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Evaluation of the Nubian sandstone aquifer system (NSAS) in Al Kufra Oasis, Southeast Libya

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ABSTRACT

Groundwater resources, developed in the Nubian Sandstone Aquifer System (NSAS), in Al Kufra Oasis in Libya are becoming increasingly vulnerable due to increasing pressures to meet the demand of economic development. These activities are represented mainly by agriculture activities in addition to the inefficient water use by other consuming sectors. Their misuse and violations are a result of the country's political instability, in addition to the lack of effective legislation, policies, strategies, and law enforcement instruments in current Libyan water management practices. This research investigates, examines and brings to the fore the groundwater conditions in Al Kufra oasis in terms of water quantity and quality, and evaluates the current management practices of water resources.

Evaluation of groundwater resources in terms of quantity is made by analyzing depth to water level in 26 monitoring wells for the period from 2005 to 2015, which showed average drawdown value of about 5.54 m during 10 years in the urban area and the agriculture projects areas. In terms of water quality, water samples were collected from 16 water wells, and chemical analysis was conducted for the determination of concentration of major anions and cations. The result showed increase in the value of total dissolved solids in the urban area and the agriculture project areas, which can be interpreted as the result of the increase in the amount of water extraction or the contamination by urban activities. Groundwater classification by Piper diagram and Wilcox diagram indicated that water is still suitable for agricultural purposes. Evaluation of the water resources management practices was undertaken through a survey examining the efficacy of water institutions relative to institutional framework, functions, activities, and their influence in the current management. The results indicate that current inadequacy of water management is due to many reasons, including centralized planning and financing, limited financial resources, overlap of water institutions, lack of stakeholders' participation, lack of coordination, and organizational instability. It is clear that the current water challenge is a managerial rather than a technical one. A comprehensive reform of the water sector is needed, based on the following recommended set of actions: institutional integration and engagement of stakeholders; evaluation of the current status of the NSAS beneath the main oases in terms of groundwater quality and quantity assessment of the environmental impacts of different water uses on NSAS; and, assessment of socioeconomic conditions for the oases, and their direct and indirect relationship to the ecosystem.

Keywords: Groundwater; IWRM; Transboundary aquifer

1. Introduction

The majority of the Libyan land is categorized as arid to hyper-arid. About 90% of the land is desert characterized by low rainfall rates, diurnal temperature variations, poor soils, and seasonal winds. Groundwater accounts for 97% of total water abstracted for different uses. The available figures indicate that the county's total water abstraction is about 6.5 billion cubic meters per year (GWA, 2006) and (NWRE, 2017).The dependence on the Nubian Sandstone Aquifer System (NSAS) mostly occurs in the middle and eastern parts of the country, while other regions of the country depend on other groundwater basins. Many settlements are dependent on for The NSAS for domestic water purposes and for irrigation in agriculture projects which provide crops to the residents in the NSAS area

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as well as the rest of Libya. The country's political conflict and uprising have led to a disruption of the water management system and to a difficulty in monitoring and managing water resources. This research discusses the current situation of the NSAS aquifer in Al Kufra Oasis. The NSAS (Fig. 1) is the world's largest known fossil water aquifer system. It is located in the eastern end of the Sahara Desert and spans the political boundaries of four countries in north-eastern Africa. The NSAS covers a land area spanning over 2.2 million km^2, including north-western Sudan with an extension of 376.000 km^2, north-eastern Chad with an extension of 235.000 km^2, south-eastern Libya with an extension of 760.000 km^2, and most of Egypt with approximately 80% and extension of 826.000 km^2 (Ahmed, 2013).

2. Geology of Al Kufra

Desio (1935) introduced the term Kufra/Al-Kufrah as the general name to all geological sequences, where the greater part composed of quartzitic sandstones, which form the area of Al-Kufrah group or series. The sediments of the Al-Kufra basin are mainly continental cross-bedded sandstone intercalated with argillaceous clays and shale (Klitzch, 1970) that corresponds to the "Nubian Sandstone" in the southeastern part of Libya. The Nubian sandstone of the Al Kufra basin has a maximum thickness of 900 m and includes mainly cross-bedded sandstone, intercalated with clays and shales. Table 1 illustrates the general stratigraphic geological succession of the Al Kufra basin (Salama and El Ebaidi, 2016)

3. Groundwater resources of Al Kufra

3.1. Aquifers

Two aquifer systems are known to exist in the Kufra basin; the as the Nubian sandstone aquifer; the lower is the Paleozoic aquifer system upper one is the Mesozoic (Triassic-Jurassic-Lower Cretaceous) known (Cambrian, Ordovician, Silurian and Devonian) (Bakhbakhi, 2010). The thickness of the Paleo-Mesozoic aquifers (Cambrian to Lower Cretaceous) exceed 3,000 m at the center of the Kufra basin and consists of continental sandstones with clay and shale intercalations. According to Jones (1969), Kufra Basin covers an area of 245,000 km^2, and an available resource from storage in the groundwater reservoir of the basin is in the order of 25,000 km^3 of good quality water.

The lower Mesozoic aquifer consisting of layers of loose sand, silt, and mud, with fewer sandstones and some other sedimentary rocks and divided into (Salem, 1996):

Shallow aquifer
Water level of this aquifer extends from depths of 5–60 m, where it does not exceed 60 m below ground surface and the total dissolved solids (TDS) ranges from 300–8,000 ppm.

Fig. 1. NSAS location map (IAEA, 2013).

Table 1
General sedimentological succession of the Kufra basin (Salama and El Ebaidi, 2016)

Age	Formations & approximate max. thickness (m)	Lithology & depositional environment
Recent/Pleistocene	100 m	Sandstone and Sabkha deposits
Lower Cretaceous	Nubian Sandstone (900 m)	x-bedded sandstone, shale and conglomerates
Carboniferous	800 m	Continental sandstones
Devonian	Tadrart Sandstones (100 m)	Massive, continental x-bedded sandstones with fossil plant marginal marine deposits
Silurian	Tanezzuft Shales Acacus Sandstones (90 m)	Sandstones, marine with fossils. dark shale and silty with fossils
Ordovician	Gargaf Group (700 m)	x-bedded sandstones with some silty shale (continental/ marginal marine deposits
Pre-Cambrian	Basement	Folded metamorphic and granitic igneous rocks

Table 2
Type and number of crops (GAALMR, 2018)

Olive	Palm	Almond	Apple	Citrus fruits	Grape	Figs	Other types
446,279	1,484,990	3,797	5,060	18,509	163,604	37,733	139,385

Deep aquifer
Starts from a depth of 60 to 800 m; the TDS of this aquifer ranges from 300–4,500 ppm.

The high values of TDS in both aquifers are remarkable in some localities due to the existence of an old sabkah.

3.2. Current situation of the water use

The total abstraction from NSAS in Libya estimated at about 1,020.7 Mm^3 per year for all water uses (NWRE, 2017). The increase in freshwater demands for domestic, agricultural and industrial purposes corresponds to the increase in population. Currently, about 964,100 inhabitants living in 74 human settlements are dependent on the NSAS for domestic use and for agricultural production. The agriculture abstraction is estimated at about 504 Mm^3 per year, utilized in about 7,011 farms with different crops as provided in Tables 2–4. As for industrial use, the oil industry represents the main consumer which use water for oil production. The amount of water abstracted for industrial purposes is estimated from the available data at about 130 Mm^3 per year.

The water use for agricultural purposes in Al Kufra Oasis is the largest when compared with other uses, as shown in Table 5. The unaccounted for water in the water supply network is considered high, where remarkable frequent explosions noted in the main and secondary pipelines, due to the weakness of the current network. In addition,

Table 3
Type and production in tons for harvest (GAALMR, 2018)

Wheat	Barley	Cane	Animal feed	Beans
37,920	34,364	4,255	95,747	180

Table 4
Type and number of cattle (GAALMR, 2018)

Sheep	Goats	Camels
238,291	91,609	47,106

Table 5
Number of wells, pumping and towing rates for Kufra area (GAALMR, 2018)

Use	Project name	Abstraction Mm^3/ year	Aquifer	Depth (m)
Agriculture	Al Kufra production project	176	Deep	250–300
	Al Kufra settlement project	32	Deep	450
	Palm Project	33	Shallow	50–120
Domestic and Industrial	Private farms	75	Shallow	50–150
	Domestic and water bottling industry	26	Deep	250–450
Total		342		

most of the main and secondary pipelines are being violated when passing through private farms by illegal connections, as well as by several new residential neighborhoods which are built randomly out of the main urban plan and do not have public facilities.

3.2.1. Groundwater levels

The data of groundwater levels in Al Kufra region were collected from monitoring wells (Ahweej et al., 2017) as shown in Table 6 and mapped using geographical information system and superimposed by the main land use in the oasis, as illustrated in the Figs. 2 and 3. In the year 2005, the average depth to water level was about 17.55 m, with the lowest at 2.35 m at the southwestern part of the oasis, while in the urban and agriculture projects areas; the depth to water level reached 40.25 m. In 2015 the average water level was 23.07 m, where the lowest water level was 4.4 m at the southwestern part of the oasis, while in the urban and the agriculture projects areas water level depth reached 51.18 m. The drawdown in groundwater levels in Al Kufra area in 10 years is presented in Fig. 4 where the average drop of the water level is about 5.54 m, where it is noted that there is a significant decline in the water level at the urban area and Al Kufra agricultural production project, which recorded the highest value of drawdown, estimated at 15.2 m.

3.2.2. Groundwater quality

According to the results of the chemical analysis of water samples in the region (Table 7) (Ahweej et al., 2017), the total dissolved solids of the groundwater aquifer ranged from 172 to 900 ppm. The map of total dissolved salts (TDS) shows increasing values in urban area and the agriculture projects areas in comparison with other areas of the oasis (Fig. 5). There are two possible interpretations for this salinity increase. The first is that the increase in salinity

Table 6
Depth to water levels in monitoring wells

Well no	Water Level meter Year 2005	Water Level meter Year 2015	Drawdown meter
PZ-O4	13.54	18.72	5.18
PZ-6	25.86	36.74	10.88
PZ-8	2.35	14.14	11.79
PZ-O8	5.00	14.89	9.89
PZ-9	25.04	26.56	1.52
PZ-O9	30.28	29.96	0.32
PZ-11	6.59	21.68	15.09
PZ-13	35.98	51.18	15.20
PZ-14	29.62	35.19	5.57
PZ-15	17.80	29.31	11.51
PZ-16	32.10	42.19	10.09
PZ-17	6.30	13.32	7.02
PZ-18	12.88	23.61	10.73
PZ-19	10.80	12.19	1.39
PZ-25	10.82	13.06	2.24
PZ-26	22.22	25.85	3.63
PZ-28	28.31	29.84	1.53
PZ-30	19.85	21.05	1.20
PZ-32	22.64	24.85	2.21
PZ-33	40.25	41.00	0.75
PZ-35	3.77	4.40	0.63
PZ-37	13.54	16.50	2.96
2311	7.50	9.21	1.71
PZ-2232	8.97	10.87	1.90
PZ-2122	6.86	10.40	3.54
PZ-O4	13.54	18.72	5.18
Average	17.55	23.07	5.54
Minimum	2.35	4.40	0.32
Maximum	40.25	51.18	15.20

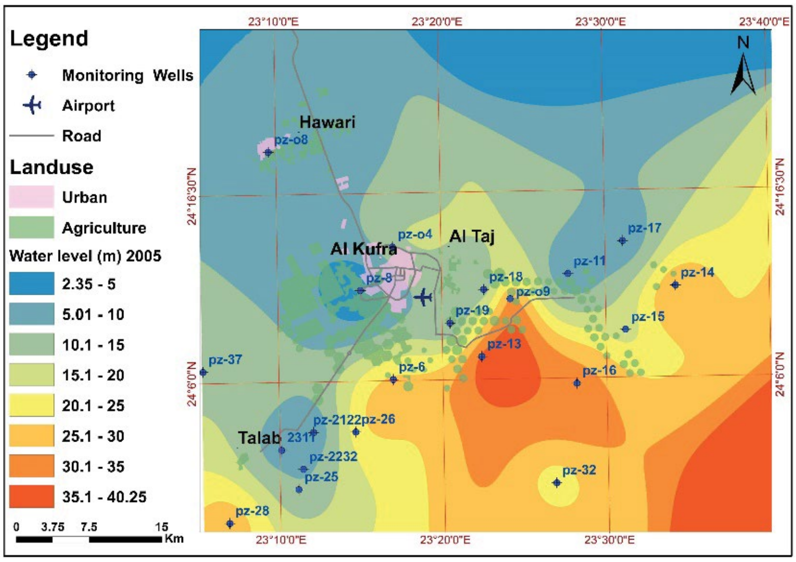

Fig. 2. Depth to water level map year 2005.

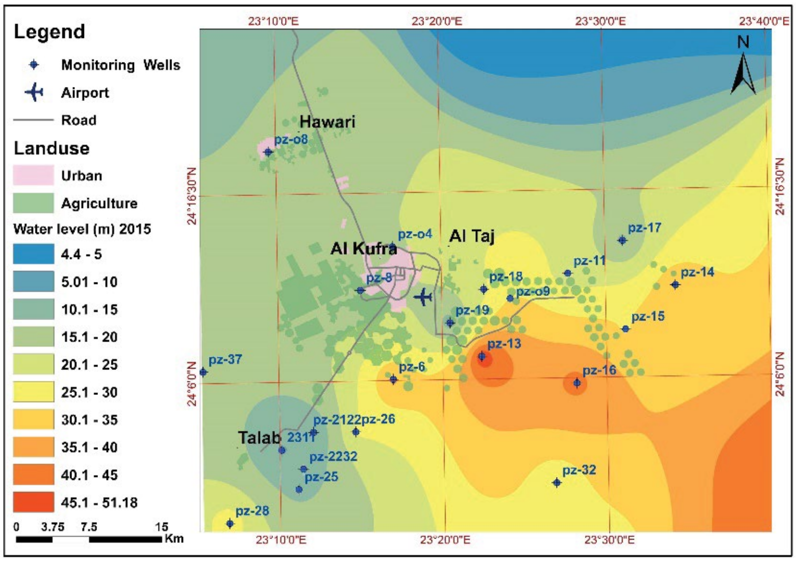

Fig. 3. Depth to water level map year 2015.

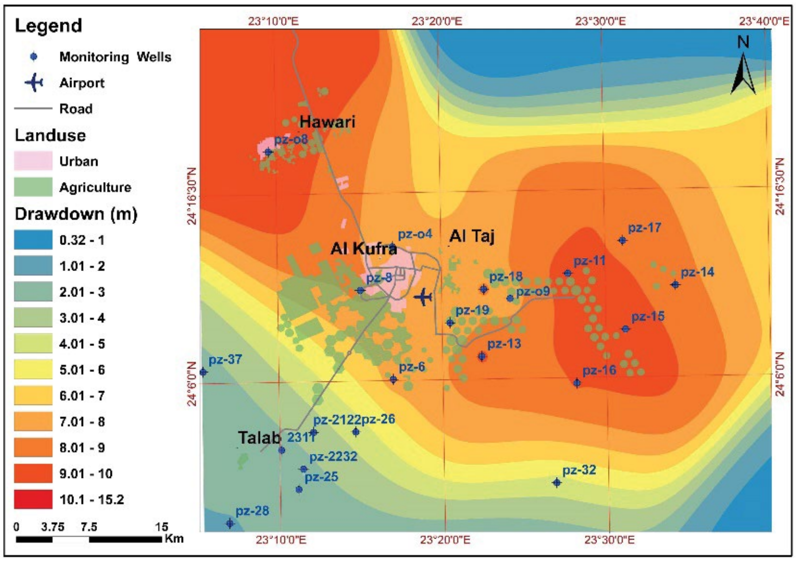

Fig. 4. Drawdown in groundwater level map.

is due to saltwater migration due to heavy abstraction, and the second is that increased salinity is a result of anthropogenic surface activities represented in irrigation return flow and wastewater return flows, where most of the city's neighborhoods and suburbs do not have sewage collection networks to groundwater. There are no major changes in the suitability of groundwater to agriculture Piper's and Wilcox diagram as illustrated in Figs. 6 and 7.

3.2.3. Groundwater management

Most of the government water institutions in Libya were established through decisions from the Ex-Ministerial Council. After the political change in 2011, the government in 2012 established the Ministry of Water Resource to be the highest water resources authority responsible in Libya to supervise and administrate all the water institutions. After two years, the Ministry of Water Resource' name was changed to the National Water Resources Establishment with the same tasks. Water institutions were characterized by administrative instability, and overlaps in responsibilities, in addition to the centralized approach in the management.

The responsibilities and tasks of the water institutions in Al Kufra Oasis can be summarized as follows (WSP 2011; GCWW 2018; JA 2018):

- *The General Water Authority (GWA)*

Formed in 1972 and responsible mainly for ground water resources exploration, monitoring, supervision on the drilling of the water, and ground water regulation.

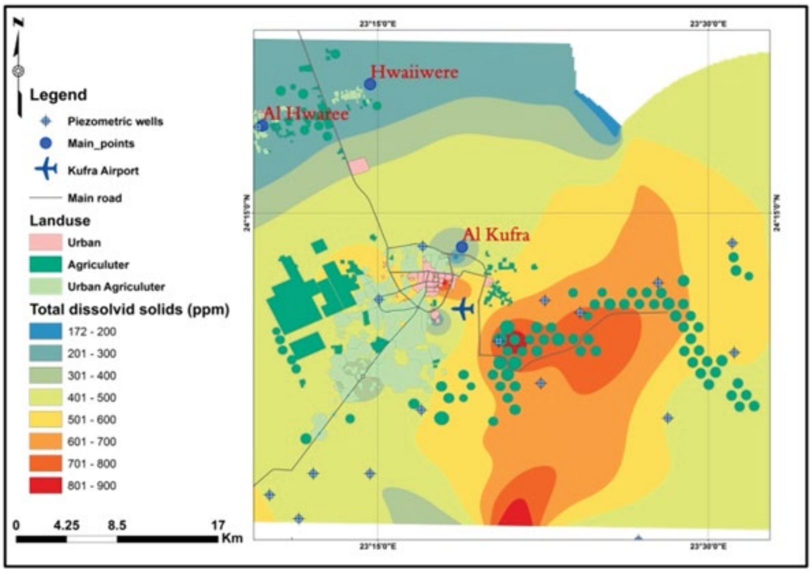

Fig. 5. Total dissolved solids map.

Table 7
Results of the chemical analysis of water samples

Well No	pH	TDS (ppm)	Bicarbonate mEq	Chloride mEq	Sulfate mEq	Calcium mEq	Magnesium mEq	Sodium mEq	Potassium mEq
1	6.8	387	0.7	2.1	1	1.2	0.7	1.74	0.16
2	6.78	387	0.7	2.2	1.21	1.3	0.9	1.74	0.17
3	6.83	172	0.7	0.7	0.52	0.7	0.4	0.7	0.12
4	6.84	660	0.8	5.1	1.63	1	1.3	5	0.23
5	6.78	823	0.7	6.6	2.5	1	1.5	6.52	0.78
6	6.87	612	0.7	3.9	2.47	1.2	1.7	3.91	0.26
7	6.98	537	0.6	3.4	2.07	1	1.6	3.26	0.21
8	6.94	365	0.6	2.1	1.18	1	1.1	1.61	0.17
9	7.08	704	0.6	5.4	1.78	1.3	1.2	5	0.28
10	7.17	237	0.7	1.3	0.74	1.1	0.5	1	0.14
11	7.1	211	0.7	0.5	1.22	1	0.5	0.82	0.1
12	7.1	260	0.7	1.2	0.88	0.7	0.6	1.3	0.18
13	6.99	233	0.65	1.2	0.86	0.7	0.6	1.22	0.19
14	7.07	401	1	2.1	0.92	1.3	0.9	1.65	0.17
15	7.04	512	0.8	3.3	1.64	0.9	0.9	3.69	0.25
16	6.96	343	0.7	1.9	0.85	1	0.8	1.48	0.17

- *The General Company for Water and Wastewater (GCWW)*

Established in 1996 and responsible mainly for water supply, construction, operation, maintenance of transmission, distribution networks, water pumping stations, and control centers, to ensure the provision of better services to the users of them. In addition to the construction, operation, and maintenance of drainage systems and related treatment plants, filtration, pumping, and monitoring.

- The Joint Authority for NSAS (JA)

An authority has been established in 1989 between the signed countries of Libya, Egypt, Sudan, and Chad under the name "Joint Authority for the Study and Development of the Nubian Sandstone Aquifer Waters" The Authority has been established to carry out the following objectives:

- Study, develop, and invest water resources in the Nubian Sandstone Aquifer System and strengthen the regional corporation between member states.
- Protection and maintenance thereof and nationalizing their use and harnessing them for searing the overall economic and social development.

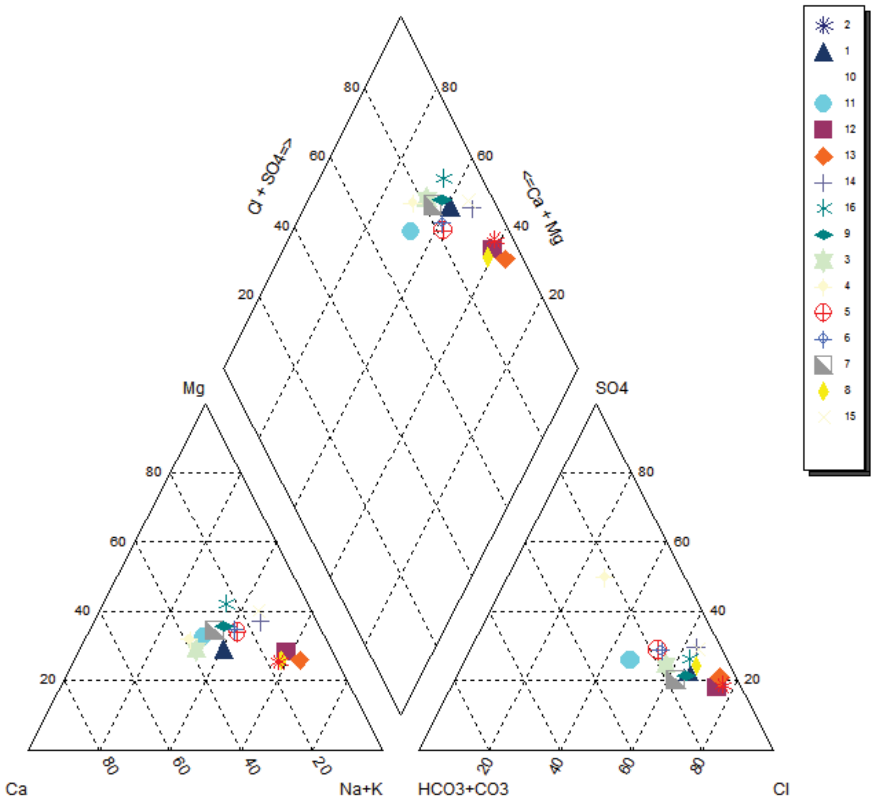

Fig. 6. Piper's diagram.

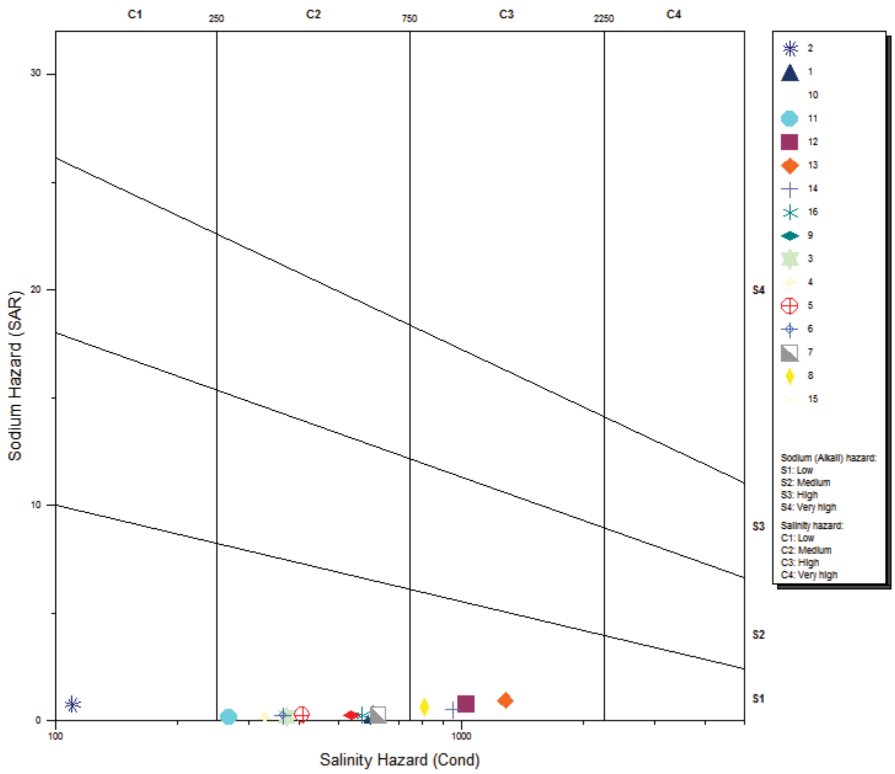

Fig. 7. Wilcox diagram.

- Development in the participant countries and the formulation of a regional strategic action plan for the sustainable utilization of the Nubian Sandstone Aquifer System and create a rule for the formulation of a regional development strategy.

These institutions suffer from the lack of highly qualified water professionals in the region, due to the public relatively low salaries, which limited income that the state paid, this has made most specialists to move to the private sector or to join other institutions outside the oasis. Furthermore, current institutions face multiplicity of mandates and conflict of interests, monopoly, in addition to inadequate enforcement of legislation and complete absence of law enforcement instruments, and lack of policies and strategies.

GCWW is the only institution largely operating and facing many challenges and difficulties, some of which are the problems of the old water networks and the explosion of transmission pipeline, and absence of sewage treatment, in addition to the violations of water utilities. However, the company suffers from the lack of adequate financial coverage to perform its tasks as required.

GWA introduced in 2006, policies and strategies concerning the delineations of risk areas for groundwater utilization, and unfortunately they did not put into practice due to the political circumstances of the country those also limits the monitoring and implementations Moreover, the GWA has a limited representation in the area in terms of the presence of specialists, offices, and laboratories to monitor and prepare hydrogeological studies, which is needed to raise awareness and ensure the implementations of the policies and the strategies in the region.

The JA is only linked to water governors and main water stakeholders at the national level in Libya. It needs to be linked with academia. The countries participating in the Commission shall bear the Commission›s budget in equal proportions for each of them. JA is needed to be reformed at the national by

- Increasing qualified staffing
- Enhancing monitoring system
- Upgrading the information systems, and support it with modern technologies
- Supporting national capacity building programs

Also, the JA needs more political support at the national level through organizing meetings, conferences, and workshops for demonstrating its activities at the national and regional levels to ensure the political commitment that will be the driver to financial support by the national government. Furthermore, there is a need for restructuring the JA in a way that allows the increase of experts and staff to ensure more geographical engagement for the areas of NSAS at the national level. Moreover, there is no participation of NGOs especially those specializing in water and environmental issues as well as the lack of water awareness activities Table 8 presents an inventory of the components of the enabling environmental indicators and institutional arrangement in the Al Kufrah Oasis.

4. Conclusion and recommendations

The NSAS is a valuable water resource in Libya, but it not managed properly and is associated with negative impacts, which might have dire consequences on the water security in the country. Currently, uncontrolled increasing water demands, driven by population growth and urbanization and agricultural activities, have led to water revels drop and quality degradation of the NSAS. Therefore, there is an urgent need for management interventions to stop this trend and ensure the sustainability of the aquifer in serving the socio-economic development needs of Libya. Moreover, assessment and analysis of the current institutional structure for water resources management in Al Kufra oasis indicate that the water challenge is probably a governance and management challenge rather than a technical one. The results of the assessment of the current water management system in Al Kufra Oasis can be summarized as follows:

- Centralized planning and financing and limited financial resources.
- Tasks overlap of water institutions, lack of coordination, and organizational instability.
- Inadequate institutional capacity at regional and local levels and limited experience in integrated water resource management (e.g., insufficient consideration of the socio-economic dimensions).
- Inadequate stakeholders participation.
- socio-economic dimensions are not involved in the current scheme of the management

Table 8
Enabling environmental indicators and institutional arrangement

Indicator	Unit	Year: 2018
Water resources policies based on IWRM principles	Yes/No	No
Water institutions	Number	3
Inter-institutional integration	Yes/No	No
Stakeholder participation	Yes/No	No
Existence of a supreme national authority	Yes/No	Yes
Application of laws to violators of the Water Law	Yes/No	No
Academies that provide training in the field of water in the region	Number	0
Awareness and water awareness activities per year	Number/YEAR	0

- Limited capacities in water management and lack of skilled labour to cope with future challenges.
- Lack of organized approach of awareness.
- limited monitoring system and lack of data quality.

These issues should be taken into consideration for the proper management of this precious resource. The following are the recommended actions that will need to be implemented in order to achieve an effective and sustainable water management system:

- Addressing issues that support institutional integration and engagement of stakeholders to enhance their cooperation in the field of water resources and ecosystem management. Thus, to ensure aspects of socio-economic aspects of engagement for future planning and assessment are scaled up relative to their direct and indirect relationship of the ecosystem.
- Evaluation of the current status of the NSAS beneath the main oases in terms of groundwater quality and quantity where the drawdown might have consequences which need to be investigated. Also, the salinity increase may be due to saltwater migration as a result of heavy abstraction or the increased salinity resultant from anthropogenic surface activities represented by irrigation return flow wastewater return flows since most of the city's neighbourhoods; and, suburbs that do not have sewage collection networks, necessitates the immediate implementation of a monitoring programme.
- Assessment of the environmental impacts resulting from differential water usage on NSAS and increasing knowledge about the ecosystem and its challenges. For example, the impact of the drawdown of the water level on the ecosystem of the oases can affect the growth of palm trees, and other desert species. The development of dry water bodies such as small sabkha, which leads to the migration of certain living species that thrive on them in addition to land subsidence resulting from groundwater obstruction.
- Investigating the institutionalization programme of capacity development and building to support the rational and equitable management of the NSAS.

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