Original Research Article

Relation of ~~some~~ selected hydrochemical variables with hydrogen sulphide ~~(H_2S)~~ levels in the sediments of Lake Burullus ~~sediments~~, Egypt.

Abstract

Lake Burullus, ~~is~~ one of the northern deltaic lakes in Egypt, is ~~. It has~~ an important economic, recreational and fish bre~~a~~eding ~~importance~~reservoir. ~~So we aimed to focused~~The study used nine georeferenced stations to assess ~~on studying an important parameter namely;~~ hydrogen sulphide (H_2S) levels, its relationship ~~and~~ with selected ~~relation with some~~ hydrochemical parameters, and the ~~for~~ implication on ~~its effect on~~ thise lake's biota ~~inhabiting the lake~~. ~~Nine georeferenced stations were selected covering the lake for further analysis for some parameters.~~

The study reveals ~~It's noticeable~~ that areas mostly affected by drainage water with high load of organic matter, aid to the production of H_2S into sediments and dispersion to water. The present results indicate~~d~~ that H_2S in lake sediment is increase~~d~~ with increasing water temperature, biological oxygen demand, and ~~the~~ load of organic matter in water. Correlation analysis show that ~~On the other hand~~ areas with high oxygen levels and clear water aid in reducing sulphide levels in sediments. ~~as proved from correlation analysis.~~ The distribution maps (of what?) ~~take similar pattern for~~reveal positive correlation~~ed relation~~ of parameters ~~as~~ of organic matter ~~with~~ and H_2S. The huge amount of different wastes, particullay when in large quantities, -increase~~s~~ the level of H_2S, and therefore ~~that~~ affected on biota badly so it is highly recommended to treat wastewater to ~~serve~~ conserve the biodiversity of thise lake.

Comment [111]: Please note: you can use "hydrochemicals" for clarity, without losing the meaning. That is, the term variables can be omitted for clarity

Comment [112]: Please be consistent: use variable or parameter (noting the scientific usage of each)

Comment [113]: Please be consistent: is it plain "sulphide" or is it H_2S?

Comment [114]: There's a missing word here

Comment [115]: Please revise the usage of this term. Do you mean variables? Parameters is from the population, and not from the sample.

Comment [116]: may be negatively affected, or reduced...

Comment [117]: Please be specific. reduced? decimated? increased? "badly" is not scientific

Keywords: Lake Burullus, Pollution, Hydrochemical Parameters, Hydrogen Sulphide

Introduction

The bottom sediments of Lake Burullus ~~is~~ are mainly derived from the suspended load (i.e. the total suspend particulate matter in water), clay and silt (citation needed). These (what) are carried annually into the lake through the drain water, sea water and wind. The lake's bottom along the northern shores extending from the lake-sea connection westwards is mainly clayey-sand; silty sand with some patches formed molluscan shells. The eastern and western regions of the lake are silty clay. The southern shore sediments which receive directly the drain discharges which formed from clay and silt with small areas covered with molluscan shells (Med. Wet. Coast Project, 2005).

Comment [118]: may be these particals?

Abdo (2005) ~~stated~~ explains that the total organic matter in sediments plays an important role in the accumulation and release of pollutants in lagoon water, and it is a source of nutrient for the living fauna in the lagoon.

Hydrogen sulphide concentration in water and sediment in many aquatic system is considered good indicator ~~about~~ of oxygen levels in the water and sediment as regards ~~to~~ assessing the lake's water suitability for supporting biota ~~if the lake water is suitable for living organisms or not~~ (Golterman, 1975). Naturally, hydrogen sulfide occurs in the process of decomposing organic substances containing sulfur used by bacteria in anaerobic conditions (Wongsin, 2015). Also, Berner (1984) stated that surface sediments, which contain large amounts of the freshly deposited planktic organic compounds, are very important in the production of H_2S by sulfate reducing bacteria.

It is an extremely potent metabolic poison, lethal at low concentrations (<1 ppm) to most vertebrates alike (Evans, 1967, Smith *et al.,* 1976; Oscid and Smith 1974 a, b).

Hydrogen sulfide is a colorless, flammable and toxic gases smell like rotten eggs, even at low concentrations (Tuntoolavest and Tuntoolavest, 2004)

The toxicity of hydrogen sulphide for some fauna (*Tilapia gallilae*; Nauplii larvae of *Artemia salina* (*Ocenebra erinacea*) and *Idotea baltica* have been recorded by Tayel and Shriadah (1991). Oxidation of hydrogen sulphide in natural waters either produces or consumes hydrogen ions, depending on products and other conditions (Tayel and Shriadah 1991).

Thus

$$2HS^{-}+O_2 \rightarrow 2H_2O + 2S$$

$$2HS^{-} + 2O_2 \rightarrow H_2O + (S_2O_3)^{-2}$$

$$2HS^{-} + 4O_2 \rightarrow 2(SO_4)^{-2}+2H^{+}$$

In absence of biological activity, sulphide can be slowly oxidized to sulpher which then combines with remaining sulphide to form polysulphide. The aim of this research is to study the interrelationship between ~~some~~ selected hydrochemical parameters and H_2S level in the sediments of Lake Burullus, Egypt.

2. Material and Methods

2.1. Study area

Burullus Lake is one of the five Mediterranean Lakes ~~of~~ in Egypt, and ~~which~~ is used for ~~many purposes including~~ fishing, recreation, and contains many organisms. It is ~~is~~ bordered ~~from~~ in the north by Mediterranean Sea and ~~from~~ in south by agricultural lands and fish farms between 30° 30\` 31° 10\`E and 31° 20\` 31° 35\`N (citation needed). It extends for a distance 41.8km within area of about 460 km^2. Lake Burullus is connected to the Mediterranean Sea through the El-Burullus outlet (Boughaz El-Burullus) which is about 250 m wide and 5 m deep (citation needed).. The depth of the Lake varies between 40 cm in its

Comment [119]: what is it? name it here

Comment [1110]: take to Methods

Comment [1111]: take this to Methods

Comment [1112]: See previous comment

Comment [1113]: Be consistent: Burullus Lake OR Lake Burullus middle sector and near the shores and 200 cm near the outlet to the sea (citation needed)..

The lake receives (4 milliar m^3/y^{-1}) drainage water from several drains which were considered the main source of pollution in the lake (citation needed).~~—~~ The maximum amount of drainage water discharge from drain 9 at the middle sector of the lake (citation needed). The lake receives drainage water from several drains which were considered the main source of pollution in the lake. The maximum amount of drainage water discharge from drain 9 at the middle sector of the lake. The estuarine water of Rosetta mouth of the River Nile is mixed with the lake water through Brimbal canal. Sea water may also flow into the lake at Burullus outlet (El-Bayomi, 1999; Al-Sayes *et al*., 2007; Zahran and Willis, 2009).

Surficial sediment samples were collected from nine stations covering~~ed~~ Lake Burullus~~,~~ (Figure 1). The description of these locations ~~was~~ is as shown in Table (1).

Comment [1114]: check spelling

Comment [1115]: add a sentence explaining the source of these drains. Are they sewer drains? municipal drains? rainwater drains?

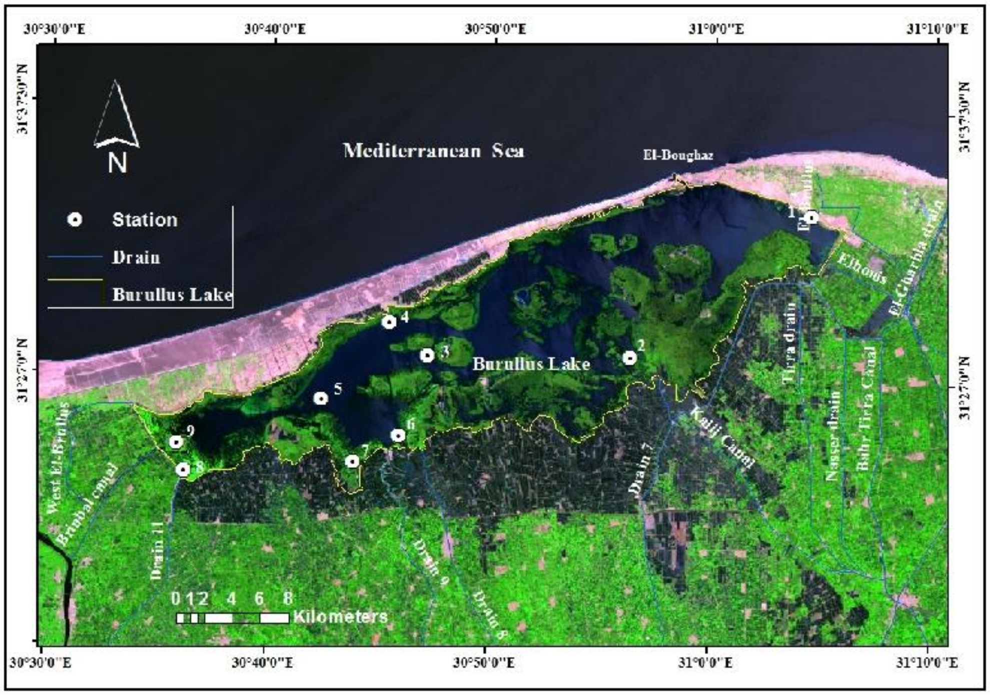


Fig.1. Sampling stations at Lake Burullus

Table (1): Latitudes and longitudes of the sampling stations at Lake Burullus

St. NO	Station name	Latitude N	Longitude E
1	El-Burullus (east)	31° 33` 29.9``	31° 04` 25.3``
2	inf. of drain 7	31° 27` 56.1``	30° 56` 17.5``
3	El-Zankah	31° 27` 53.3``	30° 47` 10.0``
4	Mastarouh	31° 29` 09.0``	30° 45` 24.4``
5	Abo-Amer	31° 26` 07.0``	30° 42` 23.3``
6	El-Tawelah	31° 23` 43.8``	30° 43` 52.8``
7	inf. of drain 8 & 9 (Shakhlobah)	31° 24` 46.9``	30° 45` 54.9``
8	inf. of drain 11 (El-Hoksa)	31° 23` 15.5``	30° 36` 15.3``

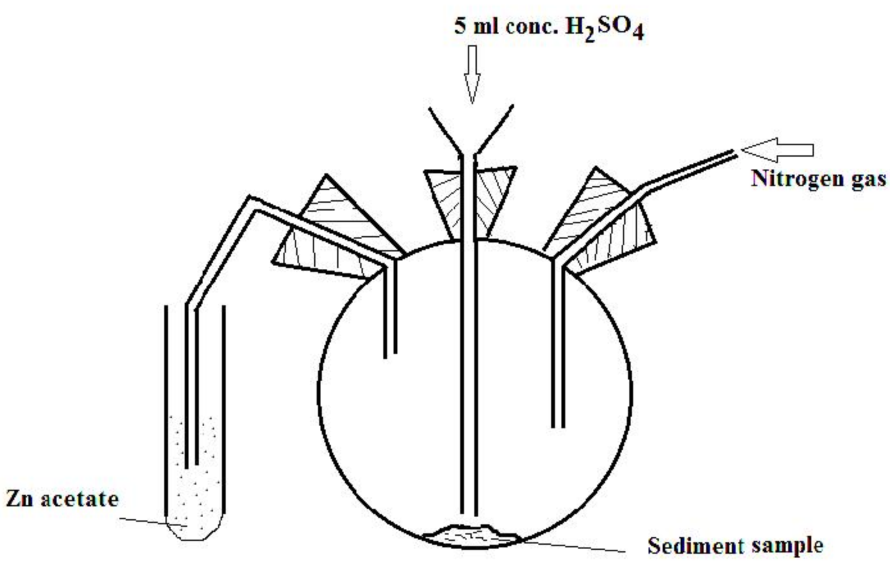
9	inf. of Brimbal Canal	31^o 24` 06.0``	30^o 35` 00.4``

St= station inf= infront

2.2. Analytical methods

Nine geo-referenced water samples were collected within Lake Burullus. In the field, water temperature and DO were measured using the DO meter (Lutron YK-22 DO meter). pH ~~is~~ was measured using pH-meter (Model Lutron YK-2001, pH meter). EC was determined using EC-meter (Thermo, Orion 150 A+ advanced conductivity). The BOD determination was carried out using the conventional Winkler method (APHA, 1998). OM is determined by Permanganate oxidation method (FAO, 1975).

Estimation of hydrogen sulphide in sediment samples occurred as follow: 0.1 –0.8gm wet acidified samples with nearly 5ml Conc H_2SO_4 in closed system, (Figure 2). The involved hydrogen sulphide gas was displaced with oxygen free nitrogen gas into zinc acetate traps. The recovery of sulphide in this manner is 99% efficient. Sulphide collected in the traps was measured calorimetrically using methylene blue method (Youssef, 1999). Results are expressed as mg/gm.



Comment [1116]: Please write out in full, and then can abbreviate

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Fig. 2. The apparatus used for estimation of hydrogen sulphide

2.3. Statistical analysis:

The statistical analysis for the data were carried out to determine the correlation coefficient (r) using the formula

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{\left[n\sum x^2 - (\sum x)^2\right]\left[n\sum y^2 - (\sum y)^2\right]}}$$

Where X the concentration of H_2S and Y is the corresponding concentration of variant and n is the number of data.

2.4. Geo-statistical Analysis

Inverse distance weight (IDW) is a deterministic interpolation procedure that estimates values at prediction points (V) using the following equation

$$V = \frac{\sum_{i=1}^{n} v_i \quad (\frac{1}{d_i^p})}{\sum_{i=1}^{n}(1/d_i^p)}$$

Where d is the distance between prediction and measurement points, Vi is the measured parameter value, and p is a power parameter (Isaaks *et al.* 1989). The main factor affecting the accuracy of inverse distance interpolator is the value of the power parameter p, as well the size of the neighborhood and the number of neighbors are also relevant to the accuracy of the results (Burrough and McDonnell, 1998).

3. Results and discussion

Results of hydrogen sulphide concentrations in sediments as well as concentrations of some related parameters in the water as organic matter, dissolved oxygen, biological oxygen demand and hydrogen ion concentration were shown in Table (2) and the spatial distribution maps (of what) were as shown in Figure 3 (A-G).

H_2S concentration in sediments ranged between 4.3 at Abu-Amer and 7.7 at El-Tawelah and Brinbal canal with mean value of 6.72 mg/g. T~~t~~he highest value was recorded at Brinbal, and may attributed to the nature of sediment characteristics of clay and high content of organic matter that aid in the release of H_2S in sediments. Radwan and Lotfy (2002) estimated that sediments of Lake Burullus have a complex nature. More specifically, ~~T~~the sediments change from coarse particles-sand, usually abundant in the northern coast and at the coast of islets, whereas it's muddy in the southern parts of lakes.

Organic matter also takes the same distribution of H_2S as its high percent content was found at Brinbal canal may attributed to agricultural wastes from different agricultural areas. High discharge of drained water in the southern part of the lake led to the consumption of DO due to oxidation of such OM. This is agreed with observations of El-Ghobashy (1990) in Lake Manzala.

In Lake Burullus ~~Lake~~, the highest concentrations of organic matter and organic carbon were distributed at the western, southern and eastern parts of the lake; this agrees with Masoud (2011) and El-Alfy (2015).

The ~~souther~~southern parts are described ~~by~~ as having clayey sediments or fine particles which contain high amount of organic carbon not as sandy soils which are very poor with organic matters at the northern parts of the lake~~s~~ (Palma *et al*. 2012).

~~He~~ The site ~~of~~ at Brinbal canal is distinguished by high density of vegetation especially hydrophytes i.e. *Eichhornia crassipes* and other vegetative plants. So it's an important reason for high concentration of OM in these areas as may attributed to sinking and decaying of dead plants on the bottom (Nafea, 2005).

Comment [1119]: Please write out in full, and then can abbreviate. If this is organic matter (OM), then write as such, and only then can you abbreviate.

These results are in agree~~d~~ment with Moussa *et al.* (1994) and Khalil *et al.* (2007) for lake Edku where the content of OM in sediment was controlled by the amount of clay and silt in addition to the plant detritus from nearby vegetatative areas.

EC fluctuated between 3.9 at Brinbal canal (source of fresh water from Rosetta Branch /River Nile) to 30.9 at east of El-Burulls (this sites is near from El-Boughaz area) so it may be highly affected by the sea water intrusion.

Hydrogen sulphide was produced in the anoxic part of the sediment, with reduction of sulphate. It's noticeable that, the reduction of sulfate in sediments reaches a percent of nearly 13% of total organic matter in acidic conditions and to 50% in marine sediment (Kühl and Jorgesen, 1992).

pH is very significant parameter in the metabolic and physiological processes that is important in growth of aquatic organisms (Lawson, 2011). Values of pH changed within different sites. As it was acidic especially in the outlets of drains, as t ay attributed to release of different nutrients like ammonia that responsible for acidification and decreasing of pH. This is in agreement~~d~~ with Koerkamp *et al.* (1998) and Ibrahiem *et al*. (2012). Also Abbas *et al.* (2001) and Sayed (2003) stated that low pH values are attributed to liberation of H_2S during the decompositions of OM. The highest value of pH was recorded in site 5, may attributed to high density of hydrophytes as increase of pH value is accompanied by a flourishing photosynthesiz~~s~~ing organisms (El-Sonbati *et al.* 2009).

The excess of OM produced during photosynthesis process in the euphotic zone eventually sinks down through the water to the sediments where respiration processes dominate. The depth of the Lake does not exceed 1.5 meter, thus, a significant difference often exists between the oxygen rich euphotic zone and underlying oxygen-poor aphotic zone. The presence or absence of oxygen has significant effect on the oxidation-reduction chemistry, also attributed to the anaerobic bacteria where the biological oxygen demand is an empirical test used to determine the relative oxygen requirements needed for the biochemical decomposition and oxidation of OM and inorganic material.

Comment [1120]: units?

Comment [1121]: sulphate or sulfate? please be consistent

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The highest concentrations of BOD were recorded in stations close to the point of discharges as pronounced at station 7 (drains 8&9), where huge amount of OM originated from drains led to more consumption to DO by the bacterial activities which leads to oxygen depletion and rise in H_2S level in the sediment.

Comment [1123]: see previous comment

Sedimentary production of hydrogen sulphide can increase the oxygen demand rate of sediment leading to a reduction in dissolved oxygen in the overlying water as shown in our investigation at stations 5 and 9. Utilizing~~e~~ combined oxygen as sulphate, purification then occurs resulting from decomposition of OM to hydrogen sulphide as end product (Klein, 1962). From the results obtained in Table 2, its clear that, the whole water body of the lake is well aerated and oxygenated during the time of sampling with a minimum of 5.1mg^{-1} at station 7 (in front of drain 8,9) a maximum of 10.6 mg^{-1} at station 5 in the middle sector.

Comment [1124]: use one or the other, but not both

From the statistical analysis (Table 3), it is obvious that highly inverse significant proportion was observed between hydrogen sulphide and dissolved oxygen (r= - 0.67). Meanwhile, there ~~relation~~ was a positive significant correlation with organic matter (r= 0.74). On the other hand, the relation was insignificant between hydrogen sulphide, biological oxygen demand, (r= 0.32), pH (-0.24) and with water temperature (r= 0.47). The distribution maps (of what?) as shown in figure (3) proved the relation between the presences of different parameters within the H_2S, which highly attributable~~ed~~ to drainage waters from different drains. El-Amier *et al*. (2016) and El-Alfy *et al*. (2017) used geostatistical and deterministic methods for creating spatial distribution maps ~~for~~ of different pollutants in ~~Burullus~~ Lake Burullus.

Comment [1125]: If this is what is earlier abbreviated as BOD, then spell out from the beginning

Comment [1126]: From different drains is not a scientific reason? Do you mean different waste drains?

Comment [1127]: This is it! replace all other places with this. This is very clear: spatial distribution maps of different pollutants in Lake Burullus.

Conclusion

Comment [1128]: Please re-copy the revised concluding points in the abstract here. That is, replace some points in this conclusion with what is now revised abstract

It's concluded that areas besides drainage water as drains recorded high levels of H_2S. Strong relation between drained water containing low concentrations of dissolved oxygen, high concentration of BOD and high levels of OM in sediments with the levels of H_2S. Areas with low pH values or characterized by acidic nature may be indication for high levels of H_2S in sediments of lake. So it's highly recommended to reduce organic load to the lake by using different methods of remediation aid in reducing of H_2S sources in sediments to keep the aquatic life. Also removal~~ing~~ of unneeded aquatic plans from Lake Burullus’ ~~lake~~ water could aid to solve such problems.

Comment [1129]: plants? do you mean invasive plants?

Table (2): Hydrogen sulphide concentration (mg/g) in sediment and concentration of some related hydrochemical parameters in water of Lake Burullus.

St.	H_2S mg/gm	OM %	DO mg/l	BOD mg/l	pH	T°C	EC	Depth
1	6.9	1.8	8.5	3.8	8.67	22.7	30.8	70
2	7.2	3.1	5.8	6.5	8.78	23.0	9.11	60
3	7.2	2.4	9.1	5.7	8.55	23.0	10.1	90
4	6.8	2.9	8.1	11.4	8.78	22.8	9.29	110
5	4.3	1.6	10.6	7.3	8.83	22.1	9	120
6	7.7	3.6	5.9	13.5	8.0	25.0	8.61	100
7	6.8	2.9	5.1	18.3	7.86	24.0	4.52	70
8	5.9	2.1	7.4	10.6	6.88	25.0	4.1	80
9	7.7	4.4	6.0	21.4	6.37	25.7	3.9	90
σn	0.997	0.842	1.728	5.596	0.8518	1.1935	7.74	18.72
σn.1	1.058	0.893	1.833	5.936	0.9035	1.2658	8.21	19.61
X	6.722	2.7525	7.38	10.944	8.08	23.700	9.94	87.77

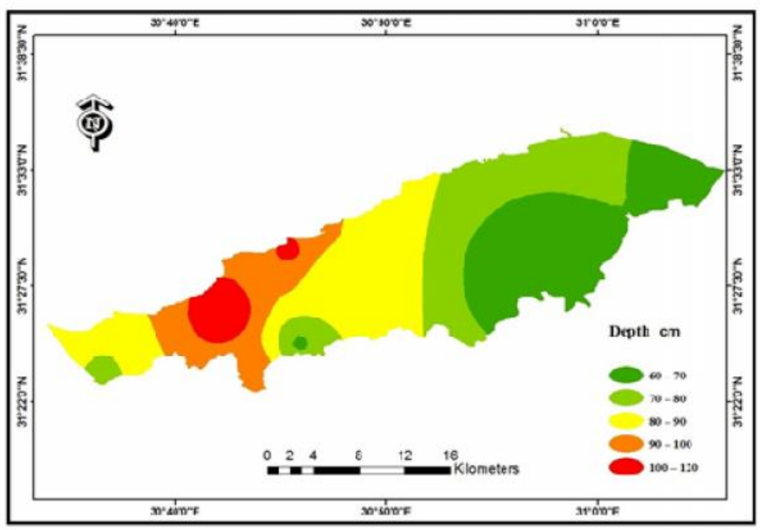
Comment [1130]: Please spell out the abbreviations below the table: H2S, OM, DO, BOD, EC ......

Table (3): Pearson moment correlation matrix between some hydrochemical parameters and H_2S in sediments.

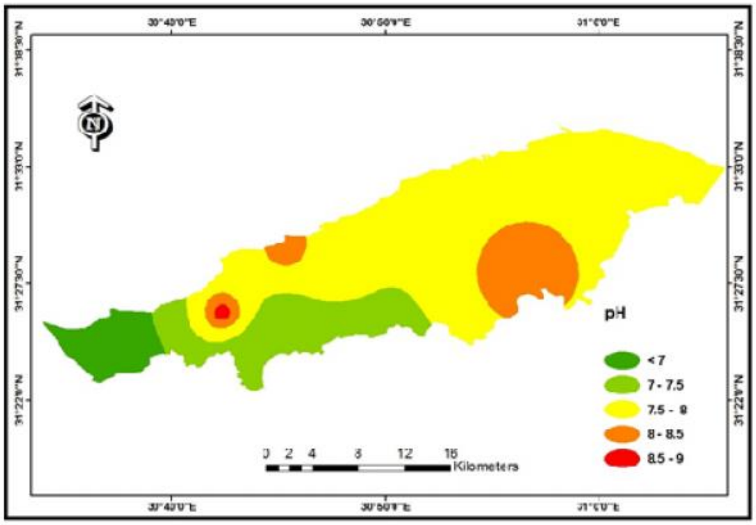
Variables	H_2S	OM	DO	BOD	pH	TºC
H_2S	1					
OM	0.743*	1				
DO	-0.675*	-0.741*	1			
BOD	0.329	0.756*	-0.648	1		
pH	-0.246	-0.524	0.471	-0.734*	1	
TºC	0.48	.692*	-0.666	0.754*	-0.917**	1

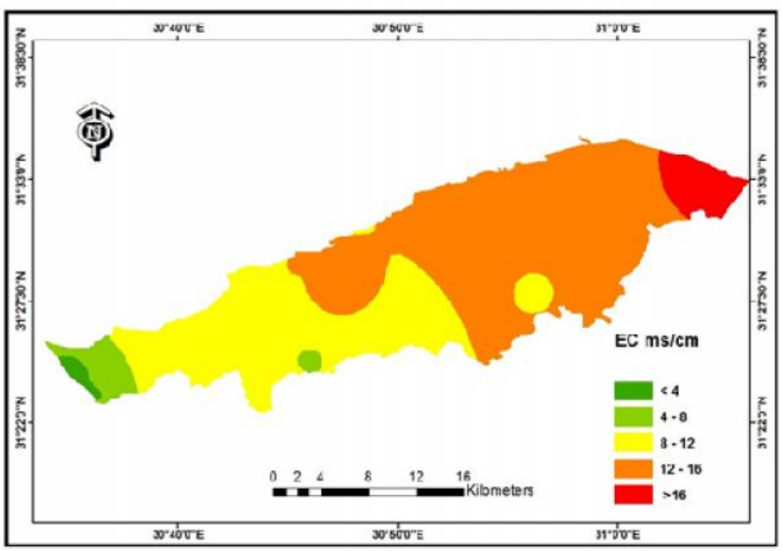
*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

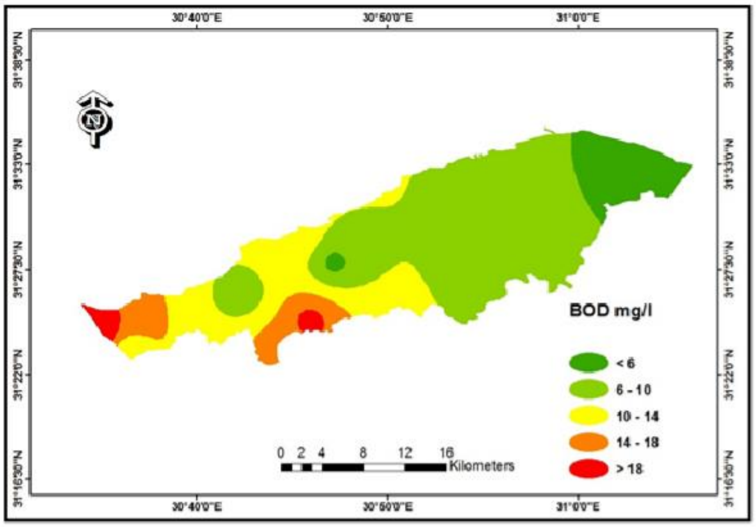
Comment [1131]: Please spell out the abbreviations below the table: H2S, OM, DO, BOD ……



A)

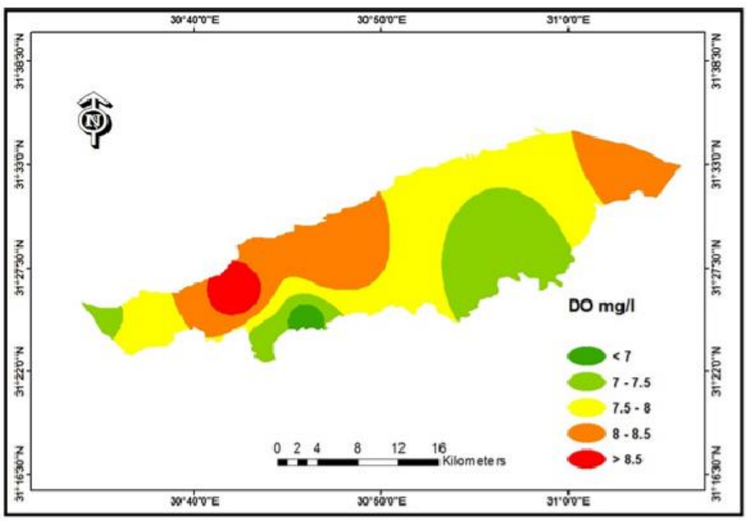

pH
< 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
0 2 4 8 12 16
Kilometers
B)


EC ms/cm
< 4
4 - 8
8 - 12
12 - 16
>16
0 2 4 8 12 16
Kilometers
30°40'0"E
30°50'0"E
31°0'0"E
C)



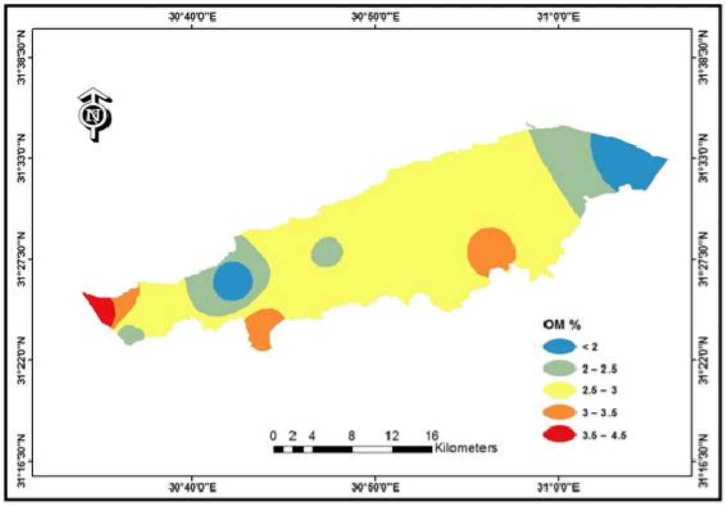
BOD mg/l
< 6
6 - 10
10 - 14
14 - 18
> 18
Kilometers

D)



DO mg/l
< 7
7 - 7.5
7.5 - 8
8 - 8.5
> 8.5
Kilometers

E)



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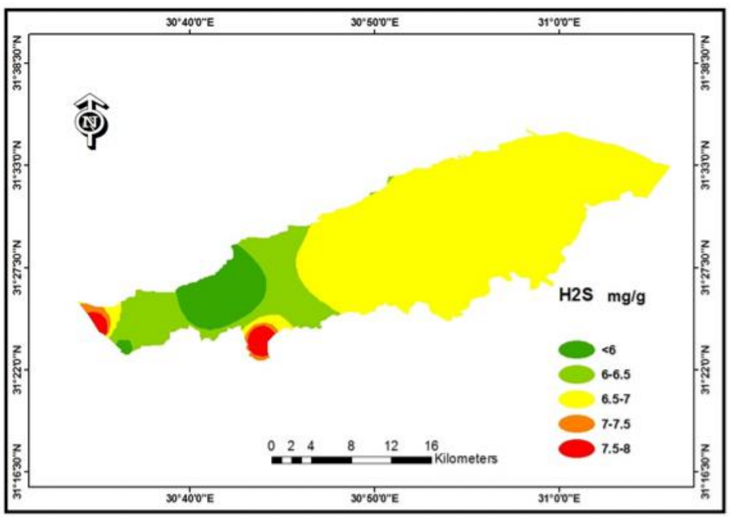

G)

Fig. 3.(A-G) Spatial distribution of depth, pH, EC, BOD, DO, OM and H_2S within water and sediment of Burullus Lake.

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