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Assessment of Heavy Metal Contamination and Water Quality in the Kitchener Drain: Implications for Agricultural Irrigation and Environmental Health in the Middle Nile Delta

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Abstract

Examining Heavy Metal and Water Quality in Kitchener Drain: Impacts on Agriculture and Environment in Middle Nile Delta. The drain, a conduit for agricultural drainage to the Mediterranean, carries a mix of pollutants, with 75% from agriculture, 23% domestic, and 2% industrial sources. Local communities rely on this water for irrigation, emphasizing the need to assess heavy metal content, specifically Cd, Pb, and Hg. Analyses at nine sites along the drain revealed Pb>Cd>Hg in water. Cd levels averaged 0.002 mg/l, peaking at 0.003 mg/l at site No. 4, attributed to pesticide use. Pb reached 0.02 mg/l at site No. 4 in September 2020, potentially from various pollution sources. Hg peaked at 0.003 mg/l in site No. 5. Sites No. 4 and 5, receiving drainage from El-Gharbia and Kafr El-Sheikh, showed higher metal concentrations due to industrial and sewage discharges. Kitchener drain, contaminated with salts, pesticides, heavy metals, and solid waste, exhibits self-cleaning potential with observed dissolved oxygen and pH levels. Electrical conductivity within normal range, except at sites No. 4 and 5, indicated industrial influence. Chemical oxygen demand (COD), biological oxygen demand (BOD), and nitrate concentration exceeded Egyptian law limits, highlighting environmental concerns.

Keywords: Heavy Metal, Water Quality, Kitchener Drain, Agricultural Pollution, Middle Nile Delta

Introduction:

The Nile Delta of Egypt is one of the earliest deltaic systems in the **world (El Banna MM *et al*., 2009)**. It was formed by sedimentary processes between the upper Miocene and the present period and built up by the alluvium brought by the old former seven active branches of the Nile.

The Nile Delta, approximately 22,000 km^2 in area, is among the largest deltas in the world and it has been intensively farmed for at least 5000 yr. With approximately 2% of total Egypt's area, the Nile Delta hosts more than 50% of the population in Egypt representing one of the tops densely populated areas on Earth **(Hegazy *et al*., 2020).**

Kitchener drain streams from south into north direction reaching the Mediterranean Sea and releases about 1.9 billion cubic meter per year. According to **(Abdel Rashid, 2002)** the water is mixture of 75% agricultural drainage water, 23% domestic water, and 2% industrial water, respectively. It receives pollutants from various effluents discharged from industries and domestic sewage. The aquatic environment is considered the major source controlling the state of health and disease. This drain was constructed to discharge agricultural drainage water (1.9 BCM/ yr.) from some of the delta lowlands to the Mediterranean Sea. In addition to, the lack of farmer's awareness about the use of low-quality water for irrigation has led to hygiene problems for farmers and farm animals as result of pollutants and parasites **(Taha *et al*., 2012)**. While reusing the drainage water without suitable treatment may cause adverse effects on soil, crops, animal, and human health **(El-Bady, 2014)**.

Several sewage discharges of untreated water from Governorates of El-Gharbia and Kafr El-Sheikh as well as other cities and towns along the drain are problematic. Law No 4/1994 addresses the protection of the Nile and related fresh waterways from pollution. It prohibits to dispose any industrial wastes, insecticides, and other poisonous and radioactive materials in the Egyptian waters **(El-Gayar, 2003; Abdel-Dayem, 2011).** In the absence of exact treatment plans, the reuse of drainage water will create serious bad effects on soil, crops, animal, and human health **(El-Bady, 2014).** One among those serious problems is the accumulation of heavy metals in the soil **(Singh *et al*., 2009)** that are carcinogenic and the health effects include neurological impairment and nerve disorders and disfunctions **(Markus and McBratney, 2001; Nadal *et al*., 2004)**. Having ready access to clean water has always been important. However, the community's water sources were not always clean, and it becomes a reason for death and disease in the world.

In this context, approximately 87 children under the age of five are losing their lives every hour, equating to around 2088 deaths per day due to water-related diseases **(WHO and UNICEF, 2013)**. Conversely, the environment is rich in toxic chemical components such as heavy metals, primarily due to their widespread application. Even at low concentrations, these metals can lead to severe illnesses **(Wenjun Jiang et al., 2013)**. Presently, industrial activities are on the rise in Egypt, posing a significant challenge in managing and treating the effluents produced by these operations. The untreated or partially treated discharge of industrial waste products in Egypt increases the likelihood of heavy metal contamination. Consequently, utilizing river and lake water, which is connected to sources of heavy metal pollutants, for irrigation and drinking purposes can result in serious and irreversible health issues.

To address the issues of heavy metal contamination and problems related to turbidity, it is imperative to develop cost-effective and efficient adsorbent materials that are readily available in large quantities and economically viable.

Materials And Methods

Kitchener drain is one of the largest drainage systems in the Nile Delta which is located in the central part of Middle Nile Delta as shown in (Figure 1). It originates in El-Gharbia governorate north of Tanta City and extends through Kafr El-Sheikh Governorate in the north direction till the Mediterranean Sea at Baltim city. It has a total catchments area of about 472,500 acres **(El-Gammal, 2016)**. As Kitchener drain collects El-Gharbia governorate agricultural, industrial drainage water and sewage wastewater and sewage drainage water of Kafr El-Sheikh city and industrial drainage of spinning factories of Kafr El-Sheikh. So, drainage water is therefore contaminated with salts, agricultural chemicals (pesticides and heavy metals) and other pollutants as municipal solid waste from residential area **(Gad and Fadi, 2015)**. Nine sites were taken using GPS for identifying latitude and longitude with description of site (Table 1).

Table 1: *sites of samples collection along Kitchener drain*

Governorate	City	No. of Sites	
Gharbia	Tanta	T1 T2	*(30°49'33.92"N, 31° 0'49.93"E)* *(30°53'39.96"N, 31° 1'0.40.0"E)*
	Qutur	Q1 Q2	*(30°57'47.07"N,31° 0'1.36"E)* *(31° 1'8.84"N, 30°59'29.49"E)*
Kafr El-Shikh	El-Hamoul	H1 H2	*(31°14'2.40"N,31° 7'27.90"E)* *(31°18'17.75"N, 31° 8'29.09"E)*
	Baltim	B1 B2	*(31°27'28.25"N, 31°10'0.09"E)* *(31°34'41.25"N, 31°10'58.50"E)*
	Kafr El-Shikh	K1	*, (31° 8'4.02"N, 30°57'8.67"E*

Sampling analysis

In the field

Water temperature and Dissolved Oxygen (DO) were measured using the DO meter (Lutron YK-22 DO meter). The pH was measured using the pH-meter (Model Lutron YK-2001, pH meter). EC was determined using the EC-meter (Thermo, Orion 150 A+ advanced conductivity).

Laboratory sample analysis

Wastewater Sample Collection and Preparation

The water sample was obtained from the Kitchener drain two times in September 2020, and March 2021. Washed plastic bottles were used to collect the water sample with 1 litter volume.

The samples were collected in the morning to avoid the crowded and the hot weather and some parameters were determined in the field, such as DO, EC and pH.

Collected water samples were filtered through CF/C glass fiber filters and stored at 4 °C in dark bottles to be used for chemical analyses. Biological oxygen demand (BOD), chemical oxygen demand (COD) and organic matter were determined according to methods of APHA (1998 & 1999). Ammonia (NH_4) and nitrite (NO_2) were determined as described by (Grasshoff *et al*. 1999).

Analysis of heavy metals:

The Monochromator is eliminating scattered light of other wavelengths by a number of lenses and mirrors to focus the radiation and the detector is typically a photomultiplier tube that converts the light signal to an electrical signal proportional to the light intensity.

Statistical Analysis

While optimizing the experimental variables, the mean difference of the response variable at different experimental factors' levels was compared by the independent sample t-test using SPSS version 22.

Results

The results of sample analysis

The results of first sample analysis

In September 2020 and March 2021, two samples of water were collected from the Kitchener sewer, (Table 2, 3) illustrates the results of the first analysis of nine samples.

Parameter	Unit	T1	T2	Q1	Q2	H1	H2	B1	B2	K1
PH	-	7.13	7.60	7.69	7.69	**8.02**	7.25	7.34	7.17	6.89
Temperature	°C	26.00	25.00	25.40	28.22	**28.13**	26.4	25.7	25.5	26.2
EC	ds/m	1.26	1.70	1.92	3.38	3.41	1.32	1.25	1.19	1.22
TDS	ppm	62.0	51.00	54.00	61.12	**63.00**	49.88	50.15	51.30	53.12
DO	mg/l	2.78	2.65	2.7	1.94	2.21	1.45	1.47	3.25	**3.45**
COD	mg/l	198	145	159	220	**234**	176	135	165	148
BOD	mg/l	45	**72**	60	55	45	65	68	58	57
NO_3^-	mg/l	1191.9	1172.2	1073.6	1285.57	**1374.21**	1050.42	1082.35	1213.42	1190.87

Table 2: First Water Sample analysis in the nine locations during September 2020

Parameter	Unit	T1	T2	Q1	Q2	H1	H2	B1	B2	K1
PH	-	7.41	7.35	7.62	7.11	**7.71**	7.25	7.48	6.87	7.05
Temperature	°C	22.0	22.8	**23.1**	19.0	18.2	21.2	20.7	20.3	22.0
EC	ds/m	1.30	1.27	1.33	1.40	**2.85**	1.65	1.52	1.60	1.40
TDS	ppm	41.0	43.0	41.8	**58.0**	48.5	45.3	43.7	40.1	42.6
DO	mg/l	2.55	2.35	**3.01**	1.75	1.96	1.75	2.2	2.47	2.9

COD	mg/l	125	137	146	**154**	142	139	142	118	128
BOD	mg/l	45	48	53	**72**	60	57	52	44	46
NO_3^-	mg/l	931.9	955.4	967.3	1014.2	**1015.6**	981.4	951.7	951.2	941.0

Table 3: Second Water Sample analysis in the nine locations during March 2021

pH Levels:

The average pH in both sample analyses falls within the normal range, suitable for irrigation (7.42 in the first sample and 7.32 in the second sample). Site H1 had the highest pH in the first sample (8.02), indicating alkalinity, while the lowest was in site T1 (7.13). In the second sample analysis, site H1 again had the highest pH (7.71), and the lowest was in site B2 (6.87).

Temperature:

The average water temperature in the first sample analysis was 26.3°C, while in the second sample analysis, it was 21.0°C. Site Q2 recorded the highest temperature in the first sample (28.22°C), and site T2 h Table 3: Second Water Sample analysis in the nine locations during March 2021ad the lowest (25.00°C). In the second sample analysis, site Q1 recorded the highest temperature (23.1°C), and site H1 had the lowest (18.2°C).

Electrical Conductivity (EC):

The average EC in the first sample analysis was 1.85 ds/m, and in the second sample analysis, it was 1.59 ds/m. Site H1 and site Q2 recorded the highest EC in the first sample (3.41 ds/m), exceeding the recommended range for irrigation water. In the second sample analysis, site H1 had the highest EC (2.85 ds/m) within the range, and site T2 had the lowest (1.27 ds/m).

Total Dissolved Solids (TDS):

The average TDS in the first sample was 55.06 mg/l, and in the second sample, it was 44.88 mg/l. Site H1 recorded the highest TDS in the first sample (63.00 mg/l), while site B1 had the lowest (50.15 mg/l). In the second sample, site Q2 recorded the highest TDS (58.00 mg/l), and site K1 had the lowest (40.10 mg/l).

Dissolved Oxygen (DO):

The average DO in the first sample was 2.43 mg/l, and in the second sample, it was 2.33 mg/l. Site K1 had the highest DO in the first sample (3.45 mg/l), and site H2 had the lowest (1.45

mg/l). In the second sample, site Q1 recorded the highest DO (3.01 mg/l), and site Q2 had the lowest (1.75 mg/l).

Chemical Oxygen Demand (COD):

The average COD in the first sample was 175.5 mg/l, and in the second sample, it was 136.7 mg/l. Site H1 had the highest COD in the first sample (234 mg/l), and site B1 had the lowest (135 mg/l). In the second sample, site Q2 recorded the highest COD (154 mg/l), and site T1 had the lowest (125 mg/l).

Biological Oxygen Demand (BOD):

The average BOD in the first sample was 58.3 mg/l, and in the second sample, it was 53 mg/l. Site T2 had the highest BOD in the first sample (72 mg/l), and site H1 had the lowest (45 mg/l).

Nitrate Concentration (NO_3^-):

The average NO3- in the first sample was 1181.6 mg/l, and in the second sample, it was 967.7 mg/l. Site H1 had the highest NO3- in the first sample (1374.21 mg/l), while site H2 had the lowest (1050.42 mg/l). In the second sample, site H1 again had the highest NO3- (1015.6 mg/l), and site T1 had the lowest (931.9 mg/l).

Heavy Metals (Cd, Pb, Mg):

The concentrations of Cd, Pb, and Mg were within acceptable limits according to Egyptian environmental regulations. In the initial sample analysis, the mean concentration of cadmium (Cd) was determined to be 0.0015 mg/L. In the subsequent sample analysis, this concentration increased to 0.003 mg/L. Similarly, the mean concentration of lead (Pb) in the wastewater was found to be 0.004 mg/L in the first sample analysis and decreased to 0.002 mg/L in the second sample analysis. The average concentration of mercury (Hg) in the wastewater was 0.0015 mg/L in the first analysis and 0.0013 mg/L in the second analysis. During the first sample analysis, the highest recorded concentration of Cd occurred at sites Q2 and H1, measuring 0.003 mg/L. In the second sample analysis conducted in March, the site H1 exhibited the highest measured Cd concentration, registering at 0.01 mg/L."

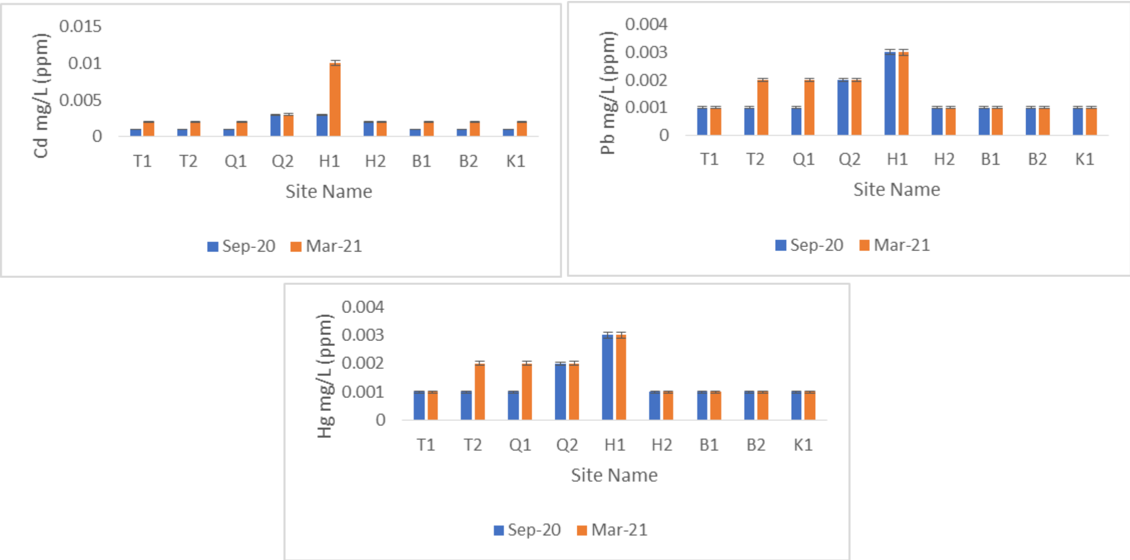

Figure 1: Cd , Pb and Hg along nine locations during the First, and Second water sample analysis

Discussion

Professional resources management combining nutrients and water management is a challenging task. Individual farmers usually do not have the knowledge and competence to address these issues properly by themselves. This study tried to focus on the different pollution sources along the study area to identify the location of the pollutant and proposed the required measure to mitigate and to improve the water quality of the drain water. A preliminary assessment of Kitchener drain water was performed on water samples taken from the drains. Analysis of various chemical parameters including sum parameters, concentrations were performed. Kitchener drain collects agricultural, industrial, and sewage wastewater, contaminating water with salts, agricultural chemicals, and pollutants. Three metals (Cd, Pb, Hg) in total and available form were determined in nine sites along the drain. The order of these metals in water was as follow; Pb > Cd > Hg.

The measurement of pH in water, including water in drains, is significant for several reasons as it provides valuable insights into the chemical characteristics and potential impacts of the water on various ecosystems **(Hou et al, 2013)**. The changes in pH values among the studied sites could be due to the different types of drainage waters and contents of soil organic matter **(Jayalath *et al*., 2016).** Regarding the TDS values, we concluded that the main sources of TDS load are the domestic wastewater and the solid wastes. The high TDS loads may also be attributed to the huge water quantities at the drain.

In general, a DO concentration of 1.75 - 3.45 mg/l, it means that there is a sufficient amount of dissolved oxygen for growth and metabolism **(Martínez et al., 1998)**.

COD level is a little bit higher at beginning and the end of the drain, because of the inflow of pure water. Regarding the load values, we concluded that sites Q2 and H1 are the most critical because they have the highest COD loads when compared to the K1. The main sources of COD load are domestic wastewater and solid wastes. In the second sample analysis in March the highest measured BOD was in site Q2, and it was recorded at 72 mg/l, while the lowest measured in second sample analysis was 44 mg/l in site B2.

BOD load on the drain was calculated and it is concluded that the highest concentration was recorded in the T2 and Q2. The highest values of BOD were recorded during first sample analysis November 2020 (72 mg/l), while the lowest values (44 mg/l) were recorded during second sample analysis March 2021. Maximum value of BOD was observed during November 2020 and this may due to higher rate of decomposition of organic matter at higher temperature and less water current **(Sanap *et al*., 2006).**

There are numerous mineral matters, water, air, organic matter and living organisms in soil. So heavy metals contamination in agricultural soil is a potential environmental threat **(Chopra *et al*., 2009; Simon *et al*., 2016).** Cadmium is an element that occurs naturally at low levels in the environment.

Atomic absorption spectrometry AAS is a quantitative method of metal analysis suitable for the determination of approximately 70 elements **(García & Báez, 2012).** This method measures the concentration of the element by passing light in specific wavelength emitted by a radiation source of a particular element through cloud of atoms from a sample. Concentrations of heavy metals generally fall within acceptable limits, as per Egyptian environmental regulations. However, the presence of lead in site Q2 in both sample analyses raises questions about potential sources and requires further investigation. Lead is the most immobile element and its content in soil is closely associated with clay minerals **(Yaylali-Abanuz, 2011).**

The range of Cd in studied locations was (0.002 mg/l), while the highest value was (0.003 mg/l) in site No. 4 in both sample analysis times November 2020, and March 2021. This could be attributed to using of pesticides in agriculture **(Flaherty et al., 2013)**. The highest value of Pb was recorded at site No. 4 in first sample analysis November 2020, and it was recorded (0.02 mg/l), may attributed to incorporation of Pb to agricultural soil through various types of pollutions (**Maslennikov et al., 2018).**

The highest measured Hg in first sample analysis was in sites H1, and it was recorded (0.003 mg/l). The higher concentration of heavy metals was measured in the sites Q2 and H1 which Kitchener drain collects El-Gharbia governorate agricultural, industrial drainage water and sewage wastewater and sewage drainage water of Kafr El-Sheikh city and industrial drainage of spinning factories of Kafr El-Sheikh. So, drainage water is therefore contaminated with salts, agricultural chemicals (pesticides and heavy metals) and other pollutants as municipal solid waste from residential area.

All mean concentrations of heavy metals were in the limits of Environmental law No. 4 for year 1994, and the law No. 48 for year 1982. It prohibits the discharge into the Nile River, irrigation canals, drains, lakes, and groundwater without a license issued by the Ministry of Water Resources and Irrigation **(Freestone, 1994).**

All mean concentrations of available metals were within the acceptable limits. This could be related to untreated wastewater which used in irrigation and attributed to the phosphate and superphosphate which be used in agricultural activities as fertilizers **(Abd El-Fattah, 2015 and El-Amier et al., 2017)**.

Conclusion:

The pollution load calculations associated with the estimated domestic wastewater flow that is discharged to the Kitchener Drain were based on the respective daily maximum per capita generation per pollutant, and the assumption that all wastewater quantities corresponding to unserved or under construction areas are discharged to the drain as untreated wastewater. Further, the wastewater treatment plant condition assessment surveys revealed that most of the existing wastewater treatment plants in the examined area are either using the emergency by-pass and discharge untreated wastewater, or they are lacking treatment capacity, or they require rehabilitation to operate in high efficiency, which led to the assumption that existing Wastewater Treatment Plants are currently operating in 50% efficiency.

In conclusion, the water quality in the drain is suitable for irrigation purposes, but certain sites show variations that need attention. a comprehensive and continuous water management strategy is necessary to address the identified issues and ensure the long-term sustainability of water resources in the examined drain.

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