | | ns | ns | ns | ns | ns | ns |

$V_1$ and $V_2$ represent wheat varieties Sids 12 and Sakha 93, respectively.

$L_1$ and $L_2$ represent 8.64 Ec and 4.6 Ec levels, respectively.

L.S., level of significance.

* $P < 0.05$

Non-significant (ns)

# Chapter II

## Soil Salinity Monitoring in Sinnuris District, El Fayoum Governorate, Egypt

## 2.1 INTRODUCTION

Soil salinity is considered as one of the major limiting factor to crop production in arid and semi-arid regions of the planet. Thus, monitoring and analyzing such problem is of critical importance for land and water resources management and, accordingly, the improvement of agricultural production. In order to assess the degree of soil salinity over a specific span of time, it is mandatory to map salinity. Various techniques of mapping have been used over the time. Geo-statistics is becoming one of the effective techniques for spatial data interpolation. Recently, Kriging is widely used in different disciplines as one of the most powerful data interpolation methods. Therefore, it is here used for soil data interpolation in order to generate salinity map of the study area; the generated maps are then analyzed for monitoring salinity changes and for assessing the main factors related to and causing salinity.

The Electrical Conductivity (EC) value is a combined result of soil's both physical and chemical properties. It has possible applications in agriculture for delineation of management zones and management decisions. For agriculture applications, EC information acts the best when yields are primarily affected by factors that are best related to EC, i.e. salinity level ( Di Shabbir, *et al.*, 2013).

**According to Department of Environment and Primary Industrial**

(http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/water_spotting_soil_salting_class_ranges)

The Soil Salinity Class Ranges are: 1) ECe range: < 2 dS $m^{-1}$ is non saline. 2) ECe range: 2 - 4 dS $m^{-1}$ is slightly saline. 3) ECe range:4 – 8 dS $m^{-1}$ is moderately saline. 4) ECe range: 8 – 16 dS $m^{-1}$, Highly saline and ECe range: > 16 dS $m^{-1}$ is extremely saline.

## 2.2 Theoretical Background

### 2.2.1 SOIL SALINITY

Soil salinity is, mainly, a natural characteristic, while soil salinization is mainly a human induced process (Zinck & Metternicht, 2009). Salinization and alkalinization are the most common soil degradation processes, in arid and semi-arid regions in particular. While such areas being under huge pressure to provide the required food and fiber for the surrounding rapidly increasing inhabitants (Farifteha *et al.*, 2006.) Under such water regime and inappropriate natural drainage systems conditions, there is a real hazard of salt accumulation in land. Basically, this is due to the application of waters containing salts, from both primary and secondary minerals in land, organic matter decay and water table instability (Poshtmasari *et al*., 2012 and Daeia *et al*., 2009). Salinity of soil is considered one of the oldest environmental problems and is counted as one of the seven main reasons to desertification (Kassas, 1987). Due to the accumulation of soluble salts at or near the surface of the land, soil salinity is characterized as in-situ form of soil degradation (Bouaziz *et al*., 2011). Water resources and soil salinity is a pandemic problem among more than 100 countries (Nezami & Alipour, 2012). As a consequence of sodic saltiness, 50 to 100 thousand hectares of arable land become a waste land every year (Nezami & Alipour, 2012). The use of saline water leads to three significant impacts on plants and soil. The first impact is soil aggregates damaging because of the dispersion of the soil particles. The second one is the weakness in the capability of plants to uptake water via increasing osmotic potential. The third impact is that the effects on ionic balance of the soil solution due to the reduction of nutrient absorption (Poshtmasari *et al.,* 2012, *Daeia et al.,* 2009, Pisinaras *et al.*, 2010, Gawel, 2009).

Assessment of salinity of the soil is of vital importance for the strategies of water allocation and agricultural management as well. The mapping of soil salinity demands a considerable effort in collecting soil samples and measuring the electrical conductivity (EC) (Utset *et al.*,

1998) Soil salinity evaluation can be achieved via two main criteria, namely, EC and concentration of the chloride anion (Cl-). The laboratory analysis of soluble Cl- and Na+ is more expensive and timely consuming than that of EC, thus, the relationship between EC with Cl- and Na+ may have a certain value for salinity estimation. In soil extract, the dominant soluble salts are sodium chloride (NaCl), because Cl- and Na+ are dominant. Sodium sulphate comes second the second important level while calcium chloride and magnesium are at the third important level which is dark in color and has a high levels of hygroscopic salts (Alavi-Panah & Zehtabian, 2002)

The study of soil salinity and its variability is vital in order to evaluate the extent of salt build-up and to propose an appropriate management practices to magnify crop yield. The soil salinization processes may operate at a local or regional scale (Castrignano *et al.*, 2008).

- **Approaches To Monitoring Soil Salinity**

Zinck & Matternicht, 2009, recorded that there are several approaches to monitoring soil salinization have been developed, still, case studies that uses full data integration are still the exception. These approaches as the following:

1- Coping with Salinity Change Uncertainties, 2- Incorporating Contextual Landscape Information. 3- Recycling Ancillary Data in GIS Context, 4- Incorporating Geophysical Data, 5- Integrating Soil Salinity and Hydrology, and 6- Comparing Historical Soil Salinity Maps.

- **Geographic information system**

Geographic information system (GIS) and remote sensing (RS) technologies are introducing ways for rapid field data collection and data processing prompting (Donia, 2009.) Spatial distribution of soil salinity is considered as an important source of understanding the impact of soil management in fields with different climates. There are a number of statistical methods available, i.e. regression models; local interpolators like the inverse distance weighting

(IDW,) thin plate splines, or geostatistical techniques such as kriging (Nezami & Alipour, 2012.).

- **Geostatistical Analysis**

Geostatistic is one of the important techniques used in the spatial distribution of soil properties estimation (Asadzadeh *et al.*, 2012.) It provides an appropriate model for regional parameters (variables) description via considering the complications of spatial statistic. In geostatistic, a relationship between values of the quantity in samples society, distance and orientation of sample places in relation to each other can be developed. Thus, Geostatic is able to specify the spatial changes of soil characteristics. Such method can also be, easily, used in lands where sampling is budgetary and timely consuming (Goovaerts, 1998.) Geostatistic application in soil science began in the 1980s, later on, that applying of geostatistical methods in soil science became commonly used. In recent years, usage of these methods for estimating chemical and physical soils characteristics have increased (Kollias *et al.*, 1999, Asadzadeh *et al.*, 2012.) Furthermore, geostatistical mapping can be defined as analytical production of maps by using field observations, explanatory information, and computer programs that calculate values at locations of interest (Hengl, 2009.) Geostatistics is based on the theory of a regionalized variable which is distributed in space (with spatial coordinates) and shows spatial autocorrelation such that samples close together in space are more alike than those that are further apart. Geostatistics uses the variogram technique (or semivariogram) to calculate the spatial variability of a regionalized variable, and produce the input parameters for the spatial interpolation of kriging (Krige, 1951, Goovaerts, 1999, Webster & Oliver, 2007). Geostatistical tools do not replace, but complete, the usual statistical tools. Therefore, it is better to perform an exploratory data analysis before computing sample variograms and other spatial statistics. For example, computing usual univariate and bivariate statistics such as histograms, posted maps, scatterplots, box plots, and stem-and-leaf plots. Multivariate methodologies such as principal component analysis or cluster analysis can be used, also, to minimize the multivariate problems to uni-variate ones (Chilès & Delfiner, 2012.)

Semi-variograms are a key tool in regionalized variables theory and are produced by three constituents: sill, range, and nugget. Semi-variance is increased to a maximal asymptotic value (sill) with increasing lag between samples. The lag, is known also as range beyond which variables are independent with no correlations. Nugget produced when semi-variogram is not started appropriately at an intersection of coordinates. This could be, generally, due to errors during laboratory test, a sharp variation of soil properties, or even when sampling distance is greater than lag or range. Initial slope intensity in semi-variogram exhibits variability as a function of distance and minimization of correlation between samples (Mashayekhi *et al.*, 2007.)

An experimental variogram (Figure 15) is a plot presenting a half of the squared differences between the sampled values (semi-variance) changes with the distance between the point-pairs. The values of a target variable are more similar (smaller semi-variances) at shorter distance, up to a specific distance where the differences between the pairs are lesser equal to the global variance (Hengl, 2009).

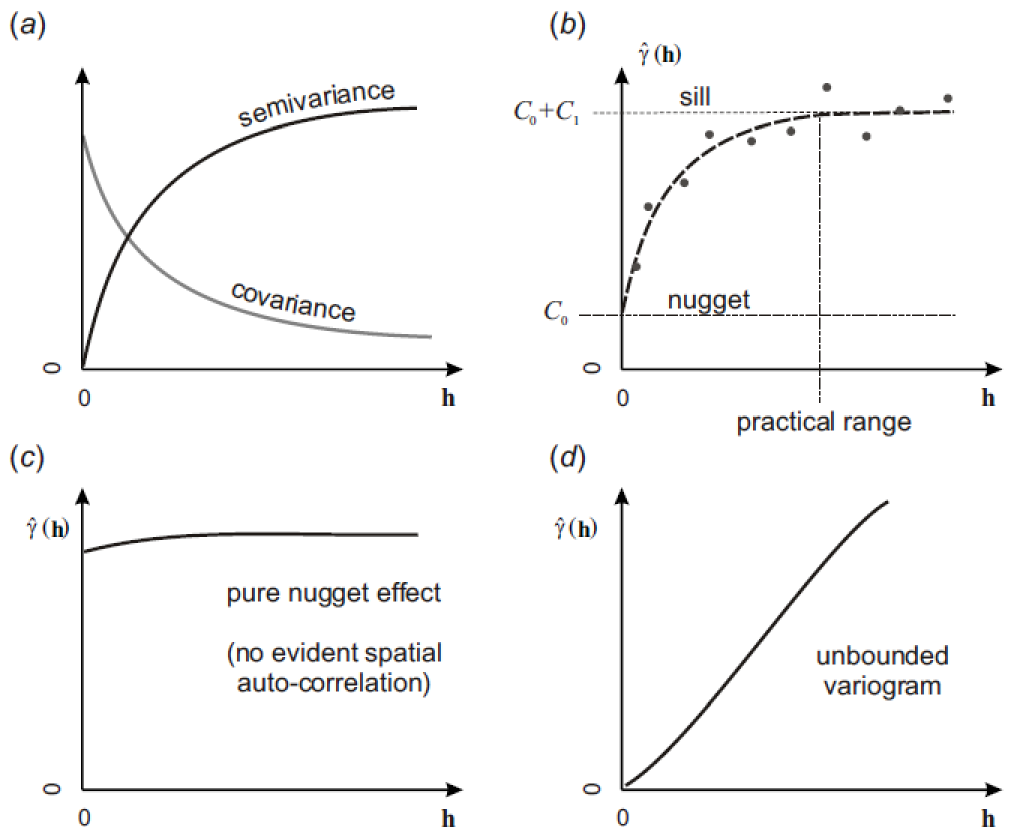



*Figure 15: Some basic concepts about variograms: (a) the difference between semi-variance and covariance; (b) it is often important in geostatistics to distinguish between the sill variation (C0 + C1) and the sill parameter (C1) and between the lag parameter (R) and the practical range; (c) a variogram that shows no spatial correlation can be calculated by a single parameter (C0); (d) an unbounded variogram (Hengl, 2009).*

Once an experimental variogram is calculated, it can be fitted using some of the authorized variogram models, i.e. exponential, spherical, circular, linear, Gaussian, Bessel, power, etc... The variograms are commonly fitted by iterative re-weighted least squares estimation, usually, the weights are determined based on the point pairs' count or based on the distance (Hengl, 2009.) Thus, solving an interpolation problem can be achieved via two steps: (1) fit a theoretical model to this sample variogram and (2) compute a sample variogram that approximates the regional variogram (Chilès & Delfiner, 2012).

- **Kriging**

A main problem in geostatistics is the rebuilding of a phenomenon over a domain on the basis of values examined at a limited number of points (Chilès & Delfiner, 2012.) Between the geostatistical techniques, kriging is an important tool. Kriging is a linear interpolation process that provides a best linear unbiased estimation for quantities which vary in space. Kriging estimates are calculated as weighted sums of the adjacent sampled concentrations. That is, if data appear to be highly continuous in space, the points closer to those estimated receive higher weights than those farther away (Cressie, 1990). Kriging (Krige, 1951) is regarded as an optimal method of spatial prediction. It is a theoretical weighted moving average:

$$\hat{z}(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i)$$

Where $z(X_0)$ is the value to be estimated at the location of ($X_0$), $z(X_i)$ is the known value at the sampling site ($X_i$) and n is the number of fields from the search area used for the estimation. The variable n is based on the size of the moving window and is defined by the performer. Kriging varies from other methods (i.e. IDW), due to the fact that the weight is no longer arbitrary. The weights is related to the parameters of the semi-variogram model and the sampling rules are decided under the circumstances of unbiasedness and minimized estimation variance (Deutsch & Journel, 1998, Zhang & McGrath, 2004, Robinson & Metternicht, 2006, Poshtmasari *et al.*, 2012.)

Lately, kriging methodology is commonly used in various studies. Poshtmasari *et al.*, (2012) reported in his study that, geostatistical techniques are more accurate compared to IDW and RBF. The performance of methods was evaluated by Mean Absolute Error (MAE) Mean Bias Error (MBE) and Root Mean Square Error (RMSE) Kriging (Spherical model) resulted in the highest precision and lowest error, thus, it is considered the best technique to estimate pH.

While, the exponential model-based kriging had the highest precision for estimation of soil EC in this area.

## 2.3 Materials and Methods

In order to study the changes in soil salinity during the period from 2009 to 2014, different data sources were integrate. In addition to the fieldwork which has been carried out during the 2014 winter season. The soil samples were collected and analyzed, then the Geographic Information Systems (GIS) was utilized for spatial and geostatistical analysis of the soil salinity data.

### 2.3.1 STUDY AREA

The study area was selected to represent the most affected areas with soil salinization in El Fayoum area. Thus, Sinnuris district was selected as a case study (Figure 16) and covers an area about 23536.05 hectares**Errore. L'origine riferimento non è stata trovata.**. It is located in the north part of El Fayoum and bordered with the southern and eastern shores of Lake Qaroun.

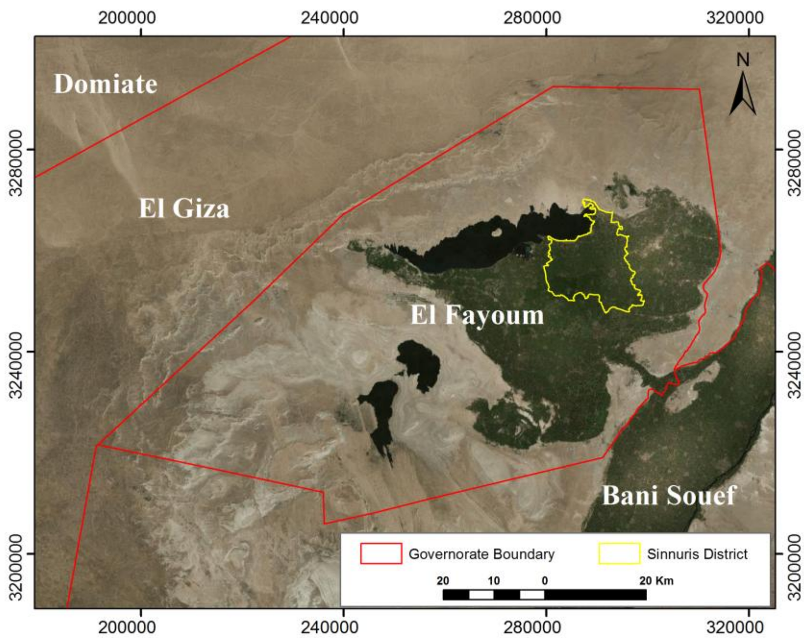



*Figure 16; Location of the study area.*

### 2.3.2 FIELD WORK AND GIS DATA PREPARATION

This stage includes data preparation for the fieldwork. Three topographic maps (scale 1:50,000) were georeferenced and used to delineate the selected area of Sinnuris district, with the aid of ArcGIS to create a shape file (coordinate system: UTM, WGS84, zone 36) for further processing. This shape file was used in the process of creating grid system with spacing distance of 2 kilometers, which defines the sampling locations covering the total area of Sinnuris district, El-Fayoum, Egypt (Figure 17).

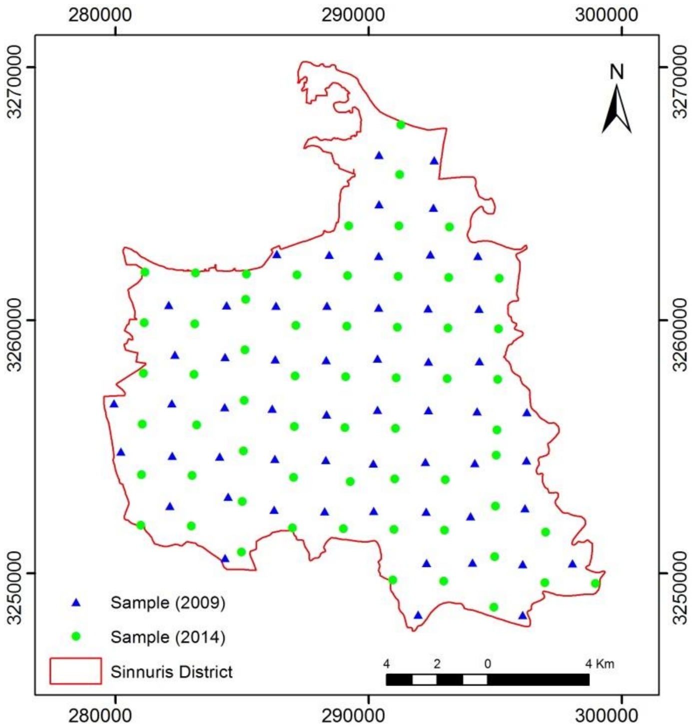



*Figure 17; Location of the soil samples for years 2009 and 2014.*

- **Fieldwork, and GPS application**

The fieldwork, equipped with global positioning system, was carried out during the period of January and February 2014 in Sinnuris district. The location of the sampling sites, which were generated in the previous step, were identified using Global Positioning System (GPS) model Garmin 12, as shown in Figure 17. Moreover, sampling points were exported to a valid format (KML) for the Google Earth to be overlayed on its high-resolution imageries, which facilitate the navigating the study area (Figure 18).  Two samples were taken from each site; the first one from the surface layer at depth 0–20 cm and the second one representing the sub-surface layer at depth 20–40 cm. The total number is one hundred and twenty soil samples collected from sixty sites.

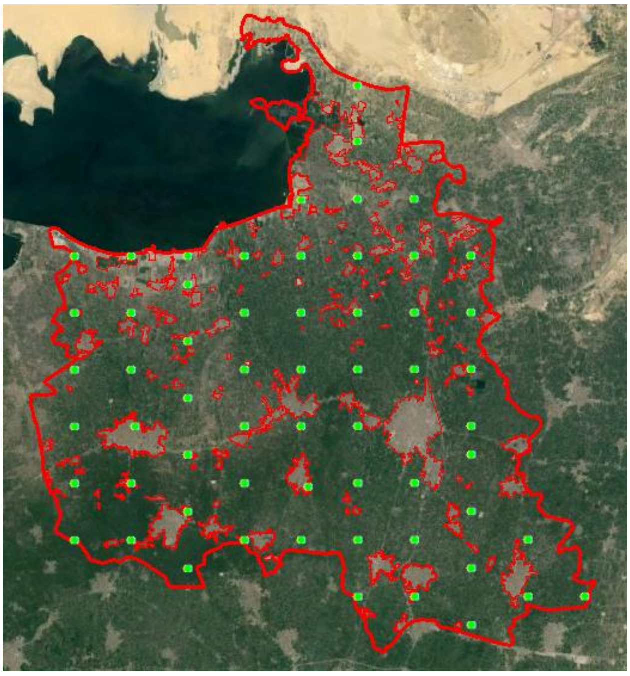


*Figure 18; Screenshot from Google earth, showing the location of the sampling location and the urban areas.*

***Ancillary data***

Previous studies have been conducted (Ahmed Harby thesis,2011) to investigate the soil salinity in Sinnuris district and this study used the data of 2009 to evaluate the changes during that period (2009 to 2014). Ancillary data were collected from different reports and sources to facilitate the research process. Reports and records about population growth in the study area were collected from the Central Agency For Public Mobilization And Statistics. Data on the driving factors of land use land cover in El Fayoum were collected in interviews with crop producers (farmers) and agriculture officers as key informants, reports and records about land and crop production in the study area. The interview focused on the land use process, problems in irrigation and drainage system and the history of land use during the same period over the past years.

### 2.3.3 LABORATORY ANALYSIS

During the fieldwork, disturbed soil samples were collected. Afterward, these samples were air-dried, grind gently, and sieved through 2 mm sieve to obtain the fine earth. Then some chemical properties were determined as follows: EC and Ph.

The measurements of these chemical properties were carried out using the techniques described by Page *et al.*, (1982) as follow:

- Soil pH, was estimated in soil saturation paste using Beckman pH meter.
- Total soluble salts, the Electrical Conductivity (EC) was determined in the soil saturation paste extract solution by using the EC-meter.

The soil properties data were stored in the attribute table of the point map.

- **GIS applications**

The organization, manipulation, and graphic display of spatial soil and ECa data are best accomplished with a geographic information system (GIS).

- **Kriging**

Soil properties maps were generated using the interpolation of the point distribution of these properties. Kriging as a geostatistics technique was chosen and utilized for such interpolation. For each soil property, different variogram models were tested and compared in order to find the most suitable model. A common means of determining which method is the best to use for a particular spatial data set is to use the statistical approach of jackknifing to establish the interpolation method that minimizes the prediction error (Isaaks & Srivastava, 1989). Then the suitable variogram model with respect to spatial structure of each parameter event was fitted. Moreover, the Log-transformation was applied to the data that were not normally distributed. Then by using variogram models and its parameters (nugget effect, sill, and the range) interpolation was carried out using the best Kriging method.

The obtained interpolation maps were converted to raster and classified, and then the area for each class can be compared in both datasets (2009 and 2014).

- **Masking of residential areas**

In order to evaluate and monitor soil salinity and different chemical properties, residential areas mask was created to exclude these areas from the calculations. The topographic maps (1:50000) covering the study area, and a recent Landsat 8 image were used to digitize the residential areas. This mask was used in both cases of 2009 and 2014 salinity mapping as show at Figure 19.

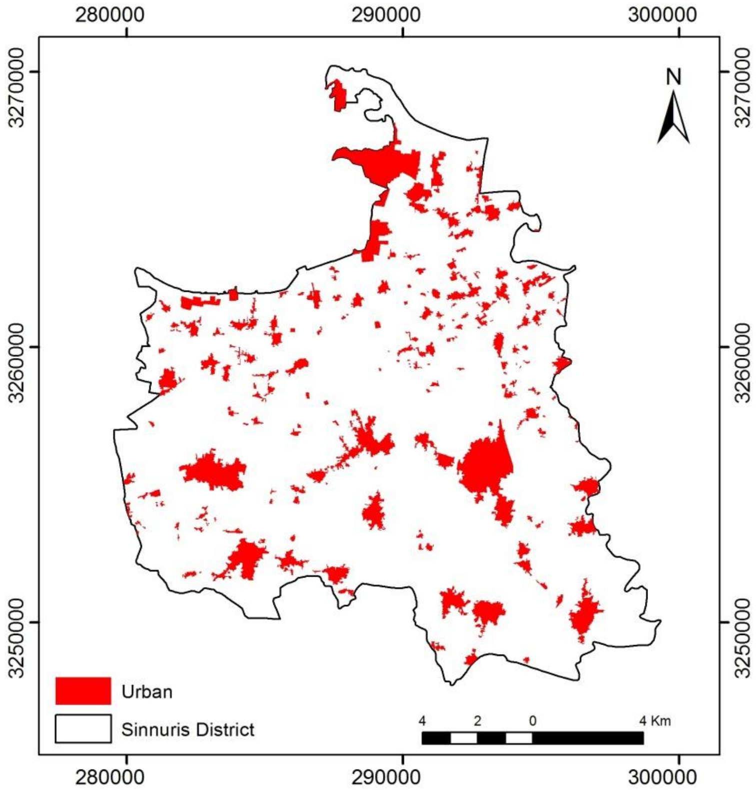



*Figure 19; Urban area in Sinnuris District 2014.*

## 2.4 Results and Discussions

### 2.4.1 DATA STATISTICS

The data obtained were analyzed through geostatistic methods, and soil salinity mapping was carried out using the Geographic Information System (GIS). Data analysis indicated that raw ECe values for the two data sets (2009 and 2014) did not follow the normal distribution, but log-transformed values have performed better to follow the normal distribution. The graphical histogram test was chosen to test the normality of data (Figure 20 and Figure 21). Log transformation was used for converting skewed distributions into normal distributions.

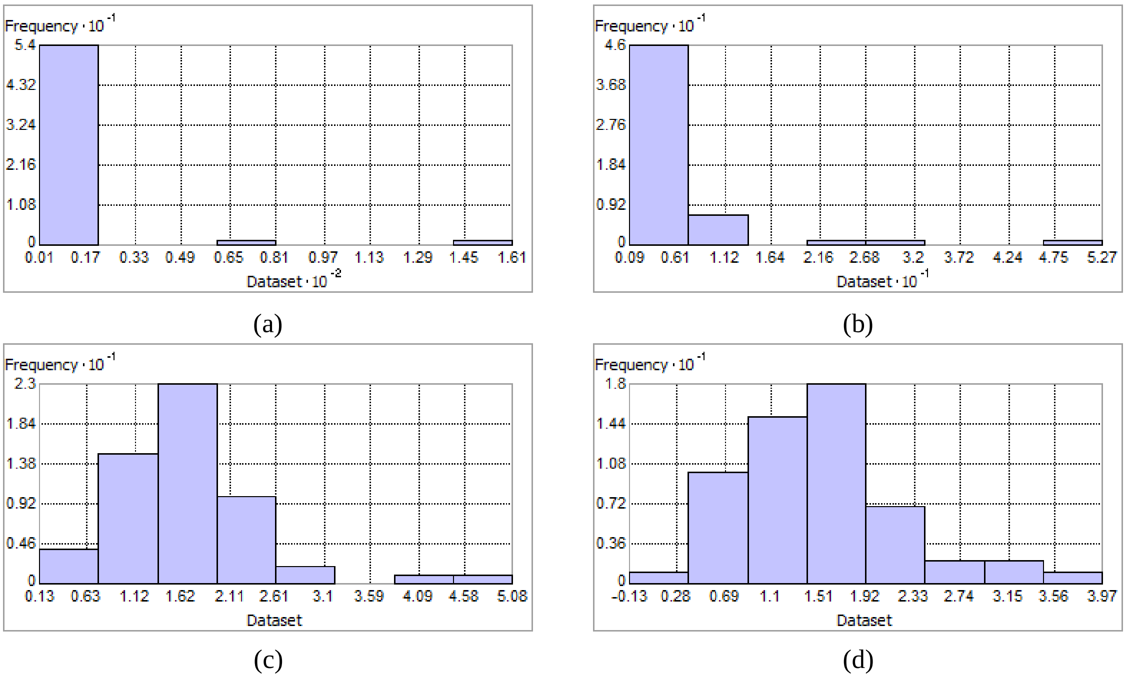
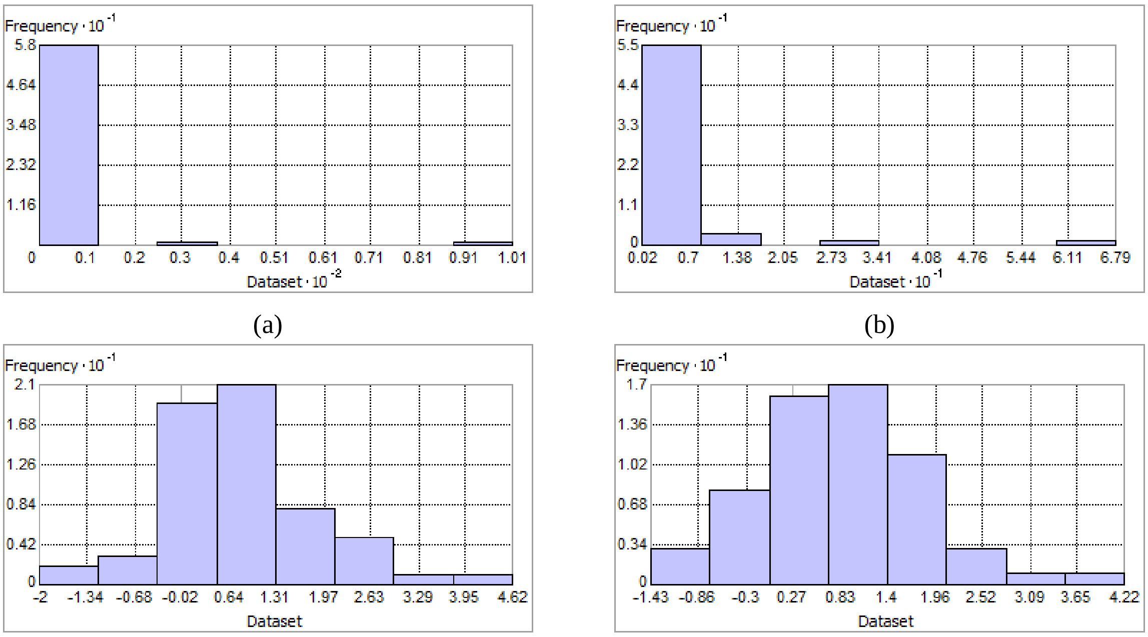



*Figure 20; Frequency distribution of the ECe values of 2009; (a) surface layer, (b) sub-surface layer, and Log ECe; (c) surface layer, (d) sub-surface*




(a) (b) (c) (d)

*Figure 21; Frequency distribution of the ECe values of 2014; (a) surface layer, (b) sub-surface layer, and Log ECe; (c) surface layer, (d) sub-surface.*

Table 47 lists the summary statistics of the raw and log-transformed ECe data, including mean, maximum, minimum, standard deviation, skewness, and kurtosis.

*Table 47; Summary statistics of the original and log-transformed ECe data.*

| | Depth | Minimum | Maximum | Mean | Standard deviation | Skewness | Kurtosis | Median |
|---|---|---|---|---|---|---|---|---|
| 2009 Raw Data | 0 - 20 | 1.14 | 160.62 | 9.5671 | 22.147 | 6.0496 | 40.638 | 4.79 |
| | 20 - 40 | 0.88 | 52.73 | 6.3161 | 7.927 | 4.2543 | 23.374 | 4.325 |
| 2009 Log Transformed | 0 - 20 | 0.13103 | 5.079 | 1.7073 | 0.79474 | 1.7326 | 8.4175 | 1.5665 |
| | 20 - 40 | -0.12783 | 3.9652 | 1.5141 | 0.71704 | 0.97492 | 4.8902 | 1.4644 |
| 2014 Raw Data | 0 - 20 | 0.135 | 101 | 4.9183 | 13.296 | 6.5388 | 47.186 | 1.885 |
| | 20 - 40 | 0.24 | 67.9 | 4.4401 | 9.333 | 5.7073 | 37.813 | 2.31 |
| 2014 Log Transformed | 0 - 20 | -2.0025 | 4.6151 | 0.7907 | 1.0713 | 0.65704 | 5.0269 | 0.63364 |
| | 20 - 40 | -1.4271 | 4.218 | 0.83055 | 1.0285 | 0.50256 | 4.0656 | 0.8371 |

As shown in Table 47, Kurtosis and skewness values for original ECe values were high; therefore, the data sets were logarithmically transformed before performing geostatistical analysis. Logarithmic transformation resulted in reduced skewness and kurtosis values.

### 2.4.2 VARIOGRAM MODELS:

Different models were tested, and then the parameters of the theoretical models fitted to the experimental variogram models were compared in order to select the best model. The obtained parameters are shown in Table 48, Table 49, Table 50, and Table51.

*Table 48; Alternative models fitted to the logarithm of ECe of the surface layer (2009).*

| Parameter | Model | | | | |
|---|---|---|---|---|---|
| | Circular | Spherical | Exponential | Gaussian | Stable |
| Samples | 56 | 56 | 56 | 56 | 56 |
| Mean | -2.3069 | -2.3277 | -2.36586 | -2.28208 | -2.282 |
| RMS | 21.65469 | 21.687 | 21.7684 | 21.60009 | 21.6 |
| MS | -0.32316 | -0.3388 | -0.3681 | -0.30814 | -0.30814 |
| RMSS | 3.0494 | 3.11920 | 3.2151961 | 3.02260 | 3.0226 |
| ASE | 5.78899 | 5.7450316 | 5.67564774 | 5.8342962 | 5.834296 |
| Lag Size | 2138.8 | 2138.8 | 2138.8 | 2138.8 | 2138.8 |
| # Lags | 12 | 12 | 12 | 12 | 12 |
| Nugget | 0.29838 | 0.28321 | 0.17781 | 0.37965 | 0.37965 |
| Partial Sill | 0.57832 | 0.54736 | 0.63239 | 0.51864 | 0.51864 |
| Major Range | 17111 | 17111 | 17111 | 17111 | 17111,2 |

*Table 49; Alternative models fitted to the logarithm of ECe of the sub-surface layer (2009).*

| | Circular | Spherical | Exponential | Gaussian | Stable |
|---|---|---|---|---|---|
| Samples | 56 | 56 | 56 | 56 | 56 |
| Mean | -0.608 | -0.62629 | -0.65917 | -0.57130 | -0.5713066 |
| RMS | 7.225 | 7.24539 | 7.3016 | 7.1663467 | 7.1663467 |
| MS | -0.110825 | 0.122249 | -0.15359 | -0.086842 | -0.08684 |
| RMSS | 1.566 | 1.605088 | 1.697248 | 1.503826 | 1.503826 |
| ASE | 3.9712 | 3.93928 | 3.899755 | 4.012419 | 4.0124197 |
| Lag Size | 2138.8 | 2138.8 | 2138.8 | 2138.8 | 2138.8 |
| # Lags | 12 | 12 | 12 | 12 | 12 |
| Nugget | 0.23207 | 0.22051 | 0.13749 | 0.29969 | 0.29969 |
| Partial Sill | 0.48878 | 0.46042 | 0.52383 | 0.44079 | 0.44079 |
| Major Range | 17111 | 17111 | 17111 | 17111 | 17111,2 |

*Table 50; Alternative models fitted to the logarithm of ECe of the surface layer (2014).*

| | Circular | Spherical | Exponential | Gaussian | Stable |
|---|---|---|---|---|---|
| Samples | 60 | 60 | 60 | 60 | 60 |
| Mean | -1.021104 | -1.00688 | -0.948339 | -1.025825 | -1.02582 |
| RMS | 12.75037 | 12.749767 | 12.74205 | 12.75691 | 12.75691 |
| MS | -0.163763 | -0.1682721 | -0.160636 | -0.173343 | -0.1733435 |
| RMSS | 1.77007 | 1.77387 | 1.7564198 | 1.7752388 | 1.7752388 |
| ASE | 5.341763 | 5.38848593 | 5.544671 | 5.349090 | 5.3490900 |
| Lag Size | 1250.3896 | 1287.2179 | 1978.0258 | 974.1533 | 974.15334 |
| # Lags | 12 | 12 | 12 | 12 | 12 |
| Nugget | 0.61559 | 0.59051 | 0.52501 | 0.69563 | 0.69563 |
| Partial Sill | 0.66368 | 0.67028 | 0.83568 | 0.52 | 0.52 |
| Major Range | 10003 | 10298 | 15824 | 7793.2 | 7793.2,2 |

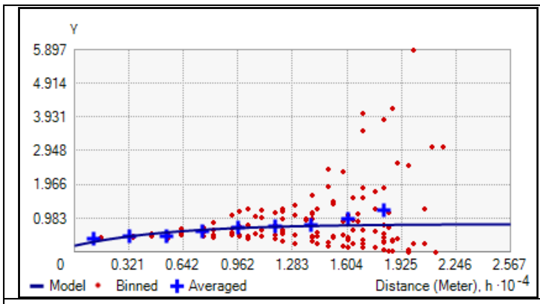
*Table 51; Alternative models fitted to the logarithm of ECe of the sub-surface layer (2014).*

| | Circular | Spherical | Exponential | Gaussian | Stable |
|---|---|---|---|---|---|
| Samples | 60 | 60 | 60 | 60 | 60 |
| Mean | -0.58146 | -0.57077 | -0.46736 | -0.67337 | -0.67337 |
| RMS | 8.64899 | 8.63312 | 8.48072 | 8.68489 | 8.68489 |
| MS | -0.04190 | -0.03946 | -0.02464 | -0.04539 | -0.04539 |
| RMSS | 1.22985 | 1.21976 | 1.14774 | 1.26086 | 1.26086 |
| ASE | 4.57221 | 4.58779 | 4.86871 | 4.44285 | 4.44285 |
| Lag Size | 1002.85 | 1179.86 | 929.94 | 732.96 | 732.96157 |
| # Lags | 12 | 12 | 12 | 12 | 12 |
| Nugget | 0.39526 | 0.3817 | 0.089892 | 0.48901 | 0.48901 |
| Partial Sill | 0.73633 | 0.77363 | 1.0252 | 0.51149 | 0.51149 |
| Major Range | 8022.8 | 9438.9 | 7439.5 | 5863.7 | 5863.7,2 |

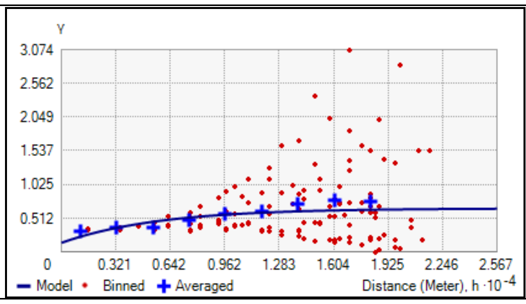
As shown in Tables (48 and 49), the Gaussian and stable models have the lowest values for "mean and RMSS". This means that these two models would perform better than the other models to estimate the spatial distribution of the ECe values of the year 2009. On the other hand, for the exponential model was the best model to estimate soil salinity in non-sampled areas in case of the data of 2014.

Resulted maps of ECe in 2009 using Gaussian model were compared with the measured data, it was found that the area around the lake Qaroun is under-estimated. Therefore, the exponential model was selected to be applied for both salinity datasets (2009 and 2014).

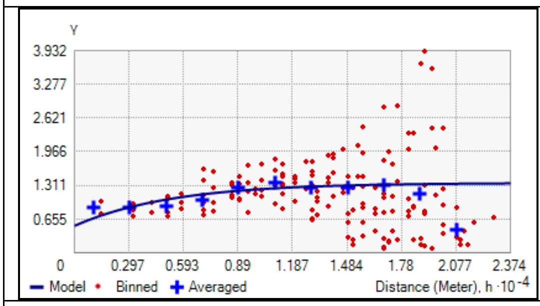
Examples of the variogram models are shown in Figure 22 representing the exponential model in case of the 2009 and 2014 datasets.



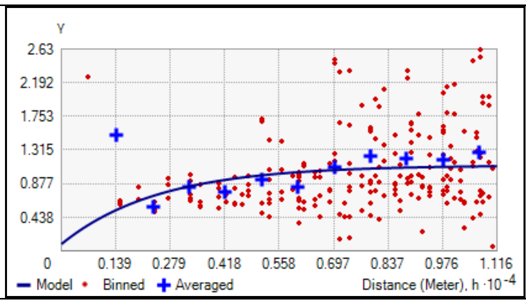

2009 – 0-20




2009 – 20-40




2014 – 0-20




2014 – 20-40

*Figure 22; Variogram of the salinity data with the exponential model.*

### 2.4.3 ELECTRIC CONDUCTIVITY MAPS:

Selected variogram models were used for data interpolation and generating a surface representing the studies variables. The selected model in each case was applied and the obtained results are shown in Figure 23.

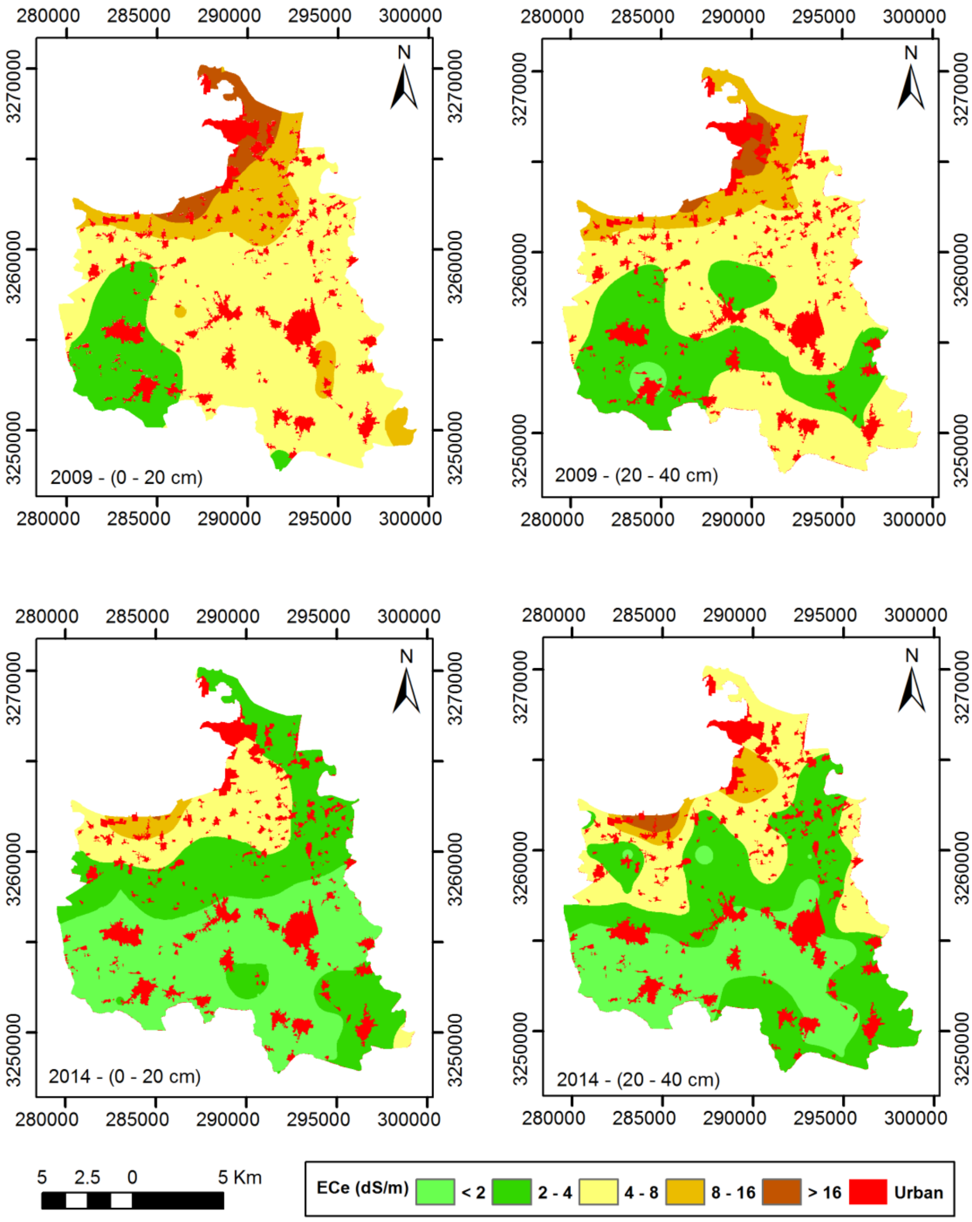



*Figure 23; Electric conductivity maps of the study area in 2009 and 2014 for the top-/sub-layers.*

### 2.4.4 ELECTRIC CONDUCTIVITY MONITORING

It is obvious in electric conductivity maps of years 2009 and 2014 (Figure 23) that the soil salinity has been improved in 2014. This can be attributed to the new construction of sub-surface drainage system in the study area. The construction of sub-drainage system started in

2007. Nowadays, most of the study area is served by this system except a small area in the western-north part of the study area.

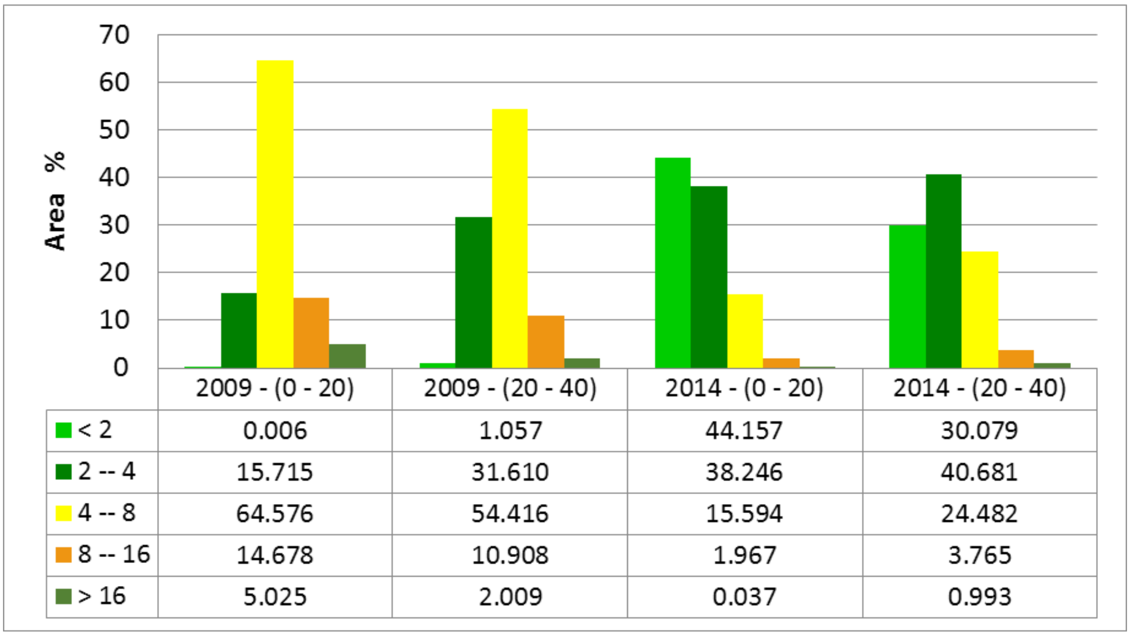
As illustrated in Table 52 the largest area in 2009 was that of moderate saline soil (4 – 8 dS $m^{-1}$) of the surface layer with 13336.03 ha. This area is bounded on the north by elongated area having higher salinity values of strong salinity (8 – 16 dS $m^{-1}$) and very strong salinity (> 16 dS $m^{-1}$). These highly saline soils are located adjacent to Lake Qaroun where the shallow saline water and poor drainage conditions causing rise in soil salinity level.

*Table 52; Electric conductivity classes' area (hectare) in 2009 and 2014.*

| **ECe** (dS $m^{-1}$) | **Layer 0 – 20 cm** | | **Layer 20 – 40 cm** | |
|---|---|---|---|---|
| | **2009** | **2014** | **2009** | **2014** |
| **< 2** | 1.28 | 9119.16 | 218.26 | 6211.88 |
| **2 - 4** | 3245.43 | 7898.45 | 6528.1 | 8401.42 |
| **4 - 8** | 13336.03 | 3220.37 | 11237.84 | 5056.02 |
| **8 - 16** | 3031.36 | 406.13 | 2252.69 | 777.45 |
| **> 16** | 1037.71 | 7.69 | 414.91 | 205.03 |

On the other hand, for the surface layer in 2014, the largest area was that of none saline soils (< 2 dS $m^{-1}$) with an area of 9119.16 ha. This area represents significant improvement in soil salinity where about 9118 ha improved form higher salinity levels to the non-saline soils. The very slight saline soils (2 - 4 dS $m^{-1}$) come in the second class with an area of 7898.45 ha, and the areas for higher salinity levels decrease as the salinity increase. Which shows a significant improvement in soil salinity in the study area. While still the area having the highest salinity is that adjacent to the Lake Qaroun.

Figure 24 shows the Areas of different soil salinity classes in the study area (%).




| | 2009 - (0 - 20) | 2009 - (20 - 40) | 2014 - (0 - 20) | 2014 - (20 - 40) |
|---|---|---|---|---|
| < 2 | 0.006 | 1.057 | 44.157 | 30.079 |
| 2 -- 4 | 15.715 | 31.610 | 38.246 | 40.681 |
| 4 -- 8 | 64.576 | 54.416 | 15.594 | 24.482 |
| 8 -- 16 | 14.678 | 10.908 | 1.967 | 3.765 |
| > 16 | 5.025 | 2.009 | 0.037 | 0.993 |

*Figure 24; Areas of different soil's electric conductivity classes in the study area (%).*

Figure 25 shows the spatial distribution of the changes of soil salinity between 2009 and 2014. It illustrates that the western north area performed low improvement in soil salinity. This can be attributed to the shortage in drainage system, as the sub-surface drainage system is not covering this area.

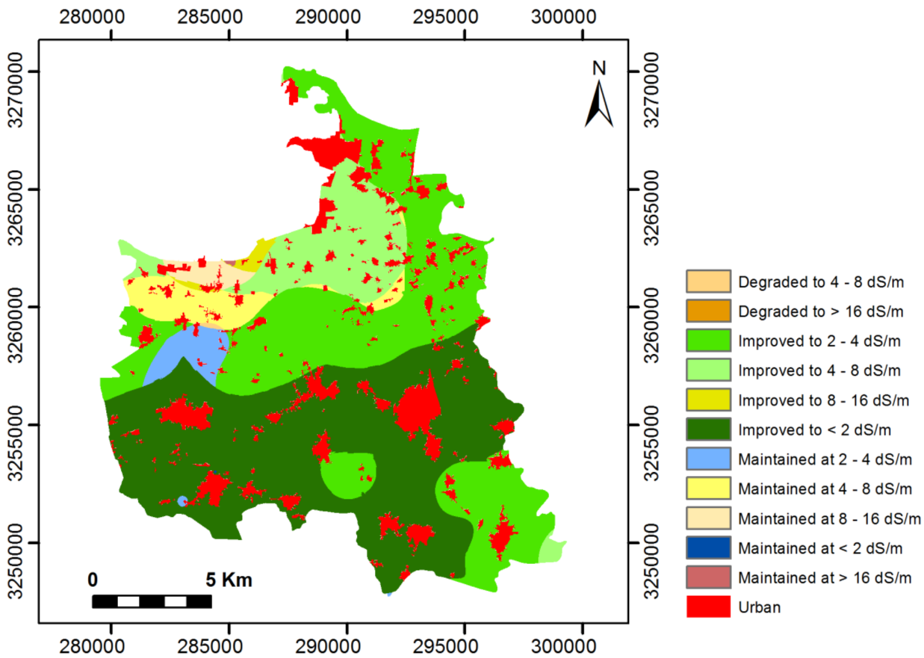



*Figure 25; Distribution map of the changes in soil electric conductivity of the study area.*

**Soil pH**

Soil pH was measured for the soil samples collected in 2014. The obtained data was interpolated to produce a spatial distribution map for soil pH (Figure 26) using the Inverse Distance Weighted (IDW) as an interpolation method. The results showed that, the pH of the surface layer ranges from 7.64 to 8.16 where 99.6 % of the area with pH values less than 8. On the other hand, for the sub-surface layer, soil pH ranges from 7.57 to 8.54 where pH of 61.6% of the area is less than 8 and 38.4% of the study area is greater than 8 ( Table 53).

*Table 53; pH classes' area (hectare) in 2014.*

| **Top-layer (00 - 20 cm)** | | **Sub-surface layer (20 - 40 cm)** | |
|---|---|---|---|
| **pH** | **area (ha)** | **pH** | **area (ha)** |
| **7.64 - 7.8** | 3900.2 | **7.57 - 7.8** | 2155.28 |
| **7.81 - 7.9** | 13379.15 | **7.81 - 8** | 10565.75 |
| **7.91 – 8** | 3283.63 | **8.01 - 8.32** | 7769.56 |
| **8.01 - 8.16** | 88.55 | **8.33 - 8.54** | 160.94 |

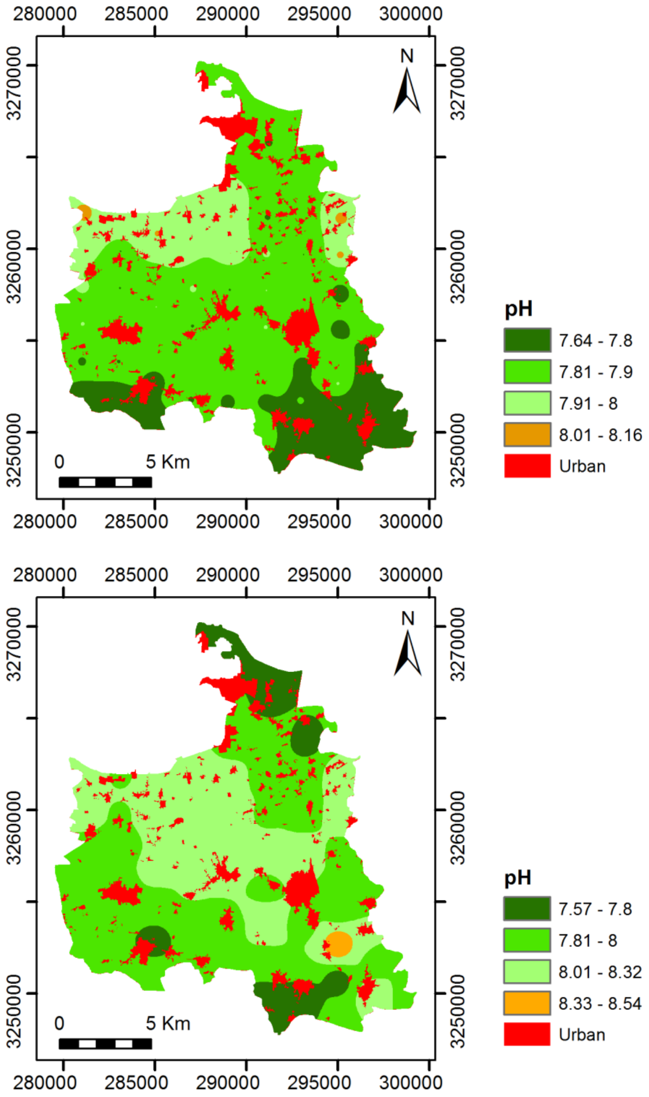



*Figure 26; Spatial distribution maps of soil pH using IDW methods.*

## 2.5 Conclusion

Geo-statistical Kriging technique was utilized in order to produce the soil salinity map for Sinnuris District for the periods 2009 and 2014. Then, a detailed comparison between recent and older map was performed. The results show a significant improvement in soil salinity, with an increase of the area of low electric conductivity (i.e. < 2 dS $m^{-1}$) from 1.28 ha in 2009, to 9119.16 ha in 2014. This impressive result could be related to the construction of a new sub-surface drainage system in the area, which started in 2007, and demonstrate the effectiveness of water management policies in Sinnuris District.

# Chapter III

## Land use and land cover change detection in El Fayoum region, Egypt, using remote sensing data

## 3.1 INTRODUCTION

Land use/ land cover change analysis using satellite remote sensing data opens the opportunity to better understand transformations of the agro-ecological landscape at regional level with a long term temporal perspective. The integration of this level of analysis with field experiments and local case-studies is fundamental to place the whole research in its historical context and to understand the main past and current trends and the most important drivers of landscape change.

The general objective of this study is to analyze the land use/land cover changes occurred in the last three decades in El-Fayoum Governorate, Egypt, with specific focus on urban expansion, land reclamation, and agricultural transitions. In order to achieve such objectives, multi-temporal Landsat imageries covering three periods (TM 1984, TM 1998 and OLI-TIRS 2013) were classified. Subsequently, a post-classification change detection approach was used to analyze the main transition processes. For data calibration and validation, ground truth data have been collected in the field during the summer season in 2013.

### 3.1.1 LAND USE/COVER CHANGE DETECTION USING REMOTE SENSING

Land cover is the description of the physical cover of the earth's surface from space. The observations can be made from different "sources of observation as the human eye, aerial photographs, satellite sensors" at different distances between the source and the earth's surface. Land use is the description of areas by their socio-economic utilization: areas used for residential, industrial or commercial, for farming or forestry, for recreational or conservation, etc. Linking land use with land cover is possible: particularly, it may be possible to infer land use from land cover and vice versa. Land use and land cover data are important to monitor and manage a variety of resources and territories, including natural resources, productive areas, residential areas, industrial development sites (Anderson *et al.,* 1976 and Abd El-kawy *et.al.,* 2011), recreational areas as well as energy resources (El-Asmar & Hereher, 2011).

Change detection is the process of identifying and providing the knowledge of how much, where, what type of land use and land cover change. This is important for understanding and monitoring land development patterns through land use and land cover data (Weng, 2002). Digital change detection is the process of determining and/or describing changes in land-cover and land-use properties based on co-registered multi-temporal remote sensing data. Numerous researchers have addressed the problem of accurately monitoring land-cover and land-use change in a wide variety of environments (Belal & Moghanm, 2011 and El-Asmar & Hereher, 2011). It can be useful for changes resulting as a result of human modification of the environment (Belal & Moghanm, 2011), as well as for rapid land use/land cover (LULC) changes mainly due to government policies and environmental calamities - such as drought, agricultural expansion and environmental changes as a result to rapid urbanization (Biro *et al.,* 2013 and Weng, 2002).

### 3.1.2 LAND USE/COVER CHANGE DETECTION AND LAND DEGRADATION IN EGYPT

The population development of the world is expected to increase continuously to 9.3 billion in 2050 (Taubenböck *et al.,* 2012). Land degradation is a global problem coupled with desertification, and rapid urban growth – with dry land covering some 47% of the Earth's surface. Africa is particularly affected by land degradation, having 65% of global agricultural degraded land. The primary reasons for land degradation in Africa are conflicts and wars, unplanned soil management, variations in climatic conditions and intrinsic characteristics of fragile soils across diverse agro-ecological zones (Biro *et al.,* 2013).

In the world generally, and developing countries in particular, population growth is one of the major factors leading to change of land use and land cover. In Egypt most of the population (95%) is concentrated around the River Nile (Shalaby & Tateishi, 2007). The rapid population growth, coupled with the economic developing activities in the whole Egypt, lead to loss and damage of agricultural lands (Belal & Moghanm, 2011). The primary types of land degradation in Egypt are related to soil salinization and sodicization (El Baroudy, 2011). Nearly all arable lands in Egypt are in the Nile Valley, the Nile Delta and the El Fayoum depression. Egypt's arable land constitutes around 3% of its total area, and in some estimates, it may be around 4% (Abdel-Salam *et al.*, 2005). The average farm size is small: more than 80% of the farms in the Delta have a size equal to less than one hectare (Lenney & Woodcock 1997). The human-induced salinization and alkalinization in the middle part of Nile Delta can be due to two main causes: firstly, the result of poor management of irrigation schemes; secondly because of human activities leading to an increase in evapo-transpiration of soil moisture in areas of high salt-containing parent materials or with saline ground water (El Baroudy, 2011).

Other major changes in Egypr are related to water resource management and land reclamation projects. After constructing the High Dam in 1964 in Aswan, both positive and negative impacts on environment and socio-economy in the Nile region were observed. One of the positive effects is increase in irrigated land yield where the cropping area has risen to about 14.0 million acres compared with about 9.3 million acres in 1952 (Abu-Zeid *et al.*, 1997). On the other side, the High Dam stopped sediments from reaching the Mediterranean Sea: during the twentieth century the annual sediment load arriving at the Mediterranean Sea was estimated at 84 billion $m^3$ (El-Asmar & Hereher, 2011). Egyptian development policies aimed at reclaiming new areas, particularly in the Western Desert, in order to increase the area of arable land to meet the needs of agriculture production (Abdel-Salam *et al.*, 2005). The rate of reclamation of land in the Western Desert of Egypt and coastal regions is high, therefore impacting land use/land cover (Lenney *et al.*, 1996).

Various applications of remote sensing data have been implemented to detect changes in Egypt. Satellite remote sensing proved to be a powerful tool for monitoring land-use change at high temporal resolution and lower costs than the use of traditional methods (Belal & Moghanm, 2011).

Among the studies leveraging remote sensing to investigate land use and cover, (Abd El-kawy *et al.,* 2011) made post-classification comparisons of classified images taken for the western Nile delta of Egypt. The study indicated that the major change consisted of barren land shifting into agricultural land for 28%, 14%, and 9% in the periods 1984-1999, 1999-2005, and 2005-2009, respectively.

Belal & Moghanm (2011) studied the urban areas in Tanta and Quttour, showing their increase by 7.17–5.84%, while the agricultural areas decreased by 7.17% and 5.84%, from the year 1972 to 2005. Such urban expansion caused loss of productive agricultural lands as well. Urbanization growth during the course of the 48-year period (from 1952 to 2000) in the East Delta region of Egypt was investigated by Abdel-Salam (2005). The results of this study show urban encroachment onto cultivated land and a loss of productive lands. Reduced productivity was observed for 3.74% of agricultural land from 1984 to 1993 in the Nile Delta also by Lenney *et al.,* (1996). While in the old agricultural Delta area it was noted a decrease of arable areas and an increase of urban areas, in the new reclamation area the trend was different (increase of the arable area with a decrease of the non-arable desert land). Between 1989 and 1995 in the same area the increase in arable land was 14.18%, and 5.36% between years 1995 and 2000. The trend of land reclamation was thus considerable slackened. The non-arable land in 1989 was 63.47% of the total area), 49.29% in 1995 and 43.92% in 2000. Thus between 1989 and 1995 (6 years), the decrease in non-arable land was equal to 14.18%, and between years 1995 and 2000 (5 years) to 5.36% (Abdel-Salam *et al.,* 2005).

Many case studies in Egypt were addressed at understanding coastal region change and degradation patterns. Coastal erosion was severe near Damietta Egypt promontory and decreased eastward; however, accretion was observed near Port Said (El-Asmar, 2011). In the coastal zone between Damietta Nile branch and Port Said, it was shown that about 50% of the coastal strip was under erosion and 13% was under accretion from 1973 to 2007. In addition, a remarkable decline (34.5%) of the Manzala lagoon surface area was estimated from 1973, 1984 to 2003. These changes were attributed mainly to the control of the River Nile flooding as well as to land use change by anthropogenic activities (El-Asmar & Hereher, 2011).

Change in the degree of naturalness in the northwestern arid coast of Egypt was observed from 1955 to 1992, especially on the coastal sand dunes and further inland on the slopes and at the top of the first rocky ridge. The artificial and artificial/natural classes increased by 20% and 11%, respectively, while semi-natural and semi-natural/natural classes increased slowly between 1955 and 1977 (from 6 to 10 and 5 to 6%, respectively) and then almost disappeared in 1992. The Natural classes decreased gradually from 86% in 1955 to 68% in 1992, with a total decrease of 18%. The decreases in natural, semi-natural and combination classes of semi-natural/natural was in favor of both artificial and artificial/natural combinations which indicates an abrupt change of the landscape substituting its intermediate activity compositions with more artificial activities (Ayad, 2005).

## 3.2 Theoretical Background

### 3.2.1 REMOTE SENSING OVERVIEW

Remote sensing can be defined as the field of study associated with extracting information about an object without coming into physical contact with it (Schott, 2007). It may be also defined as the use of sensors installed on aircrafts or satellites to detect electromagnetic energy scattered from or emitted by the Earth surface.

There are several regions of the electromagnetic spectrum, which are useful for remote sensing. The visible wavelengths cover a range from approximately 0.4 to 0.7 μm. The light that human eyes can detect is part of the visible spectrum. The next one is the infrared (IR) part of the electromagnetic spectrum covering the range from roughly 0.7 μm to 1 mm. The infrared region can be divided into two categories based on their radiation properties - the reflected IR, and the emitted or thermal IR. After that, the microwave which covers region from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing.

Imaging systems that depend upon an energy source such as the sun or the earth itself are referred to as passive remote sensing. On the other hand, in active remote sensing systems, the energy is radiated from a platform onto the Earth surface then the energy scattered back to the platform is recorded. Such system is known as active remote sensing since the energy source is provided by the platform. The reflection is characterized by the scattering coefficient for the surface material being imaged. This is a function of the electrical complex permittivity of the material and the roughness of the surface in comparison to a wavelength of the radiation used (Richards & Jia, 2006).

***Prosperities of Remotely Sensed Images***

The most essential property for utilizing most of the remotely sensed data is the resolution. There are four types of resolution for remote sensing imagery: spatial (or geometric), spectral, radiometric, and temporal:

The spatial resolution is directly connected with the instantaneous field of view (IFOV) of the sensor that refers to the size of the region that reflects the energy at a given epoch. The higher the spatial resolution the smaller the ground objects that can be discriminated. (Tso & Mather, 2009). High spatial resolution images reduce the number of mixed pixels, especially if the landscape is highly fragmented with irregular shape (Gao, 2009; Tso & Mather, 2009).

Spectral resolution can be defined as the ability of the sensor to separate the subtle differences radiance of the same ground surface at different wavelengths. The total energy measured in each spectral band of a certain sensor is a spectrally weighted sum of the image irradiance measured over the entire spectral range (Schowengerdt, 2007). Hence, the higher the spectral resolution is the more information is available about the reflecting target. Accordingly, higher spectral resolution images enrich the abilities to discriminate different land uses/covers. In general, the usage of multiple spectral bands during the classification phase can enhance the classification accuracies (Gao, 2009).

The radiometric resolution of a remote sensing sensor refers to the capability of distinguishing small variations in the intensity of the radiant energy from the reflecting target. Radiometric resolution is also known as the radiometric sensitivity that defines the digital quantization levels used to present the collected data. In general, the higher the quantization level, the greater the radiometric details collected by a specific sensor (Mather, 2004).

Temporal resolution defines the temporal frequency at which the same region/target is sensed consecutively by the same system. In satellite remote sensing systems, the temporal resolution is directly related to satellite orbital periods. Consequently, high temporal resolution means that the sensing platform makes more revolutions per time (i.e. the platform repeats its paths in shorter periods).

The selection of a specific sensor for a given remote sensing application is a critical step of the analysis, and it is fundamentally made as a compromise between the different properties of available satellite sensors. High spatial and radiometric resolution sensors have generally lower spectral or temporal resolution, and vice versa.

***Spectral Signature of Land Surfaces***

The spectral signature of a material is the reflectance of the surface as a function of wavelength, measured at an appropriate spectral resolution. Different materials have different spectral signatures. Thus, multispectral remote sensing can differentiate between different surfaces using the differences in their spectral signatures (Schowengerdt, 2007).

To illustrate this concept, the spectral reflectance curves for some explicative surfaces are here described.

Figure 27 illustrates the typical shape of vegetation spectral signature from 400 to 2,500 nm. The main biophysical controls of the main absorption/reflection features are vegetation pigments in the visible, canopy structure in the near infrared, and water content in the shortwave infrared. Changes in the biophysical properties of vegetation thus determine variations in different portion of the spectrum. For example, when the leaf begins to change, due either to stress conditions or senescence, chlorophyll production slows down, reflection in the blue and red bands increases, and reflection in the green band is reduced. If other pigments remain in the leaf, they will dominate the reflection and the leaf will change color (McCoy, 2005). Due to the fact that vegetation has seasonal and long-term phenological changes, varies with age, and differs completely from a plant to another, the spectral signature for vegetation is extremely variable and informative.

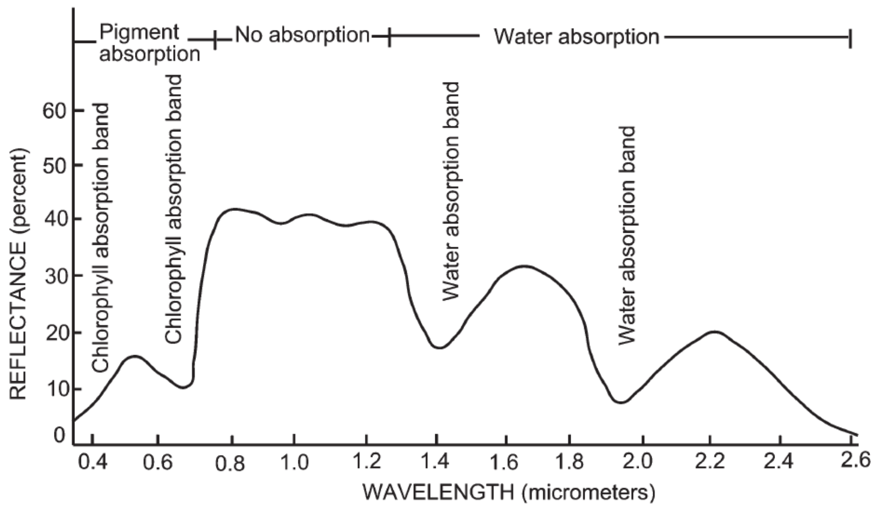



*Figure 27; Spectral signature of vegetation. From McCoy (2005).*

The reflection from the water surface and the upper volume of the clear water is spectrally similar to sunlight, except for reaching the zero reflectance around 760 nm (Figure 28) The peak of the reflectance curve is around the 580 nm wavelengths and it reaches a maximum of about 6% of the incident radiation (McCoy, 2005). Distinctively, water reflects about the 10% or less of the energy in the blue-green range, a smaller percentage in the red domain and no energy in the infrared. The reflection from the bottom could be observed in cases of the water contain suspended sediments or if the clear water body is shallow enough. In these cases, an increase in the apparent water reflection may occur, including a small but significant amount of energy in the near infrared range, as a result of reflection from the suspension or bottom material (Richards & Jia, 2006).

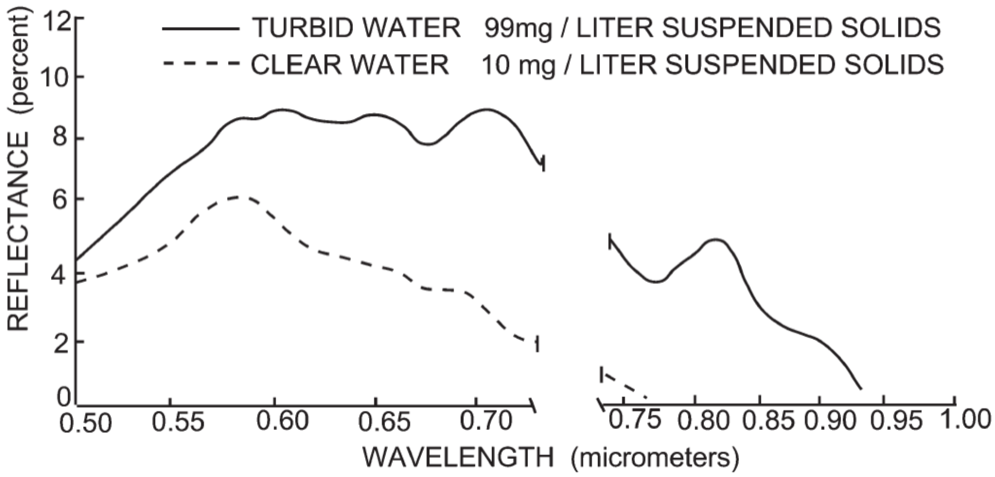



*Figure 28; Spectral signature of turbid river water and clear lake water (McCoy, 2005).*

The spectral response curves of soil, rocks, and minerals are not so distinctive as both vegetation and water cases. The soil spectral signature rises within the visible and near infrared, and may continue rising less steeply from 1000 to 2500 nm (Figure 29). Soil properties - such as moisture, organic matter, soil texture, or iron oxide content - affect significantly spectra reflectance curves, the soil moisture having the highest impact (McCoy, 2005).

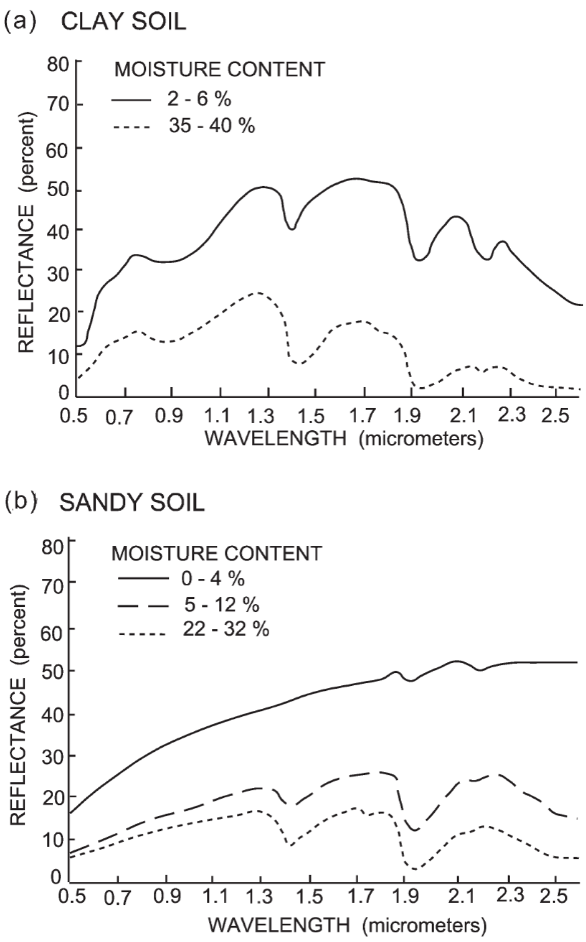



*Figure 29; Spectral response of soils changes with the loss of moisture. Dried sandy soil (b) shows almost no presence of the water absorption bands, while dried clay soil (a) still shows some effect of the water absorption (McCoy, 2005).*

### 3.2.2 THE LANDSAT SYSTEM

The LANDSAT program is the longest running mission acquiring multi-spectral data of the earth's surface from space. The Landsat earth resources satellite system was the first designed to provide near global coverage of the earth's surface on a regular and predictable basis and it is still now one of the most important sensors for remote sensing scientific applications. The program has operated continuously since LANDSAT 1 was launched in 1972. LANDSAT program have successfully launched six out of seven satellites. All 6 satellites have a repetitive, circular, sun-synchronous, near-polar orbit and on each dayside pass, scan a ground swath 185 km wide beneath the satellite. The first three satellites were equipped with the

Multi-spectral Scanner (MSS) as the main imaging instrument and a Return Beam Vidicon (RBV). The paths of these satellites were inclined 99 degrees with an 18-day repeat cycle and an equatorial crossing of between 8:50 and 9:30 am local time The Thematic Mapper (TM) sensor and the MSS were mounted on LANDSAT 4 and 5 satellites. They operated on 98 degrees inclined orbit, temporal cycle of 16 days. LANDSAT 6 was equipped with different sensors compared to the previous satellites of the program. An enhanced Thematic Mapper was mounted on its board while it has no MSS. Unfortunately this satellite, launched in early 1993, was lost on launch without any backup. LANDSAT 7 was launched in 1999. The Enhanced Thematic Mapper Plus (ETM+) sensor was mounted on board. The ETM+ measures the solar radiation reflected or emitted by the Earth's surface. In eight bands (e.g. visible and infrared band) with a spatial resolution of 30 m in the optical domain Finally, LANDSAT 8 was launched in 2013 to allow continuity with the previous missions. LANDSAT 8 carries the Operational Land Imager (OLI), with increased radiometric resolution compared to its predecessors, and the Thermal Infrared Sensor (TIRS).The spectral characteristics of LANDSAT 7 and 8 sensors, which are currently active, are summarized in Table 54.

*Table 54: The spectral characteristics of LANDSAT 7 and 8 sensors.*

| Landsat-7 ETM+ Bands (µm) | | | Landsat-8 OLI and *TIRS* Bands (µm) | | |
|---|---|---|---|---|---|
| | | | 30 m Coastal/Aerosol | 0.435 - 0.451 | Band 1 |
| Band 1 | 30 m Blue | 0.441 - 0.514 | 30 m Blue | 0.452 - 0.512 | Band 2 |
| Band 2 | 30 m Green | 0.519 - 0.601 | 30 m Green | 0.533 - 0.590 | Band 3 |
| Band 3 | 30 m Red | 0.631 - 0.692 | 30 m Red | 0.636 - 0.673 | Band 4 |
| Band 4 | 30 m NIR | 0.772 - 0.898 | 30 m NIR | 0.851 - 0.879 | Band 5 |
| Band 5 | 30 m SWIR-1 | 1.547 - 1.749 | 30 m SWIR-1 | 1.566 - 1.651 | Band 6 |
| Band 6 | 60 m TIR | 10.31 - 12.36 | *100 m TIR-1* | *10.60 – 11.19* | Band 10 |
| | | | *100 m TIR-2* | *11.50 – 12.51* | Band 11 |
| Band 7 | 30 m SWIR-2 | 2.064 - 2.345 | 30 m SWIR-2 | 2.107 - 2.294 | Band 7 |
| Band 8 | 15 m Pan | 0.515 - 0.896 | 15 m Pan | 0.503 - 0.676 | Band 8 |
| | | | 30 m Cirrus | 1.363 - 1.384 | Band 9 |

Source: http://landsat.gsfc.nasa.gov/?page_id=7195

### 3.2.3 CLASSIFICATION OF DIGITAL IMAGES

Image classification is the process of assigning image pixels with similar spectral/spatial/temporal behavior to a “homogeneous” class with or without a pre-defined class meaning.

There are mainly two approaches of classification, namely: unsupervised and supervised classification.

Unsupervised classification (also known as cluster analysis) classify each image pixel in classes basely solely of a statistical criterion, without any information used to train the algorithm.

Unsupervised classification is preferred when the user does not have prior knowledge about the existent assignment and the different names of the involved classes. Unsupervised classification does not necessitate that the selected training data set to characterize a certain object. Particularly, the user specifies only the number of clusters to be generated, and these operations are managed independently and automatically by software applications. Alternatively, the number of clusters can be detected automatically by the software application itself.

A common unsupervised classification algorithm is the IsoData Clustering (Iterative Self Organizing Data Analysis Techniques). It repeatedly performs an entire classification and recalculates the statistics. The procedure begins with a set of arbitrarily defined cluster means, usually located evenly through the spectral space. After each iteration, new means are calculated and the process is repeated until there is some difference between iterations. This method produces good result for the data that are not normally distributed and is also not biased by any section of the image (Malgorzata, 2010).

The supervised approach requires the user to select representative training data for each of the predefined number of classes. The user’s experience can be very helpful in identifying and locating training areas. Ideally, the training areas should be homogeneous examples of known cover types. A supervised statistical classification can be carried out by the following three steps described by Tso & Mater (2009):

1. Define the number and nature of the information classes, and collect sufficient and representative training data for each class,

2. Estimate the required statistical parameters from the training data,

3. Use an appropriate decision rule.

The most common approach for supervised classification is the Maximum Likelihood Classifier (MLC) (Abd El-kawy, *et al.*, 2011, El Baroudy, 2011 and Xiao, *et al*., 2006). The maximum likelihood procedure is a supervised statistical approach to pattern recognition. The probability of a pixel belonging to each of a predefined set of classes is calculated, and the pixel is then assigned to the class for which the probability is the highest (Tso & Mather, 2009).

## 3.3 MATERIAL AND METHODS

Various Software products were employed in the present study following the different requirements of the work. ENVI (Environmental Visualization) software version 4.7 and version 5.03 were used for image processing, masking and classification. Meanwhile, ArcGIS software 10.1 was employed for database development and for producing thematic maps.

### 3.3.1 STUDY AREA

The study area is located in the El Fayoum region, which was described in details in general Introduction (Study area).

The selected study area is a subset (Figure 30) of El-Fayoum Governorate, which includes all the cultivated and residential areas as well as the part of the surrounding desert area where an expansion of cultivated lands can be recognized.

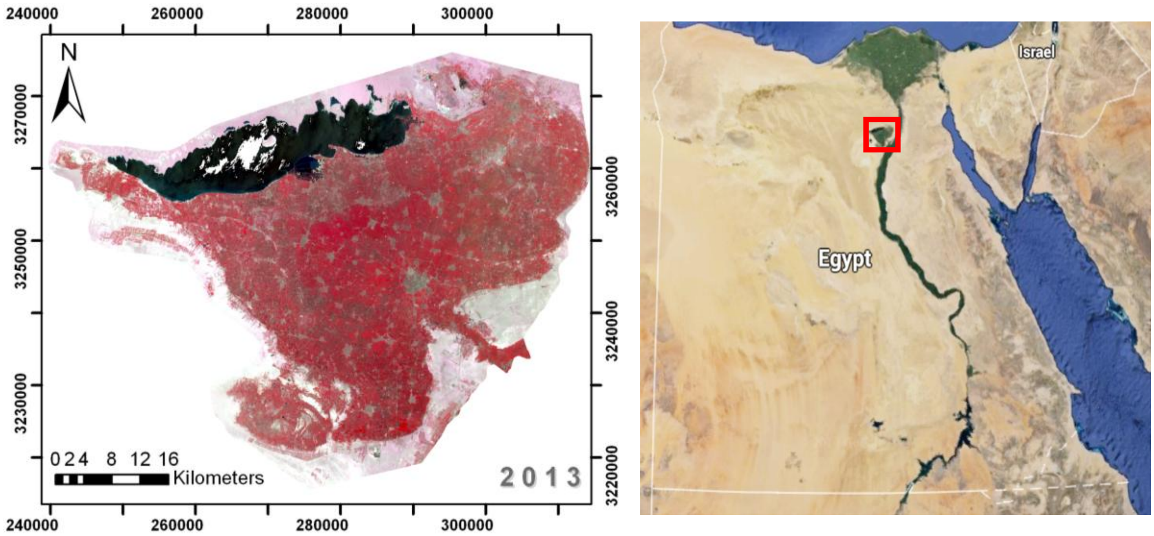



*Figure 30; The selected study area is a subset of El-Fayoum Governorate.*

### 3.3.2 FIELDWORK AND DATA COLLECTION

***Remotely sensed data***

The remote sensing data used for this research were downloaded from the Landsat archive data of the United States Geological Survey (USGS) (http://glovis.usgs.gov). The imageries were chosen to be as much as possible acquired in the same period of the season, depending on the availability and the quality of the images. Table 55 summarizes the selected images and their dates. The datasets covering the study area include Landsat 5 (TM) for 1984, Landsat 5 (TM) for 1998 and Landsat 8 (OLI_TIRS) for 2013 (Table 54).

*Table 55; Characteristics of used Landsat satellite imagery.*

| **Satellite** | Landsat 5 | | | | Landsat 8 |
|---|---|---|---|---|---|
| **Sensor** | TM | | | | OLI_TIRS |
| **Acquisition date** | 11 Sep 1984 | 20 Sep 1984 | 17 Aug 1998 | 17 Aug 1998 | 26 Aug 2013 |
| **Path/raw** | 177/40 | 176/40 | 177/40 | 177/39 | 177/40 |

The fieldwork was conducted during summer 2013. The GPS ground reference data for the existing land use/cover were collected in the field with a hand-held GPS GARMIN 12 (250 point were collected). The reference points in 2013 were selected based on pre-classified maps for the imagery. Subsets of ground truths (training samples) were used in image classification, while the rest was used in the accuracy assessment. On the other hand, ancillary data were collected from different reports and sources to facilitate the research process, such as meteorological data, reports and records about population growth in the study area.

Data on the driving factors of land use land cover in El Fayoum were collected by interviewing crop producers (farmers) and agriculture officers as key informants as well as reports and records about land and crop production in the study area. The interview focused on the land use process and the history of land use during the same period over the past years.

### 3.3.3 IMAGE PROCESSING

***Atmospheric correction***

As the used imageries were acquired in different dates with different atmospheric condition and collected by different sensor types, the application of atmospheric correction is essential for the current study. In order to remove the atmospheric effects, the data has to be calibrated then the atmospheric correction must be performed. On the one hand, calibration step transforms the collected radiance values (i.e. raw-data) into absolute atmospheric radiance or into relative reflectance values at the top of the atmospheric layer. While, on the other hand, the atmospheric correction converts these values to either ground radiance or ground reflectance. Nevertheless, absolute atmospheric correction requires knowledge of physical parameters characterizing the atmosphere at time of satellite overpass. As this is often not possible, especially for past images, relative atmospheric correction methods can be used to normalize for different atmospheric conditions across a set of images.

Various methods are available for relative atmospheric correction. For the current study both the Quick Atmospheric Correction (QUAC) and Dark Object Subtraction (DOS) methods were used. QUAC was used for images satellite 1984 and 1998 and DOS was used for image satellite 2013.

QUAC is an in-scene approach implemented in the ENVI software (ITT) that provides the ideal combination of high accuracy, less computational power demand, and liberation from prior knowledge (ground truth, sensor calibration, measurement geometry, etc.). QUAC works with any collection of visible and near infrared–short wave infrared (VNIR-SWIR) (e.g., VNIR only, SWIR only) bands for both multispectral and hyperspectral sensors, in contrast to physics-based methods, which require the presence of specific bands (Bernstein *et al.,* 2012).

The DOS technique removes the effects of scattering from the image data based on the signal reaching the satellite sensors from a dark object. It requires only the presence of a dark invariant surface (e.g. water) and derives the corrected DN (Digital Number) values solely from the digital data with no outside information.

***Geometric processing***

Despite all obtained images were geometrically corrected, re-projection was required in order to have the all datasets with the same datum and coordinate system, which is WGS84, UTM projection, Zone 36 North

When necessary, image mosaics were generated. Image mosaic is a process of merging two and more images in order to obtain a single one that covers the studied area. This procedure was necessary both for 1984 and 1998 datasets

### 3.3.4 IMAGE CLASSIFICATION

Digital image classification is the process of sorting all the pixels in an image into a finite number of individual classes based on the spectral information and characteristics of these pixels. The classification is resulting in a classified image that is essentially a thematic output of the original image. Remote sensing image data were classified by supervised and unsupervised classification. Maximum likelihood classification (MLC) was used for supervised classification, while Iso-data algorithm was used for unsupervised classification.

The unsupervised classification was used to identify the classes that could be potentially well discriminated by supervised methods, while deemed relevant for the study objectives. The following classes were selected: (1) water bodies, (2) desert area, (3) agriculture land, (4) orchard area, (5) urban and (6) bare soil.

The maximum likelihood classification algorithm requires training areas to be identified for every class. These training areas were chosen to represent the spectral behavior within every class.

Region of interest (ROI) were used to derive the land use and land cover-training test as shown in Figure 31. The land use land cover classes were adopted for image classification based on the authors’ a priori knowledge of the study area, the visual interpretation of the image and ground truth GPS data collected in the field. The separability of classes within the training test (Table 56) was computed using the Jeffries-Matusita and Transformed Divergence method implemented in ENVI (Richards, 1999). Values over 1.9 indicate good separability. Some difficulties were observed to spectrally separate the urban and bare lands.

*Table 56; pair separation 1984, 1998, 2013.*

| Pair | 1984 | 1998 | 2013 |
|---|---|---|---|
| **Urban and Bare soil** | 1.08841665 | 1.38643045 | 1.37801297 |
| **Vegetation land and Trees** | 1.97029633 | 1.89810391 | 1.94001358 |
| **Desert and Bare soil** | 1.99759667 | 1.99182232 | 1.99676366 |
| **Trees and Bare soil** | 1.99933687 | 1.9941041 | 1.9968852 |
| **Vegetation land and Bare soil** | 1.99941479 | 1.99990503 | 1.99919933 |
| **Desert and Urban** | 1.99991565 | 1.99999629 | 1.99990918 |
| **Vegetation land and Urban** | 1.99997231 | 1.99999673 | 1.99998425 |
| **Water and Bare soil** | 1.99999486 | 2 | 1.99999878 |
| **Trees and Urban** | 1.99999868 | 2 | 1.99999993 |
| **Water and Desert** | 1.99999982 | 2 | 1.99999995 |
| **Desert and Vegetation land** | 1.99999986 | 2 | 2 |
| **Water and Urban** | 2 | 2 | 2 |
| **Desert and Trees** | 2 | 2 | 2 |
| **Water and Vegetation land** | 2 | 2 | 2 |
| **Water and Trees** | 2 | 2 | 2 |

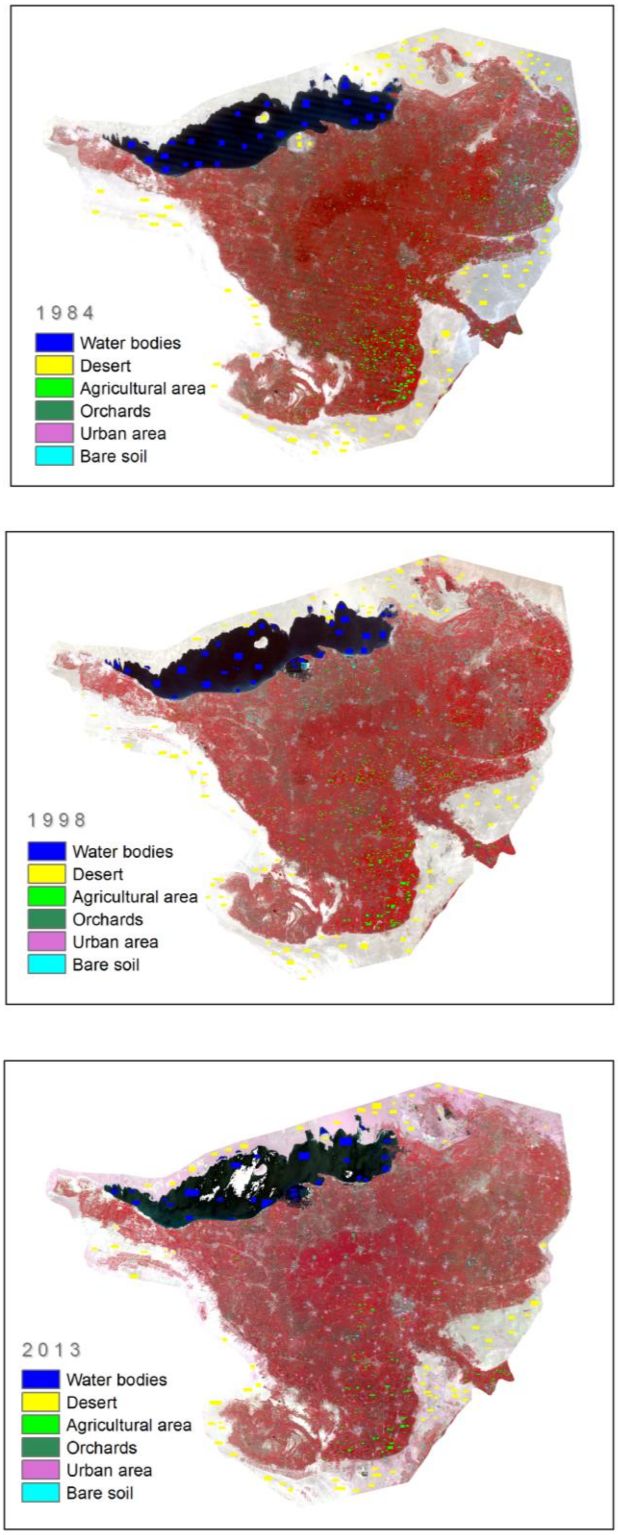



*Figure 31; ROI defined on the study area for 1984 and 1998 reported over false color Landsat images (RGB: B4, B3, B2) .  False colour for Landsat image 2013 R:B5, G:B2, B:B3) .*

*Classification accuracy assessment*

The accuracy assessment was computed by comparing the results of the supervised classification with an independent set of testing data. The accuracy is represented as the percentage of the righteously and erroneously labeled pixels of each class. These percentages are finally reported world widely as 'The error matrix'(Lillesand *et al.*, 2004). For the accuracy assessment of the classified images a set of 120 (20/classes) 3x3 pixel regions was used. The accuracy was evaluated in terms of overall percentage of correctly classified pixels and Cohen's Kappa coefficient (K) (Congalton, 1991), which reflects the difference between actual agreement and the agreement expected by chance

### 3.3.5 CHANGE DETECTION

Post-classification comparison (change detection) of the imageries was applied to determine the changes in land use and land cover that had occurred in the study area over time. Therefore, all imageries were classified independently. Post-classification is used to observe the different land use and/or land cover changes. It provides the user with precise information about the initial and final various land usages as a complete matrix of change direction (Fan *et al.*, 2008). In the change detection application, the magnitude, rate and nature of the land use land cover change and conversion and change map were derived as well.

## 3.4 Results and discussion

### 3.4.1 VISUAL INTERPRETATION

The images below visually present the changes in the soil between 1984 and 2013. The images showed frequent changes in the agriculture area. Figure 32 and Figure 33 show examples of the effect of land reclamation projects; many new cultivated lands can be noticed in the images of 2013 and 1998, which were not seen in the image of 1984.

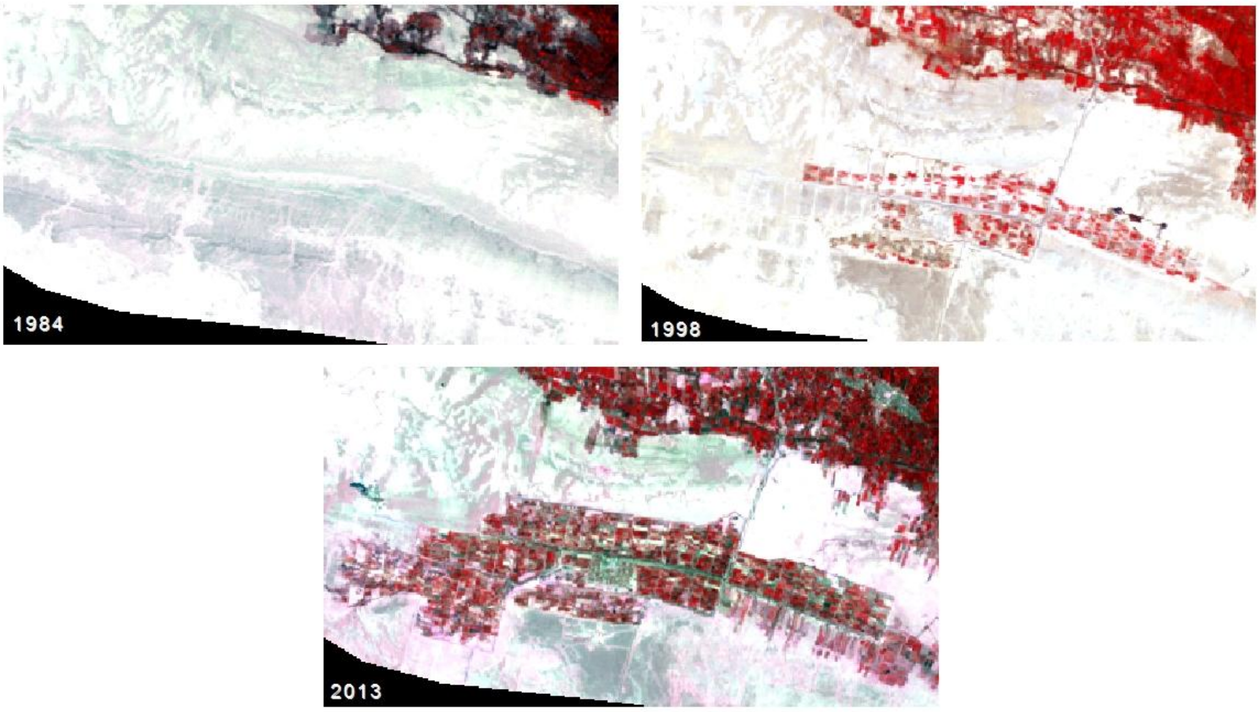



*Figure 32; example of changes from desert area to agriculture land (false colour Landsat images R:B4, G:B2, B:B3. . False colour for Landsat image 2013 R:B5, G:B2, B:B3 )*

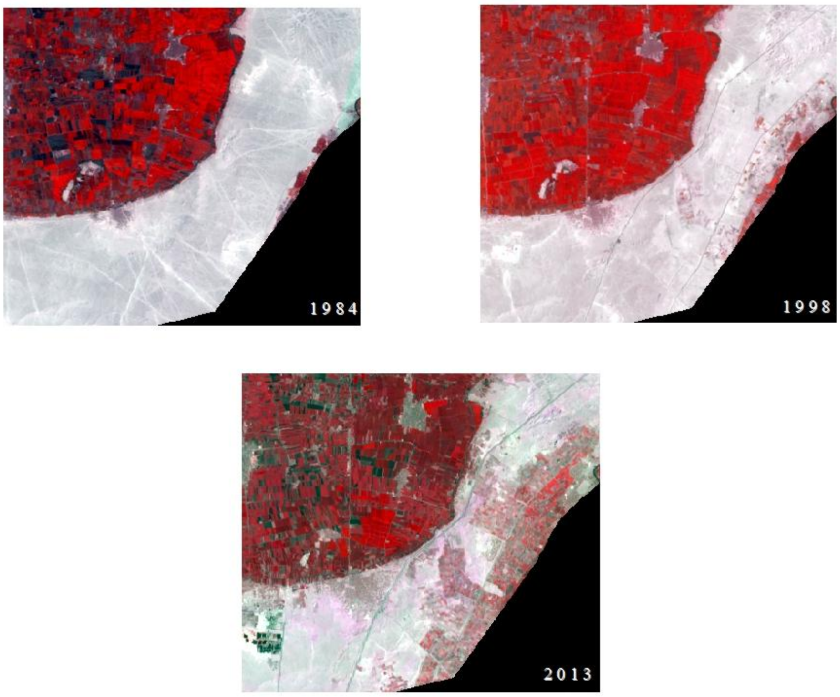



*Figure 33; example of expansion of agricultural land (false colour Landsat images 1984 and 1998 R:B4, G:B2, B:B3. False colour for Landsat image 2013 R:B5, G:B2, B:B3 )*

Also, noticeable changes were detected regarding urbanization, as shown in the example illustrated in Figure 34; urban areas were extensively extended in the images of 2013 and 1998 compared to 1984.

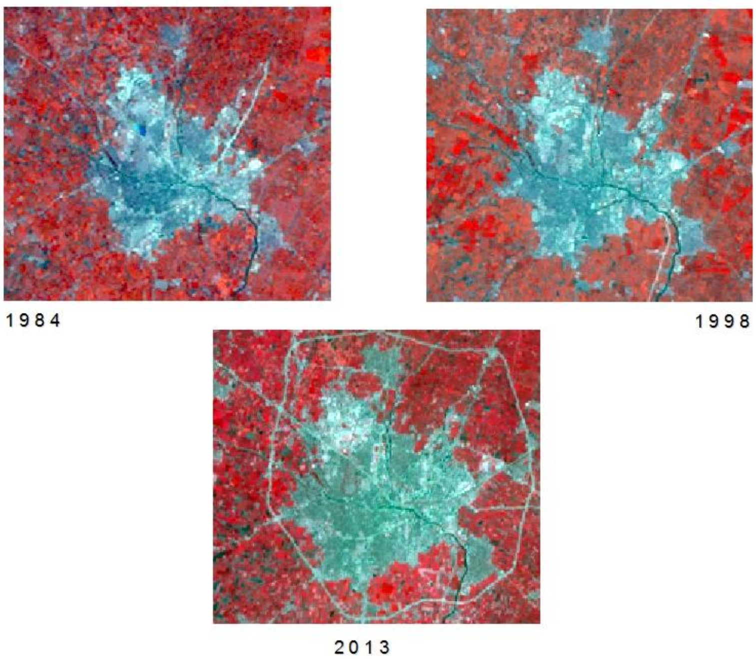
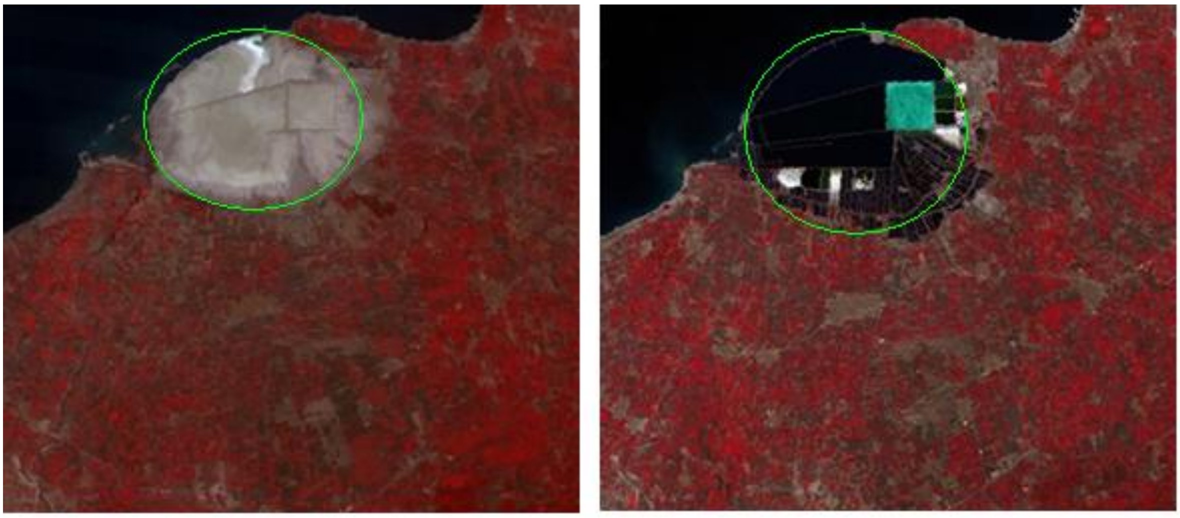



*Figure 34; exempla of urban area expansion (false colour Landsat images R:B4, G:B2, B:B3. . False colour for Landsat image 2013 R:B5, G:B2, B:B3 ).*

Other interesting changes observed by visual analysis are located near the lake Qaroun. It can be noticed that some areas around the lake in 1984 in 2013 were transformed into fish farming and factory (see, Figure 35).

Overall, visual interpretation resulted particularly useful for a preliminary qualitative screening of major changes in the study area, which allows a better planning of the quantitative analysis based on classification and change detection techniques.



1984 2013

*Figure 35; example of areas been transformed into fish farming (false colour Landsat images R:B4, G:B3, B:B2).*

### 3.4.2 LULC OF EL FAYOUM REGION

Supervised classification was carried out using maximum likelihood classifier using all spectral bands of the three images acquired on 1984, 1998 and 2013. Figure 36 shows the result of the classification according to the produced LULC map. Table 57, Table 58, and Table 59 illustrate the area coverage of the different classes.

*Table 57: Areas of different land classes on 1984.*

| Classes | % | Hectare |
|---|---|---|
| **Water** | 8.39 | 22183.92 |
| **Desert** | 31.42 | 83053.26 |
| **Agriculture land** | 26.30 | 69530.22 |
| **Orchard area** | 4.87 | 12879.27 |
| **Urban** | 2.70 | 7135.47 |
| **Bare soil** | 26.32 | 69589.08 |

*Table 58; Areas of different land classes on 1998.*

| Classes | % | Hectare |
|---|---|---|
| **Water** | 8.75 | 23144.85 |
| **Desert** | 27.62 | 73024.11 |
| **Agriculture land** | 35.85 | 94789.62 |
| **Orchard area** | 4.10 | 10839.24 |
| **Urban** | 3.26 | 8605.89 |
| **Bare soil** | 20.41 | 53970.75 |

*Table 59; Areas of different land classes on 2013.*

| Classes | % | Hectare |
|---|---|---|
| **Water** | 9.21 | 24343.74 |
| **Desert** | 21.17 | 55955.52 |
| **Agriculture land** | 30.06 | 79474.68 |
| **Orchard area** | 2.44 | 6447.69 |
| **Urban** | 5.06 | 13376.07 |
| **Bare soil** | 32.07 | 84777.48 |

### 3.4.3 CLASSIFICATION ACCURACY

Overall LULC classification accuracy levels for three dates of satellite images ranges from 92 to 94 per cent, with Kappa indices of agreement ranging from 91 to 93 per cent (as reported in Table 60, Table 61, and Table 62). This results is overall satisfactory for our study area because it exceeds the minimum of 85 per cent accuracy as stipulated by the Anderson classification scheme (Anderson *et al*., 1976). The image-processing approach was thus found to be effective in producing compatible LULC data over time. This result was achieved thanks to an appropriate selection of images (i.e. same period of the year, high data quality) and of the land cover classes (i.e. with good spectral separability), as well as a proper definition of the training set. Meanwhile, some uncertainty remains in the discrimination of bare lands and urban areas. Bare soils are to some degree confused with urban areas in all images. This was rather expected, as these classes are often difficult to separate, having similar spectral properties or being extremely fragmented, thus mixed within a single pixel.

**Overall Accuracy = (677/729) 93%  Kappa Coefficient = 0.9133**

| *Ground Truth 1984 (Percent)* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Class** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Total |
| **Water** | 99.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.38 |
| **Desert** | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 5.93 | 19.62 |
| **Agriculture land** | 0.00 | 0.00 | 99.26 | 0.00 | 0.00 | 0.00 | 18.38 |
| **Orchard area** | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0.00 | 7.41 |
| **Urban** | 0.00 | 0.00 | 0.00 | 0.00 | 94.81 | 25.93 | 22.36 |
| **Bare soil** | 0.74 | 0.00 | 0.74 | 0.00 | 5.19 | 68.15 | 13.85 |
| **Total** | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

*Table 60; Accuracy statistics for the classification results of year 1984.*

**Overall Accuracy = (697/738) 94%  Kappa Coefficient = 0.9324**

| *Ground Truth 1998 (Percent)* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Class** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Total |
| **Water** | 95.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.29 |
| **Desert** | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 2.21 | 18.70 |
| **Agriculture land** | 3.52 | 0.00 | 100.00 | 7.41 | 0.00 | 0.00 | 19.51 |
| **Orchard area** | 0.00 | 0.00 | 0.00 | 92.59 | 0.00 | 0.00 | 6.78 |
| **Urban** | 0.00 | 0.00 | 0.00 | 0.00 | 88.97 | 8.82 | 18.02 |
| **Bare soil** | 1.41 | 0.00 | 0.00 | 0.00 | 11.03 | 88.97 | 18.70 |
| **Total** | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

*Table 61; Accuracy statistics for the classification results of year 1998.*

**Overall Accuracy = (741/784) 94%  Kappa Coefficient = 0.9328**

| *Ground Truth 2013 (Percent)* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Class** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Total |
| **Water** | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 24.23 |
| **Desert** | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 4.48 | 17.98 |
| **Agriculture land** | 0.00 | 0.00 | 100.00 | 16.67 | 0.00 | 0.00 | 18.37 |
| **Orchard area** | 0.00 | 0.00 | 0.00 | 83.33 | 0.00 | 0.00 | 5.74 |
| **Urban** | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 20.90 | 20.92 |
| **Bare soil** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 74.63 | 12.76 |
| **Total** | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

*Table 62; Accuracy statistics for the classification results of year 2013.*

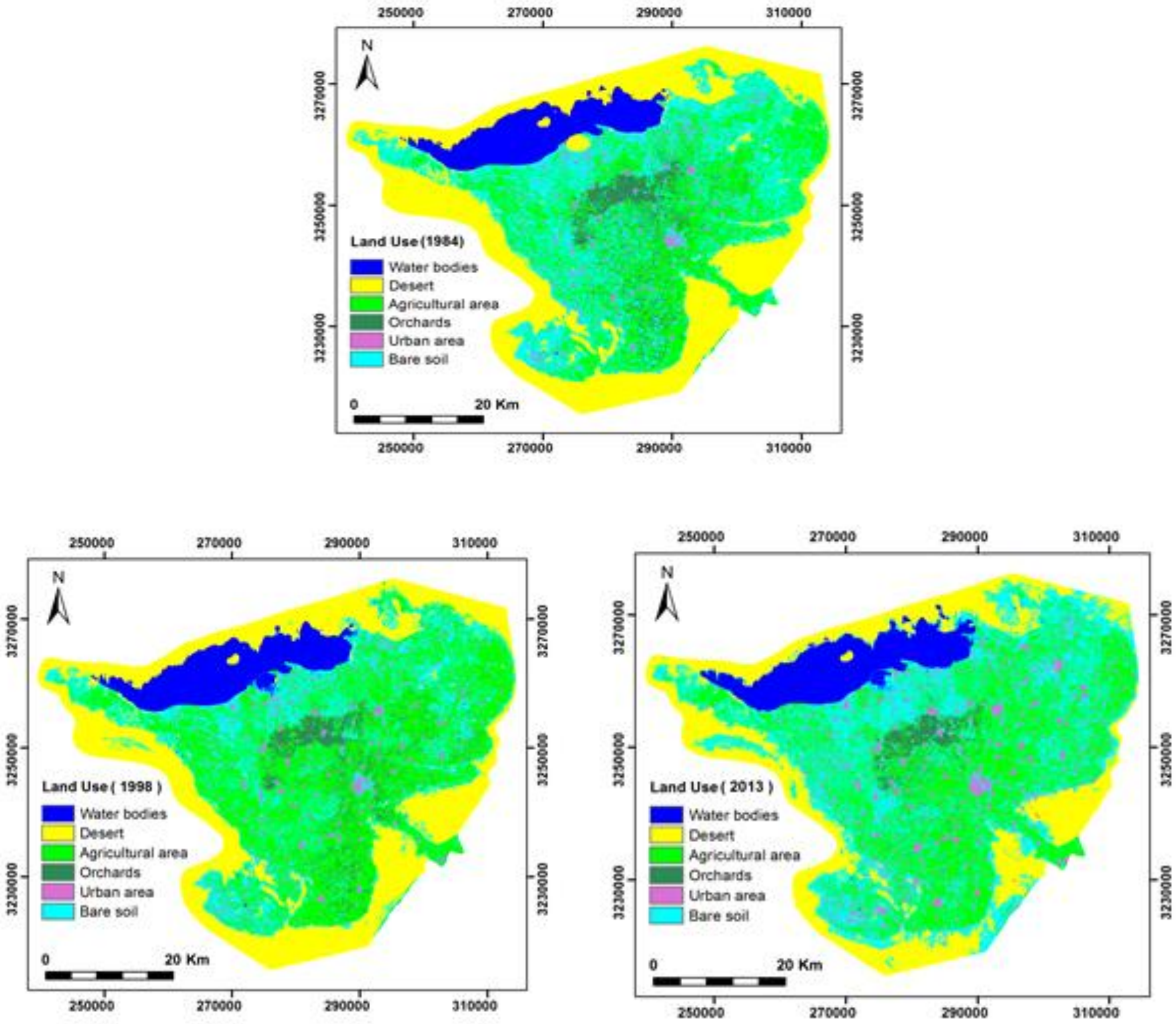



*Figure 36; Map of Land use/cover supervised classification for El Fayoum region, Egypt temporally projected over the years 1984, 1998, and 2013.*

### 3.4.4 CHANGE DETECTION

In this study, post-classification change detection technique was implemented. Post-classification is the most used method for change detection, which requires the comparison of independently produced classified images. It is proved to be the most effective technique, because the data used from three dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between three dates. Cross-tabulation analysis was carried out to analyze the spatial distribution of different changes in land use and the changes in the land type as well.

Table 64, Table 66, and Table 68 report the change detection in terms of percentage (%). The changes in the nature of land and its use in El Fayoum between 1984-1998 and 1998-2013 and 1984-2013 are evident in the results. Between 1984 and 1998 the most remarkable change is observed in the agriculture land area that increased by 36.33 % that is equivalent to 25305.57 ha. This increase is associated with the decrease of both desert and bare land, which were converted into agricultural land. The desert area decreased by 12.08 % (1029.15 ha), consequently, it added up 1.84% (1531.53 ha) to agriculture land area. Bare soil has decreased by 22.46 % (equivalent to 15605.46 ha). It summed up an extra 47.74 % (equivalent to 33221.61 ha) to the agricultural lands.

On the one hand, the urban land increased by 20.61% (equivalent to 1470.42 ha) due to the urbanization of 6.35% (4420.53 ha) of the bare soil. On the contrary, the orchard land decreased by 15.84% (equivalent to 1470.42 ha) due to the mass transformation of 49.14% (6328.17 ha) of the orchard land of the 1984 into agricultural lands on 1998.

Between the year 1998 and 2013, mutual transformations occurred between the different land use/cover. While agricultural and orchard land decreased by 16.16% (equivalent to 15314.94

ha) and 40.52% (equivalent to 4391.55 ha) respectively, both urban lands and bare soil added up additional size of 55.43% (equivalent to 4770.18 ha) and 57.08% (equivalent to 30806.73 ha) to their original size of the year 1998.

The increase of the bare soil area was the main factor behind the loss of the agricultural land. On the one hand, the agriculture land loses 33.823% (32060.43 ha) of its 1998 area into bare soil on 2013, while the bare soil of 1998 lose 9.38% (5060.88 ha) in favor to the urban area on 2013. The other main contribution was through the transformation of 2.43% (2304.63 ha) of the 1998 agricultural land into urban extents.

Generally, over the whole period of 30 years from 1984 to 2013, the orchard area shrank by 49.94% (equivalent to 6431.58 ha) due to its transformation of 48.75% (equivalent to 6278.58 ha) and 18.53% (equivalent to 2386.98 ha) into agricultural land and bare soil, respectively. Additionally, the desert land was reduced by 32.63% (equivalent to 27097.74 ha) of its original size. 26.63% (equivalent to 22113.27 ha) of the 1984-desert land was transformed to bare soil, while 2.96% (equivalent to 2459.34 ha) was converted in agricultural land.

Agricultural land added up 48.75% (equivalent to 3954.15 ha) of the 1984-orchard land and 38.28% (equivalent to 26636.40 ha) of the 1984-bare soil. Consequently, the 2013-agriculture land accumulated extra 14.30% (9944.46 ha) of its 1984-original size. The bare soil added up 21.83% (15188.40 ha) to its original 1984-area by cutting out 33.45% (2386.98 ha) of the 1984-urban land and 33.24% (23110.74 ha) of the 1984-agriculture land.

*Table 63; Change detection (Ares in ha) 1984-1998. Diagonal values indicate unchanged areas, while out-of-diagonal values indicate areas, which changed from 1984 to 1998.*

| **Area (Hectare)** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Class Total |
|---|---|---|---|---|---|---|---|
| **Water** | 21950.64 | 866.97 | 15.57 | 2.52 | 13.32 | 291.87 | 23144.85 |
| **Desert** | 67.59 | 72323.19 | 12.69 | 0.45 | 5.22 | 614.97 | 73024.11 |
| **Agriculture land** | 4.14 | 1531.53 | 51897.69 | 6328.17 | 1806.48 | 33221.61 | 94789.62 |
| **Orchard area** | 0.09 | 3.15 | 4246.74 | 5092.65 | 56.43 | 1440.18 | 10839.24 |
| **Urban** | 0.27 | 163.71 | 856.26 | 66.69 | 3098.43 | 4420.53 | 8605.89 |
| **Bare soil** | 160.56 | 8164.71 | 12501.27 | 1388.7 | 2155.59 | 29599.92 | 53970.75 |
| **Masked Pixels** | 0.63 | 0 | 0 | 0.09 | 0 | 0 | 0.72 |
| **Class Total** | 22183.92 | 83053.26 | 69530.22 | 12879.27 | 7135.47 | 69589.08 | 0 |
| **Class Changes** | 233.28 | 10730.07 | 17632.53 | 7786.62 | 4037.04 | 39989.16 | 0 |
| **Image Difference** | 960.93 | -10029.15 | 25259.4 | -2040.03 | 1470.42 | -15618.33 | 0 |

*Table 64; Change detection (in percentage) 1984-1998. Diagonal values indicate unchanged areas, while out-of-diagonal values indicate areas, which changed from 1984 to 1998.*

| **Percentages** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Class Total |
|---|---|---|---|---|---|---|---|
| **Water** | 98.948 | 1.044 | 0.022 | 0.02 | 0.187 | 0.419 | 100 |
| **Desert** | 0.305 | 87.08 | 0.018 | 0.003 | 0.073 | 0.884 | 100 |
| **Agriculture land** | 0.019 | 1.844 | 74.64 | 49.135 | 25.317 | 47.74 | 100 |
| **Orchard area** | 0 | 0.004 | 6.108 | 39.541 | 0.791 | 2.07 | 100 |
| **Urban** | 0.001 | 0.197 | 1.231 | 0.518 | 43.423 | 6.352 | 100 |
| **Bare soil** | 0.724 | 9.831 | 17.98 | 10.782 | 30.21 | 42.535 | 100 |
| **Masked Pixels** | 0.003 | 0 | 0 | 0.001 | 0 | 0 | 100 |
| **Class Total** | 100 | 100 | 100 | 100 | 100 | 100 | 0 |
| **Class Changes** | 1.052 | 12.92 | 25.36 | 60.459 | 56.577 | 57.465 | 0 |
| **Image Difference** | 4.332 | -12.076 | 36.329 | -15.84 | 20.607 | -22.444 | 0 |

*Table 65; Change detection (Ares in ha) 1998-2013. Diagonal values indicate unchanged areas, while out-of-diagonal values indicate areas, which changed from 1998-2013.*

| **Area (Hectare)** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Class Total |
|---|---|---|---|---|---|---|---|
| **Water** | 22791.42 | 815.49 | 38.88 | 0 | 5.04 | 692.28 | 24343.74 |
| **Desert** | 7.92 | 55201.05 | 60.3 | 0.09 | 7.11 | 679.05 | 55955.52 |
| **Vegetation land** | 12.15 | 692.46 | 57880.44 | 5606.91 | 685.17 | 14597.55 | 79474.68 |
| **Orchard area** | 0.54 | 0.18 | 2444.94 | 3576.51 | 6.12 | 419.31 | 6447.69 |
| **Urban** | 5.85 | 514.53 | 2304.63 | 101.97 | 5388.21 | 5060.88 | 13376.07 |
| **Bare soil** | 326.97 | 15800.4 | 32060.43 | 1553.76 | 2514.24 | 32521.68 | 84777.48 |
| **Class Total** | 23144.85 | 73024.11 | 94789.62 | 10839.24 | 8605.89 | 53970.75 | 0 |
| **Class Changes** | 353.43 | 17823.06 | 36909.18 | 7262.73 | 3217.68 | 21449.07 | 0 |
| **Image Difference** | 1198.89 | -17068.59 | -15314.94 | -4391.55 | 4770.18 | 30806.73 | 0 |

*Table 66; Change detection (in percentage) 1998-2013. Diagonal values indicate unchanged areas, while out-of-diagonal values indicate areas, which changed from 1998-2013.*

| **Percentages** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Class Total |
|---|---|---|---|---|---|---|---|
| **Water** | 98.473 | 1.117 | 0.041 | 0 | 0.059 | 1.283 | 100 |
| **Desert** | 0.034 | 75.593 | 0.064 | 0.001 | 0.083 | 1.258 | 100 |
| **Agriculture land** | 0.052 | 0.948 | 61.062 | 51.728 | 7.962 | 27.047 | 100 |
| **Orchard area** | 0.002 | 0 | 2.579 | 32.996 | 0.071 | 0.777 | 100 |
| **Urban** | 0.025 | 0.705 | 2.431 | 0.941 | 62.611 | 9.377 | 100 |
| **Bare soil** | 1.413 | 21.637 | 33.823 | 14.335 | 29.215 | 60.258 | 100 |
| **Class Total** | 100 | 100 | 100 | 100 | 100 | 100 | 0 |
| **Class Changes** | 1.527 | 24.407 | 38.938 | 67.004 | 37.389 | 39.742 | 0 |
| **Image Difference** | 5.18 | -23.374 | -16.157 | -40.515 | 55.429 | 57.08 | 0 |

*Table 67; Change detection (Ares in ha) 1984-2013. Diagonal values indicate unchanged areas, while out-of-diagonal values indicate areas, which changed from 1984-2013.*

| **Area (Hectare)** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Class Total |
|---|---|---|---|---|---|---|---|
| **Water** | 22125.33 | 1704.51 | 37.98 | 0.63 | 18.72 | 452.61 | 24343.74 |
| **Desert** | 3.69 | 55558.98 | 24.84 | 0.27 | 5.4 | 362.34 | 55955.52 |
| **Agriculture land** | 1.8 | 2459.34 | 42755.67 | 6278.58 | 1342.89 | 26636.4 | 79474.68 |
| **Orchard area** | 0 | 0.54 | 1669.32 | 3954.15 | 34.56 | 789.12 | 6447.69 |
| **Urban** | 0.72 | 1216.62 | 1931.67 | 258.66 | 3346.92 | 6621.48 | 13376.07 |
| **Bare soil** | 52.38 | 22113.27 | 23110.74 | 2386.98 | 2386.98 | 34727.13 | 84777.48 |
| **Class Total** | 22183.92 | 83053.26 | 69530.22 | 12879.27 | 7135.47 | 69589.08 | 0 |
| **Class Changes** | 58.59 | 27494.28 | 26774.55 | 8925.12 | 3788.55 | 34861.95 | 0 |
| **Image Difference** | 2159.82 | -27097.74 | 9944.46 | -6431.58 | 6240.6 | 15188.4 | 0 |

*Table 68; Change detection (in percentage) 1984-2013. Diagonal values indicate unchanged areas, while out-of-diagonal values indicate areas, which changed from 1984-2013.*

| **Percentages** | Water | Desert | Agriculture land | Orchard area | Urban | Bare soil | Class Total |
|---|---|---|---|---|---|---|---|
| **Water** | 99.736 | 2.052 | 0.055 | 0.005 | 0.262 | 0.65 | 100 |
| **Desert** | 0.017 | 66.896 | 0.036 | 0.002 | 0.076 | 0.521 | 100 |
| **Agriculture land** | 0.008 | 2.961 | 61.492 | 48.75 | 18.82 | 38.277 | 100 |
| **Orchard area** | 0 | 0.001 | 2.401 | 30.702 | 0.484 | 1.134 | 100 |
| **Urban** | 0.003 | 1.465 | 2.778 | 2.008 | 46.905 | 9.515 | 100 |
| **Bare soil** | 0.236 | 26.625 | 33.238 | 18.534 | 33.452 | 49.903 | 100 |
| **Class Total** | 100 | 100 | 100 | 100 | 100 | 100 | 0 |
| **Class Changes** | 0.264 | 33.104 | 38.508 | 69.298 | 53.095 | 50.097 | 0 |
| **Image Difference** | 9.736 | -32.627 | 14.302 | -49.937 | 87.459 | 21.826 | 0 |

The changes observed showed a decrease in desert area through the three different stages of change detection on 1984-1998, 1998-2013, and 1984- 2013, where part of desert was transformed into agriculture land and urbanized by land reclamation projects.

Unlike the changes in desert, bare soil area recorded a decrease between 1984 and 1998, followed by an increase between 1998 and 2013. These opposite trends lead to an overall increase when the full period between 1984 and 2013 is considered.

The lands converted from either bare soil and/or agricultural to urban are mainly distributed as circles around the 1984-urban areas. This has been caused by the significant increase of the population that required the urban expansion and concentration of housing. On the other hand, increased agriculture lands were mainly converted from desert and bare soil in pursuing a higher economic return through desert reclamation project executed within the 30 years of study. However, a significant proportion of the lands reclaimed between 1984 and 1998 were then reconverted in bare soil in the following period.

The loss of orchard has mostly been converted to vegetable land as a desire for entailing the better and higher economic returns from vegetable cultivation comparing to the original use as orchards.

### 3.5 Conclusions

The results of this study can be summarized as follows.

(i) In the time span between 1984 and 1998, it is observed an increase in the urban areas and a parallel increase in agricultural land at the expenses of desert, bare soil, and orchards. This trend suggests that the increase of population growth was initially sustained by a concurrent increase of agriculture, also by means of land reclamation projects.

(ii) In the following period, from 1998 to 2013, the urban area continued to increase. Moreover, an increase of bare lands was also observed. On the contrary, despite land reclamation projects continued, both agricultural areas and orchards were reduced. These trend is possibly related to overexploitation of the resource in the area, with consequent decrease of land productivity and soil degradation processes.

(iii) Soil salinization is reported as a major land degradation factor in the area and according to this study, reclaimed lands for agriculture are often re-converted to bare soils after few years, demonstrating the inefficiency of this land management strategy. Given the observed land degradation trend and demographic increase, it seems of primary importance to design and implement efficient irrigation and water management strategy to reverse soil degradation processes and sustain agricultural production.

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