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Evaluation of water resources for various applications in New Assiut City, Egypt

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Abstract. The Wadi El-Assiuty region relies heavily on groundwater for agriculture and other uses, while surface water from the Assiut Water Treatment Plant is the most suitable for human consumption. This study uses a Water Quality Index (WQI) to assess the quality of groundwater in the reclaimed areas. The WQI evaluates 14 parameters, including Sodium Adsorption Ratio (SAR), Electrical Conductivity (EC), Residual sodium carbonate (RSC), Magnesium Hazard (MH), Kelly's Ratio (KR), Soluble Sodium Percentage (SSP), Permeability Index (PI), Chlorides (Cl^-), main ions, and total salinity. All groundwater samples were found to be suitable for various functions, with pH, ion levels, Total Hardness (TH), and Total dissolved solids (TDS) levels within acceptable ranges. The research area's groundwater is suitable for raising livestock and poultry, commercial purposes, and irrigation. The WQI results show that 85.7% of the samples were suitable for human consumption, with EC, SAR, and MH values ranging from "good" to "excellent."

Keywords: *Water Quality Index, Wadi El-Assiuty, New Assiut, Drinking water, and water examination.*

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Abbreviations

TDS	Total Dissolved Solids	WHO	World Health Organization
EC	Electrical Conductivity	EDTA	Ethylenediaminetetraacetic acid
SAR	Sodium Adsorption Ratio	L/S	liters/second
MH	Magnesium Hazard	mm	Millimeter
KR	Kelly's Ratio	CFU	Colony forming unit
PI	Permeability Index	TC	Total coliform
SSP	Soluble Sodium Percentage	FC	Fecal coliform
RSC	Residual Sodium Carbonate	MTF	Multiple Tube Fermentation
TH	Total Hardness	MPN	Most Probable Number
Ca.H	Calcium Hardness	MF	Membrane filter technique
FAO	Food and Agriculture Organization	NTU	Nephelometric Turbidity Unit

1. Introduction

New Assiut City was established in 2000 and is located east of the Nile River at 27°16'40"N and 31°17'06"E. New Assiut City and El-Rehab area rely primarily on Nile River water for drinking purposes after it is purified in a water treatment plant with a capacity of 52,000 cubic meters per day. The drinking water distribution networks extend 364 km in length, with diameters ranging from 160 mm to 900 mm, serving approximately 60,000 residents of New Assiut City. The sewage system consists of three lift stations with a total capacity of 1,630 L/s. The city also includes groundwater wells with moderate iron and manganese content. These wells can be treated to remove iron and manganese and reuse them as potable water.

New Assiut City, its surrounding metropolitan areas, and the farming regions of Wadi El-Assiuty feature two types of supplies of water: surface water and groundwater. In the deserts east and west of the Nile Valley, new agricultural and urban settlements are being created to accommodate the country's extensive reclamation projects, urbanization, and growing population. Among these new settlements, agricultural reclamation projects have been set up in the desert Wadi El-Assiuty region, primarily using groundwater, which is recognized as the only source of water for farming. In addition to human activity, excessive aquifer exploitation for irrigation, such as waste disposal and industrial operations, is a frequent cause for the decline in groundwater quality across various regions in Egypt, including the Wadi El-Assiuty desert (Farrag, 2007; Redwan & Abdel Moneim, 2016).

The essential component of life on Earth is freshwater, which is getting more and more limited. According to Sampat (2000), 33% of people worldwide and 75% in Europe rely on groundwater as their main supply of drinking water. However, human activity has put this resource's quantity and quality under jeopardy in several countries. 88 developing nations, which are home to half of the world's population, are currently experiencing water scarcity (Howard & Gelo, 2002). Surface water refers to any water source that is exposed to the atmosphere and influenced by runoff from surrounding land. Therefore, the presence of microorganisms capable of causing disease, including more serious and often fatal infections, is highly likely. A considerable amount of surface drinking water in some areas comes from bank filtration, which needs to be purified because it contains a wide range of contaminants and pathogens (Tufenkji et al., 2002). Selecting the best available water sources is the most crucial step in providing safe drinking water to a region; the more protected the water sources, the easier and less expensive their conversion to safe drinking water will be. In contrast, groundwater is covered by soil and sediment and is thought to be less vulnerable than surface water, but its extraction requires drilling and pumping equipment that is not always available or sustainable, especially in developing countries. As populations grow, groundwater extraction is expected to increase over the next century, while sites available for surface aquifers become more scarce (Medema et al., 2003). Freshwater availability fluctuates throughout time and space. There is an unequal distribution of the renewable fraction of freshwater on Earth, which is usually found as surface water. Although the majority of groundwater is nonrenewable fossil water, it is dispersed more equally. Several factors, including population density, land use, and economic conditions, influence a region's water use, in addition to the presence of natural groundwater. Municipalities are legally obligated to supply people with high-quality water in industrialized nations, but this isn't always the case in underdeveloped nations. As a result, the economics of a town influence its funding and views on water development and treatment.

Storage, transportation, treatment, and distribution systems make up municipal water supply networks. The amount of water that needs to be treated, the specific needs of the user or consumer, and the water quality all play a role in the development of these facilities. People frequently use surface water in extensive urban water supply systems, where rivers and lakes supply substantial and consistent amounts of water. Smaller communities typically prefer wells and spring-fed gravity systems over surface water for water supply. This preference is brought on by the high expense of surface water treatment and delivery, as well as the unreliability of maintenance and operation. There are many benefits to using surface water for home water supply. Its benefits include the simplicity of surface water extraction through direct pumping, post-use treatment, and river return. Surface water, however, needs ongoing treatment because it is seasonal.

Aquifers contain groundwater, a significant global source of drinking water. Geographically, aquifer hydrological recharge varies greatly and is influenced by several different factors, such as land use, vegetation, soil type, climate, and geology (Scanlon et al., 2002). Rainfall replenishes groundwater, which either artificial recharge or natural surface water infiltration enhances. Groundwater provides 40% of industrial water and 20% of irrigation water worldwide (Millennium Assessment, 2005). There are many benefits to adopting groundwater as a resource for household water supply. Large amounts of groundwater are found in most populous regions of the world, and even while they are withdrawn in significant amounts, they are frequently readily restored. The topsoil layers also serve as a filter against biological, chemical, and physical deterioration and are efficient in terms of both cost and quality. Lastly, because groundwater is readily available locally, has a high tolerance to drought, and is often of adequate quality with no treatment, it frequently provides substantial cost benefits per unit volume when compared to surface water (Burke & Moench, 2000). The hydraulic characteristics of the rocks and soil that make up an aquifer control the flow of pollutants inside it. Unless adsorption limits or delays them, dissolved materials flow with the water. The most permeable places are therefore typically where contaminants flow; the farther they originate from the groundwater discharge zone, the deeper they enter the groundwater system, and the greater the area that is eventually impacted (U.S. Environmental Protection Agency, 1993).

2. Materials and Methods

2.1. Study area

The area undergoing study is exactly ~68.6 km², of which 29 km² represent drinking water networks. The area is located between 31° 15' 5.771" - 31° 23' 49.650" East and 27° 17' 40.268" - 27° 13' 5.342" North (Figure 1).

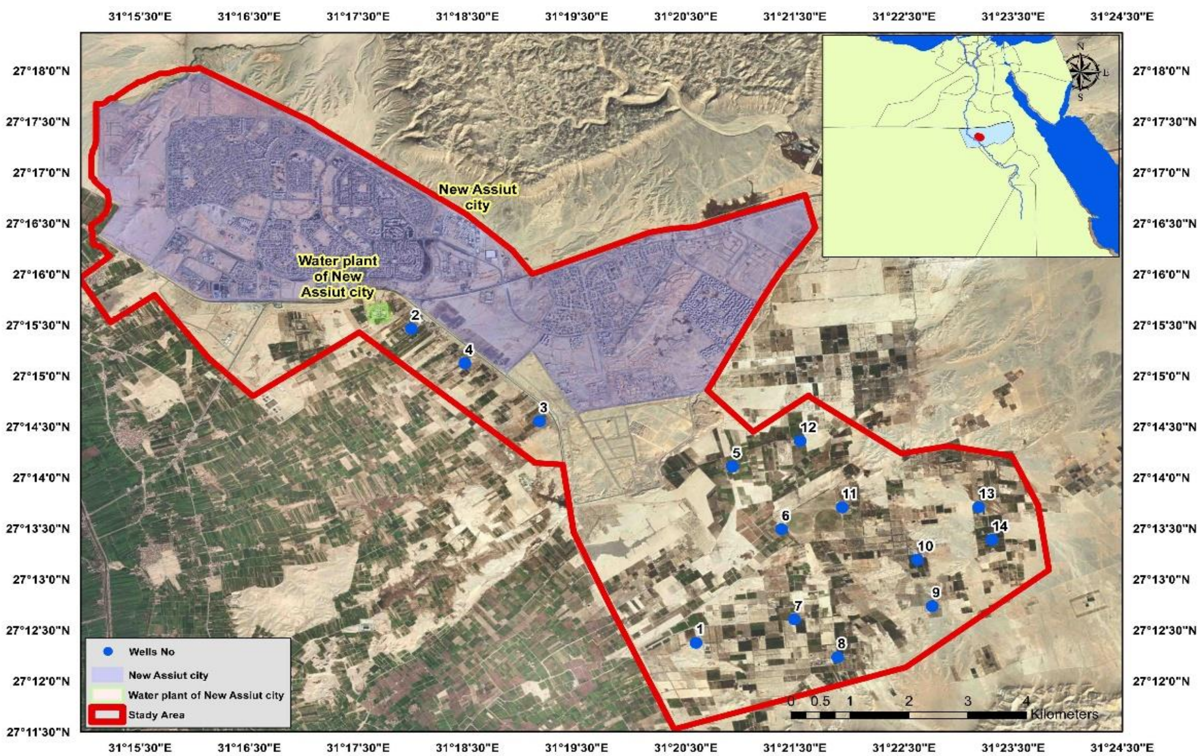

Figure 1. The study area's location map

2.2. Collection of water samples

Sterilized glass or plastic bottles with a 1000–500 mL capacity were used to collect groundwater samples from the New Assiut city, while other pumping wells that were already in existence were utilized to treat the surface water that was taken up each month from the Nile River. In order to undergo physical, chemical, and bacteriological examination, the collected samples were kept in an ice box for storage.

2.3. Characterization of the samples

The quality of drinking water parameters (pH, turbidity, temperature, electrical conductivity (EC), alkalinity, sulfate, TDS, NH_3, Na^+, K^+, Ca^{++}, Mg^+, Mn^{+2}, iron, Cl^-, NO_3^-, and NO_2^-) was examined in accordance with Egypt Decree No. 458 of 2007 and WHO standards.

Total dissolved solids (TDS), electrical conductivity (EC), and pH were measured directly using various meters (Van Ginkel et al., 2010). According to APHA, inductively coupled plasma mass spectrometry was used in the lab to quantify the concentrations of the principal cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), as well as Fe and Mn (Clesceri et al., 1998). Titrimetric techniques were used to measure the amounts of Cl^- and HCO_3^-, while a spectrophotometer was used to quantify the concentrations of SO_4^{2-} and NO_3^-.

2.3.1. Determination of chlorides (Cl^-)

Chloride ions were measured by adding silver nitrate ($AgNO_3$ 0.0141N) to a 50 mL water sample, using potassium chromate ($KCrO_4$) to show a color change from yellow to buff (Clesceri et al., 1998).

2.3.2. Determination of alkalinity (Titrimetric method)

The most common method used is titration with a strong acid, typically sulfuric acid (H_2SO_4), to measure the presence of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydroxide (OH^-) ions. This method involves titrating a 50 mL water sample with H_2SO_4 (0.02 N) while using bromocresol green as an indicator, which changes the color from blue to yellow (Clesceri et al., 1998).

2.3.3. Determination of the total hardness

The concentration of calcium (Ca) and magnesium (Mg) ions primarily contribute to the hardness of water. The most common method used for this analysis is EDTA titration, a complexometric titration technique. This method involves adding a solution of ethylenediaminetetraacetic acid (EDTA 0.01 M) to a 50 mL water sample, using erichrome black t as an indicator that changes to blue.

2.3.4. Determination of calcium hardness ($CaCO_3$)

This method involves titrating a 50 ml water sample with 0.01 M ethylenediaminetetraacetic acid (EDTA) while using murexide as an indicator, which changes the color from wine red to purple (Clesceri et al., 1998).

2.3.5. Determination of sulfate

Sulfate ions in water sample was estimated using 100 mL of the sample and 20 mL buffer solution, add 0.2 g of $BaCl_2$ then stir for 60 second at constant speed. Fill the photometer's absorption cell with the solution, then measure the barium sulfate turbidity after 5 minutes (Clesceri et al., 1998).

2.3.6. Determination of nitrates (NO_3^-)

This technique suitable for screening clean water, it measures NO_3^- absorbance at 220 nm (little amount of organic matter) (Clesceri et al., 1998).

2.3.7. Determination of Nitrites (NO_2^-)

It is determined by adding the sample to a color reagent (indicator) and then measuring it on a spectrophotometer apparatus (Clesceri et al., 1998).

2.3.8. Determination of Ammonia (NH_4^+)

Add 2.5 mL of oxidizing solution, 1 mL of sodium nitroprusside solution, and 1 mL of phenol solution to 25 mL of the sample, and then mix everything well until the color appears at room temperature (Clesceri et al., 1998).

2.3.9. Indexing approach

2.3.9.1. Irrigation Water Quality Indices (IWQIs)

Evaluating groundwater quality for irrigation involves assessing various water quality indices (WQIs) to assess if it is appropriate for use in agriculture. The equations (Table 1) carried out the IWQIs' calculations.

WQIs	Equation	Reference
SAR	$\frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+})/2}}$	(Richards, 1954)
EC	TDS /0.68	(Todd, 2004)
RSC	$(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$	(Eaton, 1950)
MH	$\frac{Mg^{2+} \times 100}{(Ca^{2+} + Mg^{2+})}$	(Raghunath, 1987)

KR	$\frac{Na^{+} \times 100}{(Ca^{2+} + Mg^{2+})}$	(Kelly, 1940)
PI	$\frac{Na^{+} + \sqrt{HCO_3}}{(Ca^{2+} + Mg^{2+} + Na^{+})}$	(Doneen,1964)
SSP	$\frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}) \times 100}$	(Wilcox, 1955)

2.3.9.2. Irrigation Water Quality Index (IWQI)

Permeability Index (PI). High levels of Na^{+}, Ca^{++}, Mg^{++}, and HCO_3^{-} in irrigation water have an effect due to excessive irrigation water use (Gautam et al., 2015). The following represents the permeability index (PI) value that Doneen (1964) introduced:

$$PI = \frac{Na^{+} + \sqrt{HCO_3}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100$$

2.3.10. Detection of polluted drinking water

2.3.10.1. Multiple tube fermentation technique

The Multiple Tube Fermentation (MTF) technique is a widely used method for detecting and quantifying coliform bacteria in water samples using the most probable number (MPN) method.

Different dilutions of the water samples were cultured in lactose broth (LB). The cultures were incubated at 35°C for 24-48 hours, and the results were observed. Then transfer the positive tubes from the presumptive test to brilliant green lactose bile broth and incubate at 35°C for 24-48 hours.

Gas formation confirms the presence of coliform bacteria. Next, spread the positive samples onto eosin methylene blue (EMB) agar and incubate at 44°C for 24 hours, then check the appearance of the colonies. Perform Gram staining to confirm Gram-negative, non-spore-forming rods. The number of positive tubes in different dilutions is compared to MPN tables to estimate bacterial density (Clesceri et al., 1998).

2.3.10.2. Membrane filter technique (MF)

To detect members of the coliform groups, thermotolerant coliforms, and fecal Streptococcus and Enterococcus bacteria, pass 100 mL of the water sample through a 0.45 µm membrane filter using a vacuum pump. The membrane filter should then be immediately placed on m-Endo, m-FC agar, and m-Enterococcus agar with a rolling motion and incubated at 35°C, 44.5°C, and 35°C for 24 hours, respectively. Total coliforms are counted by their golden-green metallic sheen, while thermotolerant coliforms are identified by blue colonies. Streptococci and enterococci are counted based on red or pink colonies (Clesceri et al., 1998).

2.3.11. Analysis of statistics

The SPSS 21.0 software was used to do a one-way ANOVA on the data. Three replicates' means and standard errors were computed. The Duncan's multiple range tests was used to compare the means, and the 5% level of statistical significance was established.

3. Results and Discussion

3.1. Water quality measurements

The subsequent treated water from the Nile River classification was measured using physicochemical parameters. The results indicated that the pH ranges from 7.50 to 7.61 for the treated water (Table 1), with the analytical results of the treated water content of turbidity ranging from 0.25 to 0.41 NTU. In the current study, the measurement of the electrical conductivity indicated that there is a low variation along the year, ranging from between 295 and 350 (µs/cm). The measurement of the total dissolved solids showed that it ranged between 152 and 223 mg/L, and the total alkalinity was 115-140 mg/L (Table 1).

In general, tests on treated water in the research area showed that the total hardness of these samples includes total hardness (83-125 mg/L), calcium hardness (50-75 mg/L), and magnesium hardness (30-50 mg/L) (Table 1). Soluble anions, i.e., Cl^{-}, SO_4^{2-}, NO_2^{-}, and NO_3^{-} in the water samples, are presented in table (1). The main soluble anions were Cl^{-} (16-25 mg/L), then SO_4^{2-} (20-42 mg/L), followed by nitrates (0-0.04 mg/L), and after that nitrites (0 mg/L). In the present study, the average concentrations of the trace elements Fe, Mn, and Al^{3+} in the treated water were (0-0.03 mg/L), (0 mg/L), and (0-0.1 mg/L), respectively (Table 1). The table also indicates that the microbiological examination of the samples confirmed they were free of total and fecal coliform bacteria. Therefore, all 14 samples taken monthly from the New Assiut City treated drinking water plant fall within the permissible limits according to Egyptian Standard Specification No. 458 of 2007 and the World Health Organization. As a result, they are safe for human consumption and free of total and fecal coliform bacteria.

Table 1. The Nile River treated water samples' physicochemical analysis

Months in 2024	pH	Tur. (NTU)	EC (μs/cm)	T.D.S (mg/L)	T-Alk (mg/L)	Water Hardness (mg/L)			Cl- (mg/L)	NH_3 (mg/L)	Trace elements (mg/L)		Sulphate (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Al^{3+} (mg/L)	Microbiological examination	
						T.H.	Ca-H	Mg-H			Fe^{+2}	Mn^{+2}					TC CFU/100 mL	FC CFU/100 mL
January	7.5	0.25	306	168	136	115	70	48	19	0.0	0.0	0.0	31	0	0	0.07	Nil	Nil
February	7.5	0.25	305	155	130	118	70	48	19	0.00	0.00	0.00	30	0	0.03	0.09	Nil	Nil
March	7.52	0.36	312	152	135	120	72	48	19	0.00	0.00	0.00	32	0	0.02	0.08	Nil	Nil
April	7.55	0.33	318	152	125	110	68	45	20	0.00	0.00	0.00	30	0	0.04	0.06	Nil	Nil
May	7.61	0.36	295	190	125	125	73	50	17	0.00	0.00	0.00	20	0	0	0.08	Nil	Nil
June	7.6	0.3	300	180	128	120	73	37	18	0.00	0.00	0.00	21	0	0	0.1	Nil	Nil
July	7.59	0.3	340	199	115	89	53	35	16	0.00	0.00	0.00	40	0	0	0.09	Nil	Nil
August	7.55	0.28	350	200	125	85	50	31	17	0.00	0.00	0.00	42	0	0	0.09	Nil	Nil
September	7.59	0.35	350	200	125	83	50	33	17	0.01	0.00	0.00	40	0	0	0	Nil	Nil
October	7.56	0.41	321	223	134	118	75	43	25	0.01	0.00	0.00	40	0	0	0	Nil	Nil
November	7.53	0.29	315	160	131	120	75	45	18	0.01	0.03	0.00	35	0	0	0	Nil	Nil
December	7.5	0.3	300	162	140	125	50	30	21	0.01	0.03	0.00	32	0	0	0	Nil	Nil
Minimum	7.5	0.25	295	152	115	83	50	30	16	0	0	0	20	0	0	0	0	0
Maximum	7.61	0.41	350	223	140	125	75	50	25	0.01	0.03	0	42	0	0.04	0.1	0	0
Egypt decree (2007)	6.5-8.5	1	---	100-1000	500	50-500	350	150	250	1	0.3	0.4	250	0.5	50	0.2	Nil	Nil

3.2. Groundwater measurements

Physicochemical parameters were used to measure the ensuing groundwater categorization. The quality of groundwater is important when determining whether it is appropriate for a certain use. The findings showed that the groundwater's pH ranges from 7.45 to 7.90 (Table 2). The electrical conductivity (EC) of the groundwater in the current investigation ranged from 1390 to 3235.29 µS/cm (Table 2); the research area's total dissolved solids (TDS) level ranges widely, from 895 to 2200 mg/L. Table (2) shows the analytical results of the soluble cations (Na^+, Ca^{2+}, Mg^{2+}, and K^+) groundwater content. The primary cations in groundwater samples in the study region were frequently Na+, which varied from 164 to 493.00 mg/L, followed by Ca^{2+}, which ranged from 21 to 64 mg/L, Mg^{2+}, which ranged from 11 to 21.50 mg/L, and K^+, which ranged from 1.8 to 7.80 mg/L. Table (2) lists the soluble anions, or Cl^-, SO_4^{2-}, and HCO_3^-, in the water samples. Cl^- (162-850 mg/L) and sulfate (44.7-335.00 mg/L) were the most abundant soluble anions in all water samples, followed by bicarbonate (35.7-180.00 mg/L). According to Table (2), the average concentrations of Mn and Fe in the groundwater samples within the study area are 0.00 and 0.13 mg/L and 0.01–1.00 mg/L, respectively. Additionally, Table (2) shows that the groundwater's total hardness (TH) ranged from 149 mg/L to 215 mg/L.

3.3. Quality of drinking water

The pH, TDS, TH, EC, cations, and anions had an impact on the groundwater's drinking water quality (Table 3). It is recommended that the drinking water should be devoid of organic matter, hazardous materials, and chemical and biological substances that negatively impact human health. Total dissolved solids (TDS) are a critical parameter for evaluating the quality of irrigation water. The increase in salts in the irrigation water results in a higher concentration of salts in the soil, which subsequently leads to the deterioration of plant health. TDS of the groundwater in the study area ranges between 895 and 2200 mg/L (Table 3). Therefore, potable groundwater samples represent 50% of the samples, while the rest of the samples are considered non-potable.

Table 2. The physicochemical examination of samples of groundwater

Sample Number	pH	EC µS/cm	TDS (mg/L)	Cations (mg/L)				Anions (mg/L)				Trace elements (mg/L)		TH (mg/L)
				Na^+	Ca^{+2}	Mg^{+2}	K^+	Cl^-	SO_4^{-2}	HCO_3^-	NO_3^-	Fe^{+2}	Mn^{+2}	
1	7.9	1390.00	895	360	50	15	7.8	500	209	56.1	0.09	0.04	0.1	205
2	7.45	1414.71	962	164	56	18	3	520	200	80	0.1	0.03	0.13	180
3	7.56	2205.88	1500	430	29	20	2.8	508	220	121	0.2	0.01	0.11	178
4	7.64	1498.00	997	172	27	19	4.8	162	160	74	0.1	0.02	0.01	197
5	7.8	1463.24	995	380	53	21	7.2	530	44.7	38.25	10	0.01	0.07	210
6	7.57	2249.00	1550	400	26	17.8	3.1	542	130	85	0.2	0.02	0.01	156
7	7.7	1470.59	991	191	24.9	21.5	7.5	185	320	35.7	0.1	0.01	0.08	149
8	7.85	1420.65	985	385	60	16	2.2	191	335	175	0.16	0.01	0.02	195
9	7.59	1410.00	982	392	25	11	2.5	196	190	178	0.17	0.02	0.03	215
10	7.64	3235.29	2200	432	62	18.9	1.9	800	300	180	15	1	0	210
11	7.55	3161.76	2150	453	64	12	2.3	820	180	140	0.14	0.3	0	187
12	7.67	2235.29	1520	461	32	11.5	2.1	831	167	129	0.1	0.2	0.12	176
13	7.62	2088.24	1420	481	25.2	16.4	1.8	850	187	149	0.3	0.5	0	185
14	7.58	2250.00	1532	493	21	15.8	2.1	849	180	160	0.6	0.3	0	202

Iron and manganese (Mn^{2+}) are typically found together (Appelo & Postma, 2004). The average Fe^{2+} concentration in groundwater samples within the research area is between 0.01 and 1.00 mg/L. Accordingly, 7% of the groundwater samples have levels of iron that are higher than what is safe to drink. There are various methods for treating the iron and manganese content of drinking and household water. Using a water softener is intended to remove iron and manganese if they are present in trace amounts. By adding oxygen, chlorinating, and feeding ozone or hydrogen peroxide, iron is precipitated out of the water. The water is then filtered to eliminate iron. Iron and manganese could be eliminated by mixing potassium permanganate feed, manganese green sand filters, and some newly created synthetic media.

Table 3. Drinking water quality in the research area's groundwater

The criteria	WHO (2011)	WHO (2004)	Egypt decree (2007)	Current research	% of samples in the research region that are over the desired limit
pH	6.5-8.5	6.5-9.2	6.5-8.5	7.45-7.90	0%
TDS (mg/L)	500-1000	500-1500	500-1000	895-2200	50%
TH (mg/L)	500	250-500	500	149.00-215	0%
EC µs/cm	500	----	----	1393-3235.29	50%
Na^+ (mg/L)	200	----	200	1643-493	78.57%
K^+ (mg/L)	12	----	12	1.83-7.80	0%
Ca^{+2} (mg/L)	75	75-200	75	21.3-64	0%
Mg^{+2} (mg/L)	30	50-150	30	11.3-21.50	0%
HCO_3^- (mg/L)	500		500	35.3-180	0%
Cl^- (mg/L)	250	200-600	250	1623-850	71.43%
SO_4^{-2} (mg/L)	250	200-400	250	44.3-335	21.43%
Fe^{+2} (mg/L)	0.3	0.3-1.0	0.5	0.03-1.0	7.14%
Mn^{+2} (mg/L)	0.1	0.1-0.5	0.2	0.03-0.13	0%

3.4. Livestock and poultry purposes

The maximum TDS concentrations for animal water are as follows, following McKee and Wolf (1963): 2860 mg/L for poultry, 6435 mg/L for horses, 7150 mg/L for dairy cattle, 10,100 mg/L for beef cattle, and 12,900 mg/L for adult sheep. Half of the groundwater samples in the research region are deemed excellent for use by livestock and poultry based on the standards proposed by Ayers and Westcott (1985); however, the remaining samples have been determined to be highly satisfactory for use by all classes of livestock and poultry (Table 4). The primary criteria for determining the water quality used by poultry and animals in the study region are connected with the findings of sample analysis, as shown in Table (4).

Table 4. The research area's livestock and poultry water quality

The category	TDS (mg/L)	Character	Present study
I	< 1000	Comparatively low salinity level. Ideal for all livestock and poultry classes	50%
II	1000–3000	Suitable for all livestock and poultry classes. It can lead in watery feces in poultry and brief, moderate diarrhea in animals that are not used to them.	50%
III	3000–5000	Livestock find it satisfactory, although animals that are not used to them may initially reject them or suffer temporary diarrhea. Particularly in turkeys, inadequate water for birds frequently results in water faces, higher mortality, and slower growth.	—
IV	5000–7000	Sheep, pigs, horses, and dairy and beef cattle can all use it with a fair degree of safety. Animals that are pregnant or lactating animals should not be used. Unsuitable for poultry	—
V	7000–10,000	Unsuitable for pigs and most likely for poultry. Use of this product poses a significant risk to sheep, horses, cows, or their young when they are pregnant or lactating cows. Although elderly cattle, horses, poultry, and swine may survive on them in specific situations, use should generally be avoided.	—
V	> 10,000	It is not advised to use this extremely saline water in any situation due to the considerable risks involved.	—

3.5. Water irrigation purposes

Numerous classification tools were used in relation to irrigation water quality. Total dissolved solids (TDS), sodium absorption ratio (SAR), electrical conductivity (EC), residual sodium carbonate (RSC), permeability index (PI), magnesium hazard (MH), Kelly's ratio (KR), and soluble sodium percentage (SSP) are some of the crucial factors that must be taken into account when evaluating water for irrigation.

Table 5. SAR and EC readings are used to evaluate water for irrigation applications

Samples number	SAR	EC μS/cm	Category of water	Samples number	SAR	EC μS/cm	Category of water
1	11.45	1390	Good	8	11.39	1420.65	Good
2	4.87	1414.71	Good	9	16.41	1410	Good
3	15.03	2205.88	Good	10	12.31	3235.29	Good
4	6.20	1498	Good	11	13.61	3161.76	Good
5	11.17	1463.24	Good	12	17.76	2235.29	Good
6	14.79	2249	Good	13	18.31	2088.24	Good
7	6.76	1470.59	Good	14	19.77	2250	Good

Salinity can have a major effect on crop output when it builds up in the root zone (Jain et al., 2011). Water is considered satisfactory if TDS is below 450 mg/L, while water is viewed as unsuitable for agriculture if TDS exceeds 2000 mg/L (Davis & De Wiest, 1966). The groundwater in the study region has TDS levels ranging from 895 to 2200 mg/L. Ayers & Westcott (1985) state that readings over 2000 mg/L are considered severe, while values between 450 and 2000 mg/L are generally seen as suitable for irrigation. As a result, the majority of the research area's groundwater samples are categorized as moderate for irrigation.

By limiting water absorption, altering the osmotic process in the root zone, and decreasing soil permeability, salinity can have an impact on plant growth (Kumar et al., 2007). The EC can be used to determine the salinity of groundwater (Allam et al., 2015). The EC, SAR According to the current study, the groundwater's EC values varied from 1390 to 3235.29 μS/cm, which indicates the presence of excess ions in the groundwater. The values of the SAR in the groundwater ranged from 4.87 to 19.77 meq/L (Table 5). The United States Salinity Laboratory Staff and Richards plot these values (1954) in a diagram (Figure 2).

Ayers and Westcott (1985) defined "Excellent" water as having an EC value of less than 700 μS/cm for irrigation purposes, "Good" water as having an EC value between 700 and 3000 μS/cm, and "Fair" water as having an EC value greater than 3000 μS/cm, which would significantly impact crop yield. According to the results of the current analysis, the groundwater is "Good." Even though there are other factors influencing agricultural productivity in the research area, these results can still be indicative of it. The EC of the water divides into C1, C2, C3, and C4 (Table 6), and SAR is categorized as S1, S2, S3, and S4 (Table 7). Figure 2: Diagram of the US Salinity Laboratory Staff and Richards (1954) displays water sample parameter representations, showing that every sample of groundwater falls within the C3–S1, C3–S2, C3–S3, C3–S4, C4–S3, and C4–S4 classifications. According to this diagram, only 7% of the groundwater samples were categorized as "good" water for irrigation (C3–S1), while 43% were classified as "bad" for irrigation (36% as C3–S4 and 7% as C4–S4, unsuitable for irrigation under normal conditions). Additionally, 36% were classified as "intermediate" (29% as C3–S3 and 7% as C4–S3), and 14% as "moderate."

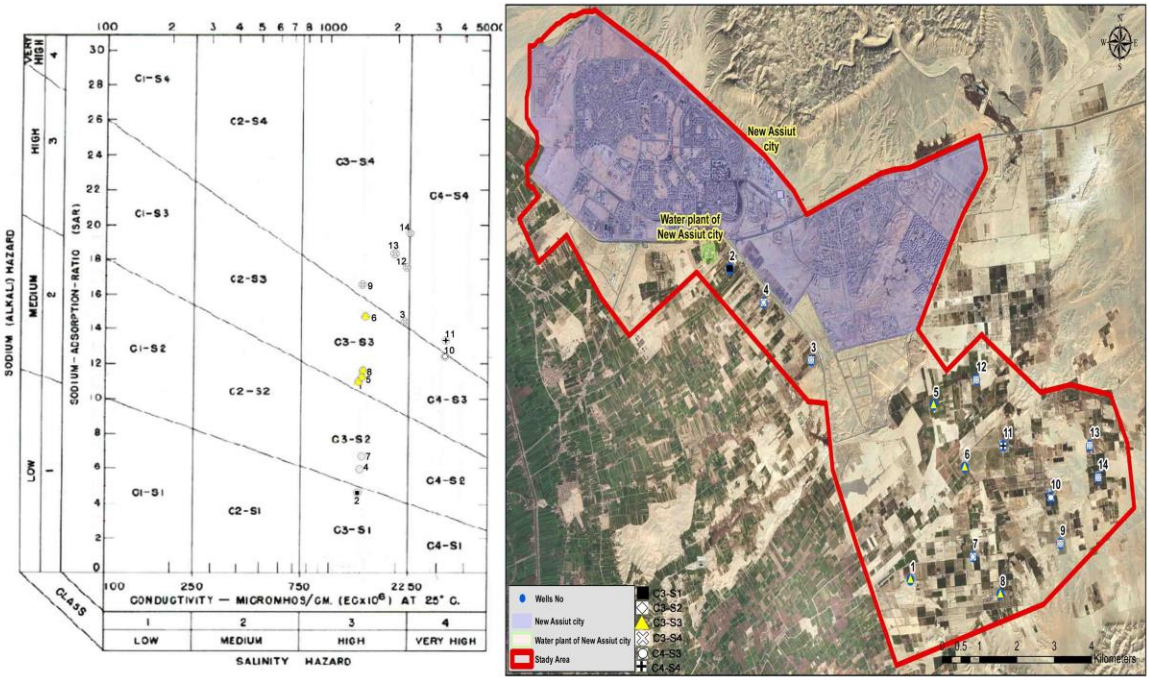

Figure 2. Classification of irrigation water quality for the area under study using the guidelines by the US Salinity Laboratory Staff and Richards (1954)

Accordingly, 43% of the groundwater samples in the research area were unsuitable for irrigation, yet 57% of them were. Table (7) shows that, in contrast to the other indices, 85.7% of the computed SAR values fell between 10 and 18, or "excellent" to "good," suggesting that the majority of the samples were appropriate for irrigation usage based on the SAR. Higher SAR values will reduce the osmotic action of the plant and prevent water from getting to the branches and leaves, which will lower the pace of production. The current study's groundwater samples' SAR and EC values demonstrate the satisfactory quality of the water for irrigation.

Table 6. Water sample categorization in the research area based on EC

EC class	Water quality	EC range (µS/cm)	Usage	Water class	EC values of water samples (present study)
C_1	Low salinity	0-250	Most crops can be irrigated with it on most soil types	Excellent	___
C_2	Medium salinity	250-750	If there is moderate leaching, it can be used.	Good	___
C_3	High salinity	750-2250	Not fit for use in areas with limited drainage	Permissible	85.7%
C_4	Very high salinity	> 2250	Under normal circumstances, it is not appropriate for irrigation	Doubtful	14.3%

Table 7. SAR-based classification of water samples in the analyzed area

Class	SAR	Water quality	Class	Hazard	Utilization of water for irrigation	present study
S_1	0-10	Low sodium	Excellent	No bad effects from sodium	In every type of soils	21.4%
S_2	10-18	Medium sodium	Good	Sodium-sensitive plants have issues with fine-textured soils, particularly in low-leaching environments, but they can be applied to sandy soils with adequate permeability.	In coarse textural soils with high permeability and rich in organic matter	64.3%
S_3	18-26	High sodium	Fair	A negative impact could be expected. Coarse in the majority of soils, and gypsum or other amendments would be required to exchange sodium ions.	Requires good drainage and chemical amendments	14.3%
S_4	>26	Very high sodium	Poor	In general, inappropriate for Very unsuitable for irrigation	Very unsuitable for irrigation; needs gypsum addition, good drainage, and water with a low salinity.	___

RSC, residual sodium bicarbonate, is produced because of the buildup of bicarbonate in water and Na+ with precipitation of Ca^{2+} and Mg^{2+}, which in turn enhances pH value. The results indicate that the RSC values in the groundwater were -3.75 and 0.76 meq/L. This means that 100% of groundwater samples have a content percentage from RSC of less than 1.25, which is due to water-bearing sediments in the area. Thereby, according to RSC content (Richards, 1954), the water is safe for irrigation (Table 8).

Table 8: Values of residual sodium carbonate (RSC) in the research area

Sample number	RSC meq/L	Sample number	RSC meq/L
1	-2.82	8	-1.45
2	-2.97	9	0.76
3	-1.11	10	-1.71
4	-1.70	11	-1.89
5	-3.75	12	-0.43
6	-1.37	13	-0.17
7	-2.43	14	0.27

The range of the groundwater samples' permeability index (PI) is 76% to 98% (Table 9). According to Doneen (1964), water used for irrigation is categorized as class I if its PI value is greater than 75%, class II if it is between 25 and 75%, and class III if it is less than 2%. Based on PI values, 14 (100%) samples are categorized as class I. As a result, the water is perfect for agriculture.

Table 9. Values of the PI, MH, KR, and Cl parameters in the research area

No.	PI %	MH %	SSP %	KR meq/L	Cl^- mg/L	No.	PI %	MH %	SSP %	KR meq/L	Cl^- mg/L
1	86%	33%	80.93	4.19	500.00	8	88%	31%	79.55	3.88	191
2	76%	35%	62.73	1.67	520.00	9	98%	42%	88.81	7.91	196
3	92%	49.7%	85.84	6.04	508.00	10	87%	33%	80.18	4.03	800
4	83%	54%	72.29	2.57	162	11	89%	24%	82.51	4.70	820
5	83%	39%	79.23	3.77	530.00	12	95%	37%	88.75	7.87	831
6	92%	50%	86.34	6.29	542.00	13	96%	52%	88.93	8.01	850
7	80%	50%	73.81	2.75	185.00	14	97%	55%	90.14	9.12	849

Magnesium Hazard (MH) in most waters, Ca^{2+} and Mg^{2+} maintain a state of equilibrium hazard index is an important ratio introduced by Paliwal (1972). A high amount of Mg^{2+} was caused by exchangeable Na^+ in irrigated soils. The soil becomes more alkaline and the crop output is negatively impacted by the high magnesium hazard value, which is more than 50% (Gupta & Gupta, 1987; Raghunath, 1987). The following formula is used to determine MH percentages:

$$MH\% = \frac{Mg^{2+} \times 100}{(Ca^{2+} + Mg^{2+})}$$

The research's MH groundwater analyses range from 24% to 55%. According to the results, 14.3% of the groundwater samples have levels above 50%, making them unfit for irrigation. According to Table (9), 85.7% of groundwater samples have a percentage below 50%, making them appropriate for irrigation.

One of the intriguing factors used to assess if water is suitable for irrigation is the Soluble Sodium Percentage (SSP). Permeability decreases as a result of the buildup of Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- in the soil. The groundwater's SSP varied from 62.73 to 90.14 percent (Table 9). A high SSP value lowers the permeability of the soil and permits it to react with Na+.

Kelly's Ratio (KR) is a criterion used to assess the suitability groundwater is for irrigation. KR > 1 indicates excess sodium, and KR < 1 indicates sodium insufficiency (Kelly, 1940). Kelly (1940) asserts that waters with KR values greater than one (KR > 1) are unsuitable for agriculture. All of the groundwater samples in the current investigation had KR values more than 1, which indicates that they are unsuitable for irrigation (Table 9). The KR values varied from 1.67 to 9.12.

Chlorides (Cl^-): A very little quantity of chloride is essential for plants, while high quantities are bad for crops. The groundwater samples' chloride contents range from 162 to 850 mg/L (Table 9). Chloride levels below 70 mg/L are generally acceptable for all vegetation; sensitive plants show damage between 70 and 140 mg/L; moderately tolerant plants show damage between 141 and 350 mg/L; and over 350 mg/L may cause major problems, according to Bauder et al. (2011). Some of the groundwater samples in the area have chloride concentrations between 141 and 350 mg/Ll, which indicate that plants are moderately tolerant. The remaining samples have higher concentrations than 350 mg/L, which result in severe issues when used for irrigation. This information indicates that 28.57% of the groundwater samples are moderately suitable for irrigation, while the remaining samples are unsuitable.

Table 10. The U.S. National Academy of Sciences has established water quality criteria for specific businesses (Council, 1974)

Industry					Boiler feed water			Current research
The features	Fruit and vegetable	Paper	Textile	Petroleum	Low Pressure 0-10 atm	Intermediate pressure 10-48 atm	High pressure 48-102 atm	Groundwater
pH	6.5-8.5	-	-	6-9	7-10	8.2-10	8.2-9	7.45-7.9
TDS	500	200-500	100-200	3500	700	500	200	895-2200
Alkalinity ($CaCO_3$)	250	75-150	50-200	500	350	100	40	121.4-158.2
Hardness ($CaCO_3$)	250	100-200	0-50	900	350	1.0	0.07	78-205.4
$Na^+ + K^+$	-	-	-	230	-	-	-	165.8-500.8
Ca^{+2}	100	-	-	-	-	0.4	0.01	21-64
Mg^{+2}	-	-	-	85	-	0.25	0.01	11-21.5
HCO_3^-+ CO_3^{--}	-	-	-	480	170	126	48	35.7-180
SO_4^{-2}	250	-	100	900	-	-	-	44.7-335
Cl^-	250	0-200	100	1600	-	-	-	162-850
Fe^{+2}	0.2	0.1-1.0	0-0.3	15	1	0.3	0.05	0.01-1
Mn^{+2}	50	20-100	25	85	30	10	0.7	0-0.13

3.6. Water irrigation purposes

It should be obvious that different industrial processes have rather diverse requirements for the water quality they use and that these differences necessitate that different kinds of water have varying degrees of acceptability. The water quality criteria for several industries at the point of use are shown in Table (10) along with a comparison to the values discovered in the present study. All of the groundwater samples in the research area are clearly available for use by numerous industry sectors. The U.S. National Academy of Science (Council, 1974) conducted analyses that contrasted with these findings.

4. Conclusions

This study aims to assess the water resources in New Assiut City and determine their suitability for various uses. Nile water is the primary source of fresh drinking water, which is treated at the New Assiut Water Plant. Experimenting with groundwater resources for drinking purposes is infeasible due to the construction of temporary plants to remove iron and manganese, and the construction of a water network connecting these plants to the internal network. Chemical assessments of groundwater samples indicate that most samples are suitable for consumption, except for high concentrations of Fe^{2+} and Mn^{2+} exceeding allowable thresholds. Half of the samples are excellent for raising livestock and poultry, while the remainder are highly pathogenic. Most groundwater samples are suitable for irrigation purposes, but sewage release can damage farmland due to soil salinization processes. Groundwater is ideal for livestock and poultry, highly appropriate for industrial use, and ranges from highly to minimally suitable for irrigation.

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