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Comprehensive Water Quality Assessment of the Kitchener Drain Using Standard Indices

Youmna Gamal[1], Hoda K. Soussa[1], Eman Abo El-Rakha[2], Reda M. El- Shahat[2], Shaimaa Fathy[1]

[1] *Faculty of Engineering, Ain Shams University, Egypt*

[2] *Agricultural Microbial Department, Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt.*

Abstract

Water scarcity and increasing wastewater discharge into surface water bodies have intensified the need for evaluating drainage water quality for reuse. This study assesses the irrigation suitability of Kitchener Drain in Egypt's northern Nile Delta through physicochemical analyses and trace metal quantification across three locations. Parameters including ammonia, phosphorus, and chromium were found to exceed both national (Law 48/1982) and international (FAO 1985) standards, while Water Quality Index (WQI) values classified the water as very poor. The Permeability Index indicated moderate soil compatibility, while the Metal Quality Index signaled cumulative trace metal risks, particularly from chromium. These findings suggest that without remediation, continued use of this water in agriculture may threaten soil health and food safety. Immediate attention to treatment strategies is necessary to mitigate ecological and public health risks.

Key words

Kitchener drain

Water Quality Assessment

Water Quality Index

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I. Introduction

In the coming decades, more than a quarter of the global populationand nearly one-third in developing countriesis projected to live in regions experiencing severe water scarcity [1].Water is essential for sustaining life and ecological balance, making pollution prevention critical for both human well-being and environmental health. Investigating the physicochemical characteristics and heavy metal concentrations in water is key to identifying contamination sources, guiding remediation efforts, and shaping effective policies. In recent decades, significant attention has been given to assessing water quality through various indices [2,3,4]. Egypt's water sector faces a combination of longstanding and emerging challenges. While water availability remains fixed, population growth continues to rise, intensifying demand. Geopolitical tensions with Nile Basin countries and the 2011 independence of South Sudan have added complexity to regional water negotiations. Additionally, the unpredictable effects of climate change pose long-term threats to water security. Compounding these issues, widespread pollution from industrial discharge, agricultural runoff, and domestic wastewater endangers public health and undermines the sustainability of Egypt's water resources [5].The Nile Delta relies heavily on its drainage network for irrigation, yet many drains are burdened with untreated domestic, industrial, and agricultural wastewater. Kitchener Drain, one of the largest in the region, is recognized as a major hotspot for severe environmental pollution, accordingly many researchers have assessed the water quality of Kitchener Drain for irrigation use. In 2017 El-Alfy, M. A. et al. found that Kitchener Drain irrigation has led to elevated heavy metal levels in agricultural soils, with most metal concentrations exceeding international safety standards. Risk assessments showed significant non-carcinogenic and carcinogenic health risks for local populations [6]. In 2023 Metwally, A. A. et al. conducted a seasonal study of Kitchener Drain and found elevated levels of heavy metals in water and fish, especially during summer, health risk assessments indicated that consuming these fish may pose potential health hazards due to metal exposure [7].In 2021 Abosena, A. et al. carried out aseasonal study of El-Gharbia Drain that revealed while water met chemical standards for irrigation, biological contamination and high cadmium enrichment in sediments pose serious risks. Metal sources were traced to both natural and human activities, highlighting the need for treatment before reuse [8].In 2023 Ameen, M. M. et al examined the spatial variation of physicochemical parameters and heavy metal contamination in the Kitchener and New Damietta drains in Egypt's Nile Delta, both of which are heavily polluted by industrial, municipal, and agricultural waste. Analysis of water and sediment samples revealed elevated concentrations of heavy metals which exceeded limits, with Kitchener Drain showing higher values. The average water quality index (AWQI) confirmed very low water quality, and sediment hazard indices reflected significant environmental risk. These findings highlight the urgent need for remediation efforts and improved management of contaminated water and sediment in both drainage systems [9].In 2019 Aitta, A. et al made a study near Kitchener Drain assessed seasonal and spatial variation of trace elements (TEs) in soil, water, and plant tissues, results showed higher TE concentrations in soils and plants while water samples showed lower levels due to sediment bonding. Risk assessments indicated ecological threats from anthropogenic sources, urging further monitoring and pollution control in region [10]. In 2021 Abd-Elfattah, E. A. et al. carried out a recent assessment of Kitchener Drain showing excessive contamination across most sampling sites, surpassing international irrigation standards. These findings highlight serious ecological risks and make the water unsuitable for agricultural or domestic use [11].

This study aimed to assess the water quality of the Kitchener Drain in the Nile Delta, Egypt. Key physicochemical parameters and concentrations of selected elements were measured to evaluate the extent of contamination. The results were compared against both national and international water quality standards, water quality index was assessed to determine the suitability of the drain's water for irrigation reuse and environmental safety.

II. Materials and methods

2.1. Study location

The study was conducted in the Kitchener Drain within Kafr El-Sheikh governorate, located in the northern Nile Delta of Egypt. Originating in Gharbia governorate, the drain flows northward through Kafr El-Sheikh, which is bordered by Dakahlia to the east, El-Beheira to the west, and Gharbia to the south. Located approximately 10 km east of the UNESCO-listed Lake Burullus, the Kitchener Drain ranks among the largest drainage channels in the Nile Delta, stretching 47 km through Kafr El-Sheikh governorate with a width ranging from 40 to 53 meters and a depth between 5 and 6 meters.It crosses roughly 196,980 hectares (469,000 feddans) of agricultural land in a low-lying coastal region. The drain's flow ranges from 20 to 80 m^3/s, and twelve pumping stations discharge over 46 million m^3 [12].

2.2. Data Collection

A field visit to Kitchener Drain was conducted in April 2024, to collect water samples for analysis. Three locations along the Kitchener Drain were visited as shown in Table 1.

Table 1: The coordinates of the three locations visited along Kitchener Drain.

Location	Northing	Easting
Kafr Dakhamis	31°08'33.6"	31°03'14.9"
Al Karakat	31°12'07.1"	31°07'22.7"
El Hamoul	31°18'34.4"	31°08'33.8"

And it was found that farmers rely on the drain water for irrigation, as numerous pumps were installed along the drain to draw water directly for field use without prior treatment.As reported by Abosena, A. et al [8]due to high costs and limited availability of irrigation water, farmers had no choice but to rely on drainage water from the Kitchener drain for agricultural use, despite their unwillingness.

Figure1: Kitchener Drain (The three locations)

2.3. Water Quality Guidelines

Following the analysis of water samples from the three locations, the results were assessed against irrigation water quality standards specified by Egyptian regulations (Law 48/1982), along with international guidelines set by the FAO (1985) [13,14,15].

2.4. Water Quality Index:

The Water Quality Index (WQI) is a composite indicator that translates multiple water quality variables into a single score reflecting overall suitability for use. In this study, the weighted arithmetic index approach was applied. This method, first introduced by Brown et al. (1972) [16], is widely used because it incorporates both the relative importance of each parameter and the degree to which measured concentrations deviate from recommended standards.

The general expression for WQI is shown in Equation 1:

$$WQI = \frac{\Sigma_{i=1}^{n} Q_i W_i}{\Sigma_{i=1}^{n} W_i} \quad (1)$$

Where:

Q_i = quality rating of the i[th] parameter, W_i = unit weight of the i[th] parameter, n = total number of parameters considered.

Calculation of $Q_i$value

$$Q_i = \frac{(V_i - V_o)}{(S_i - V_o)} x\ 100$$

Where: V_i is the observed value of parameter i, S_i is the standard permissible value by water quality guidelines, V_o is the ideal concentration in pure water (taken as zero for most parameters, except for pH= 7 and DO= 14.6 mg/L).

Calculation of unit weight (W_i) value

The relative weight for each parameter is calculated inversely to its guideline value:

$W_i = \frac{K}{S_i}$, Where, $K = \frac{1}{\Sigma_{i=1}^{n} \frac{1}{S_i}}$

This ensures that the parameters with more restrictive standards carry greater weight in the index.

Classification of Water Quality

The computed WQI values are interpreted using the following categories shown in Table 2.

Table 2: Water quality rating as per weight arithmetic water quality index method.

WQI value	Classification
0 – 25	Excellent
26 – 50	Good
51 – 75	Poor

76 – 100	Very Poor
>100	Unsuitable

2.5. Permeability Index

The Permeability Index (PMI) was employed to assess the influence of irrigation water on soil permeability and long-term suitability for agriculture. This index integrates the relative concentrations of sodium, calcium, magnesium, and bicarbonate ions, as these are the dominant species affecting infiltration and soil structure. The PMI was computed using Doneen's equation [17] (Equation 2).

$$\text{PMI} = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Na^{+} + Ca^{2+} + Mg^{2+}} \; x\; 100 \qquad (2)$$

where all ionic concentrations are expressed in milliequivalents per liter. Following Doneen's classification, irrigation water is categorized as suitable when PMI > 75%, moderately suitable between 25–75%, and unsuitable when PMI < 25%. This index provides an important measure of compatibility between irrigation water chemistry and soil conditions, helping to identify potential risks of reduced permeability that could limit crop productivity.

2.6. Metal Quality Index

To determine the metal contamination of Kitchener drain, there are two different indices are used: ***Pollution index (PI)***was employed to evaluate the effect of individual metals on water quality, by comparing the measured concentration of each element with its permissible limit. It's calculated using Equation 3 that was introduced by Caeiro et al. (2005) [18].

$$\text{PI} = \frac{C_i}{(MAC)_i} (3)$$

C_i: the measured concentration of each element, MAC: maximum allowable concentration
Categories of water pollution index are shown in Table 3.

Table 3: Water pollution index rating

PI value	Class
<1	No effect
1-2	Slightly affected
2-3	Moderately affected
3-5	Strongly affected
>5	Seriously affected

Metal Quality Index (MI)was applied to assess the cumulative effect of heavy metals on irrigation water quality. Unlike the Pollution Index, which evaluates each element separately, the MI provides an overall measure of the combined impact of all metals present. The index is calculated as the sum of the ratios between the observed concentration of each element (C_i) and its corresponding maximum allowable concentration (MAC_i)using the equation that was described by Tamasi & Cini (2004) [19] shown in Equation 4.

$$\text{MI} = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i} \qquad (4)$$

where n is the number of metals considered. A value of MI ≤ 1 indicates that the water is within safe limits, while MI > 1 signals a threshold of warning, meaning that the collective metal load poses potential risks for long-term irrigation use.

III. Results and Discussion

The chemical analyses of the three water samples of Kitchener drain are shown in Table 4. The water samples indicate that several parameters exceeded the recommended irrigation standards. pH and electrical conductivity (EC) were within acceptable limits, suggesting that salinity and alkalinity hazards are minimal. Major cations such as calcium, magnesium, and sodium were also below their respective thresholds, and the calculated sodium adsorption ratio (SAR) remained well below the critical limit of 3, reflecting low sodicity risk. However, bicarbonate and chloride concentrations were higher than the permissible levels, pointing to a potential threat of soil alkalization and salinity if the water is applied continuously. Trace metals including zinc, copper, nickel, cobalt, and iron were all within the guideline values, while cadmium was undetectable. In contrast, chromium levels exceeded the standard in all locations, and lead concentrations were close to the maximum allowable limit. The most critical concern was the exceptionally high concentrations of ammonia and phosphorus, which were many times greater than the irrigation guidelines. These nutrient surpluses, together with moderate chromium enrichment, strongly influence the overall water quality classification and may pose long-term risks to soil structure and crop health if corrective measures are not adopted.

Table 4: Water Sample analysis of the three locations Kitchener drain.

Parameter	Location 1	Location 2	Location 3	Unit	Standard limits
pH	7.3	7.3	7.3	-	[a,b] 6.5-8.5
EC	1	1	1.18	[1] dS/m	[b] 3
Ca^{+2}	4.55	4.55	6.67	[2] me/L	[b]20
Mg^{+2}	3.51	3.51	2.94	me/L	[b] 5
HCO_3^-	3.87	3.58	4.15	me/L	[b] 1.5
Cl^-	5.48	5.48	6.78	me/L	[b]4
SO_4^{-2}	2.16	2.7	2.56	me/L	[b]20
Na^+	3.07	3.28	3.42	me/L	[b]3
K^+	0.33	0.37	0.45	me/L	-
[3] SAR	1.53	1.64	1.56	-	[b] 3
Zinc (Zn)	0.25	0.28	0.44	[3]mg/L	[a,b]2
Copper (Cu)	0.16	[4]<d.l.	0.19	mg/L	[b]0.2
Chromium (Cr)	0.2	0.2	0.27	mg/L	[b]0.1
Lead (Pb)	0.051	0.062	0.065	mg/L	[b]0.1
Cadmium (Cd)	<d.l.	<d.l.	<d.l.	mg/L	[b]0.01
Nickel (Ni)	0.011	0.011	0.017	mg/L	[b]0.2
Cobalt (Co)	0.018	0.022	0.034	mg/L	[b]0.05
Iron (Fe)	0.539	0.638	0.824	mg/L	[b]5
Ammonia (NH_4)	21.5264	19.4432	16.6656	mg/L	[a] 0.5
Phosphorus (P)	9.086	4.484	3.422	mg/L	[a]1

[1] dS/m = deciSiemen/meter in SI Units (equivalent to 1 mmho/cm), [2] me/l = milliequivalent per liter, [3]mg/l = milligrams per liter = parts per million (ppm), [4]<d.l. = below detection limit (0.001 mg/L), ([a]): The local Egyptian standards for the drainage water reuse (Law 48/ 1982), ([b]): Guidelines FAO (1985)

Water Quality Index

The calculated Water Quality Index (WQI) values for irrigation use for the three locationsare shown in Table 5. According to the weighted arithmetic classification, all three sites fall within the “very poor” category, reflecting a substantial deviation from the irrigation standards. The high index values are largely attributed to excessive concentrations of ammonia and phosphorus, which contributed disproportionately to the overall score. Although other parameters, such as pH and electrical conductivity, remained within acceptable limits, the elevated nutrient load dominated the index outcome. These findings suggest that while the general ionic balance of the water may not pose a severe hazard, nutrient enrichment significantly lowers the irrigation suitability of the samples.These findings are consistent with those reported by Ameen, M. M. et al., who concluded that the Kitchener Drain exhibits poor water quality, as indicated by a high WQI, and poses a serious threat to aquatic ecosystem[9].

Table 5: WQI and its categorization of Kitchener Drain for irrigation use

Location	WQI	Class (per index scale)
1	86.34	Very poor
2	77.16	Very poor
3	80.51	Very poor

Permeability Index

The calculated Permeability index (PMI) values for the three locations are shown in Table 6. Permeability Index values were 45.3%, 45.6%, and 41.9% for Locations 1, 2, and 3, respectively. According to Doneen’s classification, values between 25% and 75% indicate moderate suitability for irrigation. This means that the three sites present a moderate risk of permeability reduction in soils, largely due to the combined effect of sodium and bicarbonate relative to calcium and magnesium. Although the PI values do not fall in the unsuitable range, they suggest that continued use of this water for irrigation could gradually influence soil structure, particularly under long-term application without management practices.

Table 6: Permeability Index for the three locations in Kitchener Drain

Location	PMI (%)	Class
1	45.3	Moderately suitable
2	45.6	Moderately suitable
3	41.9	Moderately suitable

Pollution Index

The Pollution Index values were assessed for metalsZn, Cu, Cr, Pb, Cd, Ni, Co, and Fe at the three locations in Kitchener drain (Table 7) it is based on single metal calculations. Most of these elements had PI values below one, indicating no pollution effect under the irrigation standards. Zinc, nickel, cobalt, and iron remained well within permissible limits at all sites, and cadmium was not detected in any of the samples. Copper and lead were also below their respective thresholds, though their values approached the guideline levels in some cases. The only element that consistently exceeded the allowable concentration was chromium, which recorded PI values of 2.0 at Locations 1 and 2 and 2.7 at Location 3. Based on the classification proposed by Caeiro et al. (2005), these values correspond to moderate pollution, highlighting chromium as the major contributor to metal-related water quality concerns in the study area.

Table 7: Pollution index of the measured metals in Kitchener Drain according to guideline level.

Metal	Zn	Cu	Cr	Pb	Cd	Ni	Co	Fe
MAC (mg/L)	2	0.2	0.1	0.1	0.01	0.2	0.05	5
Location 1 (PI)	0.125	0.8	2	0.51	0	0.055	0.36	0.108
Location 2 (PI)	0.14	0	2	0.62	0	0.055	0.44	0.128
Location 3 (PI)	0.22	0.95	2.7	0.65	0	0.085	0.68	0.165
Effect Class*	<1 No effect	<1 No effect	2–3 Moderate	<1 No effect	<1 No effect	<1 No effect	<1 No effect	<1 No effect

Metal Quality Index

The Metal Quality Index (MI) values calculated for the three sampling locations were 3.96, 3.38, and 5.45, all of which are above the threshold value of 1. This indicates that, when considered collectively, the trace metals present in the water place all sites under a warning condition. Although most individual metals were within the acceptable irrigation limits, the cumulative contribution of chromium, lead, and copper elevated the overall index values. Among the three sites, Location 3 exhibited the highest MI, reflecting the stronger influence of chromium concentrations at this point. These findings emphasize that even when individual metals do not exceed guideline values substantially, their combined effect can still compromise irrigation water quality and should be carefully monitored to prevent long-term soil and crop contamination. Table 8 shows the MI results for the three locations.

Table 8: Metal Quality Index for the 3 locations in Kitchener Drain.

Location	MI Value	Interpretation
Location 1	3.96	Warning (MI > 1)
Location 2	3.38	Warning (MI > 1)
Location 3	5.45	Warning (MI > 1)

Figure 3 presents a graphical comparison of lead (Pb), chromium (Cr), ammonia (NH_4^+), and phosphorus (P) concentrations in the three sampling sites of the Kitchener Drain with the corresponding irrigation water quality standards. These parameters were selected because their measured values were notably higher than or close to the permissible limits across all locations, as indicated in the analytical results. The figure highlights the critical role of nutrient enrichment (NH_4^+ and P) and trace metal contamination (Pb and Cr) in lowering the irrigation suitability of the studied water.

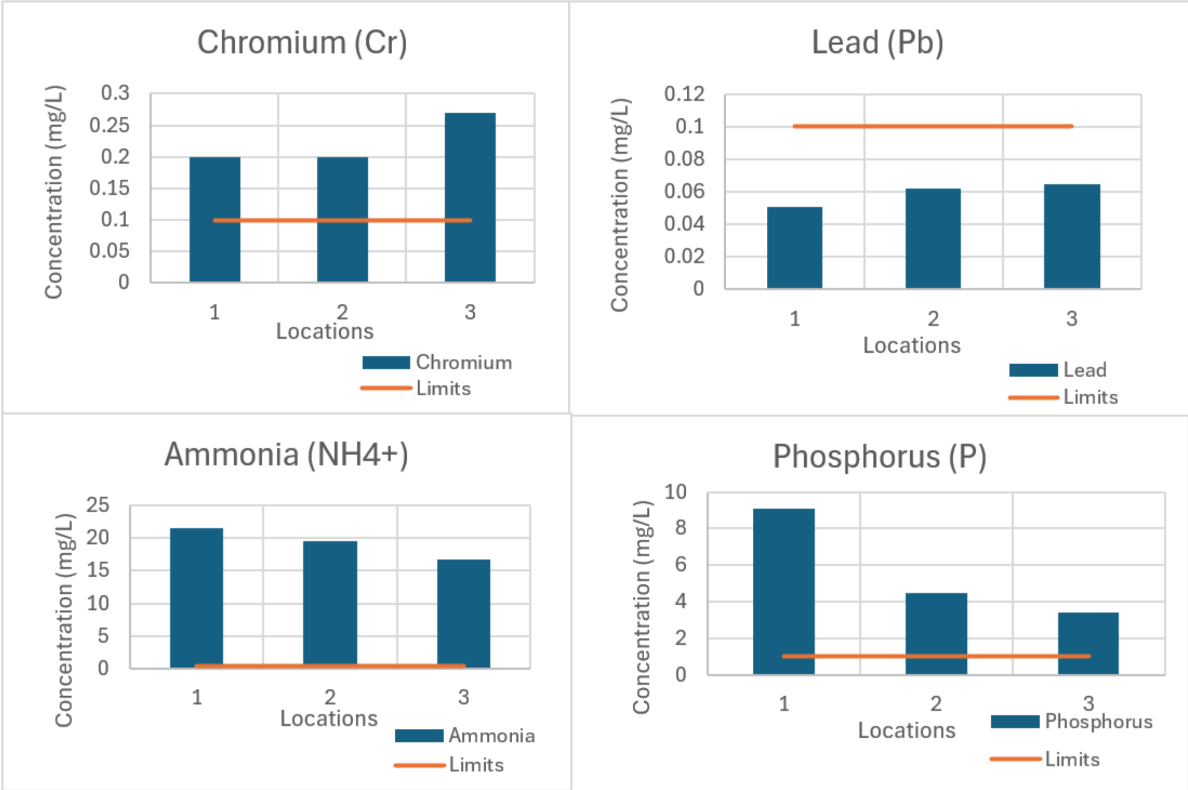

Figure 2: Graphical comparison of lead (Pb), chromium (Cr), ammonia (NH_4^+), and phosphorus (P) concentrations in the studied water samples with the corresponding irrigation water quality standards, showing the parameters that exceeded or closely approached the permissible limits.

IV. Conclusion

This study confirms that water from the Kitchener Drain does not meet national or international standards for irrigation, primarily due to elevated concentrations of ammonia (up to 21.53 mg/L), phosphorus (up to 9.09 mg/L), and chromium (up to 0.27 mg/L), all of which significantly exceed the allowable limits set by Egyptian Law 48/1982 and FAO (1985) guidelines. The calculated Water Quality Index (WQI) classified all samples as very poor, while the Metal Quality Index (MI) exceeded 1 in all studied locations, indicating cumulative heavy metal risk despite individual elements like Pb and Ni falling within acceptable thresholds. The Permeability Index (PMI), ranging from 41.9% to 45.6%, places the water in a moderate category, signaling potential risks to soil structure if used over extended periods.These results highlight an urgent need for treatment strategies before reuse in agriculture to avoid long-term deterioration of soil quality and threats to food safety. Without mitigation, the continued use of this water may contribute to heavy metal accumulation in crops and pose serious health risks to exposed communities. Remediation efforts such as nutrient reduction, sediment filtration, or blending with freshwater are recommended as immediate actions for safer water reuse in the region.

V. Recommendations

To improve the understanding and management of drainage water reuse, future studies should examine seasonal changes in water quality and include microbiological testing to assess health risks more thoroughly. It is also important to study how heavy metals from Kitchener Drain accumulate in crops and soil. Applying health risk models can help estimate the potential impact on humans through different exposure routes. In addition, testing affordable treatment options such as phytoremediation and constructed wetlands could offer practical solutions. Finally, reviewing and updating current policies based on real field data would support safer and more sustainable water use practices.

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