Integration of Geochemical Modeling, Hydrodynamic Condition, and Change Detection Supported with Machine Learning For Sustainable Development of the Water Resources in Western Desert, Egypt

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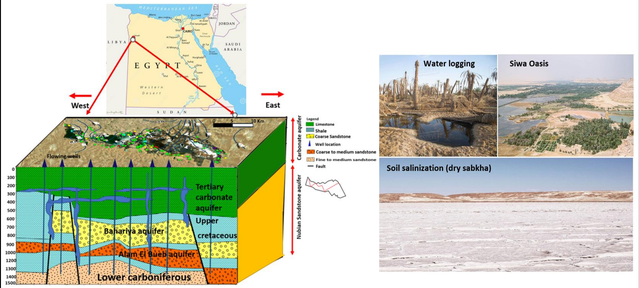
Introduction

Groundwater represents a critical freshwater resource for human survival, agriculture, and ecosystem maintenance, especially in semi-arid countries like Egypt. Water and soil salinization and water depletion in non-rechargeable aquifers are among the causes endangering the sustainability of Siwa Oasis in the western desert of Egypt. The water resources include the tertiary carbonate aquifer (TCA), Nubian sandstone (NSSA), springs, drains, and hypersaline lakes.



Methodology

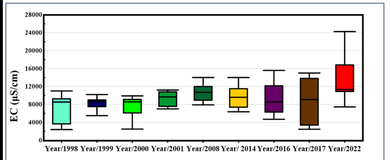
153 samples were collected 2022 from NSSA, TCA, springs, Drains, and salt lakes. Physicochemical parameters, heavy metals, and stable isotopes were measured.

The groundwater salinity of TCA was monitored from 1998 to 2022 using EC. Remote sensing and machine learning were utilized to detect the change in the land cover from 1990 to 2020 (water logging, soil salinization, surface area of hypersaline lakes).

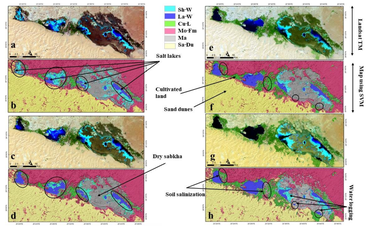
A pressure depth profile was used to determine the hydrodynamic condition in the aquifer system.

Application of stable Isotopes to determine the recharge source of the groundwater. K-means cluster analysis, geochemical, and mixing model to determine the salinity origin of the TCA using PHREEQC and NETPATH. The water quality was evaluated using SAR, Na%, Ps, and MH for irrigation purposes. A water management plan was performed for sustainable development.

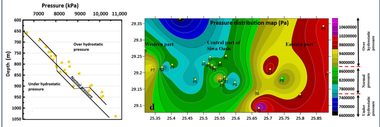
Results



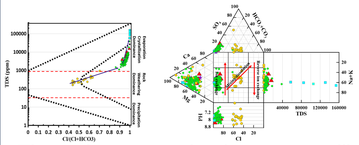
There has been a rapid increase in the water salinity of the TCA.



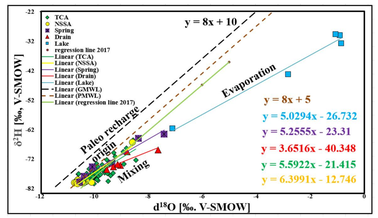
There has been a rapid increase in surface area of salt lakes, salt marches, and water logging from 1990 to 2020.



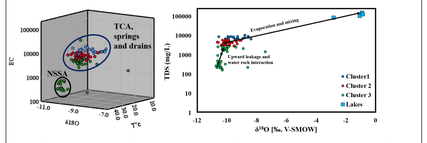
The water pressure of NSSA declined in the central part of Siwa Oasis due to over-abstraction.



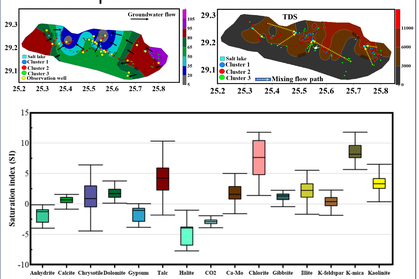
The primary mechanisms controlling the water chemistry are rock weathering and evaporation, according to Gibbs and Durov diagrams.



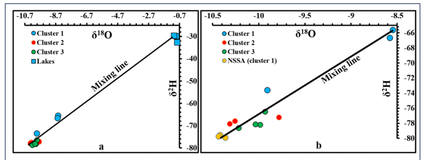
All the groundwater in TCA and NSSA is paleo meteoric water, and there is no recharge where the rainfall is neglected in Siwa Oasis.



The groundwater samples were grouped into 3 clusters based on K-means clustering. All the springs originated only from TCA. The deep NSSA recharges the TCA through the fault planes and makes dilution in the eastern and western parts of Siwa Oasis.



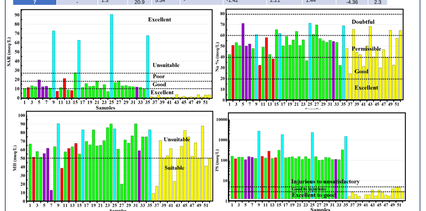
The water samples were supersaturated with calcite, dolomite, talc, Ca-montmorillonite, chlorite, gibbsite, illite, K-mica, hematite, chrysotile, and kaolinite, which decrease the permeability of soil after the irrigation process.



The mixing model confirmed salt lakes' contribution in increasing the TCA salinity by 2% to 4%.

Model number	Location	Model type	Initial 1	Initial 2	Final	Mixing Percentage calculated Initial 1	Mixing Percentage calculated Initial 2	Mixing Percentage computed Initial 1	Mixing Percentage computed Initial 2
1	(Zeitoun)	Reaction and mixing	9 (TCA, cluster3)	27	20	0.84	0.16	0.97	0.02
2	(Zeitoun)	Reaction and mixing	10 (TCA, cluster 3)	27	21	0.82	0.18	0.99	0.009
3	(Zeituna)	Reaction and mixing	7 (TCA, cluster2)	27	21	0.82	0.18	0.96	0.04
4	Siwa	Reaction and mixing	144 (TCA, cluster3)	92	93	0.98	0.02	0.99	0.006
5	Siwa	Reaction and mixing	117 (TCA, cluster2)	92	87	0.96	0.04	0.98	0.02
6	Zeituna	Reaction and mixing	21 (TCA, cluster1)	4	15	0.26	0.74	0.13	0.87
7	Siwa	Reaction and mixing	87 (TCA, cluster1)	56	68	0.14	0.86	0.37	0.63

Model number	Phase precipitated or dissolved Calcite	Dolomite	Halite	Gypsum	Ca-Montmorillonite	Na-Montmorillonite	Chalcedony	Illite	Exchange	Ev
1	-1.2	0.8	41.7	-1.6	-	-1.2	-	1.2	1.2	1.04
2	-3.15	1.5	30.3	-	-0.72	-	0.03	0.73	-7.3	1.6
3	-	1.2	58.4	0.9	-	-4.38	1.87	4.4	-19.4	1.5
4	-	-0.48	38.4	-0.69	-	-0.6	0.01	0.6	-5.7	1.6
5	-15.3	7.2	0	-2.01	-	0.41	-0.15	-0.4	-10.8	1.4
6	3.29	-2.29	0	0.98	-	0.25	-0.17	-0.27	1.27	2.07
7	-	1.3	20.9	5.34	-	-1.42	2.21	1.44	-4.36	2.3



The NSSA is suitable for irrigation purposes, while TCA is not suitable for irrigation regarding magnesium hazards (MH) and potential salinity (PS).

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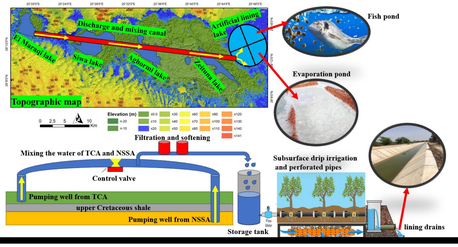
Management Implications

Mixing of the NSSA (freshwater) with brackish water of TCA. Treatment of the mixed water through filtration and softening to decrease the hardness and saturated minerals. Application of subsurface drip. Drill canal connects the four main lakes. It discharges its water in an artificial lake covered by impermeable material in the eastern part of Zeitoun. Create a drainage system of drains covered with cement materials and perforated.



Conclusion

The evaporation, rock weathering, mixing with old trapped sea water and seepage of saline water from salt lakes are the main processes responsible for the mineralization and salinization of the water resources in the TCA. All the groundwater in TCA and NSSA are paleo meteoric water, and there is no recharge where the rainfall is neglected in Siwa Oasis. Mixing water of TCA and NSSA could be the best management of the water resources in Siwa Oasis as well as the application of subsurface drip irrigation. Drilling canal connect between the four main lakes and discharge its water in artificial lake covered by impermeable material in eastern part of Zeitoun lake to prevent seepage of hyper saline water to the TCA and decrease the salinity of and surface area of the hyper saline lakes where the eastern part of Zeitoun is empty land with soil unsuitable for agriculture.

Acknowledgment

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