# The Effect of Secondary-Treated Municipal Wastewater Discharge on Nutrient Concentrations in Leaves and Soils of Gray Mangrove in Bahrain

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## Abstract

The wastewater discharge into the marine environment may affect the integrity of the mangrove ecosystem. In this context, the possible effect of secondary-treated municipal wastewater discharge on the nutrient concentrations in the leaves and soils of Tubli Bay gray mangrove (*Avicennia marina* (Forsk.) Vierh.) was assessed at three sites. Physical properties and the percent of organic matter content in mangrove soil were measured. The nitrogen concentration was measured using the Kjeldahl method. Extractable phosphorus was quantified using the dry-ash method. Plant and soil concentration of K, Ca, Mg, and Na was determined using an inductively coupled plasma analyzer. Soil organic matter was estimated using the dry-ash method. The results showed no significant differences in the mangrove leaves' nutrient concentration between sites regarding all the measured variables except N and Na. Wastewater discharge significantly affects mangrove leaves N content at the Tubli site where heavy wastewater loads are discharged. Leaf nutrients' concentration followed the order: Na> K> N> Mg> Ca> P. Nutrients were concentrated in the topsoil layers in the following order: Ca > Mg > Na > K > N > P. Nutrient level showed a decreasing pattern with soil depth, except for Ca. Significant differences were observed in N and P's levels in the soil layers between the affected site and the other two sites. Furthermore, the soil analysis indicated significant differences in N and P levels in the Tubli site soil compared to the other two sites due to wastewater discharge. No significant correlations were found between nutrient levels in the leaves of mangrove and its underlying soils. Additionally, the release of wastewater into the Bay significantly increased soil organic matter in the affected site. The study's findings indicate that the continued release of the secondary effluent into the Tubli Bay may alter the Bay ecosystem's Physico-chemical properties in general and mangrove survival in particular.

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## Introduction

*Avicennia marina* (Forssk.) Vierh. and *Rhizophora mucronata* Lam. are two species of mangroves known to exist along the Middle East coasts, covering

0.4% of the world mangrove area (Spalding, et al., 2010). The first species is called gray mangrove and found in patchy locations along the Arabian Gulf shores. The other grows mainly on the Red Sea coasts and the Gulf of Aden and is known as red mangrove. In Bahrain, the gray mangrove grows in the intertidal zone of Tubli Bay in four core communities. The species is nationally categorized as critically endangered (ARC-WH, 2017).

It was reported that the discharge of partially treated wastewater to the marine environment affects the integrity of the mangrove ecosystem (Bartolini, et al., 2011) alters nutrients uptake (Nyomora and Njau, 2012), changes soil microbial activity (Tam, 1998), and increases mangrove soil fluxes of $CH_4$, $N_2O$, and $CO_2$ (Chen, et al., 2011). Such an impact is often linked to the wastewater's diluting effect and high nutrient loads (Stark, et al., 2016; Barcellos, et al., 2019).

The amount and availability of nutrients are governed by a complex of abiotic and biotic factors that control the flow and recycling of nutrients in the mangrove ecosystem (Reef, et al., 2010 Singh et al., 2016). Furthermore, nutrient amounts vary spatially and temporally in mangrove media due to several variables: the soil grain size, tidal effect, and nutrient loading (Wong, et al., 1995; Rahaman, et al., 2013; Medina, et al., 2015adult, old, and senescent. We measured changes in concentration of essential elements (N, P, S, K, Mg, Ca, Mn, Fe). Many mangrove soils are low in nutrient availability to the extent that may limit mangroves' growth and productivity (Feller, et al., 2003*;* Lovelock, et al., 2004; Naidoo, 2006; Reef, et al., 2010). In this respect, nitrogen and phosphorus are the two most vital nutrients that control plant growth in general and mangrove in particular (Reef, et al., 2010; Dangremond and Feller, 2014; Deborde et al., 2015).

Nutrient levels in mangrove leaves are species-dependent (Sereneski-De Lima, et al., 2013a Madi, et al., 2015). However, variations exist due to site conditions, seasons, and the biotic alteratins of the environment's physicochemical setting (Deborde, et al., 2015; Medina, et al., 2015). For instance, higher K levels in the leaves of two Brazilian mangroves; *R. mangle* and *Laguncularia racemose* were reported in the dry season, whereas Ca and Cu were found to be high in the rainy season (Bernini, et al., 2010; Madi, et al., 2015).

Mature leaves were used as an indicator of the nutritional status of mangrove stands (Boto and Wellington, 1983). Furthermore, leaf nutrients in mangroves can be used to monitor mangrove coastal ecosystem enrichments by sewage discharge (Gritcan, et al., 2016). The relationship between mangrove leaf nutrient concentrations and its underlying soil is equivocal and least searched in the Arabian Peninsula's gray mangroves. Moreover, little is known about the municipal secondary-treated wastewater discharge effect on nutrient levels in leaves and mangroves' soils. This study aimed to investigate the impact of secondary-treated sewage input from the Tubli Water Pollution Control Centre (TWCC) on nutrient concentrations in the leaves and soils of gray mangrove in Bahrain.

## Material and Methods

### 1. Study Area

Tubli Bay is a shallow sheltered water body with a total area of $10Km^2$. The depth of seawater at the Bay ranges from a few centimeters to about 5 meters. The average pH is 7.9, while salinity varies from 39.7 to 44.8%. The average seawater temperature ranges between 18.4 and 33.5°C (SCE, 2012). Tides occur twice a day. The climate of Bahrain is arid. The average rainfall is 70.8mm per year, while the average annual temperature is 26.5°C. However, summer temperatures may rise to 46.7°C. The daily evaporation rate averages 5.75mm, with an average annual rate of 2099 mm (Fig.1).

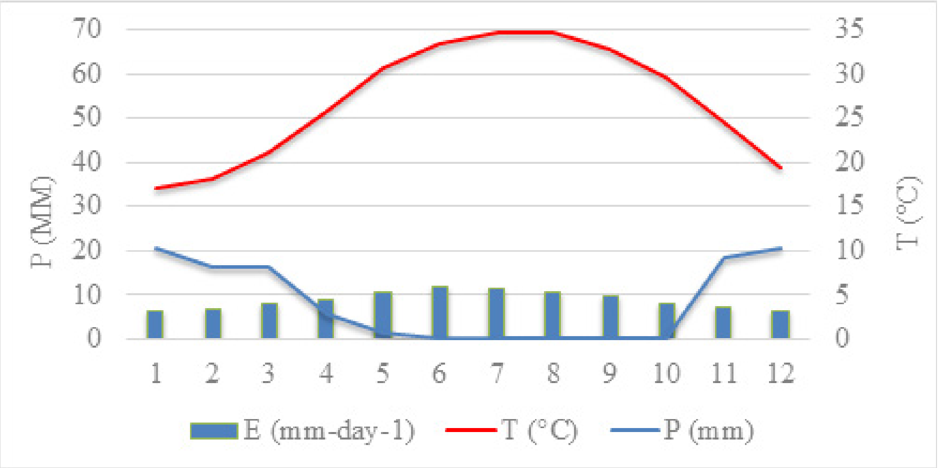


**Figure 1.** *Bagnouls and Gaussen's ombrothermic diagram with daily evaporation rate for Bahrain.*

The Bay receives a discharge of more than 100,000 $m^3$ $day^{-l}$ of secondary level treated municipal wastewater. The discharged wastewater pH is 7.5, and 2.1 mmhos/cm EC with high nitrogen (6.8 $NH_{3,}$ 0.4 $NO_2$, 3.44 $NO_3$) mg $l^{-1}$ and (1.39 total phosphate) mg $l^{-1}$ content. The total dissolved and suspended solids are 1352 and 90.4 mg $L^{-1}$, respectively (Al-Nuaimi, 2018). One of the mangrove communities grows near the WPCC discharge outlet. Trees are bushy in shapes and reach a height of 5.5 m.

## 2. Sampling Procedures

Three mangrove sites were selected along the Tubli Bay seashore: Tubli (26°11'46N 50°33'38E), where secondary-treated wastewater outfall is located; Sitra (1) (26° 9'16N 50°36'27E); and Sitra (2) (26°8'52N 50°36'59E) located 1 Km apart and about 7 Km from the wastewater outfall (Fig.2).

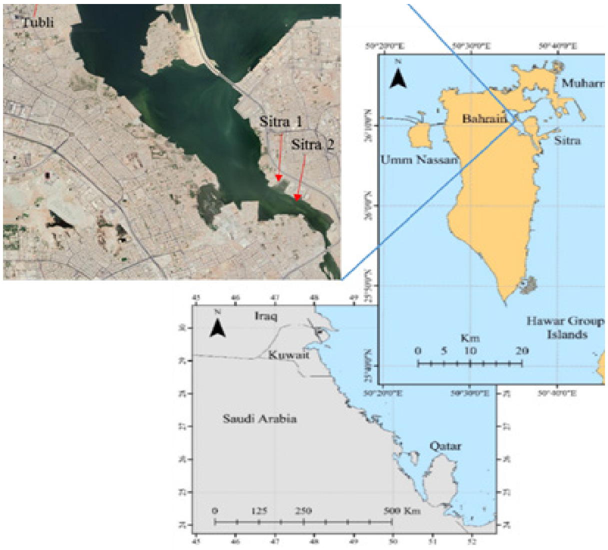


**Figure 2.** *Location of the study sites.*

### 2.1. Plant sampling

Six randomly selected branchlets were taken from each study site, washed with distilled water, and oven-dried at 60°C till constant weight is obtained. The Kjeldahl and the dry-ash methods were used to determine N and extractable P, respectively (Ryan, et al., 2001). The level of K, Ca, Mg, and Na was determined in the filtrates of digested samples according to EPA 3050B using inductively coupled plasma optical emission spectroscopy (ICP-OES Optima 8000).

### 2.2. Soil sampling

A soil core was taken at three depths (0-5, 5-15, and 15-30cm) in six replications from each study site. Samples were air-dried, homogenized, and passed through a 2mm sieve. Soil texture was assessed using the hydrometer method and identified according to the USDA textural triangle (Estefan, et al., 2013). Electrical conductivity (EC) and pH of soil samples were measured using 1:1 (soil: water) extract (Estefan, et al., 2013). The samples' total nitrogen was determined using the Kjeldahl method (Ryan, et al., 2001). Extractable P was determined in air-dried soil samples using the modified sodium bicarbonate procedure (Kovar and Pierzynski, 2009). The absorbance of the sample solution was read on a spectrophotometer at 882nm wavelength. The concentration of K, Ca, Mg, and Na was determined, according to Krishna et al. (2012), using ICP-OES. Soil organic matter (SOM) was estimated using the mass loss method by placing samples in a muffle furnace at 440°C overnight (Estefan, et al., 2013). Sampling and measurements were made in the winter of 2018. The analyses were carried out in the Sultan Qaboos soil and water Laboratory of Arabian Gulf University.

### 3. Statistical Analysis

One and two-way ANOVA were applied as appropriate in this study. Differences in measured parameters among sites were assessed at a 5% level of significance using the Student t-test. Pearson's correlation between factors was conducted. The JMP 10 Software (SAS) package (JMP®) was used for statistical analysis.

## Results and Discussion

### 1. Soil physical attributes

The result of soil texture analysis showed that sandy loam, loam to clay loam, and sandy clay loam to sandy loam prevail in the Tubli, Sitra (1), and Sitra (2) sites, respectively. Soil texture of the Tubli site was mainly comprised of sand particles (70±5%) compared to Sitra (1) and Sitra (2), where sand particles constituted 34±2% and 51±4%, respectively (Fig. 3). Meanwhile, soil texture at 0-30 cm depth in Sitra (1) was composed of silt particles that comprised 42±1% of soil due to silt deposits of the effluents discharged from a nearby sand-washing plant. The soil bulk density (BD) increased with the depth of soil in the study sites. It averaged 1.37 g $cm^{-3}$, 1.45 g $cm^{-3}$, and1.09 g $cm^{-3}$ in Tubli, Sitra (1), and Sitra (2) sites, respectively. The values of BD found in this study are in line with Ukpong's (1998) findings in Nigeria and Saha and Choudhury's (1995) in Indian mangroves. Hossain and Nuruddin (2016) reported conflicting results of various studies in different regions of the World on the structure of mangrove soils. Nevertheless, they stated that the clay loam soil texture prevails among all mangrove soils. Local factors like geographical setting and anthropological pollution can play an essential role in altering mangrove soil composition.

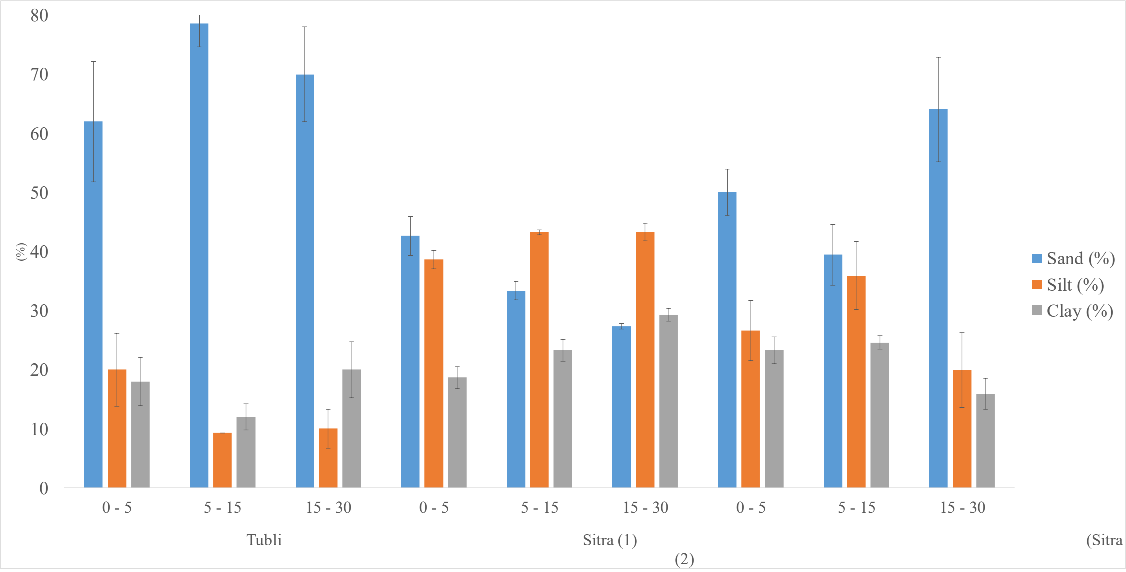


**Figure 3.** *Soil texture at the study sites.*

Our results revealed that spatial variations in EC existed among sites (Table 1). The average soil EC was significantly higher in Sitra (1) and Sitra (2) than the Tubli site. However, no differences in EC existed between the first two sites. The lower EC in the Tubli site can be attributed to the dilution effect caused by the discharged low EC wastewater (2.4– 4.5dS $m^{-1}$), whereas the dilution effect was diminished at the other two sites with no significant effects. The EC values decreased with the depth of soil profile at the Tubli site. However, mixed results were obtained for the other two sites where no clear EC trend was observed.

Significant differences in pH were observed between Sitra (2) and the other two sites. The optimum pH for *Avicennia marina* is reported to be 7.5 (Joshi and Ghose, 2003). In our study, the average pH was 7.97, 7.93, and 7.46 at the Tubli, Sitra (1), and Sitra (2) sites, respectively. Similar pH values in mangrove soil were reported by Naidoo (2006) in South Africa and Cerón-Bretón, et al. (2011)total nitrogen content and several important physicochemical parameters (electrical conductivity, gravimetric moisture, salinity, pH and soil texture in Mexico. Our study's differences in pH values could not be attributed to the discharge of wastewater into the Bay.

**Table 1.** *Average and standard error (n=6) of EC and pH in the gray mangrove soil*.*

| Stand | Depth (cm) | EC ( dS m-1) | pH |
|---|---|---|---|
| Tubli | 0-5 | 14.77 ± 2.87 def | 8.00 ± 0.03 ab |
| | 5-15 | 12.03 ± 2.79 ef | 7.95 ± 0.02 abc |
| | 15-30 | 10.03 ± 2.87 f | 7.97 ± 0.03 abc |
| Average | | 12.3 ± 1.6 b | 7.97 ± 0.02 a |
| Sitra (1) | 0-5 | 16.77 ± 2.29 cdef | 8.02 ± 0.03 ab |
| | 5-15 | 12.20 ± 1.88 ef | 7.73 ± 0.24 cd |
| | 15-30 | 13.60 ± 1.19 def | 8.04 ± 0.02 ab |
| Average | | 14.2 ± 1.1 ab | 7.93 ± 0.09 a |

| | | | |
|---|---|---|---|
| | 0-5 | 17.40 ± 2.06 bcdef | 7.47 ± 0.02 de |
| Sitra (2) | 5-15 | 20.47 ± 1.88 abcd | 7.46 ± 0.03 e |
| | 15-30 | 13.57 ± 1.63 def | 7.44 ± 0.02 e |
| Average | | 17.1 ± 1.4 a | 7.46 ± 0.01 b |

*Levels not connected by the same letter are significantly different ($P \leq 0.05$)

## 2. Plant Analysis

Our results revealed that the leaf nutrients' concentration at the study sites followed the order of Na> K> N> Mg> Ca> P (Table 2). Na and K were the dominant ions in the mangrove leaves, which is typical for halophytes. No significant differences existed in the measured variables except N and Na, between the Tubli site mangroves and the other two sites. The N% in mangroves' leaves at the Tubli site was significantly higher by 29% and 25% than the Sitra (1) and Sitra (2) sites. The result is in line with Naidoo (2006) findings for dwarf mangroves in South Africa. Nevertheless, the total N and P levels in our case are far less than the reported values in New Zealand for the same species (Tran, et al., 2017). High N% in mangroves' leaves at the Tubli site could be attributed to a high N load of wastewater, high N of the soil (Table 2), and wastewater low EC. The high level of nitrogen was reflected in the superior height and diameter growth of mangrove trees at the Tubli site (Abou Seedo, et al., 2017). Nevertheless, the ratio N: P in mangrove leaves in the study sites averaged 12.8, which is lower than the global (N: P >32) (Lovelock et al., 2007) and regional averages (Almahasheer, et al., 2018) for the species. The low value of N: P in mangrove leaves of the Tubli Bay indicates nutrient deficiency despite the anthropogenic nutrient enrichment. Nevertheless, the leaves of mangroves in the Tubli site had a higher ratio of N: P (14.7) compared to 11.6 and 11.7 in Sitra (1) and Sitra (2) sites, respectively, which indicates better growth performance and nutrient enrichment of the site by the wastewater discharge.

The level of Na was significantly higher in the leaves of mangrove trees in Sitra (2) than the Tubli and Sitra (1) sites. Our result agrees with Nyomora and Njau (2012) findings on similar species in Tanzania. The Na high concentration in leaves of mangroves at Sitra (2) may be attributed to the high EC (17.1dS $m^{-1}$) of seawater at the site. In this respect, Naidoo (2006) reported a higher concentration of Na, K, Ca, and Mg for dwarf *A. marina* in South Africa. The Ca and Mg concentrations found in this study agree with Tachbibi, et al. (2013) results on the same species in southern Morocco.

**Table 2.** *Average concentrations (%) and standard error (n=6) of nutrients in the gray mangrove leaves*.*

| Stand | N | P | K | Ca | Mg | Na |
|---|---|---|---|---|---|---|
| Tubli | 2.8 ± 0.18 a | 0.19 ± 0.01 a | 3.8 ± 0.23 a | 1.1 ± 0.06 a | 0.9 ± 0.06 a | 6.4 ± 0.51 b |
| Sitra (1) | 1.98 ± 0.12 b | 0.17 ± 0.01 a | 3.0 ± 0.48 a | 1.0 ± 0.16 a | 1.2 ± 0.14 a | 6.3 ± 0.34 b |
| Sitra (2) | 2.1 ± 0.30 b | 0.18 ± 0.02 a | 2.6 ± 0.09 a | 1.2 ± 0.09 a | 1.4 ± 0.30 a | 8.2 ± 0.72 a |
| Average | 2.31 ± 0.15 | 0.18 ± 0.01 | 3.13 ± 0.25 | 1.1 ± 0.02 | 1.15 ± 0.12 | 7.00 ± 0.36 |

*Levels not connected by the same letter are significantly different ($P \leq 0.05$).

## 3. Soil Analysis

The result indicated that studied nutrients were mainly concentrated in the soil layers in the following order: Ca > Mg > Na > K > N > P (Table 3). The soil's average mineral concentration was 1260.4mg $L^{-1}$ for N, 7.5mg $L^{-1}$ for P, 3414mg $L^{-1}$ for K, 262175mg $L^{-1}$ for Ca, 34631mg $L^{-1}$ for Mg, and 11833mg $L^{-1}$ for Na. These concentrations were in the ranges found for mangrove soils (Alongi, et al., 2003; Kumar et al., 2011; Cerón-Bretón, et al., 2011). Levels of N and P showed a decreasing pattern with soil depth. On the other hand, the Ca level increased with soil depth in all of the sites. No clear trend was observed with soil depth for K, Mg, and Na.

**Table 3.** *Average concentrations (mg L-1) and standard error (n=6) of nutrients and organic matter (%) in the soil of the gray mangrove*.*

| Site | Depth | N | P | K | Ca | Mg | Na |
|---|---|---|---|---|---|---|---|
| Tubli | 0-5 | 2217 ± 79 a | 19.0 ± 2.6 a | 3694 ± 13 a | 172681 ± 14 d | 15617 ± 36 de | 12417 ± 17 abc |
| | 5-15 | 1813 ± 99 ab | 10.5 ± 2.1 b | 4095 ± 88 a | 175165 ± 18 d | 12929 ± 32 e | 9363 ± 64 bc |
| | 15-30 | 847 ± 59 ab | 8.3 ± 1.6 bcd | 4163 ± 11 a | 198358 ± 31 cd | 14889 ± 23 de | 7997 ± 87 c |
| Sitra (1) | 0-5 | 1615 ± 45 ab | 9.4 ± 2.1 bc | 4676 ± 25 a | 255794 ± 30 bc | 58564 ± 62 a | 13821 ± 15 ab |
| | 5-15 | 1208 ± 47 ab | 5.7 ± 0.8 cde | 4389 ± 63 a | 266004 ± 35 bc | 53744 ± 57 ab | 12090 ± 17 abc |
| | 15-30 | 458 ± 96 b | 2.5 ± 1.2 ef | 3186 ± 43 ab | 295500 ± 47 b | 41782 ± 68 bc | 12689 ± 15 ab |
| Sitra (2) | 0-5 | 1717 ± 46 ab | 7.4 ± 1.2 bcd | 3137 ± 18 ab | 280308 ± 90 bc | 42073 ± 59 bc | 12931 ± 21 ab |
| | 5-15 | 861 ± 12 ab | 3.9 ± 0.9 def | 2523 ± 58 ab | 329629 ± 39 ab | 43465 ± 50 abc | 15917 ± 26 a |
| | 15-30 | 608 ± 83 b | 0.7 ± 0.4 f | 864 ± 63 b | 386136± 24 a | 28618 ± 73 cd | 9270 ± 92 bc |

*Levels not connected by the same letter are significantly different ($P \leq 0.05$).

Significant differences were observed in N and P levels in the layers from 0–30cm between the Tubli site and the other two sites. The increase in N and P in the affected site's soil layers compared to the other two sites can be attributed to these two nutrients' site enrichments from the discharged wastewater. No significant differences in K levels were found between the sites, while the levels of Ca and Mg were significantly higher in Sitra (1) and Sitra (2) as compared to Tubli. The low level of the last two nutrients in the Tubli site can be attributed to soil texture, where sand particles prevail in all depths of soil layers (Fig.3). The low level of Na in the Tubli soil could be attributed to the effluent discharge's dilution effect. The lower concentration of P and higher Ca, Mg, and Na levels in our study follow Naidoo's findings (2006) in mangroves grown in salty sites.

In our results, although the soil had high concentrations of nutrients, they were not readily available to mangrove trees as no significant correlations were detected between the levels of any studied variables in mangroves' leaves and their levels in the underlying soil. This result contradicts Gritcan et al. (2016), who indicated that N and P levels in mangrove leaves could be used as an indicator for available nutrients in the mangrove ecosystems. The high N and P levels in Tubli site soil may have detrimental effects on mangrove growth and survival in the long run. In this context, Lovelock, et al. (2009) reported that nutrient enrichment of mangroves ecosystems in arid environments might increase the species' mortality and reduce mangrove resiliency.

The SOM level in the study sites ranged between 0.35 and 13% (Fig. 4). The found values are within the reported ranges in different mangrove ecosystems in regions of its distributions (Bouillon, et al., 2003; Sebastian and Chacko, 2006). Besides, the decrease in SOM with depth agreed with other scholars (Sitoe, et al., 2014; Eid and Shaltout, 2016). There were significant differences in the percentage of SOM between the Tubli site and the other two sites.



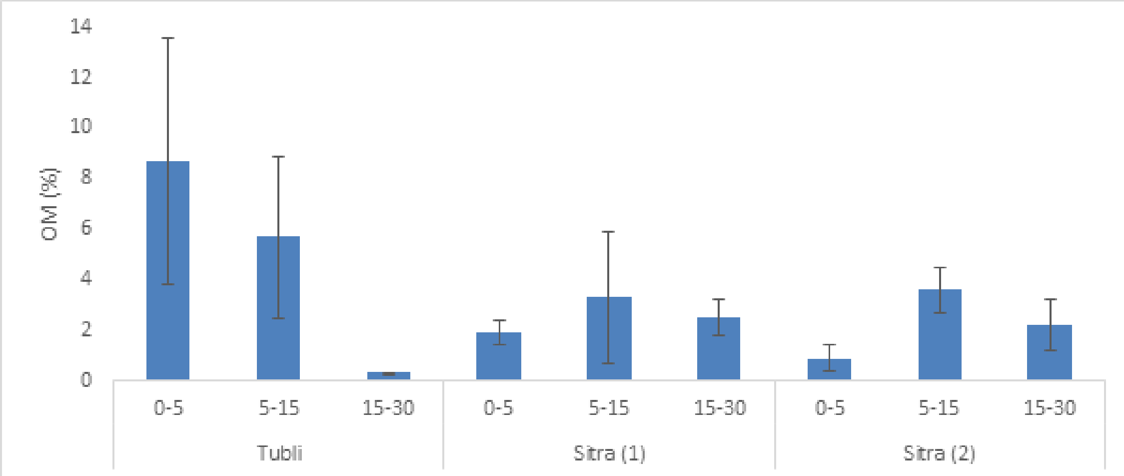


**Figure 4.** *Soil organic content of the study sites.*

The differences in SOM concentration of the mangrove soil can be attributed to interfering factors like salinity, tides, mangrove litterfall (Bouillon, et al., 2003; Chen et al., 2012), tidal flux from the adjacent coastal environments (Allison, et al., 2003; Gardner and Kjerfve, 2006), and benthic algae (Sebastian and Chacko, 2006; Yong et al., 2011). In our study, the high level of SOM in the Tubli site can be attributed to the high content of the total dissolved and suspended solids carried out by the discharged wastewater, which eventually formed a sludge area of substantial depth in the mouth of the Bay.

## Conclusion

Our results suggest that wastewater discharge has a significant effect on mangroves' N absorption, as its level in the leaves was higher at the Tubli site where heavy loads of wastewater are discharged. Moreover, the Na concentration in the Tubli site's leaves was lower than the Sitra (2) site, which is 7 Km away from the wastewater outfall. Nitrogen and phosphorus levels in the surface soil of the Tubli site were higher compared to the other two sites due to wastewater discharge. Wastewater increased SOM in the topsoil of the affected site and lowered the soil's EC while increasing the pH at the affected site. We conclude that in the long run, the release of the secondary effluent into the Tubli Bay may alter the integrity of the Bay ecosystem in general and mangrove stands in particular. Nevertheless, more studies are needed to reveal the exact impact of treated wastewater dumping on mangrove ecosystems and mangrove tolerance levels to effluent discharge. It is recommended that the plant efficiency of treating wastewater be increased, and mangrove ecosystems' conservation in the Bay is prioritized.

### Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this work.


### Acknowledgments

This study was conducted within the research plan framework in the Department of Natural Resources and Environment, Arabian Gulf University.

## Data Availability

Data is available upon request from the corresponding author.

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# تأثير تصريف مياه الصرف الصحي البلدية المعالجة ثانوياً على تركيزات المغذيات في أوراق وتربة المنغروف الرمادي في البحرين

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## المُستَخلَص

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قد يؤثر تصريف المياه العادمة في البيئة البحرية على سلامة النظام البيئي للمنغروف. في هذا السياق ، تم تقييم التأثير المحتمل لتصريف مياه الصرف الصحي البلدية المعالجة ثانوياً على تركيزات المغذيات في أوراق وتربة أشجار المنغروف الرمادي (Avicennia marina (Forsk.) Vierh.) في ثلاثة مواقع من خليج توبلي. قيست الخصائص الفيزيائية لتربة المنغروف ونسب محتواها من المادة العضوية. كما تم قياس تركيز النيتروجين فيها باستخدام طريقة كيلدال. وقدرت كمية الفسفور المستخلص بطريقة الترميد الجاف. تم قياس تركيزات كل من K و Ca و Mg و Na في النبات والتربة باستخدام جهاز بلازما الحث المزدوج. قدرت المادة العضوية في التربة باستخدام طريقة الترميد الجاف. أظهرت النتائج عدم وجود فروق معنوية في تركيز المغذيات في أوراق المنغروف بين المواقع فيما يتعلق بجميع المتغيرات المقاسة باستثناء N و Na. أثَّرت مياه الصرف بشكل معنوي في محتوى أوراق المنغروف من النيتروجين في موقع توبلي، حيث يصب جل مياه الصرف. يتبع تركيز مغذيات الأوراق الترتيب: Na> K> N> Mg> Ca> P. وتركزت العناصر الغذائية في طبقات التربة السطحية بالترتيب التالي: Ca> Mg> Na> K> N> P. أظهر مستوى المغذيات تناقصًا مع عمق التربة ، باستثناء Ca. لوحظت فروق ذات دلالة إحصائية في مستويات N و P في طبقات التربة بين الموقع المتأثر بالمصب والموقعين الأُخريين. علاوة على ذلك ، أشار تحليل التربة إلى وجود فروق معنوية في مستويات النيتروجين والفوسفور في تربة موقع توبلي مقارنة بالموقعين الآخرين بسبب تصريف المياه العادمة. لم يتم العثور على ارتباطات ذات دلالة إحصائية بين مستويات المغذيات في أوراق المنغروف وتربته. بالإضافة إلى ذلك ، أدى إطلاق المياه العادمة في الخليج إلى زيادة كبيرة في محتوى التربة من المواد العضوية في الموقع المتأثر. تشير نتائج الدراسة إلى أن استمرار تصريف المياه العادمة المعالجة ثانوياً في خليج توبلي قد يغير من الخصائص الفيزيائية والكيميائية للنظام البيئي للخليج بشكل عام ويهدد بقاء المنغروف بشكل خاص.

**الكلمات الدالة:** Avicennia marina ، البحرين ، نيتروجين ، تربة ، خليج توبلي.