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Appraisal of Nitrate Levels in Water Wells in Egyptian Fertilizers Company Headquarter, Ain Sukhna, Northwestern Gulf of Suez, Egypt

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ABSTRACT

The Egyptian Fertilizers Company (EFC) is situated in the Ain Sukhna region within the northwestern sector of the Gulf of Suez in Egypt. Twelve groundwater samples were procured from wells within the investigated area, and the presence of nitrogenous ions such as nitrate, nitrite, and ammonia was rigorously examined. To assess the quality of the water, ratios are utilized, emphasizing nitrate concentration, and the findings are juxtaposed with the guidelines established by the World Health Organization (WHO). The statistical methodologies endorsed by the United States Environmental Protection Agency (US-EPA) are employed to evaluate the health risks posed to the local populace. The findings indicate that the nitrate concentrations exceeded WHO thresholds in seven samples, nitrite levels exceeded in two samples, and ammonia contents exceeded in all samples, rendering the water unfit for human consumption. Elevated concentrations of NO_3 in the water samples were associated with anthropogenic activities, including the amalgamation of mixed wastewater and seawater intrusion. Nitrate levels surpassed the WHO (50 ppm) and US-EPA (10 ppm) standards, thereby presenting a non-carcinogenic risk from oral exposure, particularly for children, as hazard values exceeded the safety threshold (1). Conversely, dermal exposure did not present any significant risk. Nitrate can be converted to nitrite and N-nitroso derivatives via bacterial nitrification, which may induce carcinogenic effects within the digestive, urinary and excretory systems. Consequently, the remediation of the contaminated wells is imperative to safeguard the health of the local community.

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تقييم نسب النترات في آبار المياه بمقر الشركة المصرية للأسمدة، العين السخنة، شمال غربي خليج السويس، مصر

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الملخص

تقع شركة الأسمدة المصرية في منطقة العين السخنة ضمن القطاع الشمالي الغربي من خليج السويس في مصر . تم جمع اثنتي عشرة عينة من المياه الجوفية من آبار المنطقة المدروسة، وتم فحص وجود الأيونات النيتروجينية مثل النترات والنتريت والأمونيا بدقة. لتقييم جودة المياه، تم استخدام نسب تركيز النترات، ومقارنة النتائج مع الإرشادات التي وضعتها منظمة الصحة العالمية (WHO)، كما تم استخدام المنهجيات الإحصائية المعتمدة من وكالة حماية البيئة الأمريكية (US-EPA) لتقييم المخاطر الصحية التي يتعرض لها السكان المحليون. أظهرت النتائج أن تركيزات النترات تجاوزت الحدود المسموح بها من قبل منظمة الصحة العالمية في سبع عينات، بينما تجاوزت مستويات النتريت الحدود المسموح بها في عينتين، وتجاوزت الأمونيا الحدود المسموح بها في جميع العينات، مما يجعل المياه غير صالحة للاستهلاك البشري. وتم ربط ارتفاع تركيزات النترات (NO_3) في العينات بالممارسات البشرية، مثل خلط مياه الصرف الصحي والمياه المالحة نتيجة تسرب مياه البحر . تجاوزت مستويات النترات المعايير المحددة من قبل منظمة الصحة العالمية (50 جزءًا في المليون) ومعايير وكالة حماية البيئة الأمريكية (10 أجزاء في المليون)، مما يشكل خطرًا غير سرطاني نتيجة التعرض عن طريق الفم، خاصة للأطفال، حيث تجاوزت قيم المخاطر الحد الآمن (1). في المقابل، لم يشكل التعرض عن طريق الجلد أي خطر كبير. يمكن أن تتحول النترات إلى نتريت ومشتقات نيتروزو (N-nitroso) عبر عملية النترجة البكتيرية، مما قد يسبب تأثيرات مسرطنة على الجهاز الهضمي والبولي والإخراجي. بناءً على ذلك، تصبح معالجة الآبار الملوثة أمرًا ضروريًا لحماية صحة المجتمع المحلي.

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Introduction

The quality of groundwater in the northwest Gulf of Suez, including the Ain Sukhna industrial area, is seriously harmed by a mix of natural and human-made influences. Recent investigations have revealed that the groundwater in this area is extensively contaminated with numerous contaminants, mostly caused by industrial operations and inefficient waste management practices. Industrial operations encompass the sectors of ceramics, cement, bricks, and fertilizers. Groundwater has been marked by high levels of total dissolved solids (TDS), chloride, sulfate, and nitrate, which surpass permitted limits specified by WHO guidelines (Al-Awah et al., 2023; El-Rayes et al., 2023; Asmoay and Mabrouk, 2024). The confluence of industrial effluents and naturally occurring hydrogeochemical processes, including ion exchange and mineral disintegration, exacerbates the complex water quality issues confronting the aquifer systems in the region. Considering these several reasons, the groundwater in the northwest Gulf of Suez is typically regarded as unsuitable for consumption, while it may still be used for specific industrial applications with caution. This circumstance emphasizes the urgency for rigorous surveillance and strong environmental regulations to preserve public health and the environment in this quickly industrialized area (Al-Awah et al., 2023; El-Rayes et al., 2023; Asmoay and Mabrouk, 2024).

The adverse health consequences of nitrate contamination in groundwater have become an urgent issue globally, particularly in regions that depend on groundwater for drinking and irrigation. Numerous investigations have identified nitrate levels that surpass the WHO-recommended limit of 50 ppm in Egypt (WHO, 2022; Al-Awah et al., 2023; El-Rayes et al., 2023; Asmoay and Mabrouk, 2024). The leading cause of nitrate excess in groundwater is the overuse of synthetic nitrogenous fertilizers in agriculture, which leaches into the water supply (Saini et al., 2024; Aju et al., 2024). Animal and human excrement contribute to rising nitrate levels, especially in rural areas with deficient sanitation systems (Sun et al., 2023). Industrial discharges can increase nitrate contamination, worsening groundwater quality (Karunanidhi et al., 2024). Elevated nitrate levels can lead to hemoglobinemia, especially in kids, a disorder that affects the blood's ability to carry oxygen (Saini et al., 2024). Long-term exposure in adults has been associated with many health issues, including stomach issues (Saini et al., 2024). Researchers indicated that, compared to adults, children are more vulnerable to health risks due to nitrate exposure (Salman et al., 2019; Asmoay et al., 2023; Sun et al., 2023; Verma et al., 2023; Asmoay et al., 2024; Sun et al., 2024; Saini et al., 2024).

Identification and mitigation of nitrate pollution need ongoing groundwater quality monitoring (Karunanidhi et al., 2024; Sun et al., 2024; Aju et al., 2024). The necessity for thorough monitoring and management measures is becoming more widely acknowledged due to the serious health hazards associated with nitrate contamination in groundwater, especially for vulnerable people. Policymakers, researchers, and communities need to collaborate on solving these issues to ensure safe drinking water and safeguard the public's health.

Ain Sukhna is a manufacturing community and tourist attraction in the northwest of the Gulf of Suez, where the Egyptian Fertilizers Company is headquartered. The research will evaluate: a) water purity; b) water chemistry; c) the causes leading to contaminated water with nitrate in the concerned area; d) the consequences on health; and e) the demand for control and oversight plans to reduce the dangers of nitrate exposure in this headquarters.

Materials and Methods

Research Area

The geographical coordinates of the EFC encompass longitudes 32° 17'-32° 18' E and latitudes 29° 37'-29° 38' N (Fig. 1). The Egyptian Geological Survey excavated groundwater wells in 1999 to uncover the subsurface strata, which indicated Quaternary deposits of 4 m thick wadi sediments, sand, and gravel covering 45 m of Upper Miocene calcareous and argillaceous sandstones. At the basal layer, a thin section of clay, sandstone, and limestone from the Middle Miocene is present, with a freshwater aquifer composed of 40 m of sandstone (Fig. 2) (Sultan et al., 2017). The average air temperature of the Ain Sukhna Zone is 36 °C in July and 9 °C in January, indicating dry conditions. In addition to the region receiving moderate yearly rainfall of roughly 60 to 75 mm, mostly in the fall and winter, the relative humidity normally ranges between 45% and 60% (Mahgoob, 2023).

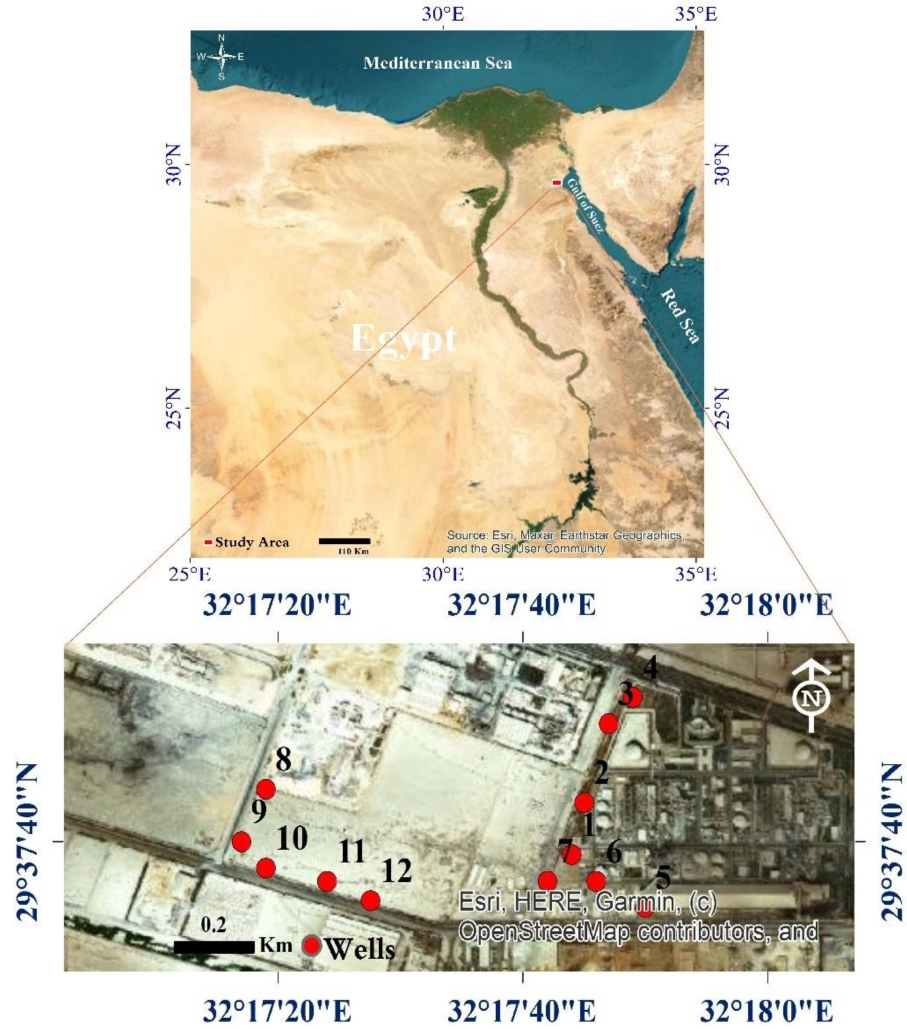

Fig. 1. Site map of the EFC area.

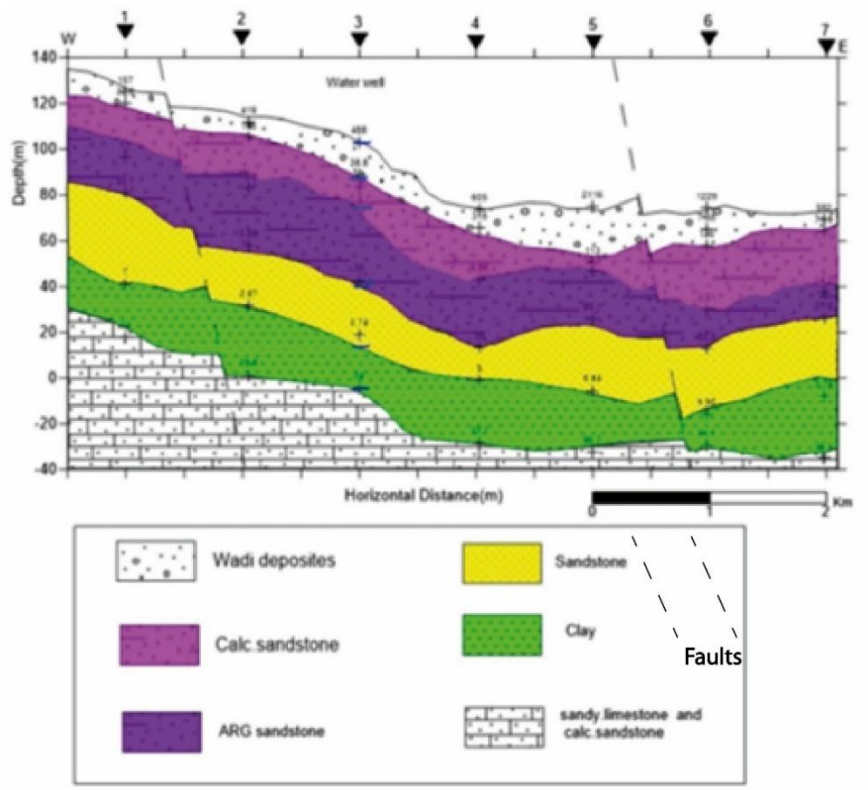

Fig. 2. Underlying geoelectrical cross-section of the research area (after Sultan et al., 2017)

Compilation of sample metrics and detection methodologies

Twelve groundwater samples were collected from EFC in June 2024 (Fig. 1), utilizing one-liter bottles that were pre-cleaned with a 1:1 diluted nitric acid solution and rinsed with distilled water. The samples underwent field preparation following standard protocols (APHA, 2017) as summarized in Table 1.

Table 1: Established procedural framework for notable ions present in the groundwater of EFC.

Parameters	Method, instrument (make)	Reagents
NO_3, NO_2 and NH_3 (ppm)	UV–Visible spectrophotometer (Spectronic 21, BAUSCH and LOMB)	Glycerol, HCl, ethyl alcohol, NaCl, $BaCl_2$, sodium sulphate Brucine-sulpanilic acid, KNO_3 and H_2SO_4

Data processing

Site maps are produced using ArcGIS software version 10.8. Statistical evaluations and graphical visualizations are conducted employing Excel version 365.

Evaluation of the risk associated with NO_3 levels in EFC subsurface water

The statistical methodology employed for the assessment of health risks utilizes quantitative techniques to evaluate the influence of hazardous water pollutants on human health. This evaluative framework encompasses hazard identification, dose-response evaluation, exposure assessment, and risk characterization (Salman et al., 2019; Asmoay et al., 2023; Asmoay et al., 2024). The present investigation examined the potential health risks associated with NO_3 in groundwater within EFC employing the widely recognized methodology established by the US-EPA (2011). The non-carcinogenic health risks were quantified utilizing Equations 1-4 (Salman et al., 2019; Asmoay et al., 2023; Asmoay et al., 2024).

$$\boldsymbol{HI} = HQ_{\ Oral} + HQ_{\ Dermal} \quad (1)$$

US-EPA has established a threshold for a non-carcinogenic hazard quotient (HQ) and hazard index (HI) of 1 (US-EPA, 2011).

$$\boldsymbol{HQ} = \frac{CDI}{RfD} \quad (2)$$

Where: *CDI* (mg.kg-1 d-1) is the consumption of daily intake; *RfD* (mg.kg-1 d-1) is the reference dose of a particular non-carcinogenic substance in water.

The primary pathways through which fluoride enters the human body include the consumption of high-nitrate water and dermal exposure to NO_3-contaminated water (Karunanidhi et al., 2024; Sun et al., 2023; Sun et al., 2024).

$$CDI_{\ Oral} = \frac{\boldsymbol{Cx\ IR\ \ x\ EF\ x\ ED}}{\boldsymbol{BW\ x\ AT}} \quad (3)$$

$$CDI_{\ Dermal} = \frac{\boldsymbol{C\ x\ SA\ x}\ K_P\ \boldsymbol{x\ EV\ x\ ET\ x\ EF\ x\ ED\ x\ CF}}{\boldsymbol{BW\ x\ AT}} \quad (4)$$

The definition and scope of various parameters employed in the EFC groundwater analysis elucidate the non-carcinogenic effects of NO_3 (Table 2) (US-EPA, 2014; Karunanidhi et al., 2024; Sun et al., 2023; Sun et al., 2024; Asmoay, 2025).

Table 2: Guidelines set by the US EPA (2014) on the subsequent coefficients.

Parametres	Significations	Children	Adults
RfD_{Oral} ($mg.kg^{-1}\ d^{-1}$)	Reference dose of a particular non-carcinogenic substance in water	1.6	1.6
RfD_{Dermal} ($mg.kg^{-1}\ d^{-1}$)	Reference dose of a particular non-carcinogenic substance in water	0.8	0.8
IR ($L.d^{-1}$)	Rate of water consumption	0.78	2
EF ($d.a^{-1}$)	Frequency of exposure	365	365
ED (a)	Duration of exposure	12	76.8
BW (kg)	Weight of residents	18.7	65
AT (d)	Life expectancy of residents	730	5475
SA (cm^2)	Skin contact surface area	1.2×10^4	1.6×10^4

K_P (cm.h^{-1})	Skin permeability coefficient	0.001	0.001
EV	Frequency of bathing	1	1
ET (h.d^{-1})	Bath duration	0.4	0.4
CF (L.cm^{-2})	Volume conversion factor	0.001	0.001

Results

The analysis results of the investigated variables are listed in Table 3. The values of various indices of the non-carcinogenic impacts are indexed in Table 4. The nitrogen cycle and non-carcinogenic ratios are depicted in Figs. 3 and 4.

Table 3: Nitrogenous ions in EFC subsurface water.

Variables	Samples Numbers												WHO Guidelines (2022)
	1	2	3	4	5	6	7	8	9	10	11	12	
NO_3 (ppm)	90	110	105	86	104	100	91	36	17	23	12	8	50
NO_2 (ppm)	2	4	1	2	1	3	6	1	2	1	1	1	3
NH_3 (ppm)	127.4	106.4	277	126	11.2	30.8	4.2	87	7	21	15.2	44	1.5

Table 4: Non-carcinogenic indices result for excess nitrate in EFC subsurface water.

Sample Numbers	Consumption of daily intake (CDI)				Hazard quotient (HQ)				Total Hazard Index (HI)	
	Oral path		Dermal path		Oral path		Dermal path			
	CDI Adults	CDI Children	CDI Adults	CDI Children	HQ Adults	HQ Children	HQ Adults	HQ Children	HI Adults	HI children
1	1.821	3.798	0.012	0.030	1.138	2.373	0.007	0.019	1.145	2.392
2	2.226	4.641	0.014	0.037	1.391	2.901	0.009	0.023	1.400	2.924
3	2.124	4.430	0.014	0.035	1.328	2.769	0.008	0.022	1.336	2.791
4	1.740	3.629	0.011	0.029	1.087	2.268	0.007	0.018	1.094	2.286
5	2.104	4.388	0.013	0.035	1.315	2.743	0.008	0.022	1.323	2.765
6	2.023	4.219	0.013	0.034	1.264	2.637	0.008	0.021	1.273	2.658
7	1.841	3.840	0.012	0.031	1.151	2.400	0.007	0.019	1.158	2.419
8	0.728	1.519	0.005	0.012	0.455	0.949	0.003	0.008	0.458	0.957
9	0.344	0.717	0.002	0.006	0.215	0.448	0.001	0.004	0.216	0.452
10	0.465	0.970	0.003	0.008	0.291	0.607	0.002	0.005	0.293	0.611
11	0.243	0.506	0.002	0.004	0.152	0.316	0.001	0.003	0.153	0.319
12	0.162	0.338	0.001	0.003	0.101	0.211	0.001	0.002	0.102	0.213

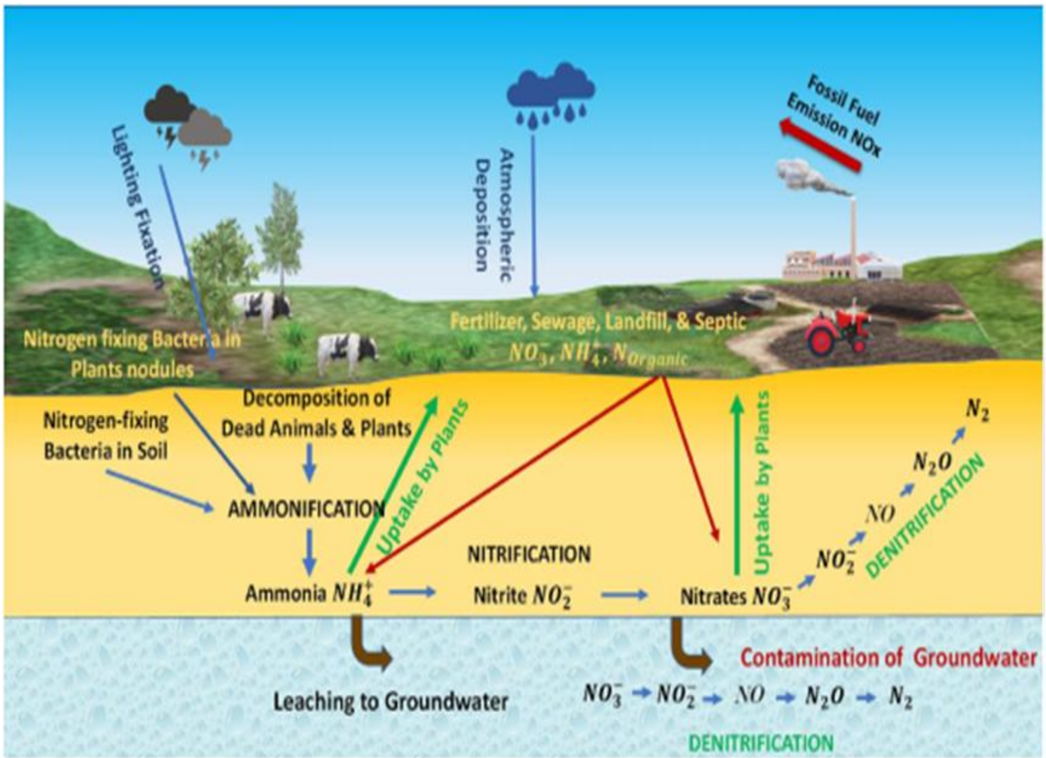

Fig. 3. Nitrogen metabolism and contamination from nitrates of groundwater (after Verma et al., 2023).

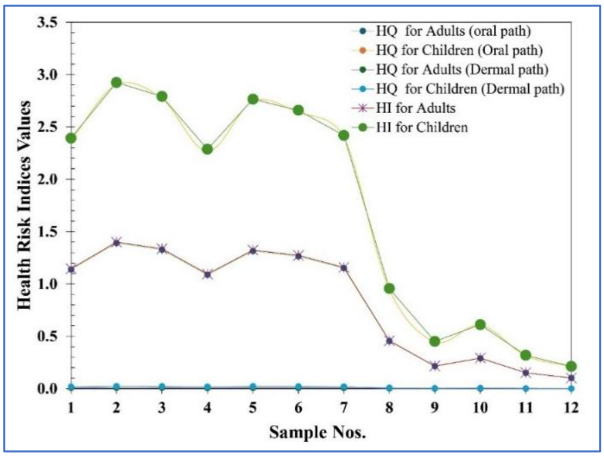

Fig. 4. Values of non-carcinogenic ratios of oral and dermal paths for individuals in water.

Discussion

Status of nitrogen ions in EFC subsurface water and their implications for health

Table 3 elucidates that nitrite (NO_3) levels exceed WHO recommendations in seven samples, while nitrite (NO_2) amounts pass the permissible limits in two samples. Ammonia (NH_3) concentrations are above the standard in all samples. Increased nitrate and nitrite levels in water may result in methemoglobinemia, especially in infants, a condition also referred to as "blue baby syndrome", which hampers the oxygen-carrying capacity of blood (Saini et al., 2024). Excessive ammonia levels in water can irritate the skin, eyes, and respiratory tract, as well as damage the liver and kidneys. Furthermore, it contributes to the eutrophication of aquatic ecosystems, leading to harmful algal blooms that can further compromise water quality and introduce additional health hazards (Saini et al., 2024). Consequently, all EFC groundwater samples are deemed unsuitable for domestic use and consumption.

Genesis of Nitrate in EFC water

The present increased levels of nitrate detected in seven wells situated within EFC denote the infiltration and amalgamation of wastewater into the groundwater system. Furthermore, the significant concentrations of ammonia are identified in the subsurface water of EFC, which are subject to conversion to NO_3 via nitrification processes, may further intensify the nitrate levels in the water (Fig. 3) (Verma et al., 2023). Consequently, the source of the elevated nitrate concentrations in the water of EFC can be ascribed to anthropogenic activities, predominantly the amalgamation with wastewater. Hence, it is imperative to evaluate the ramifications of heightened nitrate concentrations on the health of the local populace.

Overexposure to nitrate and its adverse effects on the health of EFC dwellers

Nitrate is a prominent environmental contaminant that is not only produced through natural processes but is also emitted because of various anthropogenic activities. These human-induced actions encompass the production and application of nitrate fertilizers, the combustion of fossil fuels, which contributes to atmospheric deposition, as well as the discharge from both residential and industrial wastewater treatment systems, alongside alterations in nitrogen-fixing crops within natural ecosystems (Sun et al., 2023; Verma et al., 2023; Karunanidhi et al., 2024; Sun et al., 2024). In many natural aquatic systems, nitrate constitutes a significant component of the ionic balance. Due to its detrimental effects on human health at elevated levels, NO_3 ions are incorporated into international regulations and guidelines (Karunanidhi et al., 2024; Sun et al., 2024). Nevertheless, prolonged exposure to heightened concentrations of nitrate can lead to severe health risks in children, including methemoglobinemia, commonly referred to as blue baby syndrome, and increased incidence of stomach cancer in adults (WHO, 2022; Sun et al., 2023; Verma et al., 2023; Karunanidhi et al., 2024; Sun et al., 2024). The research findings indicate that the oral ingestion of nitrate-contaminated water yields higher Chronic Daily Intake

(CDI_{Oral}) values for both adults and children compared to dermal exposure (CDI_{Dermal}) for both demographics (Table 4 and Fig. 4). Moreover, oral exposure (hazard quotient, HQ) to excessive nitrate has a more pronounced impact than cutaneous exposure, particularly among children (Table 4 and Fig. 4). The Hazard Index (HI) values for both adults and children exceed the US-EPA unitary standard in seven samples (Table 4 and Fig. 4). This underscores the fact that the health of children is disproportionately affected by the non-carcinogenic effects of nitrate compared to that of adults. These findings are consistent with the research regarding nitrate impacts in water across India (Pasupuleti et al., 2022; Karunanidhi et al., 2024).

When the nitrate content in EFC subsurface water is modified into carcinoma

Nitrate amounts in potable water that may induce carcinogenic effects typically fall below the existing regulatory limit established by the WHO of 50 mg/l and the US-EPA threshold of 10 mg/l (WHO, 2022; US-EPA, 2014). Empirical evidence suggests that even diminished levels can correlate with an augmented risk of various malignancies. Within the human body, nitrate can be reduced to nitrite and other N-nitroso derivatives, which are recognized as potentially carcinogenic (Espejo-Herrera et al., 2015; Schullehner et al., 2018; Essien et al., 2020; Su et al., 2021; Donat-Vargas et al., 2023). Specifically, nitrate exposure has been linked to colorectal cancer at concentrations exceeding 20 mg/l, gastric cancer at levels above 88 mg/l, bladder cancer at more than 5 mg/l, and prostate cancer at above 13.8 mg/l (Espejo-Herrera et al., 2015; Schullehner et al., 2018; Essien et al., 2020; Su et al., 2021; Donat-Vargas et al., 2023). Therefore, if the nitrate concentration in EFC subsurface water possesses the potential to be converted into nitrite, it may subsequently pose a carcinogenic threat.

Conclusion

Egyptian Fertilizers Company predominantly utilizes groundwater for its daily operations, necessitating a thorough assessment. Elevated nitrate levels in water, when ingested, exceed the UE-SPA standards regarding non-carcinogenic effects (1) for both adults and children, although dermal exposure is considered safe for both demographics. Elevated nitrate concentrations in water can lead to health complications, potentially resulting in cancer if converted to nitrite and other N-nitroso compounds through bacterial nitrification processes. This can trigger methemoglobinemia, commonly known as blue baby syndrome, and a heightened risk of cancers in the stomach, bladder, gastric region, prostate, and colorectal areas. Consequently, water samples contaminated with nitrate, nitrite, or ammonia require treatment to mitigate the complex health risks posed to residents.

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Conflict of Interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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