Forecasting of Groundwater Salinity Changes and Yield of Some Crops by Integration of Time Series Analysis and GIS at Wadi El-Natrun Area, Egypt

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ABSTRACT

Wadi El-Natrun region has recently undergone extensive urban and agricultural expansion. The main water resource for irrigation in this region is the groundwater aquifer. Extensive use of the aquifer water could cause a shortage in water storage and secondary salinization for this water, and a crop yield reduction. So, the objective of this study is to set efficient strategy to ensure long-term sustainability of the region's agricultural production.

The electrical conductivity (EC) database of the baseline period (1966-2014), for twenty-seven wells of Wadi El-Natrun, were used to apply the time series statistical analysis to forecast EC data of the future period (2015-2050). Multitemporal forecasted EC data was used to classify the groundwater, detect the annual and periodical changes of groundwater salinity, and determine the periodical and annual water potential risk to salinity hazards. The results of the forecasted EC data indicated that the category of very salty groundwater dominated in the northern sector, while the moderately salty and salty groundwater categories dominated in the southern sector. The annual changes of groundwater salinity increased through the period of 2015-2050. The increase ranged from 0.95% to 1.35% with annual mean of 1.13% for the southern and northern sectors.

The forecasted EC and an innovative and interpretative scale were conducted to estimate the periodical (PPRSH) and annual (APRSH) water potential risk to salinity hazard of the future period (2015-2050). The results indicated that the classes of no risk and moderately potential risk were dominant in the southern and northern sectors. Regarding the crop yield, in 1966, about 68.80% of the area under investigation produced 100% of citrus yield and 30.62% of area produced from 75 to 99% of the yield, while 89.9% of area produces 100% of tomato yield and 10.1 % of area produce between 75 to 99% of yield. Based on the forecasted groundwater salinity in 2050, the area of 100% of citrus production will be reduced to 1.41% and 52.64% of the area will produce less than 75%. At the same time, 16.44% of the area become out of citrus production. The area of 100% of tomato production will be reduced to 27.3% and 38.15% of the area will produce less than 50%.

Keywords: Forecast, Groundwater, Salinity, time series analysis, water potential risk to salinity hazard.

INTRODUCTION

Demand for the world's water supply is raising rapidly that sets the food production in the world at risk. Agricultural production, industrial, household, and environmental uses contribute for scarce water supply sources. As demands for water by all users grows, groundwater sources are being depleted; other water sources are becoming polluted and degraded (Masoud and Atwia, 2011 and Masoud, 2014). Additionally, quality of groundwater is degraded rapidly with the increasing massive industrialization, urbanization, and agricultural expansion with its associated activities. Degradation of the groundwater quality is commonly linked to its chemistry variables (Dawoud, 2004 and Kim *et al*., 2005).

Steady increase of Egypt's population must be faced by enhanced sustainable of management of newly reclaimed soils, such as Wadi El-Natrun region. The groundwater in this region is considered as a unique water resource for the irrigation purposes (Youssef *et al*., 2012). During the recent years, increasing obstacles to meet the increasing the demands for domestic supplies and expansion in desert reclaimed soils has raised concerns for the sustainability of the groundwater resource (El Arabi, 2012).

The impacts of climate change on both the supply and demand of water resources management are also becoming increasingly important globally (Green et al. 2011). For the area of Wadi El-Natrun, reference evapotranspiration is projected to increase by more than 9% by year of 2025 (Candela *et al*., 2012), while changes in precipitation are projected to be nil (Terink *et al*. 2013).

The high groundwater use and land management practices in the agricultural area of Wadi El-Natrun have resulted in the degradation of groundwater quality and quantity. Primary concerns among users are salinization from declining water levels (King and Salem, 2012; Ibrahim, 2005; and Fattah, 2011). These problems have raised questions about the sustainability and potential risks of the current water use regime on local water, food and economic security in the area, particularly as climate change is projected to add additional pressures to water demand (Switzman, 2013).

Time-series analysis is becoming an increasingly important method of studying temporal variations in groundwater quality and hydrology. It is used for building mathematical models to generate synthetic

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hydrologic records, to forecast hydrologic events, to detect trends and shifts in hydrologic records. Kim *et al*. (2005) applied time-series analysis to study the temporal variations effects of tidal pressure on groundwater quality in particular the salinity level, and how they vary over time.

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, it involves the ability to quantify temporal effects using multi-temporal data. Thus, change detection has become a major application of geographic information system (GIS) data because of repetitive coverage at short intervals and consistent image quality (Abd El-Hady *et al*. 2014 and 2015).

Accordingly, an agricultural strategy for Wadi El-Natrun region is needed for the period 2015-2050. The strategy requires future data about the groundwater quality and the crops growing in this region. Therefore, the present study aims to: (1) monitor future changes of groundwater salinity using time series analysis, (2) forecast the yield, of some crops such as tomato and citrus as function of groundwater salinity, and (3) evaluate and map the groundwater suitability for citrus and tomato productions.

MATERIALS AND METHODS

1. Studied Area

Wadi El-Natrun is a narrow depression located in the west of Nile Delta, approximately 110 km northwest Cairo, between longitudes 30º 02´ and 30º 29´ E and latitudes 30º 16´ and 30º 32´ N (Fig.1). The total area of Wadi El-Natrun region is about 281.7 Km^2 (i.e. 28406 Hectares). The region is located in a NW-SE direction and has an average elevation of 23 m below sea level. This region has considerable potential for agricultural production due to its location and to the availability of groundwater for irrigation. The origin of the underground water in Wadi El-Natrun is lateral seepage from the Nile Delta and from Moghara aquifer, due to its proximity and low level (El-Maghraby, 1990). It is also recharges from the south by Nile Delta water through Wadi El Farigh (Abdel Baki, 1983 and Sharaky *et al*., 2007). Wadi El-Natrun area is extremely arid region where the mean annual rainfall, evaporation and temperature are 41.4 mm, 114.3 mm and 21ºC, respectively (Egyptian Metrological Authority, 2006).

2. Quality of Groundwater

Salinity data of groundwater samples of twenty seven wells were collected by Wadi El-Natrun Authority and Desert Development Center (Sabbah and Metwally, 1997) to represent the groundwater wells of the northern and southern sectors of Wadi El-Natrun. The EC data period (1996–2014) is consisted as a past base line to enable for forecasting EC for the future period (2015-2050). The groundwaters of the studied wells were classified, based on the forecasted EC, according to the system of Government of Western Australia, Department of Agriculture (2015), and are shown in Table (1).

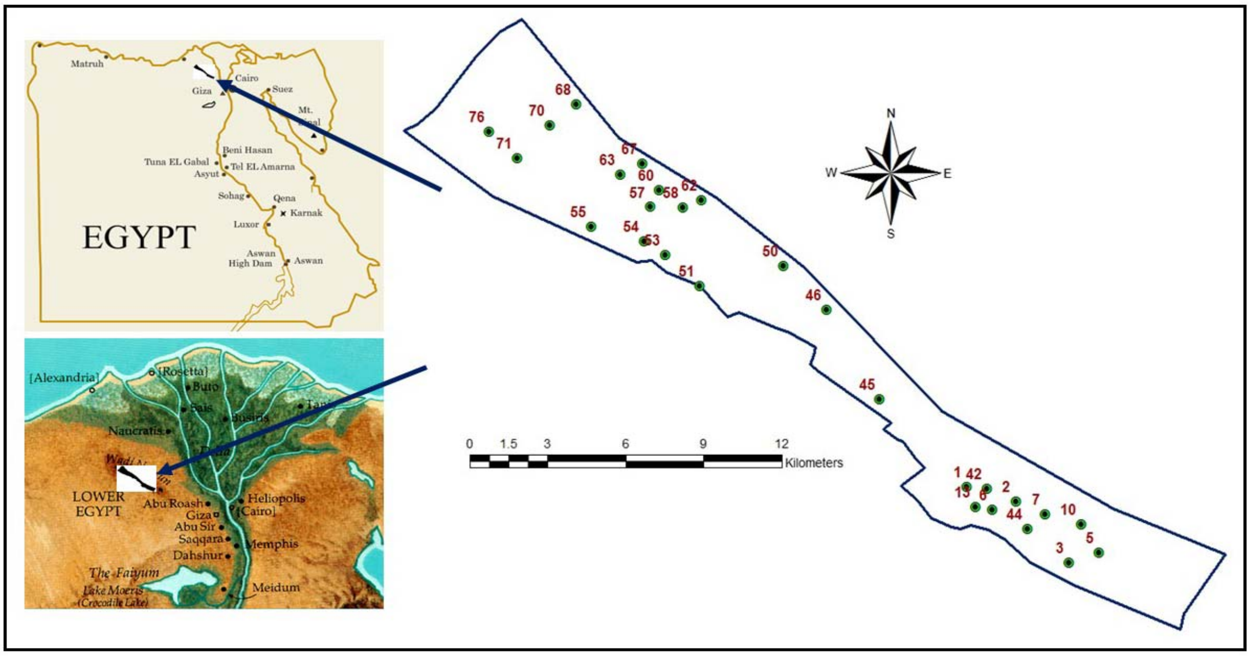

Fig1. Location of studied area and wells

Table 1. Water salinity classification

EC (dSm^{-1})	Salinity Class	EC (dSm^{-1})	Salinity Class
0.0-0.80	Low salinity	2.50-5.00	Salty
0.08-2.50	Moderately salty	>5	Very Salty

3. Forecasting Groundwater Status

(a) Forecasting EC Data of 2015-2050: The collected annual EC data of the groundwater of the baseline past period (1966-2014) wasutilized to compose the salinity and to forecast the groundwater salinity of the future period of 2015-2050. This forecasting was elaborated by using the statistical time series analysis named Zaitun Software Version 2.1 (Fathony *et al*., 2009). This Version included the following steps:

-Composition of the type of time series by selecting EC data measured, at the same time, (January of each year of the base past period: 1966-2014, to minimize data seasonality of flow time series.

- Determination of decomposition model type: The two types of model of time series decomposition are the additive decomposition model and the multiplicative model. Reliable type of the decomposition model is determined according to Trend Line (Lee and Lee, 2000; Tularam and Keeler, 2006; and wikipedia, 2015) which was the additive decomposition model.

- Determination of the fitting trend equation.

(b) Calculation of EC descriptive statistics: The descriptive statistics of the EC data of past baseline period (1966-2014) and the future period (2015-2050) were used to study periodical changes of groundwater salinity.

(c) Assessment of annual and periodical future potential risk of salinity hazards:

The indictors of periodical (PPRSH) and annual (APRSH) water potential risk with respect to salinity hazard, of the future period (2015-2050), were expressed as follows:

$$\text{PPRSH(y1 - yt)\%} = \sum_{y=t}^{y=1} 100 * ECy1 - ECyt) / ECyt$$

where:

PPRSH (%)= Periodical Potential Risk to Salinity Hazard for a period from year=1 to year=t. The mean of (PPRSH), i.e = (PPRSH) / (Y1-Yt),

APRSH (%)= Annual Potential Risk to Salinity Hazard and the interpretative scale was established to classify the studied groundwater,

ECy1 = the electrical conductivity at year 1, and

ECyt= the electrical conductivity at year t.

4. GIS Mapping of Crops Yield:

Forecasted EC data of the future period (2015-2050) were used to estimate the yield of citrus and tomato, the most common cultivated crops in the area, using Ayers and Westcot (1985). The estimated yields of citrus and tomato were incorporated with the coordinates of the groundwater wells to map the forecasted yield of citrus and tomato for the years of 1966, 2015 and 2050, using ArcMap10 GIS Package (ESRI 2010).

RESULTS AND DISCUSSIONS

1) Establishment Future EC database

- Determination of the type and composition model of EC time series:

Simply, there are two types of data time series flow and stock series. The concept of stock series was applied to compose EC data time series by selecting EC data measured at the same time (January of each year) of the baseline period (1966-2014). This time series type enabled to avoid partially the data seasonality of flow time series that conduct to unreliable forecasting. Hence, stock time series of baseline EC data could not completely remove all seasonal variation. So, it was necessary to determine type of decomposition model that is capable to remove the remaining seasonal variation.

The two types of time series decomposition models, additive and multiplicative, were formulated to investigate the behavior of the trend line of EC data (Fig. 2). The trend analysis of EC data of the baseline period (1966-2014) showed that the fluctuations effects are independent of the trend behavior; the amplitude of irregular variations does not change as the level of the trend rises or falls. In addition, cyclic effects behaved in constant manner from year to year. For these reasons, the additive model was selected to decompose this series type.

- Equations describing the trend of EC data in the baseline period:

The different types of equations describing the trend of EC data were defined to dictate the more reliable trend equation that had the minimal mean squared error (MSE). As an example, four equations expressing the trend of EC data of well No.1 are shown in Table (2). In addition, the MSE is shown. The most reliable equation is the exponential one because it has the minimal (MSE) as shown in Table 2. Similarly, all other EC data of the other wells were expressed using the exponential equation.

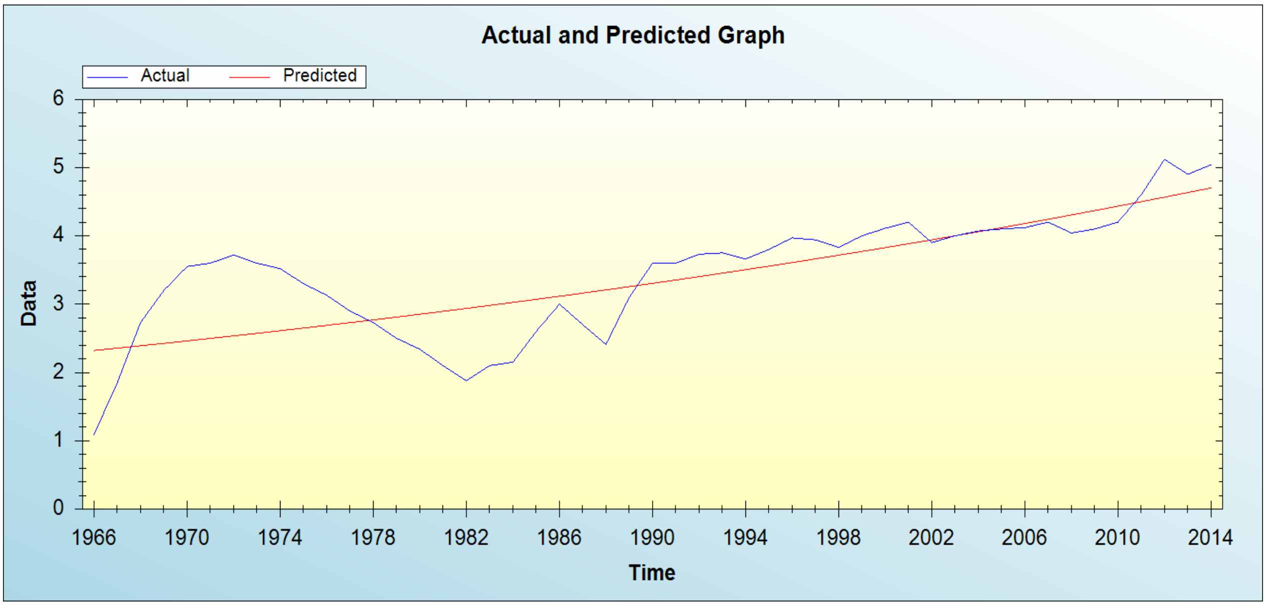

Fig 2. Trend of EC time series (1966-2014) of well No.1

Table 2. Trend equations of groundwater EC data (1966-2014) of well No.1

Type of Trend Equation	Trend Equation	Mean Squared Error (MSE)
Exponential	$Y_t = 2.2877*(1.0148**t)$	0.0090
Quadratic	$Y_t = 2.7209 -0.006*t +0.0011*t**2$	0.3075
Cubic	$Y_t = 2.742 -0.0110*t +0.0013*t**2 -3.1752E-06*t**3$	0.3143
Linear	$Y_t = 2.2722 +0.04657*t$	0.3381

The composition convenient time series, determination of decomposition model, and fitting equation conducted to forecast EC that are unbiased by any annual changes seasonal patterns over the period of 2015-2050 as shown in Table 3. These EC forecasted data composed a comprehensive database of groundwater of Wadi El-Natrun region. This could be considered a strategic water source for combating the water scarcity. It is clear from Table 3 that most forecasted EC values increase as time increase with few exception, i.e., wells No. 53 and 76.

2) Forecasting Groundwater Status:

Multitemporal forecasted EC database values enabled to forecast EC-groundwater status: (a) EC-groundwater classification, (b) Detection of annual changes of groundwater salinity, (c) Detection of periodical changes of groundwater salinity, and (d) Determination of periodical and annual water potential risk to salinity hazard.

(a) EC-groundwater classification:

The studied groundwater was classified according to water salinity classification presented in Table (1) into four salinity classes: low salinity (LS), moderately salty (MS), salty (S), and very salty (VS) as in Table (4) as follows:

Wells of southern sector of Wadi El-Natrun: The low salty category will not present in the future period, while the moderately salty class is represented by wells 44, 45, and 46. Other wells such as 2, 5, and 6 will turn up from moderately salty to salty. Wells 1, 7 and 10 lay in salty class, but well (1) will goes up to very salty category and Well (13) will be very salty class.

Wells of northern sector of Wadi El-Natrun: The low salty groundwater will not be present in the future period. The category of very salty will be dominant for the wells 57, 58, 60, 63, 67, 68, and 70. Other wells (62, 71, and 76) will join this group. Wells 50, 51, 54 will have moderately salty groundwater, but that of well 54 will turn up salty class. The groundwater of well 62 will be salty (2015- 2031) to jump to very salty (3032-2050). Masoud and Atwia (2011) studied the spatio-temporal characterization of the Pliocene aquifer conditions in Wadi El-Natrun area, Egypt. They found that groundwater of the northwestern zone is high and very high salinity hazard while southeastern zone characterized by medium to high salinity hazard.

Table 3. Total salinity (dSm^{-1}) in twenty-seven wells in Wadi El Natrun area (aquifer)

No. / year	1	2	3	5	6	7	10	13	42	44	45	46	50	51	53	54	55	57	58	60	62	63	67	68	70	71	76
1966	1.09	0.98	1.19	0.59	0.63	0.78	0.98	1.53	0.81	0.56	0.80	0.55	0.77	0.77	0.68	0.98	0.92	1.88	1.09	0.77	1.09	0.93	1.15	3.28	0.93	1.20	1.68
2014	4.76	1.67	1.34	0.96	1.42	3.30	1.56	4.10	1.12	0.95	1.35	0.93	1.03	0.88	0.81	1.81	2.73	4.95	8.51	2.63	4.18	2.85	2.79	4.17	3.72	2.30	1.61
2050	8.01	2.78	1.58	1.38	2.77	4.63	1.84	6.55	1.70	1.48	1.50	1.25	1.32	1.07	0.68	2.76	4.71	7.99	16.37	3.85	6.17	4.95	3.20	4.54	5.44	2.69	1.49

(b) Detection of Annual Changes of Groundwater Salinity:

Multitemporal forecasted EC (Table 3) was used to monitor the annual changes of groundwater salinity, of each well, over the years of the future period (2015-2050). The EC values tended to increase annually, with exception of wells (53, 76). This comprehensive EC data enabled to calculate the annual rate of increasing salinity that have positive values for all wells. Masoud and Atwia (2011) Studied the spatio-temporal characterizations of Wadi El-Natrun groundwater in 2006 and 2007. They found that the northwestern zone showed high to very high salinity hazard while the southeastern zone samples showed medium to high salinity hazard. Two wells (53, 76) had negative values (-0.34, and -0.09%, respectively). This negative sign indicated salinity decreasing tendency. These decreases may be due to lower discharge and minimum operating time in latest few years for these two wells compared to other wells.

Also, data of EC indicated that the maximal annual increasing salinity (2%) that was recorded (well 6) will occur through the period (2015-2018). In addition, the EC of the groundwater of well 68 will have the minimal salinity with of increasing rate 0.26% along the years from 2015 to 2050. The water of wells of southern and northern sectors of Wadi El-Natrun had averaged annual salinity increasing of 3.36% and 4.48%, respectively. In addition, the results showed that the annual general mean (all studied wells) salinity increasing had the value of 36.78%. According to the EC values, the studied wells can be arranged in ascending series as follows:

- The wells of southern sector of Wadi El-Natrun; 5, 46, 44, 42, 6, 3, 45, 2, 10, 7, 13 and 1.
- The wells of northern sector of Wadi El-Natrun; 53, 51, 50, 76, 54, 55, 71, 60, 63, 67, 70, 62, 68, 57 and 58.

(c) Detection of Periodical Changes of Groundwater Salinity:

The descriptive analysis of the forecasted EC means of the future period (2015-2050) were calculated to determine the mean, minimum and maximum EC data (Table 3). The means indicated that the studied wells can be classified into four groups according to their periodic salinity: (a) low salty (well No. 53 with EC of 0.74); (b) moderately salty (wells No. 2, 3, 5, 6, 10, 42, 44, 45, 46, 50, 51, 54, 71, and 76 with EC range 1.08 to 2.49); (c) salty (wells No. 7, 55, 60, 63, 67, and 70 with EC range 3.20 to 4.53); and (d) very salty (wells No. 1, 13, 57, 58, 62 with EC range 5.23 to12.03). At regional and periodical scales, wells of Wadi El-Natrun may have averaged, minimum and maximum EC values of 3.80, 0.68 and 16.37 dSm^{-1}, respectively (Table 4) during the future period. According to Abdel-Baki (1983); Wadi El-Natrun area has two water bearing horizons that separated by a thick clay layer.

The upper water horizon has high saline water while the lower water horizon has low saline water. The separated layer changes laterally to the south and east into sandy layer allowing interaction of water in the two layers.

Descriptive statistics of groundwater salinity of the baseline period (1966– 2014) were calculated from collected data and illustrated in Tables (5 and 6). The mean, minimum and maximum EC values were 1.79, 0.54 and 6.68 dSm^{-1}, respectively. The comparison of descriptive statistics of EC groundwater, of the past and future periods, indicated that the regional averaged salinity increased from 1.79 to 3.87 dSm^{-1}. The maximum regional EC value, increased from 6.68 dSm^{-1}(in the past baseline period: 1966-2014) to 16.37 dSm^{-1}(in the future period: 2015-2050).

(d) Determination of periodical and annual water potential risk to salinity hazard:

Salinity annual increasing rate was considered as a parameter to assess risk potentiality to salinity hazard. This rate was conducted to calculate the indices of periodical (PPRSH) and annual (APRSH) water potential risk to salinity hazard for the future period (2015-2050). Hence, groundwater must be classified, by potentiality to salinity hazard; it was required to establish an innovative and interpretative scale. This scale is based on calculation of the predicated EC and the groundwater salinity classification. The innovative and interpretative scale had the advantage of compiling water salinity classes and EC annual increasing percentage. It consists of five categories of risk potentiality to salinity hazard: no risk, moderately potential risk, high potential risk, very high potential risk and out of agricultural uses (Table 7).

The studied groundwater was classified to monitor the predicated change of the future period (2015-2050). The scale indicated that the classes of no risk and moderately potential risk were dominant in Wadi El-Natrun (Table 8). Table (8) also indicated that in southern sector, about 75% of wells have no salinity potential risk, while 17% of wells have moderately salinity potential risk and well No.1 has high potential risk. On the other hand, in norther sector, about 40% of wells has no potential risk also, 40% of wells has moderately potential risk, while well No.62 has high potential risk and well No.58 is out of agriculture use. The advantage of the annual and periodical future potential risk of salinity hazard guides the agricultural decision makers to plan of crops cultivation at short and long runs.

3) Yield Prediction as a function of Water Salinity Changes:

Citrus:

Table (9) and figure (3) showed area cultivated with citrus. A 68.80% of the area produces 100% of citrus yield while 30.62% of the area produces from 75 to 99% of citrus in 1966. In 2015, the corresponding areas were 17.56% and 25.71%. In 2050, 1.41% of the area will produce 100% of the citrus yield while 29.5 of the area will produce 75 to 99% of yield. It is expected that in 2050, 16.44% of the area become out of citrus production.

Tomato:

Table (10) and figure (4) showed area cultivated with tomato and its production. In the year 1966, 89.90% of the area produced 100% of tomato yield while 10.10% of the area produced from 75 to 99% of tomato yield. In 2015, the area of 100% of production was reduced to 32.20% of the area and production of 75 to 99% of production was increased to 50.80% of the area. In 2050, according to forecasted groundwater salinity, the area of 100% of production will be reduced to 27.30%, and 52.90% of the area produces between 50 to 75%. At the same time, 19.00% of the area produces less than 50% of tomato yield.

Table 4. EC-groundwater classification of Wadi El-Natrun

Well No.	EC-Forecasted Changes (EC_{min}) to (EC_{max})	Salinity Class	Well No.	EC -Forecasted Changes (EC_{min}) to (EC_{max})	Salinity Class
Wells of southern sector of Wadi El-Natrun					
1	2015 (4.76) – 2018 (5.00)	S	7	2015 (3.3) - 2050 (4.63)	S
	2019 (5.04) – 2050 (8.01)	VS	10	2015 (1.56) - 2050 (1.84)	S
2	2015 (1.67) - 2042 (2.47)	MS	13	2015 (4.10) - 2029 (4.93)	S
	2043 (2.53) - 2050 (2.78)	S		2030 (5.03) – 2050 (6.55)	VS
3	2015 (1.34) - 2050 (1.58)	MS	42	2015(1.12) - 2050 (1.7)	S
5	2015 (0.96) - 2050 (1.38)	MS	44	2015(0.95) - 2050 (1.48)	MS
6	2015 (1.42) - 2044 (2.43)	MS	45	2015(1.35) - 2050 (1.50)	MS
	2045 (2.52) - 2050 (2.77)	S	46	2015(0.93) - 2050 (1.25)	MS
Wells of northern sector of Wadi El-Natrun					
Well No.	**EC -Forecasted Changes (EC_{min}) to (EC_{max})**	**Salinity Class**	**Well No.**	**EC-Forecasted Changes (EC_{min}) to (EC_{max})**	**Salinity Class**
50	2015(1.03) - 2050 (1.32)	MS	62	2015 (4.18) -2031(4.99)	S
51	2015(0.88) - 2050 (1.07)	MS		2032 (5.06) 2050 (6.17)	VS
53	2015(0.80)-2050 (0.68)	LS	63	2015 (2.85) -2050 (4.95)	S
54	2015(1.81) -2041 (2.47)	MS	67	2015 (2.79)-2050 (3.2)	S
	2042 (2.51) -2050 (2.76)	S	68	2015 (4.17)-2050 (4.54)	S
55	2015(2.73) -2050 (4.71)	S	70	2015 (3.72) -2042 (4.99)	S
57	2015 (5.02) – 2050(7.99)	VS	71	2015 (2.30)- 2034 (2.5)	MS
58	2015(8.51) - 2050 (16.37)	VS		2034 (5.03) - 2050 (5.44)	VS
60	2015 (2.63) - 2050 (3.85)	S	76	2015(1.49) -2050 (1.62)	MS

Table 5-a. Descriptive statistics of groundwater forecasted salinity of the future period (2015-2050) of the southern sector of Wadi El-Natrun

Well No.	Descriptive Statistical Parameters			Well No.				Well No.			
	Mean	Min.	Max.		Mean	Min.	Max.		Mean	Min.	Max.
1	6.24	4.76	8.01	6	2.02	1.42	2.77	42	1.39	1.12	1.70
2	2.18	1.67	2.78	7	3.93	3.30	4.63	44	1.20	0.95	1.48
3	1.46	1.34	1.58	10	1.70	1.56	1.84	45	1.42	1.35	1.50
5	1.16	0.96	1.38	13	5.23	4.10	6.55	46	1.08	0.93	1.25

Table 5-b. Descriptive statistics of groundwater forecasted salinity of the future period (2015-2050) of the northern sector of Wadi El-Natrun

Well No.	Descriptive Statistical Parameters			Well No.	Descriptive Statistical Parameters			Well No.	Descriptive Statistical Parameters		
	Mean	Min.	Max.		Mean	Min.	Max.		Mean	Min.	Max.
50	1.17	1.03	1.32	57	6.36	5.01	7.99	67	2.99	2.79	3.20
51	0.97	0.88	1.07	58	12.03	8.51	16.37	68	4.35	4.17	4.54
53	0.74	0.68	0.80	60	3.20	2.63	3.85	70	4.53	3.72	5.44
54	2.25	1.81	2.76	62	5.11	4.18	6.17	71	2.49	2.30	2.69
55	3.63	2.73	4.71	63	3.81	2.85	4.95	76	1.55	1.49	1.62

Table 6-a. Descriptive statistics of groundwater salinity (EC) of the past base period (1966 – 2014) of the southern sector of Wadi El-Natrun

Well No.	Descriptive Statistical Parameters (EC, dSm^{-1})			Well No.	Descriptive Statistical Parameters (EC, dSm^{-1})			Well No.	Descriptive Statistical Parameters (EC, dSm^{-1})		
	Mean	Min.	Max.		Mean	Min.	Max.		Mean	Min.	Max.
1	3.44	1.09	5.12	6	0.91	0.44	1.22	42	0.85	0.48	1.08
2	1.18	0.71	1.68	7	2.62	1.44	3.11	44	0.71	0.46	0.96
3	1.20	0.86	1.45	10	1.39	1.08	1.79	45	1.27	0.80	1.64
5	0.76	0.49	0.91	13	3.02	1.4	3.58	46	0.76	0.50	1.00

Table 6-b. Descriptive statistics of groundwater forecasted salinity of the past base period (1966 – 2014) of the northern sector of Wadi El-Natrun

Well No.	Descriptive Statistical Parameters (EC,dSm-1)			Well No.	Descriptive Statistical Parameters (EC,dSm-1)			Well No.	Descriptive Statistical Parameters (EC,dSm-1)		
	Mean	Min.	Max.		Mean	Min.	Max.		Mean	Min.	Max.
50	0.87	0.67	1.12	57	3.60	1.88	4.45	67	2.52	1.84	2.81
51	0.78	0.60	0.95	58	5.64	1.09	7.27	68	3.95	3.20	4.47
53	0.91	0.68	1.48	60	2.05	0.97	2.47	70	2.89	1.68	3.57
54	1.37	0.71	1.75	62	3.24	1.09	3.88	71	2.06	1.44	2.45
55	1.90	0.88	2.33	63	1.97	0.93	2.48	76	1.72	1.48	2.09

Table 7. Interpretative scale of the annual and periodical potential risk of salinity hazard (APRSH, %)

Salinity Class	Annual increasing (%)	Predicated Increasing of EC (dSm^{-1})		Predicated EC (dSm^{-1})		Class of Salinity Potential Risk
		1 year	20 years	1 year	20 years	
0.0-0.8	25	0.2	4	1	4.8	No Risk
	50	0.4	8	1.2	8.8	Moderately Potential Risk
	75	0.6	12	1.4	12.8	High Potential Risk
	>75	>0.6	>12	>1.4	>12.8	Very High Potential Risk
>0.8-2.5	≤ 5	0.13	2.6	7.63	5.1	No Risk
	> 5 - ≤ 10	0.25	5	7.75	12.5	Moderately Potential Risk
	> 10 - ≤ 15	0.38	7.6	7.88	15.1	High Potential Risk
	> 15	>0.38	>7.6	>7.88	>15.1	Very High Potential Risk
>2.5-5.0	≤ 2.5	0.13	2.6	5.13	7.6	Moderately Potential Risk
	> 2.5 - ≤ 5	0.25	5	5.25	10	High Potential Risk
	> 5	0.50	10	5.5	15	Out of Agric. Use
> 5 - 7.5	≤0.5	0.04	0.8	7.54	8.3	Moderately Potential Risk
	> 0.5 -≤ 2	0.15	3	7.65	10.5	High Potential Risk
	> 2	0.38	7.6	7.88	15.1	Out of Agric. Use
>7.5 - 10	≤ 0.5	0.05	1	10.05	11	High Potential Risk
	> 0.5	0.20	4	10.2	14	Out of Agric. Use

Table 8. Classes of Salinity Potential Risks of groundwater

Well No.	PPRS H (%)	APRS H (%)	Max. EC (dSm^{1})	Class of Salinity Potential Risk	Well No.	PPRS H (%)	APRS H (%)	Max. EC (dSm^{1})	Class of Salinity Potential Risk
Wells of southern sector of Wadi El-Natrun									
1	27.96	1.47	6.33	High Potential Risk	10	11.21	0.59	1.71	No Risk
2	29.37	1.55	2.19	Moderately Potential Risk	13	20.22	1.06	5.30	High Potential Risk
3	10.61	0.56	1.46	No Risk	42	25.18	0.59	1.41	No Risk
5	21.89	1.15	1.17	No Risk	44	26.36	1.39	1.21	No Risk
6	38.08	2.0	2.03	No Risk	45	7.07	0.37	1.42	No Risk
7	20.32	1.07	3.96	No Risk	46	17.96	0.95	1.09	No Risk
Mean annual salinity increasing of wells of southern sector of Wadi EL-Natrun = (3.36%)									
Wells of northern sector of Wadi El-Natrun									
50	15.70	0.83	1.18	No Risk	62	28.09	1.48	5.17	High Potential Risk
51	12.82	0.67	0.98	No Risk	63	32.06	1.69	3.84	Moderately Potential Risk
53	- 6.48	- 0.34	0.8	No Risk	67	9.28	0.49	3.0	Moderately Potential Risk
54	25.23	1.33	2.28	No Risk	68	4.93	0.26	4.38	Moderately Potential Risk
55	31.58	1.60	3.66	Moderately Potential Risk	70	22.92	1.21	4.58	Moderately Potential Risk
57	27.13	1.43	6.43	High Potential Risk	71	10.37	0.55	2.50	No Risk
58	37.7	1.98	12.12	Out of Agr. use	76	-1.77	- 0.09	1.62	No Risk
60	23.05	1.21	3.24	Moderately Potential Risk	Mean annual salinity increasing of wells of northern sector of Wadi El-Natrun = (4.48%)				

Table 9. Citrus area and yield prediction with time according to water salinity

Yield (%)	1966		2015		2050	
	ha	%	ha	%	ha	%
100	5022.5	68.80	1281.6	17.56	103.3	1.41
75-99	2235.4	30.62	1876.7	25.71	2153.8	29.50
50-74	42.4	0.58	2481.6	33.99	1058.1	14.49
1-49	0.0	0.0	1606.1	22.00	2785.3	38.15
Zero	0.0	0.0	54.3	0.74	1199.9	16.44

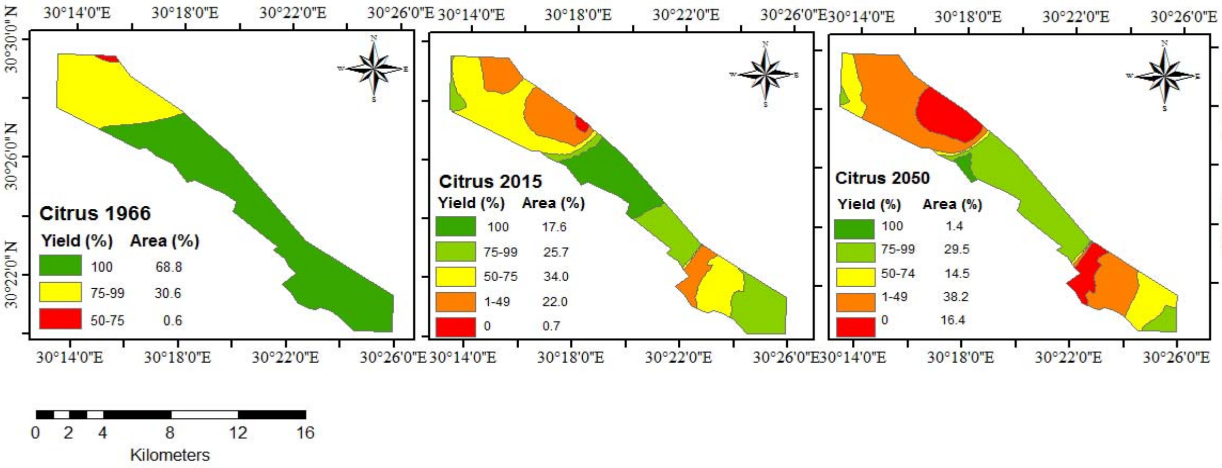

Fig 3. Predicated citrus yield related to groundwater salinity in 1966, 2015 and 2050

Table 10. Tomato area and yield prediction with time according to water salinity

Yield (%)	1966		2015		2050	
	ha	%	ha	%	ha	%
100	6565.4	89.9	2349.6	32.2	1989.7	27.3
75-99	735.1	10.1	3709.3	50.8	1495.3	20.5
50-74	0.0	0	1184.1	16.2	2366.9	32.4
1-49	0.0	0	57.5	0.8	1390.1	19.0
Zero	0.0	0	0.0	0.0	58.4	0.8

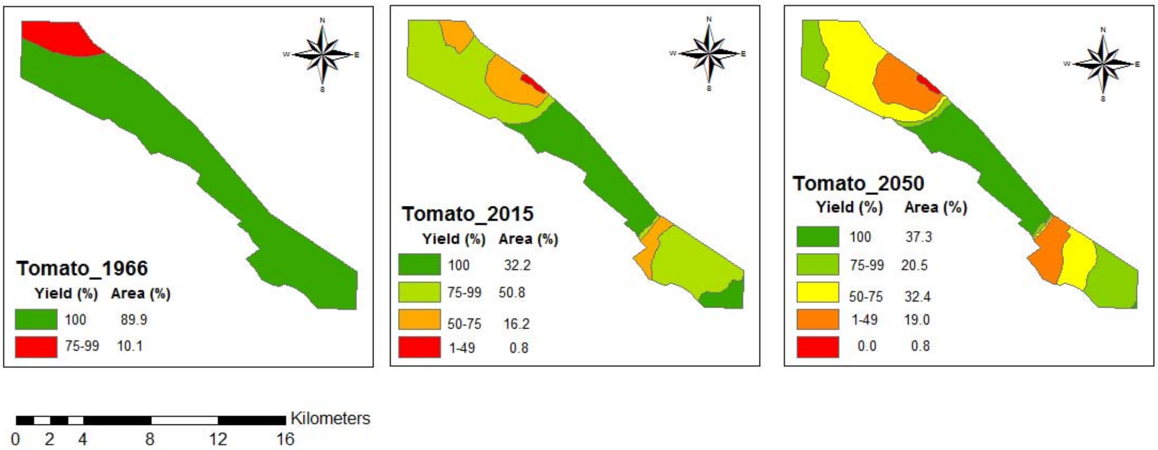

Fig 4.Predicated tomato yield related to groundwater salinity in 1966, 2015 and 2050

CONCLUSION

According to the historical data of groundwater salinity collected from the area through 1966 to 2014 and forecasting data to 2050, the results indicated that the groundwater salinity will increase with time and withdrawn of water. The results of crop production showed a reduction of all crops cultivated in the area. Thus, the results in this study is suggested to be a constructed guide for decision makers' attention about the expected groundwater salinity risk in Wadi El-Natrun to supply the area with another low salinity water source to prevent the water salinity risk. In addition, there is a serious need for efficient strategies to ensure long-term sustainability of the region's agricultural production.

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الملخص العربي

التنبؤ بتغيرات ملوحة المياه الجوفية وإنتاج بعض المحاصيل بواسطة التكامل بين تحليل السلاسل الزمنية ونظم المعلومات الجغرافية في منطقة وادى النطرون - مصر

احمد محمد احمد عجاج

تخضع منطقة وادى النطرون مؤخراً للامتداد العمرانى والزراعى وحيث أن مصدر المياه الرئيسى للرى هو خزان المياه الجوفى الموجود بهذه المنطقة. فإن الاستخدام المتزايد لمياه الخزان الجوفى تتسبب في نقص وتمليح ثانوى لهذه المياه وبالتالي انخفاض في إنتاجية المحاصيل. لذلك الهدف من هذه الدراسة هو وضع استراتيجيات كافية لتضمن استمرارية الإنتاج الزراعى على المدى الطويل.

استخدمت نتائج التوصيل الكهربى(EC) خلال فترة الأساس الماضية(١٩٦٦-٢٠١٤) لعدد سبعة وعشرون بئراً بمنطقة وادى النطرون لتطبيق التحليل الإحصائي للسلاسل الزمنية للتنبؤ بقاعدة بيانات التوصيل الكهربى للمرحلة المستقبلية(٢٠١٥-٢٠٥٠). التنبؤ المتعدد الأزمنة لقاعدة بيانات التوصيل الكهربى استخدم لتصنيف المياه الجوفية ولأكتشاف التغيرات السنوية والمرحلية لملوحة المياه الجوفية وتقدير المخاطر المحتملة من مشاكل الأملاح السنوية(APRSH) والمرحلية(PPRSH). أوضحت نتائج التوصيل الكهربى المتنبأ بها أن رتبة المياه الجوفية "عالى الملوحة" تسود في القطاع الشمالى لوادى النطرون بينما رتبتى المياه "متوسطة الملوحة" و"الملحية" تسود في القطاع الجنوبى من وادى النطرون. التغيرات السنوية في التركيز الملحى في المياه الجوفية زادت خلال الفترة من ٢٠١٥ وحتى ٢٠٥٠ وتراوحت الزيادة بين ٠,٩٥% و١,٣٥% بمتوسط سنوي ١,١٣% بالقطاعين الشمالى والجنوبى من وادى النطرون. التوصيل الكهربى المتنبأ به والمقياس المبتكر استخدما للتنبؤ بالمخاطر المحتملة واضرار الأملاح السنوي والمرحلى للفترة المستقبلية(٢٠١٥-٢٠٥٠). أوضحت النتائج أن الرتب "لاخطر" و"مخاطر متوسطة" قد سادت في القطاعين الشمالى والجنوبى لمنطقة وادى النطرون.

فى عام ١٩٦٦ حوالى ٦٨,٨٠% من المساحة تحت الدراسة تنتج ١٠٠% من محصول الموالح و٣٠,٦٢% من المساحة تنتج من ٧٥ الى ٩٩% من انتاج الموالح. بينما ٨٩,٩% من المساحة تنتج ١٠٠% من محصول الطماطم و ١٠,١٠% تنتج ما بين ٧٥ الى ٩٩% من انتاج الطماطم. بينما في عام ٢٠٥٠ وطبقاً للقيم المتنبأ بها للتركيز الكلى للأملاح فان المساحة التي تنتج ١٠٠% من الموالح سوف تنخفض الى ١,٤١% من المساحة بينما ٥٢,٦٤% من المساحة ستنتج أقل من ٧٥% من انتاج الموالح. في نفس الوقت ١٦,٤٤% من المساحة ستصبح غير صالحة لإنتاج الموالح. بينما المساحة التي تنتج ١٠٠% من الطماطم سوف تنخفض الى ٢٧,٣٠% وأيضاً ٣٨,١٥% من المساحة ستنتج أقل من ٥٠% من انتاج الطماطم. وعليه فهذه الدراسة توجه انتباه متخذى القرار لخطورة زيادة التركيز الكلى للأملاح في المياه الجوفية المتوقع في منطقة وادى النطرون وذلك لأمداد المنطقة بمصدر مائى منخفض الأملاح لمنع خطر الأملاح في مياه الرى.