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List of Abbreviations

AMSL	Above mean sea level
EC	Electrical conductivity
ECe	Electrical conductivity of the saturated soil paste extract
ESP	Exchangeable sodium percentage
GAG	General Adminstration of Groundwater of New Valley
GIS	Geographic Information Systems
GPS	Global Positioning System
NSAS	The Nubian Sandstone Aquifer System
NVAD	New Valley Agriculture Directorate
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
TDS	Total dissolved solids
USDA	United States Department of Agriculture
USSL	Untied States of Soil Laboratory Staff
UTM	Universal Transverse Mercator

5. Summary and Conclusions

This study was conducted in El-Dakhla oasis. The main objective of this study is to investigate the status of soil and groundwater salinity under El-Dakhla oasis conditions. The specific objectives of the study were:

1. To assess the chemical analysis of the groundwaters of El-Dakhla as well as to classify these waters according to the standard suitability classes of irrigation water.
2. To characterize the soil chemical properties and classify the soils of El-Dakhla oasis according to classes of the salt affected soils.
3. To study impacts of groundwater quality on soil properties.
4. To forecast the spatial distribution of groundwater and soil properties in El-Dakhla oasis using GIS software.

A total of 169 groundwater samples were collected from different wells located in El-Dakhla oasis. These wells are used for irrigation purposes.

From the area that the well covered, two composite samples were collected one from the surface soil (0-30 cm) and the other from the subsurface soil (30-60 cm). A total of 338 soil samples were collected. All sampling points were geo-referenced and sampling dates were recorded by GPS.

The results of this study can be summarized as follow:

5.1. Groundwater Chemistry and Quality for irrigation

4.1.1. Groundwater pH

Groundwater pH in El-Dakhla oasis ranged from 3.70 to 8.70. The lowest value (3.70) were recorded in Ain El-Bait well followed by Ain Abo Refae (4.00) and Ain Ali (4.38) wells in Tenieda, Al-Rashda, El-Moshiya villages, respectively. Meanwhile, the highest value was observed in Ain Sayed Al-Daba well (8.70) followed by El-Oweina 7-1 well (8.09) in El-Qasr and El-Oweina villages, respectively. Data indicated that about 20.12, 79.17 and 0.59% of samples had acidic, neutral and alkaline water, respectively.

The spatial distribution of groundwater pH noticed that the natural groundwaters ($6.50 \leq pH \leq 8.40$) covered most of the studied area (82.67% equal 4034 km^2). The acidic groundwaters came in the second rank with 17.25% (842 km^2) of the studied area. These waters concentrated in the mid part of the oasis. Very small area (0.07% equal 4 km^2) in southwest of El-Qaser village has alkaline groundwater.

5.1.2. Groundwater Electrical Conductivity (EC)

The EC_w values fluctuated from 164 to 1840 $\mu S\ cm^{-1}$. The lowest values of 164 and 169 $\mu S\ cm^{-1}$ were recorded by El-Hindaw 14-4 and El-Maasara 17-4 wells in El Hindaw and El-Maasara villages, respectively. The highest EC_w values of 1840 and 1330 $\mu S\ cm^{-1}$ were found in the groundwaters of Ain El-Baraka and Balat 44-5 wells that located in El-Qalamon village and Balat city, respectively. About 40.24% of the collected groundwater samples fall in the first class of the low salinity hazard. Meanwhile, 53.85% of these samples showed a medium salinity hazard. The rest samples (5.91%) had a high salinity hazard.

Data illustrated in kriged map indicate that about 42.01% of studied area (2050 km^2) of groundwater in the study area is excellent water (< 250 μScm^{-1}). The second groundwater salinity class ($250 \leq EC < 750\ \mu S\ cm^{-1}$) covers about 49.80% (2430 km^2) of the oasis area. The third groundwater salinity class (750-2250 μScm^{-1}) covers the remaining area (8.19% equal to 400 km^2). It can be noticed that the EC tends to increase from the eastern side towards the western side of El-Dakhla oasis.

5.1.3. Soluble Cations

5.1.3.1. Sodium

Data showed that sodium in the studied groundwater samples reached a high value as 198 mg L^{-1}, which found in water of Balat 44-5 well that located in Balat city. The lowest value of groundwater sodium (4 mg L^{-1}) was found in water of El-Hindaw 14-4 well that located in El-Hindaw village.

Kriged map indicated that the most of groundwater in the study area has no restriction on the use of the water for irrigation purpose, where the sodium concentration is basically less than 70 mg L^{-1}. This class is found in 98.87% (4825 km^2) of the studied area. On the other hand, few parts in this oasis have Na concentration more than 70 mg L^{-1}; therefore there is slight to modarete restriction for irrigation purpose in about 1.13% (55 km^2) of this oasis.

5.1.3.2. Potassium

Gharb El-Mawhob32-12 and Gharb El-Mawhob 31-13 wells have the minimum value of K concentration (2 mg L^{-1}), while the highest value (84 mg L^{-1}) was found in groundwater of Ain Abd Kareem and Ain Abo Ali wells that located in El-Maasara village and Mut city, respectively. the studied groundwater samples have K concentrations over than 2 mg L^{-1} (FAO limit) except groundwater of Gharb El-Mawhob 32-12 and Gharb El-Mawhob 31-13 wells.

The most groundwater aquifers (92.56%) are cotaining potassium greater than 2 mg L^{-1}. However, potassium content of groundwater less than 2 mg L^{-1} in the remaining area (7.44%); this area concentrated in Gharb El-Mawhob village.

5.1.3.3. Calcium

Calcium concentrations of groundwater samples ranged from 3 to 102 mg L^{-1}. The minimum value observed in water of Balat 35 well located in Balat city. On the other hand, water of Ain El-Baraka in El-Qalamon village recorded highest value of calcium. The studied groundwater samples have Ca concentrations lower than 120 mg L^{-1} (FAO limit).

5.1.3.4. Magnesium

Magnesium concentrations ranged from 2 to 57 mg L^{-1}. The minimum value recorded in Ain Al-Toufah well, while the highest value was found in water of Ain El-Baraka well that located in Balat city and El-Qalamon village, respectively. All studied groundwater samples have magnesium content lower than FAO limit (50 mg L^{-1}), except Ain El-Baraka well in El-Qalamon village. Whereas, about 0.59% of groundwater samples have magnesium higher than FAO limit.

Using kriged map, the study area was divided into two classes based on the Mg threshold given by FAO limit. The first one is safe groundwater which covers about 99.95% of the oasis. The second class is unsafe groundwater, which covers about 0.05% of the oasis.

5.1.4. Soluble Anions

5.1.4.1. Bicarbonate

Bicarbonate (HCO_3) values in groundwater samples vary from 12 to 294 mg L^{-1}. The lowest value of $HCO_3^-$was recorded by water of Ain Al-Toufah well in Balat city. Whereas, the highest one was found in water of Ain El-Baraka well in El-Qalamon village. All the groundwater samples have bicarbonate levels lower than the FAO upper limit ($HCO_3^->520$ mg L^{-1}).

The spatial distribution showed that about 91.75% of groundwaters in the studied area have no restriction. Meanwhile, the groundwaters in the remaining area (8.25%) have slight to moderate restriction against bicarbonate. These groundwaters concentrated in middle part of El-Dakla oasis (south of Mut and south of El-Mawhob).

5.1.4.2. Sulphate

Sulphate concentration ranges from 3 to 385 mg L^{-1}. Based on the previous classification, 167 (98.82%) of groundwater samples have SO_4^{2-} less than lower FAO limit ($SO_4^{2-}<200$ mg L^{-1}). This means that these waters for irrigation with none to slight corrosion attack on the irrigation infrastructures.

The majority of the groundwater (99.95% of oasis area) is good for the infrastructures against the corrosion effect. They have sulphate concentrations of less than 200 mg L^{-1}.

5.1.4.3. Chloride

Chloride content in the groundwater samples ranged between 18 and 288 mg L^{-1}. The water of Balat 14-2 well in Balat city has the lowest value of chloride, while the highest value was recorded by Ain El-Bait well in Tenieda village.

About 85.80% of the groundwater samples are safe for almost all types of plants (Cl^{-}<71 mg L^{-1}) and 9.47% of samples ($71 \leq Cl^{-} \leq 142$) are dangerous for sensitive crops. The remaining samples (4.73%) have 142< $Cl^{-} \leq 355$ mg L^{-1}, that have moderately effect on moderately sensitive plants and of course sensitive plants.

Kriged map shows that the groundwaters in 88.96% of oasis area are safe for irrigation purposes based on its chloride contain. Whereas, about 5.02% of the studied area have groundwater might cause injury to the sensitive plants. The groundwaters in the remaining area (6.03%) have negative effect on moderately tolerant plants. It was noticed that chloride concentration increased from east to west of the oasis. Moreover, the harmful effect of chloride increased in south Mut and scattered parts of the oasis.

5.1.5. Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) values of the groundwater samples in the studied area varied from 0.26 to 5.06. The minimum and maximum SAR values were recorded in El-Hindaw 14-4 well and in Balat 44-5 well that located in El Hindaw village and Balat city, respectively. The low SAR value results from the dominant levels of calcium in the water samples.

About 97.04% of the groundwater samples have SAR values less than 3 indicating no restriction in using this water on soils and plants.

The kriged map of SAR showed that the level of SAR in groundwater is below the desirable limit in most parts (99.77%) of the study area. However, some parts (0.33%), have high values above the desirable limit (south of Balat, south of El-Qalamon and north of El-Gedida).

5.1.6. Soluble Sodium Percentage (SSP)

Soluble sodium percentage values rangesed between 22.83 to 66.15%. The lowest value was recoded in Gharb El-Mawhob 39 well, while the highest value was observed in Ain Abo Refae in Gharb El-Mawhob and Al-Rashda villages, respectively.

About 33.73, 62.72 and 3.55% of the investigated groundwater samples have good, permissible and doubtful irrigation water qualities, respectively. It means that 96.45% of the studied water samples are suitable for irrigation purposes, while 3.55% of these samples are unsuitable for irrigation.

The spatial distribution map pointed out that the water quality base on SSP increased from east to west of the oasis. The kriged map of SSP also showed that the good groundwaters class based on this parameter falls in 48.54% of the study area. These waters concentrated in west of the oasis. Whereas, the permissible class of groundwaters falls in 50.60% of study area. The remaining area (0.86%) has doubtful groundwaters in separated parts.

5.1.7. The EC_w and SAR Diagram of the Studied Groundwater Samples

It is clear that 70 groundwater samples (41.42%) fall under C_1S_1 category suggesting low sodium and low salinity hazards conditions. Moreover, 90 samples (53.25%) occurs in the C_2S_1 category indicating low sodium and medium salinity hazards and only 9 samples (5.33%) take place in the C_3S_1 type suggesting low sodium and high salinity hazards.

About 94.68% of these waters (160 samples) had excellent to good quality for irrigation and 4.14% (7 samples) exhibited a good to permissible. Meanwhile, the rest samples (1.18%) showed a low quality (permissible to doubtful).

5.1.8. Residual Sodium Carbonate (RSC)

Residual sodium carbonate data revealed that the lowest RSC value (-5.05) was found in water of Balat 44-5 well. Groundwater RSC reached a high value of 0.28 which was found in Ain Mut well. Groundwater samples analysis showed that RSC of all samples within the safe quality category for irrigation.

The kriged map shows that free RSC groundwaters found in most of studied area (97.42%). However, 2.58% of area contain on low RSC groundwaters in northern Balat, south Mut and El-Maasara as well as western El-Qalamon.

5.1.9. Corrosivity Ratio (CR)

Corrosivity ratio values fluctuated from 0.46 to 9.22, 0.42 to 4.18 and 0.56 to 2.53 with an average of 2.27, 1.37 and 1.27 in Balat, Mut and El-Mawhob districts, respectively.

the kriged map indicate that about 51.02% of groundwater in the studied area can be used metal and non metal constructions with these waters, while it must be used with non-corrosive constructions with groundwaters in the remaining area (48.98%). It also indicates that the non-corrosive and corrosive groundwater are sequenced from east to west of the oasis, where, the safe groundwaters are located in the far east of the oasis followed by corrosive groundwater and so on.

5.1.10. Chloro-Alkaline Index (CAI)

Chloro-alkaline index values ranged from -1.0 to 0.78. Ain Mut well recorded the lowest value, while the highest value was found in water of Balat 7 well that located in Mut and Balat Cities. It is obvious that 45.56%

of samples gave positive values of CAI. Meanwhile, the remaining samples (54.44%) displayed negative values.

The spatial distribution indicates that partially exchange between Na+K in the groundwater with Ca+Mg in the host rock concentrated in the northern half of the oasis. It covers about 54.36% of the studied area. On the contrary, the exchange between Ca+Mg in the groundwater with Na+K in the host rock concentrated in southrn half of the oasis. It covers about 45.64% of study area aquifer.

5.1.11. Magnesium Ratio (MR)

Magnesium ratio (MR) of the studied groundwater samples varies from 20.0 to 84.75. The lowest value was recorded in water of Ain Al-Toufah well, while the highest value was recorded in water of Balat 7 well that located in Balat city. About 46.15% of the groundwater samples are within the permissible limit, while about 53.85% of samples out of the permissible limit.

Predicted data indicated that unsafe groundwaters represent about 71.84% of studied area. This could cause magenesium hazard on the plants due to use there waters for irrigation purpose. Meanwhile, about 28.16% of groundwaters in study area have not magnesium hazard.

5.1.12. Permeability Index (PI)

The permeability index of the groundwater in the study area varied from 1.19 to 7.75. Therefore, the groundwaters in whole studied area are excellent water based on Doneen's guideline. The kriged map shows that the groundwaters in whole studied area are excellent water.

5.1.13. Kelley’s Ratio (KR)

Kelley’s ratio (KR) ranged from 0.17 to 1.82. The lowest value of KR was observed in El-Qalamon 12-1 well, whereas the highest value was recorded in Ain Abo Refae well that located in El-Qalamon and Al-Rashda, respectively. About 94.67% of groundwater samples are suitable, while

5.33% of samples are unsuitable water for irrigation. Predicted data showed that the safe groundwaters for irrigation cover about 99.44% of study area.

5.1.14. Potential Salinity (PS)

The potential salinity of studied groundwater samples ranged from 0.68 to 10.60 meq L^{-1}. Balat 14-2 and Balat 44-5 wells were recorded the lowest and the highest values of the potential salinity, respectively.

Data also indicated about 95.27% of samples have excellent to good waters that can be recommended for soils of low permeability. Meanwhile, 4.14% of samples are good to injurious water, which can be recommended for medium permeability soils.

The spatial distribution showed that the first class (excellent to good) of groundwater covers about 92.496% of the studied area. The second class (good to injurious) of groundwater covers about 7.502% of the studied area. These parts are concentrated in the southwest ridge of the oasis. The unsuitable groundwater found in very small parts (0.002%) of study area.

5.1.15. Effect of Well Depth on Groundwater Chemistry

Correlation analysis reveals that positive and high significant ($p \geq 0.01$) correlation is detected between well depth and groundwater pH with correlation coefficient of 0.3658. This means that pH of groundwater is increasing due to the increases of well depth.

There were negative correlation between well depth and EC, Na, K, Ca, Mg, Cl, HCO_3 and SO_4 of groundwater with significant ($p \geq 0.05$) correlation coefficients of -0.4511, -0.4830, -0.2170, -0.5343, -0.4740, -0.4857, -0.4227 and -0.3792, respectively. Data also reveal that increasing well depth caused a reduction in the studied parameters.

5.2. Soil Properties and Classification

5.2.1. Soil Properties

5.2.1.1. Soil Texture

In surface soil samples, about 52.65, 15.98, 8.88, 7.69 and 5.92% of the total samples were sandy loam, sandy clay loam, loamy sand, clay and clay loam. About 51.48% of subsurface soil samples fall in texture class sandy loam. The textures of 14.79, 12.43, 7.10 and 6.51% of the totalsoil samples were loamy sand, sandy clay loam, sand and clay, respectively.

5.2.1.2. Soil Chemistry

5.2.1.2.1. Soil reaction (pH)

Soil pH in both surface and subsurface samples was neutral to very strongly alkaline with values ranging from 6.43 to 9.65 and 6.67 to 9.91, respectively. Bear El-Mazraa area in Mut city recorded the lowest values of pH in surface and subsurface soil. Meanwhile, the highest values of pH in surface and subsurface soil were recorded in Ain Sayed Al-Daba in El-Qasr and El-Hindaw 9 areas, respectively.

About 1.18, 35.50, 42.01, 15.98 and 2.37% of surface soil samples were found to be slightly acid, neutral, slightly alkaline, moderately alkaline and strongly alkaline in soil reaction, respectively. The remaining samples (2.96%) were very strongly alkaline soil. Meanwhile, 30.18, 44.38, 16.57, 5.92 and 2.96% of subsurface soil samples were neutral, slightly alkaline, moderately alkaline, strongly alkaline and very strongly alkaline in soil reaction, respectively.

The spatial interpolated maps of soil pH showed that increases of slightly, strongly and very strongly alkaline soils area in the subsurface (63.77, 1.49 and 4.05%) compared to surface soil, respectively. On the other hand, neutral and moderately alkaline soils decreased with increasing depth from 37.78 and 17.51% to 14.40 and 16.30%.

5.2.1.2.2. Soil Electrical Conductivity (EC_e)

The electrical conductivity of soi (EC_e) values ranged from 0.19 to 14.38 and 0.22 to 14.50 dS m^{-1} in surface soil in subsurface soil samples, respectively. El-Qasr 20 recorded the lowest values of EC_e in both surface and subsurface soil samples. However, the higher values of EC_e were observed in Al-Rashda 11 and Ain Sayed Al-Daba (El-Qasr village) areas for both surface and subsurface soil samples, respectively. There are 85.80% (145 samples) of subsurface soil samples have a higher EC_e values than those of surface one.

Data revealed that out of 169 surface soil samples, only 60 (35.50%) samples can be classed as non saline soils, which is good for all crops. The remaining samples are considered salt affected soils. Out of these 109 samples, 64 (37.87%) show very slight salinity and 36 (21.30%) samples have slight salinity. However, remaining 9 (5.33%) samples represent moderate salinity class.

Subsurface samples grouped into classes as follows: non saline (33.14%), very slightly saline (30.18%), slightly saline (24.26%) and moderately saline (12.43%).

The spatial distribution of soil salinity in the studied area revealed that the soil salinity affected by soil depth. The non saline, slightly saline and moderately saline soil areas have increased with increasing soil depth. These areas were 29.80 and 2.29% for surface soils to become 37.30 and 20.77%, respectively. Whereas, increasing soil depth caused decreasing very slightly and moderately saline soil areas that were 55.93 and 11.97% in surface soil to become 33.99 and 7.93% in subsurface soil, respectively.

5.2.1.2.3. Soil Soluble Cations and Anions

The overall view of the concentration of soluble cations was in the descending Na^+> Ca^{2+}>Mg^{2+}>K^+ in soil paste extract. Soluble sodium concentration ranges from 0.76 to 1003.65 and 1.94 and 1726.09 mg kg^{-1} soil in surface and subsurface samples, respectively. Soluble potassium concentration ranges from 1.14 to 454.69 and 1.04 and 431.83 mg kg^{-1} soil in surface and subsurface samples, respectively. Soluble calcium concentration ranges from 1.34 to 608.10 and 1.02 and 357.50 mg kg^{-1} soil in surface and subsurface samples, respectively. Soluble magnesium concentration ranges from 1.62 to 306.99 and 1.10 and 179.00 mg kg^{-1} soil in surface and subsurface samples, respectively.

The chloride content ranged from 13.33 to 1434.25 and 5.90 to 1747.02 mg kg^{-1} soil in surface and subsurface samples, respectively. The sulphate content ranged from 1.43 to 1249.90 and 1.27 to 2040.21 mg kg^{-1} soil in surface and subsurface samples, respectively. The bicarbonate content ranged between 4.90 to 2273.16 and 4.05 to 1369.09 mg kg^{-1} soil in both surface and subsurface soil samples, respectively.

5.2.1.2.4. Exchangeable Sodium Percentage (ESP)

The ESP values ranged from 0.09 to 33.16 and 0.04 to 36.92 in the surface and subsurface layers, respectively.

In surface layer, the highest value of ESP was recorded in surface layer of Ain Sayed Al-Daba area (El-Qasr village) area, while the lowest one was observed in Bear El-Mazraa (Mut city) area.

In subsurface layer, the highest and lowest values of ESP found in El-Hindaw 12-3 and El-Hindaw 9 area, respectively. The most subsurface soil samples (63.91%) had ESP values greater that surface soil samples. Meanwhile, ESP values in 36.09% (61 samples) of surface soil samples were higher than those in subsoil.

The kriged map showed that non to slight sodic (ESP<15) soil fall in about 4830 and 4569 km^2 (98.98 and 93.63% of studied area) for surface and subsurface soil. Light to moderate sodic (15≤ESP<30) soil increased from 49.74 to 309.23 km^2 in both surface and subsurface soil, respectively. This increment is concentrated in south of El-Maasara. However, moderate to high sodic (30≤ESP<50) soils fall in small areas (0.19 and 1.75 km^2

equal to 0.004 and 0.036% of study area) for surface and subsurface soils, respectively.

5.2.2. Chemical Classifications of Soils in El-Dakhla oasis

In surface layer, Data revealed that 122 (72.19%) samples can be classified as non-saline soil, 37 (21.89 %) as saline, 2 (1.18%) sodic and 8 (4.73%) as saline-sodic soils. In subsurface layer, it is clear that 105 samples (62.13%) can be classified as non-saline soil, 45 (27.22%) as saline, 2 (1.18%) as sodic and 17 (10.06%) as saline-sodic soils.

The kriged maps indicated that none saline soil area decreased from 81.37% in surface layers to 56.02% in subsurface layers of the oasis area. As well as, saline, sodic and saline-sodic soils area in the surface layers were increased from 17.15, 0.81 and 0.67% to 36.08, 1.91 and 5.98% in the subsurface layers, respectively.

Finally, it can be recommended that the assement of groundwater and soil qualities is necessary to choice the suitable management practices for these soil and groundwatr as well as exigency for a periodic analysis of soil and groundwater wells to determine the changes taking place in the salinity.