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Monitoring and Assessment of Surface Water Quality Using Physicochemical Parameters and Indexical Approaches in El Manzala Lake, Egypt

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Abstract

Physiochemical parameters and the aquatic water quality index (AWQI) were employed to evaluate the surface water purity and identify the various geo-environmental factors influencing the ecological system in El Manzala Lake during two years 2020 and 2021. Water samples were obtained from 11 points, which collected around El Manzala Lake. The obtained analytical results reflected that the surface water in El Manzala Lake was of the semi-saline water type. The physicochemical data such as, T °C, pH, TDS, DO, COD, NO_3, NO_2, NH_4, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Zn revealed mean values of 23.33, 8.3, 8378.05, 6.76, 97.81, 0.11, 0.08, 1.09, 0.00, 0.00, 0.01, 0.05, 0.00, 0.01, 0.01, and 0.01mg/L respectively in the order of Fe > Zn > Mn >Cu >Ni >Pb > Cr> Cd. The concentrations of trace elements in the collected water samples varied considerably, suggesting that the obtained samples were polluted by Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn at levels exceeding the acceptable limits recommended by the Canadian Council of Ministers of the Environment (CCME). Based on AWQI results across two years, about 45% of the water samples were classified as unsuitable, 36% of samples were very poor water, and 18% of samples were poor water for use in aquatic environments. As untreated urban and agricultural wastewaters flowed into the lake, the AWQI values increased from the northwest to the southeast directions, indicating a decline in the quality of the water close to the drainages downstream.

Keywords: Physicochemical data, indexical approach, aquatic water quality index, El Manzala Lake.

Introduction

Water is not only the most important element for all animals, plants and other species, but also the key to human life in the biosphere. Water contains many nutrients and minerals that are essential for human life **(Carr and Neary, 2006).** In Egypt, water resources are limited and rainfall is uneven and irregular. Easily accessible surface water resources are under threat due to potential pollution from agricultural and industrial activities. Therefore, regular and seasonal monitoring of surface water quality is significant to assess the potential of various water uses and overcome degradation problems to maintain surface water under different conditions in Egypt **(Bajabaa et al., 2014)**. Lakes, rivers, and springs are examples of surface water bodies that are significant freshwater sources. Surface water quality is a globally important environmental system because it is crucial for both long-term environmental preservation and economic advancement. In several earlier scientific studies the prerequisites of sustainable management, the phrase "water quality" has been widely utilized **(Parparov et al., 2006)**. One of the most significant environmental and public health concerns impacting metropolitan areas in emerging nations in recent years is wastewater management **(Premakumara et al., 2014)**. The evaluation of all accessible water resources, such as surface water, groundwater, agricultural, and residential drainage, is necessary for integrated water resources management **(LaMoreaux et al., 2008).** Toxic element poisoning of aquatic environments is a significant pollution-related concern. For instance, heavy metals as inorganic substances will have a negative impact on the ecological balance of the aquatic environment, accumulate in aquatic organisms and pose a potential hazard to human health. In addition, heavy metals are emitted in large quantities every day **(Herojeet et al., 2015**). In other words, industrial activities, the disposal of untreated wastewater, and the influx of wastewater from sewage, agriculture, and industry from densely populated areas, which have created a variety of inorganic and organic pollutants that threaten the high ecological significance of the Egyptian lakes **(Mohsen et al., 2018).** These pollutants are poisonous, persistent, biodegradable, and harmful, posing a serious threat to the food web (**Gad et al., 2021)**. The water quality index (WQI) is among the most fundamental statistics employed to assess the quality of water, which is defined as a mathematical method that combines data from two or more water quality variables (e.g., DO, pH, etc.) to produce a score water quality **(Gad et al., 2020; Elsayed et al., 2021a; Elsayed et al., 2021b)**. A number used to classify the water quality status of a body of water. The concept of using aquatic water quality index (AWQI) is significant for monitoring and developing water quality management **(Gad et al., 2022)**. In this study, several physical and chemical parameters of water quality including total dissolved salts (TDS), hydrogen ion concentration (pH), temperature (T ^{o}C), dissolved oxygen (DO), and chemical oxygen demand (COD, NO_3, NO_2, and NH_4). The objectives of this research were to (i) evaluate the surface water quality of Lake Manzara in Egypt using various physical and chemical criteria, (ii) to determine pollution levels and types of pollutants, and create water quality indicator maps.

Materials and Methods

Study Area

For this study, a case study of a coastal lake in Egypt was used, El Manzala Lake which is considered to be the largest lake in area. Its length is about 47 kilometers and its width is about 30 kilometers (**Al-Badry and Khalifa, 2017*)***. It is situated on the Nile Delta's northern coast, between longitude (31°10" to 31°40" E) and latitude (31°50" to 32°25" N) as shown in Fig. 1.

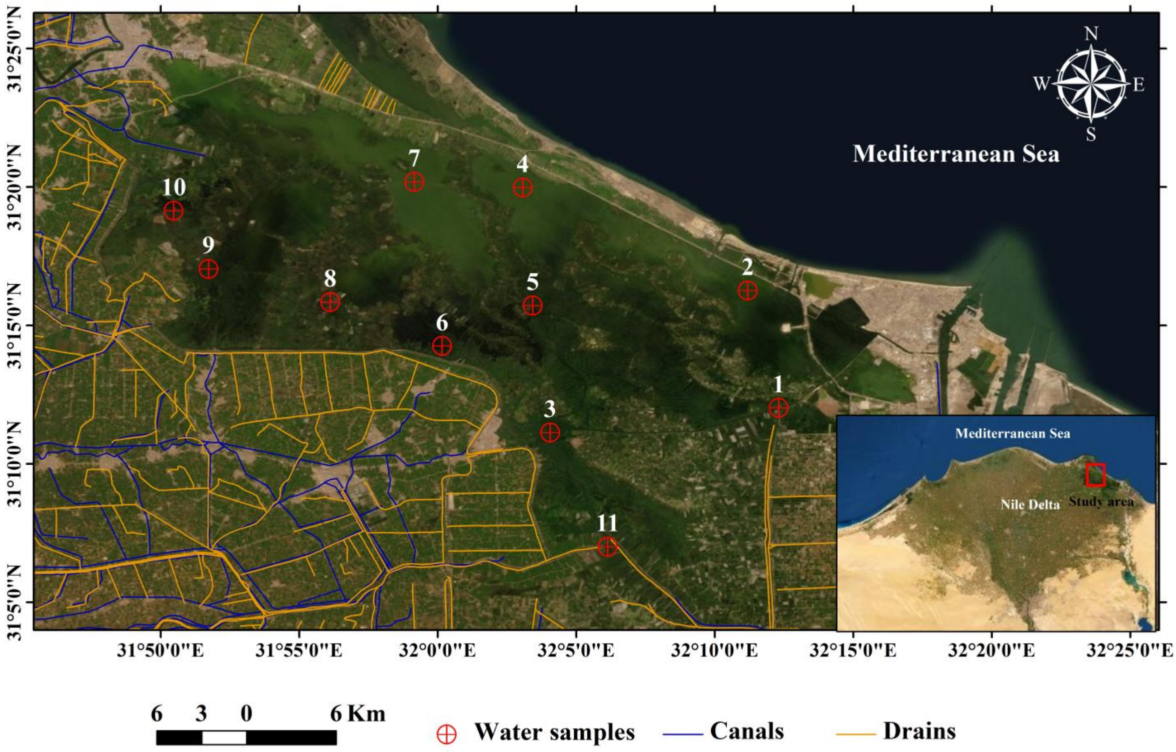

Fig. 1. Site location of El Manzala Lake and samples

Samples Collection and Analysis Surface water was collected from 11 locations in El Manzala Lake over a 4-month period in 2020 and 2021. The location of obtained samples was identified using UTM coordinates via a MAGELLAN handheld device (GPS 315). Samples were collected and stored in 1000 mL polyethylene bottles. Standard analytical procedures were then carried out in a 4°C refrigerator according to **APHA, 2017** guidelines. 2 ml of concentrated HNO_3 was added to each batch to reduce the pH below 2 to prevent adsorption and deposition on the bottle walls, and rinse the sampling bottle 2-3 times with sample water to reduce the chance of contamination.

Various physical and chemical parameters were calibrated on different field samples and at different geographical locations using devices such as pH meter, TDS meter, dissolved oxygen meter, to measure T°C, pH, and TDS in situ. Physical and chemical measurements of the samples were analyzed using traditional analytical methods **(Al-Rakaibi and Youngs, 1993).** Dissolved oxygen in water is affected by source, treatment, raw water temperature, and chemical or biological processes occurring in the distribution system. Although no health guidelines were suggested for dissolved oxygen levels, it is recommended that natural source water have a dissolved oxygen content of at least 5.0 mg/L **(CCME, 2007)**.

Additionally, NO_2^- and NO_3^- were measured using a UV-visible spectrophotometer (DR/2040-Loveland, CO, USA) and chemical oxygen demand (COD), with COD results were reported in mg/L. Milligrams of oxygen consumed per liter of sample under the conditions of a given methodology. According to this process, the sample was heated with the strong oxidizing agent potassium dichromate for two hours. The organic compounds being oxidized react, causing dichromate ions (Cr_2O_7) to be reduced to green chromium ions (Cr_3^+), and the amount of Cr_3^+ produced was measured. COD detectors also contain silver and mercury ions. Silver acts as a catalyst and mercury was used to cross-link the chloride to the lower range (0 to 150 mg/L). COD values were determined using a T80UK spectrophotometer in accordance with the approved digestion reactor method for reporting wastewater analysis, a procedure in accordance with **APHA, 2017** guidelines. A 500 ml sample was homogenized in a blender for 2 min. The DRB 200 reactor was preheated to 150 °C. Place the flask at a 45-degree angle. Pipette 2.00 ml of sample into the vial. Prepare the blank by adding 2 ml of deionized water to the vial. Samples and empty vials were inverted and placed in a preheated DR-200 reactor. The flask was heated for 2 hours. All vials were then read from the blank using a stored procedure according to APHA, 2017 guidelines. Dissolved organic NH_3-N levels and chemical oxygen demand were also measured using a visible spectrophotometer.

Aquatic Water Quality Index (AWQI)

Using routinely observed water quality criteria, the AWQI assesses the cleanliness of water. For aquatic purposes, the AWQI is the best index to use for assessing the general quality of surface water and is determined mathematically using an equation published by **Brown et al., 1972.** To calculate AWQI using formula (1), the weighted arithmetic approach was employed:

$$AWQI = \sum_{i=1}^{n} Q_i W_i \qquad (1)$$

The sub-quality indices of each variable are Q_i and W_i. The weight unit of the selected variables is W_i, and there are 8 physical and chemical properties (n = 8), expressed in mg/L. According to the CCME, the calculation of Q_i values is based on surface water concentrations (C_i) and standards for surface water parameter values for aquatic organisms (S_i) (**CCME, 2007**), according to formula (2):

$$Q_i = \frac{C_i}{S_i} \times 100 \qquad (2)$$

$$W_i = \frac{wi}{\sum wi} \qquad (3)$$

W_i is computed for every parameter using the suggested standards **(CCME, 2007)** by Eq. (4):

$$wi = K/Si \qquad (4)$$

K represents the proportionality constant.

To estimate AWQI, each surface water parameter must be assigned a weight (w_i), and the relative weight (W_i) and range of quality ratings (Q_i) were estimated. For that, W_i values were utilized to the selected physical and chemistry parameters (Table 1) and W_i was determined using equation (4).

Table 1. The AWQI values for the surface water parameters.

Variables	Aquatic Life*	Arithmetic Weight (W_i)	Sub-quality index (Q_i)	AWQI
pH	9	6.96883E-05	94.89	0.007
Temp.	28	2.23998E-05	44.29	0.001
TDS	500	1.25439E-06	510.72	0.001
DO	5.5	0.000114035	212.73	0.024
COD	7	8.95992E-05	783.71	0.070
NO_3	2.93	0.00021406	18.63	0.004
NO_2	0.06	0.010453241	874.78	9.144
NH_4	1.37	0.000457806	17.52	0.008
Cd	0.001	0.627194449	123.00	77.145
Cr	0.01	0.062719445	6.00	0.376
Cu	0.004	0.156798612	74.75	11.721
Fe	0.3	0.002090648	11.88	0.025
Pb	0.007	0.089599207	61.86	5.542
Mn	0.05	0.012543889	9.06	0.114
Ni	0.025	0.025087778	13.04	0.327
Zn	0.05	0.012543889	17.98	0.226
		$\sum w_i = 1$		$\sum (W_i * Q_i)$

Note: *Canadian Council of Ministers of the Environment (CCME) (2007), Physicochemical parameters are expressed in mg/L, except temperature (T °C) and pH.

Results and Discussions

Physical and Chemical Characteristics

Water chemistry was studied with the use of physical and chemical factors, which are also significant in determining the quality of the water. Table 2 listed the statistical description of the physicochemical properties in El Manzala Lake during the two-year period (2020-2021). Temperature is one of the factors influencing water quality and a crucial component of the aquatic ecosystem, controlling physical and chemical actions water. The water temperature ranges from a min. of 20°C to a max. of 25.88°C; the average temperature in summer and winter was 23.0°C. According to the CCME, the surface water of El Manzala Lake was within the optimal range for most aquatic life, while sudden changes in temperature can lead to direct harmful effects on fish species (CCME, 2007) for aquatic ecosystem. Moreover, the pH ranged from 7.63 to 8.71, with an average value of 8.38, which is within the acceptable water range for aquatic ecosystems recommended by the CCME (**CCME, 2007**).

The pH value of surface water samples indicates that the water was slightly acidic or alkaline, and the photosynthetic activity of phytoplankton was enhanced **(Khalifa, 2014)**. The dissolved solids values of the collected samples varied between 2801.6 and 18584 mg/L, with an average value of 8378.05 mg/L. The dissolved solids values in the obtained samples indicated that El Manzala Lake was almost saline water due to the evaporative effect caused by the high degree of dissolution and constant replenishment of agricultural, domestic, sewage and industrial wastes in the closed lake. On the other hand, the average concentrations of

Table 2. Statistical results of water quality parameters for El Manzala Lake.

Water quality parameters																
	T °C	**pH**	**TDS**	**DO**	**COD**	**NO_3**	**NO_2**	**NH_4**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Ni**	**Zn**
First year 2020 (n = 11)																
Min	23.8	8.32	2801.60	0.18	79.39	0.04	0.00	0.04	0.001	0.002	0.003	0.03	0.00	0.00	0.003	0.007
Max	25.8	8.55	16473.60	11.52	120.59	0.27	0.21	4.81	0.002	0.009	0.010	0.11	0.00	0.02	0.032	0.022
Mea	24.9	8.39	7506.93	6.52	100.93	0.09	0.07	1.04	0.001	0.004	0.005	0.05	0.00	0.01	0.008	0.012
Second year 2021 (n =11)																
	T °C	**pH**	**TDS**	**DO**	**COD**	**NO_3**	**NO_2**	**NH_4**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Ni**	**Zn**
Min	20.4	7.63	3294.40	0.00	78.54	0.05	0.01	0.03	0.001	0.001	0.002	0.03	0.00	0.00	0.002	0.006
Max	22.6	8.71	18584.00	12.76	114.06	0.38	0.25	5.53	0.002	0.002	0.018	0.06	0.00	0.02	0.005	0.019
Mea	21.7	8.37	9249.16	7.00	94.69	0.13	0.08	1.14	0.001	0.001	0.008	0.04	0.00	0.01	0.002	0.012
Data across two years (n = 22)																
	T °C	**pH**	**TDS**	**DO**	**COD**	**NO_3**	**NO_2**	**NH_4**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Ni**	**Zn**
Min	20.4	7.63	2801.6	0	78.54	0.04	0	0.03	0.001	0.001	0.002	0.03	0.00	0.00	0.002	0.006
Max	25.8	8.71	18584	12.76	120.59	0.38	0.25	5.53	0.002	0.009	0.018	0.11	0.00	0.02	0.032	0.022
Mea	23.3	8.38	8378.05	6.76	97.81	0.11	0.08	1.09	0.00	0.00	0.01	0.05	0.00	0.01	0.01	0.01

physicochemical variables, such as T°C, pH, TDS, DO, COD, NO_3, NO_2, NH_4, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn were 23.33, 8.3, 8378.05, 6.76, 97.81, 0.11, 0.08, 1.09, 0.00, 0.00, 0.01, 0.05, 0.00, 0.01, 0.01 and 0.01 mg/l, respectively. From our knowledge, trace elements and large accumulations of organic matter, ammonia and total dissolved solids in water originate from two sources: natural processes and anthropogenic activities. The collected water samples had varying quantities of trace elements, suggesting that surface water was polluted with Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn in amounts that exceeded acceptable protection standards for aquatic organisms, according to CCME **(CCME, 2007).**

The physical and chemical results obtained in the study area were consistent with the results obtained in several studies assessing metal contamination in lake water **(Goher et al., 2019).** The results showed that the contents of Cd, Cr and Pb in the upper reaches of the lake showed significant temporal differences ($P < 0.05$), while the values of Fe, Ni, Zn, Mn and Cu showed significant spatial differences ($P<0.01$). These results suggest that chemicals from raw sewage, sewage, fertilizers and pesticides discharged into the lake through valley drainage channels, as well as elevated mineral levels caused by increased rates of water evaporation, may restore the dramatic shift. In addition, long-term changes in water quality characteristics due to metal (Fe, Mn, Zn, Cu, and Ni) contaminants have been studied in highly polluted waters of Mediterranean lakes in northwestern Egypt **(Ali et al., 2017).**

Water Quality Assessment

Table 3 showed a statistical description of water quality indicator such as AWQI over 2 years. AWQI values ranged from 48.38 to 171.16 with an average value of 98.79. The results of AWQI values across two years showed that 45% of the water samples were classified as unsuitable, 36% of samples were very poor water, and 18% of samples were poor water for use in aquatic environments (Table 4). A map of the spatial distribution of surface water AWQI values increased from northwest to southeast in the study area, which showed that the greatest deterioration in surface water quality occurs near the downstream of the sewer network upstream of the Hadus, Sirr and mixed wastewater streams. At the end of the Bahr el-Baqar drainage ditch, the drainage ditch flows into the lake (Figs. 2 and 3). This can be explained by untreated agricultural and municipal wastewater entering the lake.

Conclusions

In the context of sustainable development, integrated approaches were used to evaluate water quality for El Manzala Lake using physicochemical parameters and geochemical properties. The geochemical properties of the collected water samples also indicate the type of water that affects the quality of surface waters. The physicochemical data such as, T °C, pH, TDS, DO, COD, NO_3, NO_2, NH_4, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Zn showed mean values of 23.33, 8.3, 8378.05, 6.76, 97.81, 0.11, 0.08, 1.09, 0.00, 0.00, 0.01, 0.05, 0.00, 0.01, 0.01, and 0.01mg/L, respectively in the order of Fe > Zn > Mn >Cu >Ni >Pb > Cr> Cd. According to AWQI results across two years, about 45% of the water samples were classified as unsuitable, 36% of samples was very poor water, and 18% of samples were poor water for use in aquatic environments. The AWQI values indicated that industrial wastewater and landfill/municipal wastewater leachate were considered to be the major sources of pollution by trace element in El Manzala Lake due to industrial operations and the widespread use of pesticides and fertilizers for agriculture, and inadequate sewage systems. Finally, Surface water quality degradation in the study region can be better controlled by implementing efficient wastewater treatment methods prior to discharging into the lake.

Table 3. **Sum**mary of the descriptive statistics of the determined AWQI.

Parameter	Min.	Max.	Average	Standard deviation
			First year (2020)	
AWQI	75.11	116.30	96.66	20.98
			Second year (2021)	
AWQI	48.38	171.16	95.93	33.62
			Across two years	
AWQI	48.38	171.16	98.79	8.94

Table 4. Classification of El Manzala Lake for aquatic ecosystem according to AWQI.

Index	Range	Water class	Samples (%) First year (2020)	Samples (%) Second year (2021)	Samples (%) Across two years
AWQI	0 – 25	Excellent	0	0	0
	26 – 50	Good	0	9.0 % (1 sample)	0
	51 – 75	Poor	9 % (1 Sample)	18. 2 % (2 sample)	18. 2 % (2 sample)
	76 – 100	Very poor	45.5 % (5 sample)	36.4 % (4 sample)	36.4 % (4 sample)
	> 100	Unsuitable	45.5 % (5 sample)	36.4 % (4 samples)	45. 4 % (5 sample)

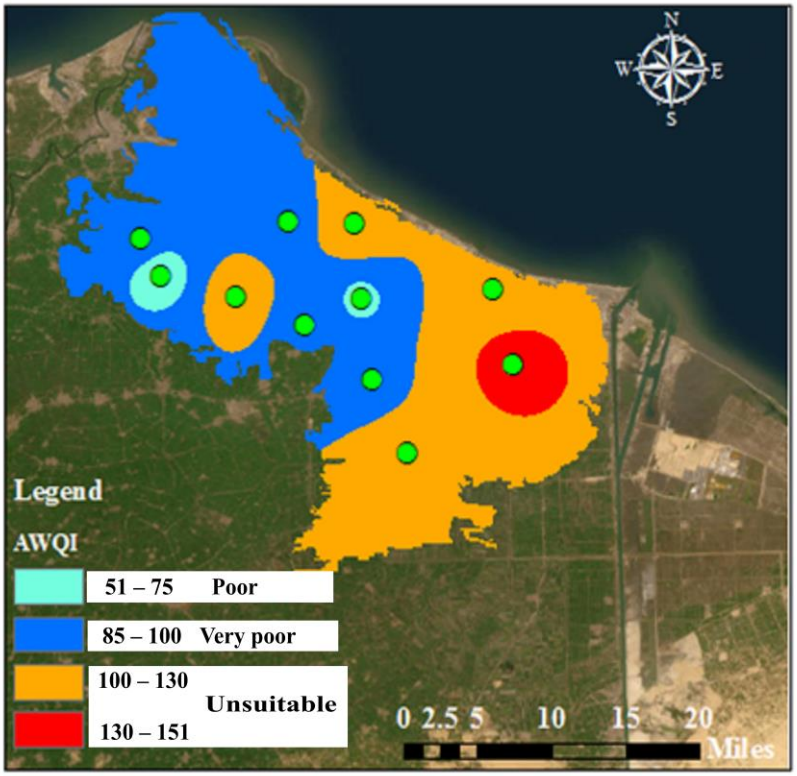

Fig. 2. Spatial distribution map of AWQI in year 2020.

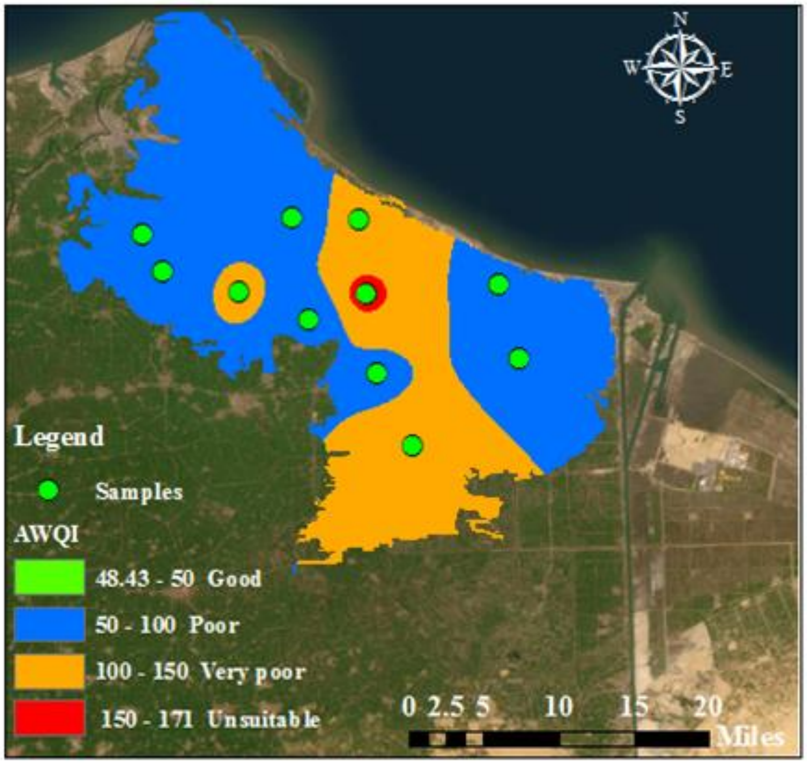

Fig. 3. Spatial distribution map AWQI in year 2021.

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