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Impact of Flood-Irrigated Sugarcane Monoculture on Groundwater Quality in the Nile Alluvial Soils

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ABSTRACT

Sugarcane is an economic crop and one of the most dominant crops worldwide. This research aim was to evaluate impacts of long-term sugar cane monoculture on some groundwater physicochemical and biological properties as indicators of water quality. Survey study covering sugar belt area of El-Minia Governorate, Egypt was conducted. This study revealed that suitability of groundwater for irrigation falls under the degree of "severe" use restriction, and continuous use of this groundwater for irrigation may increase the salinity problem in the alluvial soils. Groundwater was highly contaminated by total coliforms, *E. coli* and faecal coliform bacteria under both sugar cane monoculture and crop rotation agricultural systems. The total coliforms population ranged from 360 to 362,Cfu/100 mL, the fecal coliforms population ranged from 212 to 215 Cfu/100 mL and the *E. coli* population ranged from 248 to 256 Cfu/100mL with insignificant differences between both agricultural systems. Under sugarcane monoculture, average concentrations of cadmium, chromium, nickel and lead in groundwater was 60, 1220, 1320, and 1250 μg/L, while the average concentrations of cadmium, chromium, nickel and lead were 57, 1220, 1350, 1230 μg/L under crop rotation with insignificant differences. The mean concentration of heavy metals observed in groundwater samples often exceeded the permissible limits for irrigation water specified by the World Health Organization (WHO). Based on these findings, it can be inferred that sugarcane monoculture has greatly degraded the quality of groundwater characteristics. This highlights the pressing need for implementing more sustainable management strategies to safeguard groundwater quality in the Nile Valley.

Keywords: Sugarcane Monoculture, Heavy Metals, Water Quality.

INTRODUCTION

Water resources sustainable management in Egypt, are considered a strategic priority due to continuous increase of population and limited fresh water. Also, poor maintenance of fresh water and low irrigation efficiency and fertilization systems bring about a tangible burden on the Egyptian available natural resources (Abd El-Azeim et al., 2023). Inappropriately, impacts of irrigated sugar cane monoculture on water quality environments, ecosystem services and small-scale farmers welfare have not been scientifically approached in arid countries (Abo Shelbaya, et al., 2021a; Abo Shelbaya, et al., 2021b) even though the literature and methodology has been highlighted recently in ample scientific studies on sugar cane monoculture systems all over the tropical countries (Brazil, India, Ethiopia, Thailand, Indonesia) (Bordonal, et al., 2018). Accordingly, the appropriate management of irrigated sugar cane monoculture and intermittent monitoring of aquatic quality parameters are mandatory to guarantee secure long-term irrigated sugar cane farming systems (Abo Shelbaya, et al., 2021a). Subsequently, aquatic environments have received extensive attention in recent years. Increased population and climate change have forced the Egyptian authorities to concentrate on the present and future sustainability of their natural resources in light of the contemporary situation of water scarcity (Abo Shelbaya, et al., 2021b; Abd El-Azeim et al., 2022).

Sugar cane (*Saccharum officinarum* L.) is a perennial crop cultivated for sugar production and is also a crucial energy and forage crop species native to tropical environments of South Asia, albeit it is now cultivated in more than one hundred nations round the world (FAO, 2019; Daniel, et al., 2020; USDA, 2020). Global production raised from just under 448 million tonnes harvested over about 8.9 million hectares in 1961 to more than 1.9 billion tonnes on about 27 million hectares. Whereas, Brazil has been for years now the world sugar cane producer by 39.0% of world production in 2017 (FAO, 2019; Zulu et al., 2019; USDA, 2020). India is the second biggest world producer, by 15.7% of world's total production. Guatemala and Peru had respectively the highest sugar cane productivity level at around 121 t ha^{-1} (FAO, 2019; USDA, 2020; Abo Shelbaya, et al., 2021b).

Approximately 28.3 million hectares of sugar cane are grown in more than 100 countries with a total production of about 1.69 billion tons worldwide (Zulu et al., 2019; Abo Shelbaya, et al., 2021a). Sugar cane has been grown in Egypt since the year 710, and the sugar industry is one of the oldest industries in Egypt (Hassan and Nasr, 2008; Ahmed, et al., 2013). In 2019, Egypt's sugar cane output amounted to 1100 tons, representing a significant rise from 408 tons in 1970. This indicates an average yearly growth rate of 2.32% for the specified period (USDA, 2019). The Egyptian sugar industry contributes strongly to the country's economy, especially to rural income and local employment in Upper Egypt. However, at the agricultural level, sugar cane and sugar production still face problems related to yield, production cost, purchase price, and management practices (USDA,

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2020; Abo Shelbaya, et al., 2021b). El-Minia Governorate is a chief sugar cane farming area in Egypt and irrigation water allocated for sugar cane is much bigger than other staple crops, and accordingly drainage water amounts are hefty as well. The Eatsa sewage and drainage pumping station was established in 1902 to dispose of sewage and drainage waters in an area of 188,000 acres on the Nile River.

The existence of heavy metals in waterbodies similarly affects some physical, chemical and biological properties like biological and chemical oxygen demand (COD and BOD) which become detrimental to the aquatic organisms when they surpass certain limits (Alloway, 2013). Water resources in Egypt is by now informed to be affected by heavy metals and physical and chemical properties like NO_3-N total P and COD and BOD beyond global standards levels (Elbana et al., 2019; Haddad et al., 2019; Said et al., 2019). Therefore, the need to determine their point sources is critical since these levels were partly responsible for hyacinth growth in all these watercourses. High nutrient loads can lead to variations in water quality parameters and heavy metal concentrations in aquatic environments (Elbana et al., 2019; Said et al., 2019). Therefore, there was a need to determine pollution point sources of this sugar cane farming systems in order to suggest possible mitigation procedures and alternative management strategies that maximize agronomic benefits and maximize environmental impacts.

Sugarcane is an important and staple crop worldwide due to its multiple nutritional and industrial uses in food and economy in addition to its widespread use in the daily life of small farmers and workers in rural areas. El-Minia Governorate is a chief sugar cane farming area in Upper Egypt, as the sugarcane monoculture system is the dominant agricultural practice alongside the Nile riverbank of five Governorates in Upper Egypt notably El-Minia, Sohag, Qena, Aswan and Luxor. Yet, nothing is acknowledged about the consequences of sugar cane production on water quality. Sugar cane monoculture near the Nile River in Abu-Qurqas area were used to depict sugar cane cultivation in the major Egyptian sugar belt. Sugar cane monoculture system is the major farming technique near the Nile riverside of Abu-Qurqas district, El-Minia Governorate. Yet, little is known about the consequences of irrigated sugar cane growing on groundwater quality in Egypt. Such data is of special value to both sugar cane small-scale farmers and to environmental protection decision-makers responsible for sustainable use of water resources in irrigated sugar cane producing regions.

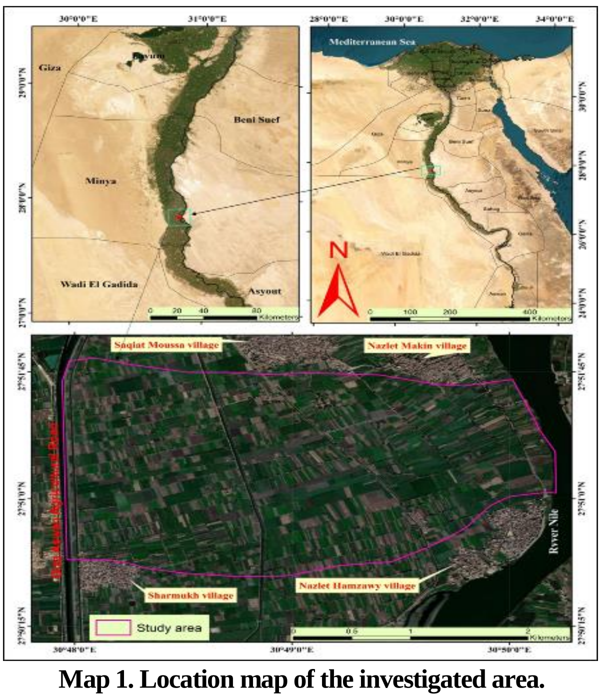
This information would be beneficial unless comparisons were conducted between monoculture system of sugar cane and the other main crop rotation agricultural system in the Governorate and uncultivated regions (control). In this study, impacts of long-term sugar cane monoculture on some groundwater physicochemical and biological properties as indicators of quality were examined under different agricultural systems of sugar cane monoculture, crop rotation system and uncultivated virgin soil as a control. Specifically, objectives were to determine some groundwater quality indicators such as levels and variations of heavy metal loads Cd, Cr, Ni, Pb, physicochemical and biological parameters viz. pH, BOD, COD, total soluble anions and cations, EC, and SAR in groundwater samples under irrigated sugar cane monoculture system. Therefore, the aim of this research was to evaluate the impacts of long-term irrigated sugarcane monoculture on water quality parameters under arid conditions to develop best management strategies that espouse agronomic benefits and protection of the aquatic environment under this farming system.

MATERIALS AND METHODS

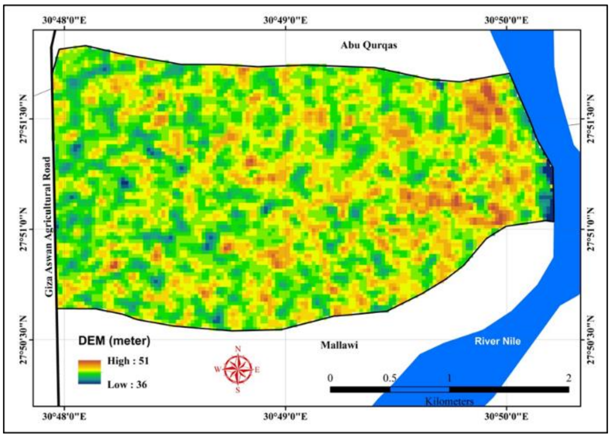
Study area and data collecting.

Studied area is situated in Upper Egypt within the narrow Nile Valley and between the Western and the Eastern deserts as a part of El-Minia Governorate. It locates between 30° 47′ 57″ to 30° 50 ′ 13 E and 27° 50′ 32″ to 27° 51′ 50″ N, covering an area of about 710 hectares as illustrated in map (1). Digital elevation model of the studied area (Map 2) illustrated that the elevation of the investigated area ranged between 36 and 51 m ASL. The dominant slope (Map 3) in the study area is varied between flat (0-0.2%) to very gently sloping (1-2%), whereas some small areas ranged from gently sloping (2-5%) to strongly sloping (10-15%). A section of Abu-Qurqas district was carefully picked as it is one of the largest sugar cane monoculture regions plus its vicinity to New Abu-Qurqas Sugar Factories. Also, Abu-Qurqas sugar cane growing belt was selected since this area is part of the rich alluvial soils of the Nile Valley and contains many small farmers who have used monoculture methods of sugar cane for long durations. A survey study spanning this region was done to examine implications of long-term sugar cane monoculture on various water physicochemical and biological parameters as indicators of water quality.

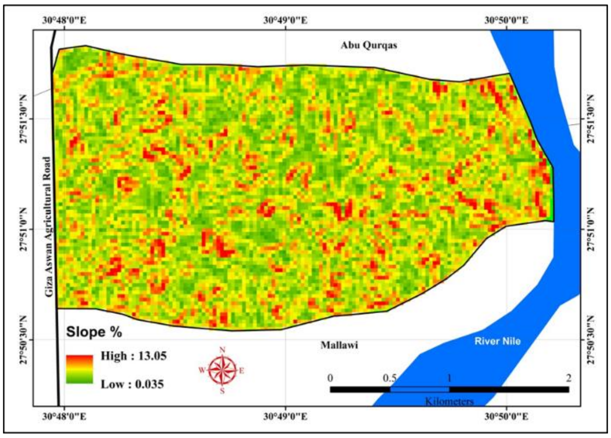
This research region is classified as an arid zone because of its desert environment, which is hot and dry in the summer and chilly in the winter. A national meteorological station provided average climate data over the previous five years, indicating that summer temperatures average about 36.68 ºC, winter temperatures average about 6.08 ºC, and humidity ranges from 55 to 87% year-round. In January and February, there is a chance of frost at night, thus the temperature might drop below zero. The yearly precipitation is just around 2.0 mm, and the only year when rainfall surpassed 53 mm was in 2023, suggesting that the phenomena of climate change may be the cause of the change.



Map 1. Location map of the investigated area.



Map 2. Digital elevation model of the study area.



Map 3. Slope map of the study area.

In the region under investigation, before achievement of the experiment data were obtained by interviewing small sugar cane farmers and the extension officials of the agricultural groups positioned in the research area. A questionnaire was administered to field interview participants in order to record information about agricultural inputs, production costs and yield, irrigation water resources and techniques, fertilization management, varieties of sugar cane, tillage, postharvest treatments, land ownership and acreage, and, lastly, the reasons for adopting the sugar cane monoculture area under investigation. A survey study covering this area using completely randomized block design with two factors (sugarcane monoculture and crop rotation systems) was used in sampling. Triplicate samples were collected randomly from 15 irrigation water wells that pass through each agricultural system of sugarcane monoculture and crop rotation to determine investigated groundwater quality indicators. As sampling was done twice a year for two years of 2021 and 2022, average of four replicated samples was calculated regarding all water quality parameters investigated.

In sugar cane monoculture and crop rotation farming systems, mineral fertilizers, especially nitrogen, phosphate and potash are being applied to an increasing extent. In Egypt, small-farmers of sugar cane or crop rotation systems fertilize mostly depending on their own expertise and buying ability. Farmers apply significant quantities of NPK fertilizers into agricultural fields to assure high yield as they feel that high input equals a high output. Intensive use of organic and inorganic fertilizers and pesticides distinguishes these farms in addition to the usage of gypsum for pre-cultivation field preparation. The crop rotation agricultural methods are generally maize/berseem/wheat rotation and vegetable/medicinal plants /berseem, although the management pattern of the latter includes occasionally greenhouse or open-air planting for vegetables. Generally, researched sugar cane and crop rotation farms are irrigated with groundwater recovered from various distributed pumping wells pertaining to the Nile groundwater aquifer. Usually, sugar cane in Egypt is picked manually and when harvesting sugar cane crop leaves behind large volumes of waste. There are no other important anthropological activities other than agricultural activities in this region that affect soil and aquatic environmental degradation and pollution.

Groundwater quality analyses and characteristics.

Fifteen water samples were gathered from wells of groundwater available for irrigation of sugar cane fields or crop rotation and examined to assess its appropriateness for irrigation and to predict reciprocal effects between sugar cane monoculture and groundwater quality. A water sample was collected from the Nile River as a reference sample analysis. During each irrigation event, water samples were obtained using a sterile plastic container that had been cleaned and dried. The samples were then filtered and kept at a temperature of 4.0 °C until they could be analyzed. The analysis was either conducted immediately or the samples were conserved following the guidelines set by the American Public Health Association (APHA, 2012). Groundwater samples were analyzed according to standard methods of the American Public Health Association (APHA, 2012).

General water analytical determination and analyses.

Sodium Adsorption Ratio (SAR).

Sodium Adsorption Ratio (SAR) is calculated by the following formula, where the concentrations are expressed in meq/L as reported in (Richards 1954).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

Residual Sodium Carbonate (RSC).

Residual Sodium Carbonate (RSC) calculation may be performed using the following formulae in (meq/L), as stated by Eaton (1950).

$$\mathrm{RSC} = (\mathrm{Hco_3^{-1}} + \mathrm{Co_3^{-2}}) - (\mathrm{Ca^{+2}} + \mathrm{Mg^{+2}})$$

Magnesium Hazard

The method for calculating magnesium hazard values, when concentrations are stated in meq/L, is provided by (Szabolcs and Darab, 1964).

$$\mathrm{Mg\ ratio} = \frac{\mathrm{Mg^{+2}}}{(\mathrm{Ca^{+2}} + \mathrm{Mg^{+2}})} \mathrm{X100}$$

Permeability Index

The Permeability Index formula has been proposed by Doneen (1964), where the concentrations are expressed in meq/L.:

$$\mathrm{Pi\%} = \frac{(\mathrm{Na^{+1}}\sqrt{\mathrm{Hco_3^{-1}}})}{(\mathrm{Ca^{+2}} + \mathrm{Mg^{+2}} + \mathrm{Na^{+1}})} \mathrm{X\ 100}$$

Kelly's Ratio

The calculation of Kelly's ratio may be determined using the following formulae, with the concentrations represented in meq/L (Kelley, 1951):

$$\mathrm{KI} = \frac{\mathrm{Na^{+1}}}{(\mathrm{Ca^{+2}} + \mathrm{Mg^{+2}})}$$

Chloro-alkaline Indices

Schoeller (1967) developed the following method to compute the value of Chloro-alkaline indices (CAI), with all concentrations reported in meq/L:

$$CAI = \frac{(CL^{-1} - (Na^{+1} + K^{+1}))}{Cl^{-1}}$$

Sodium Percentage

According to Negm and Armanuos (2017), the concentrations of sodium ions are represented in meq/L using the following formula.:

$$Na\,\% = \frac{(Na^{+1} + K^{+1})}{(Ca^{+2} + Mg^{+2} + Na^{+1} + K^{+1})} X\,100$$

Water bacteriological indicators analyses

Bacteriological indicators analyzed in irrigation water samples included faecal streptococci, E. coli, total coliforms, and faecal coliforms, as stated by APHA (2005). The data were represented as coliform forming units (CFU)/100 mL.

Water heavy metals analyses.

To determine heavy metals concentration of collected water samples, 60 mL of water was filtered for measurement of total contents of Cd, Cr, Ni, and Pb by (7700e ICP-MS) with detection limits of Cd 0.02 µg/L, Cr o.2 µg/L, Pb 0.5 µg/L and Ni 2 µg/L, in accordance with Liu and Ma (2020). For quality assurance and quality control (QA/QC), blanks and triplicate samples were processed for every 10 samples and the relative standard deviations of triplicate samples were less than 10%. To guarantee excellent accuracy and to look for any errors during the laboratory analysis, internal reference standard materials and reagent blanks were also used (Tegegne, 2016).

Statistical Analysis

The mean of three replicates was used to generate the research data. Using SPSS for Windows, SPSS, Inc., Chicago, USA, analysis of variance was performed, and Duncan's test was used to differentiate the means of three replicates based on the least significant difference ($P < 0.05$).

RESULTS AND DISCUSSIONS

The purpose of this study was to assess reciprocal impacts between sugar cane monoculture and quality of groundwater used for Irrigation. Irrigation groundwater quality was assessed mainly by pH, (EC), main soluble anions and cations, sodium adsorption ratio (SAR), Ca^{2+}/Mg^{2+} Ratio, sodium percentage (Na%), magnesium hazard (MH%), permeability index (%), Kelly ratio, residual sodium carbonate (RSC), Chloro-alkaline indices (CAI), COD, BOD and water heavy metals content and some water pathogenic bacterial indicators.

Effects of sugar cane monoculture on groundwater quality.

Table 1 shows the results on the characteristics of irrigation groundwater water quality of crop rotation farming systems and sugar cane monoculture. Typically, no significant variations in the most studied groundwater quality indicators were found between crop rotation and sugar cane monoculture. Regardless of various land uses, the suitability classes of groundwater remained at the same categories despite little and minute changes in the chemical composition and parameters of the water.

Table 1. Effects on irrigation groundwater quality of crop rotation systems and sugar cane monoculture.

Water Property				
Water chemical properties*		**Nile River**	**Groundwater quality**	
			Sugar cane monoculture	**Crop rotation**
pH		7.30 a	8.09 b	8.19 b
EC (dS m^{-1})		0.83 a	4.69 b	4.49 b
Soluble Anions ($mmolc\ L^{-1}$)	($HCO_3 + CO_3$)	4.5 a	11.13 b	11.11 b
	Cl^-	3.32 a	27.66 b	27.63 b
	SO_4^{2-}	1.32 a	23.83 b	23.82 b
Soluble Cations ($mmolc\ L^{-1}$)	Ca^{2+}	3.55 a	15.48 b	16.47 b
	K^+	0.82 a	0.59 b	0.59 b
	Mg^{2+}	2.89 a	16.88 b	17.89 b
	Na^+	5.78 a	40.78 b	39.79 b
Sodium adsorption ratio (SAR)		3.22 a	10.13 b	9.59 c
Magnesium Hazard (M.H%)		44.87 a	52.16 b	52.06 b
Ca^{2+}/Mg^{2+} ratio		1.22 a	0.91 b	0.92 b
Na^+/Cl^- ratio		1.74 a	1.47 b	1.44 b
Sodium percentage (Na %)		50.16 a	56.11 b	54.02 c
Permeability index (%)		64.65 a	60.31 b	56.15 c
Kelly ratio (KI)		0.89 a	1.26 b	1.15 b
Residual sodium carbonate (RSC)		< 1.25	< 1.25	< 1.25
Chloro-alkaline indices (CAI)		-0.49	-0.49	-0.46
Water oxygen demand (mg/L)				
COD mg/L		16.33 a	12.73 b	11.87 b
BOD mg/L		9.80 a	6.46 b	7.33 b

*** Figures followed by the same letters through entire rows are insignificantly different at <5% probability level.**

Results showed that groundwater is not suitable for irrigation under either of the two agricultural farming systems. It also falls into the same category with regard to nearly all of the suitability features that determine the water quality for irrigation, including the main soluble anions and cations, the Ca^{2+}/Mg^{2+} ratio, the magnesium hazard (MH%), the Na^+/Cl^- ratio, the sodium percentage (Na%), and the permeability index (%). In contrast, the study's findings on the water reaction (pH), residual sodium carbonate (RSC), and chloro-alkaline index (CAI) suggested that groundwater is acceptable for irrigation. While the typical pH range of irrigation water is between 6.5 and 8.4, employing this water source for soil irrigation might lead to imbalances in nutrients or changes in soil pH. According to the water suitability characteristics for irrigation, these values fall into the category of "Severe" restrictions on usage. Utilizing such water for irrigation may lead to a long-term rise in salt issues in the examined soil, as shown by Ayers and Westcot (1994). Comparatively, the findings suggested that the water from the Nile River is appropriate for irrigation based on the criteria that determine water quality for irrigation (Water for surface Irrigation, FAO 1985).

Under both agricultural systems, the magnesium hazard index varied from 52.06% to 52.16%; a magnesium ratio of more than 50% in irrigation water is thought to be toxic to plants and harmful to the qualities of the soil (Abd El-Azeim et al., 2023). Moreover, elevated exchangeable Na^+ in irrigated soils caused by high Mg^{2+} concentrations in irrigation water raise the magnesium hazard index, which may harm soil structure and have an adverse effect on crop yields and soil quality in the present research region owing to elevated alkalinity. Kelly's ratio (KI), which is based on the amount of Na^+ measured against Ca^{2+} and Mg^{2+}, is also used to evaluate the appropriateness of groundwater for irrigation (Kelly 1951). Any groundwater with a KI greater than 1.0

should not be used (Narsimha et al., 2013). Na^+/Cl^- ratios greater than one are generally found in groundwater samples from both farming systems, suggesting that both have detrimental effects on irrigation water and that repeated, intense irrigation with such water has a high effect on sodium and chloride levels in agricultural soil (Abd El-Azeim et al., 2023). Due to increased irrigation water salinity levels associated with the lack of drainage as well, higher levels of salinity associated with intensive irrigation under sugar cane monoculture also significantly increased the initial soil electrical conductivity, soil salinity build up, and soil pH (Abo Shelbaya et al., 2021a and 2021b).

The monitoring locations of the Abo-Qurqas irrigation groundwater wells have Chemical Dissolved Oxygen (COD) values ranging from 11.87 to 12.73 mg/L, and Biological Dissolved Oxygen (BOD) values ranging from 6.46 to 7.33 mg/L. The majority of the DO measurements along groundwater wells above the EG legislation 48/1982 threshold by more than 6 mg/L. The quantity of oxygen that is readily accessible in water for the flora and animals that live in the water system is measured by dissolved oxygen (DO). Surface water's dissolved oxygen (DO) may vary from 0 in really bad water conditions to a maximum of 15 mg/L in very good water. Temperature, salinity, turbulence, and the photosynthetic activity of plants and phytoplankton all affect how much oxygen is present in natural water. The Nile water or groundwater used for irrigation in the Abo-Qurqas area seems to be somewhat healthier water bodies in terms of oxygen availability, based on the Dissolved Oxygen (DO) level.

The sustainable monoculture system of sugar cane is under threat due to intensive irrigation and fertilization management practices as well as burning crop residues before or after harvest that has degraded soil and natural water resources (Ouda, 2016; Zulu et al., 2019; Abo Shelbaya, et al., 2021b). In Egypt, water and soil productivity is declining due to sugar cane cultivation systems in some areas and has reached a steady level in some other areas due to the overexploitation of natural resources and agrochemicals (Ouda, 2016; Zulu et al., 2019; Abo Shelbaya, et al., 2021a and 2021b). According to Abo Shelbaya et al. (2021a and 2021b), despite the introduction of new, improved sugar cane varieties and advancements in agricultural practices, average yields of sugar cane have stagnated at around 100.0 tons per hectare over the past ten years, suggesting no apparent productivity gains. One of Egypt's primary sugar canes producing locations is El-Minia Governorate. Notably, sugar cane monoculture requires much more irrigation water than other crops, which means that drainage water requirements are correspondingly high (Ouda 2020; Abo Shelbaya, et al., 2021a).

Also, Abo Shelbaya et al. (2021), reported that Egypt utilizes long-term sugarcane monoculture for sugar production, which involves frequent, intense surface irrigation and abundant quantities of agrochemicals. The impact of these agricultural methods on the agroecosystem should be continuously assessed. in Egypt, causes of arable soil contamination comprise the intensive use of agrochemicals, recycling of agricultural drainage waters, reuse of partly treated wastewater, polluted air, and improper disposal of solid wastes. These several resources pose a real danger to the sustainability of different farming systems and human health (Abd El-Azeim et al., 2016; Cheruben et al., 2016; Haddad et al., 2019; El-Ramady et al., 2019; Abd El-Azeim et al., 2022).

Effects of sugarcane monoculture on some bacterial indicators of groundwater quality.

In the groundwater samples under both sugar cane monoculture and crop rotation agricultural systems, the total coliforms population ranged from 360 to 362, Cfu/100 mL, the fecal coliforms population ranged from 212 to 215 Cfu/100 mL and the *E. coli* population ranged from 248 to 256 Cfu/100 mL with insignificant differences. Whereas, the total coliforms, the fecal coliforms and the *E. coli* population, recorded zero in all Nile water samples (Table 2).

Table 2. Effects of sugar cane monoculture and crop rotation farming systems on water microbial status as indicators of irrigation groundwater quality.

Water Microbial Property			
Water Microbial Indicators (Cfu/100 mL)**	**Nile River**	**Groundwater quality**	
		Sugar cane monoculture	**Crop rotation**
Total Coliforms Cfu/100 mL	*Nd	362 a	***360 a
Fecal Coliforms Cfu/100 mL	Nd	215 a	212 a
E. Coli Cfu/100 mL	Nd	256 a	248 a

***Nd: not detected; **Cfu: colony forming unit. *** Figures followed by the same letters through entire rows are insignificantly different at <5% probability level.**

There were no bacteriological indicators detected in the Nile River water. The groundwater was extremely contaminated by total coliforms, *E. coli* and fecal coliforms under both farming systems. Our investigations into the groundwater wells in the region under investigation yielded data that indicated many samples had values above the national regulations governing the quality of water used for agriculture and drinking. The finding has significance since fecal coliforms are often linked to the existence of other infections that pose a threat to human health (Letshwenyo and Mokokwe, 2020). Despite significant agricultural inputs, output decreases in the following years under sugar cane monoculture (Abo Shelbaya et al., 2021a and 2021b). Plant production is often influenced by the microbial population in the rhizosphere, especially the bacteria and fungi that interact with the root system. To increase the production of sugar cane, the soil microbial community must be managed (Chandra et al., 2021).

The detection of coliform bacteria in groundwater suggests that point sources, such as human and animal waste, have polluted the water instead of agricultural systems. Another cause is pollution from sewage systems, particularly in rural regions. According to Mallin et al. (2000), the most typical sign of fecal contamination is the release of sewage from municipalities that contains harmful bacteria and fecal coliform, particularly E. coli (Letshwenyo and Mokokwe 2020). Additionally, research on the microbial loading of food crops and soils irrigated with contaminated water has shown varying coliform loading (Abo Shelbaya et al., 2021a and b). In research on the build-up of microbiological pollutants in various plant parts and soil, Letshwenyo and Mokokwe (2020) found elevated levels of TC and *E. Coli* in the soil and plant roots that were watered with contaminated water.

The majority of the groundwater samples' average *E. Coli* and total coliform readings were higher above the allowable threshold limits for National Water Quality Standards for groundwater, according to the Environmental Protection Agency (USEPA 2005). These findings suggested that there may be a significant health risk to humans and plants from fecal pollution of groundwater. In general, residents in rural communities around the Nile River in Upper Egypt often dump human wastes, animal wastes, agricultural wastes, and home wastewaters into groundwater and water channels (Martinez 2009). Accordingly, there is a high risk of microbial contamination of Egypt's water supplies due to these effluents (Abo Selbaya et al., 2021a and 2021b).

In Egypt, 90% of the population lives in rural parts of Upper Egypt without access to sewage systems or wastewater treatment facilities. Additionally, water supply and sanitation services are not developed concurrently in Egypt. The most popular disposal location is a sewage chamber or septic tank, where the groundwater nearby is directly connected to the tank's bottom. This local sewage disposal technique turns it into a point source of pathogen, heavy metal, nitrate, and phosphate contamination (Figure 1). As a consequence, local pathogen contamination at many distinct irrigation wells leads to low water quality. Shallow groundwater samples taken near this septic chamber indicate that there is a substantial danger of pathogen contamination in these sources (Shamrukh and Abdel-Wahab, 2011). In summary, it is evident that the primary obstacle to the sustainability of Egypt's water resources is the management of water pollution through the implementation of laws pertaining to the treatment of domestic and industrial wastewater, the promotion of organic farming, and the restriction of the use of chemical pesticides and fertilizers in agriculture.

Graded sand and gravel make up the thick layer of the Nile aquifer, which is coated in a silt-clay layer and supported by impermeable clays from the Pliocene. Seepage from irrigation canals and the sewage system, as well as infiltration from overabundance of water applied to crops, are the major sources of recharge. Aquifer discharge occurs by groundwater extraction via wells and seepage into the River Nile. Soil minerals including iron and manganese naturally dissolving in water, home wastewater, and agrochemicals are the primary causes of contamination entering the Nile aquifer (Shamrukh and Abdel-Wahab 2011).

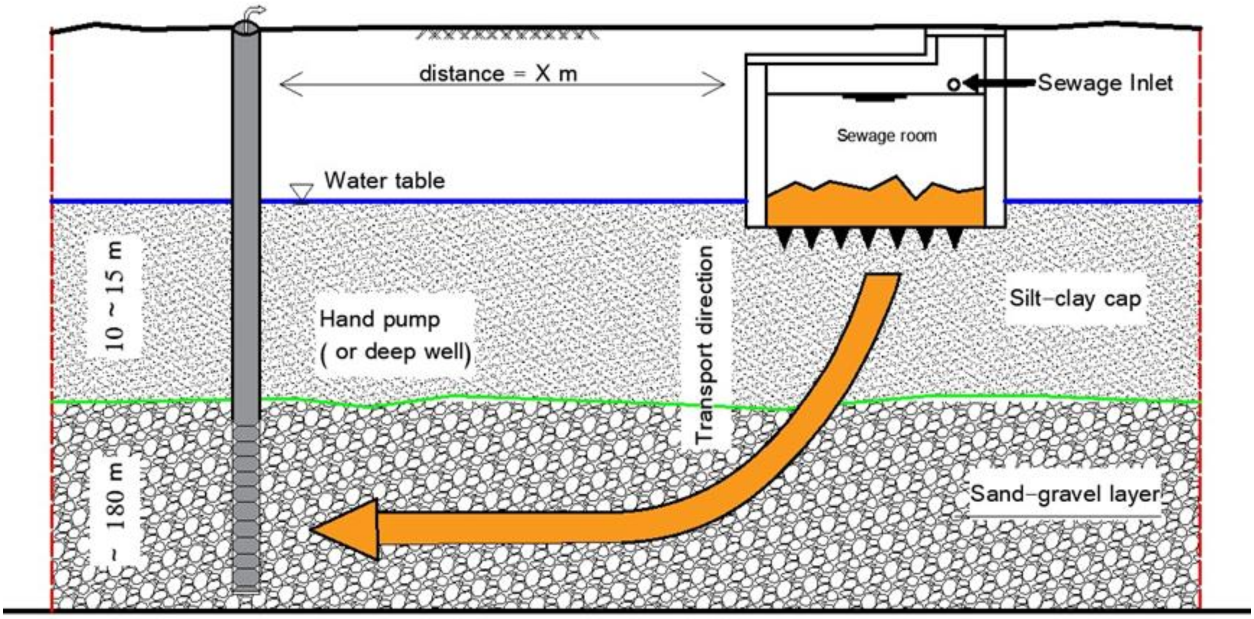


Figure 1. Schematic diagram of groundwater contamination in Egypt caused by septic tanks.

Overall, soil rhizosphere microbes are essential to plant survival and nutrition, either directly or indirectly. For this reason, examining the composition of the bacterial community is an essential part of research, particularly for crops like sugar cane that grow in multiple cycles (Chandra et al., 2021). During the past few decades, Egypt's inhabitants has triplicated while available renewable water and arable soils resources have remained unchanged. The obvious deterioration in the quality of groundwater in Egypt is a source of great concern for agricultural uses, industrial and domestic (El-Rawy et al., 2019; El-Ramady, 2019; Abo Shelbaya, et al., 2021b). Sugar cane monoculture in Upper Egypt governorates depends mainly on groundwater for irrigation although these governorates are situated in conjunction with the Nile River and irrigation water is apparently available but shortage in the irrigation infrastructure has led to intensive usages of groundwater. In the past twenty years, farmers in these governorates have fitted many pumping wells for irrigation and drinking purposes.

This is associated with a larger expansion in sugar cane monoculture driven by increasing poverty in rural areas (El-Rawy et al., 2019; Abo Shelbaya, et al., 2021b). Therefore, it is necessary to assess the suitability of groundwater for potable water and irrigation purposes to avoid potential health risks and agricultural environmental catastrophes owing to monoculture procedures for sugar cane (Abd El-Azeim et al., 2023).

Effects of sugarcane monoculture on groundwater heavy metals content.

One of the main objectives of this study was to assess level of heavy metals in groundwater under sugar cane monoculture land use for long term. The concentrations of the heavy metals in the groundwater under both sugar cane monoculture and crop rotation are shown in Table 3.

Table 3. Effects of sugar cane monoculture and crop rotation farming systems on water heavy metal concentrations as indicators of irrigation groundwater quality.

water heavy metal concentrations µg L^{-1})			
Heavy Metals Concentration (µg L^{-1})	**Nile River**	**Groundwater quality**	
		Sugar cane monoculture	**Crop rotation**
Cd µg L^{-1}	ND*	60 b	57 b
Cr µg L^{-1}	ND	1220 b	1220 b
Ni µg L^{-1}	ND	1320 b	1350 b
Pb µg L^{-1}	ND	1250 b	1230 b

***Nd: not detected; Figures followed by the same letters through entire row is insignificantly different at <5% probability level.**

From these results, the concentration of heavy metals in the groundwater were above the national threshold values for irrigation water (Abd El-Azeim et al., 2016). Under sugar cane monoculture fields, the mean concentrations of Cd, Cr, Ni and Pb in the groundwater were 60, 1220, 1320, 1250 µg L^{-1}, while the mean concentrations of Cd, Cr, Ni and Pb were 57, 1220, 1350, 1230 µg L^{-1} under crop rotation fields with insignificant differences. In water samples, the average quantity of heavy metals was found to be high, often above the World Health Organization's (WHO) allowable limits for irrigation water. Zinc, arsenic, cadmium, copper, lead, cadmium, mercury, nickel, and chromium are important heavy metals with regard to heavy metal pollution. Heavy metals may enter groundwater naturally or by human activity (Bengtson, et al., 1998; Alloway, 2013; Paul, 2017).

Heavy metal accumulation in human or animal bodies may result in a variety of serious illnesses, including edema, renal tumors, widespread kidney lesions, high blood pressure, cardiovascular disorders, cancer, and headaches (Asmoay et al. 2019; Asim and Rao 2021; Jadoon et al., 2021). High concentrations of iron and manganese, heavy metals inherited from the formation, are the primary feature of the Nile aquifer. This is because the limited aquifer of the Nile basin has a greatly reduced environment. Thus, the Ministry of Health informs various places of high heavy metal levels in groundwater (Shamrukh and Abdel-Wahab 2011). In summary, irrigation canals and drains that discharge household, industrial, and agricultural wastewater into the groundwater or the Nile River are among the several causes of the high levels of heavy metal and pathogen contamination of groundwater in the Nile aquifer. The concentration of heavy metals in groundwater can be decreased by taking steps like reducing the use of chemical fertilizers and pesticides and substituting them with less harmful organic manures; strictly enforcing environmental laws; cleaning drains by constructing sewage treatment plants near watercourse outfalls; continuously dredging irrigation canals and drains; and establishing a functional sewage system in unsewered areas (Belew et al., 2024).

This study in particular was required to give particular attention to reveal toxicity and phytotoxicity caused by high accumulation levels and availability status of heavy metals in sugar cane agricultural soils. Elbana et al., (2019), revealed that the resources of agricultural soil and water resources contamination in Egypt involve the extensive use of agrochemicals, reuse of drainage and waste waters, recycling of partially treated wastewater, polluted air, and improper disposal of solid wastes. These various resources pose a real threat to the sustainability of different agricultural systems such as monocropping and crop rotation and human health in Egypt (Abo Shelbaya, et al., 2021b; Abd El-Azeim et al., 2022; Abd El-Azeim et al., 2023).

The current study, in general, draws attention to the heavy metal, pathogenic bacterial, and salt pollution load in groundwater and urges immediate action to reduce the health risks to residents of the investigated area, as well as the surrounding areas and the Upper Egypt sugar cane belt. The lack of water for agriculture has made it necessary to investigate the use of groundwater for irrigation; yet, the buildup of contaminants in the produced food may present health risks to humans. The area under investigation is completely groundwater irrigated using injudicious surface irrigation policies and the dominant cropping pattern of sugar cane monoculture has led to a manifold increase in irrigation water demand. Excessive ground water pumping due to free energy and water coupled with irrational surface irrigation and agricultural practices have led to a situation wherein fresh groundwater resources of the investigated area have polluted and salinized at an alarming rate in most parts of the area.

While groundwater is polluted and salinized at an alarming rate, the sugar cane monoculture parts irrigated with well water alongside the riverbank are facing problems of severe salinization and temporal waterlogging due to excessive irrigation without drainage. Additionally, according to Abo Shelbaya et al. (2021b), these crop management techniques have led to the development of sugar cane soils that are low in microbial biomass, high in bulk density, low porosity, deteriorated aggregate stability and structure, and sick with salinity and heavy metals.

Soil salinity and temporal waterlogging appeared as a major obstacle to the sustainability of irrigated sugar cane fields and livelihoods of the small farmers in sugar cane monocultured areas, are the result of many reasons. These reasons include seepage from unlined drainage and irrigation canals system, drainage of septic tanks from neighboring villages directly into the groundwater using siphon technique, absence of surface and subsurface drainage, poor water management practices, intensive surface irrigation using poor-quality groundwater. In Abu-Qurqas district of irrigated sugar cane monoculture areas, indubitably there is a need to deal with the extant soil and water salinity problem is urgent. The current study's findings strongly advise the government and other relevant parties to take the required action since the long-term irrigated sugar cane monoculture in this region poses a serious risk to human health, the agroecosystem of plants and soil, and water.

Malik et al., (2017) indicated that there is a negative association between dissolved heavy metals and dissolved oxygen in water because of re-oxidation of minerals, making the dissolved oxygen level decrease with the increase in dissolved minerals. Therefore, increased dissolved oxygen also increases dissolved minerals and thus enhances their mobilization (Malik et al., 2017; Abo Shelbaya et al., 2021a; Abo Shelbaya et al., 2021b). Therefore, any agricultural activity that increases the concentrations of heavy metals will automatically reduce the chemical and biological oxygen dissolved (Abo Shelbaya et al., 2021a; Abo Shelbaya et al., 2021b). When heavy metals are introduced into an aquatic ecosystem, animals and aquatic plants may biologically accumulate these heavy metals in their systems resulting in a number of problems and most of these problems are evident in animals higher in their food chains, thus international bodies have placed restrictions on heavy metal burden and physicochemical parameters that must not be exceeded by aqueous environments (Elbana et al., 2019; Haddad et al., 2019).

Development of Integrated and Sustainable Sugar cane Management Strategy.

This study focuses on the assessment of water quality deterioration under sugar cane monoculture using some physicochemical, biochemical and biological data to make future sustainable and integrated management strategies recommendations for sustainable sugar cane production in Egypt. Results of this research indicated that factors that contribute to water environment deterioration under the monoculture of sugarcane are monoculture strategy itself, intensive fertilization with impure organic and inorganic fertilizers, intensive irrigation with saline water, excessive soil tilling during planting and soil compaction brought on by heavy equipment usage in the harvesting and tilling operations. In addition, Abo Shelbaya et al., (2021a and 2021b) stated that these crop management practices collectively has led to the development of soils low in soil organic matter, soil organic carbon, low cation exchange capacity, gravid with salinity and heavy metals, high bulk density, low porosity, degraded structure, and low microbial biomass. This, in turn, is related to the accumulation of harmful organisms in the soil, which affects the growth and health of the sugar cane root system. In addition, these crop management practices have made also the groundwater gravid with salinity, heavy metals and pathogen bacteria. Based on results of this research and the ample information collected by interviewing small sugar cane farmers and the extension officers of this research area, suggested new management practices in sugar cane fields are as following:

Integrated irrigation management strategy.

The most critical limitations facing Egypt are the growing deficiencies of water resources associated with degradation of water quality and increased population. Therefore, it is recommended to have a site-specific data for sustainable sugar cane monoculture areas to ensure water quality protection in rural areas. A periodic evaluation of these soil and water quality indicators is imperative and allows the quantification of changes caused by intensive agriculture of sugar cane monoculture and helps in maintaining the ecological balance between soil-water-climate-vegetation and the agricultural intensification desired. In practice, it allows to plan strategies to achieve a sustainable management of the soil and water resources used in this case for sugar cane monoculture production.

Sugarcane is known as one of the crops that consumes large quantities of fresh water, as one hectare planted with sugarcane in old Delta and Nile valley lands needs about 21,000 cubic meters of irrigation water compared to other field crops in Egypt (Abd El Reheem and Elwan 2016). Relatively speaking, despite the fact that sugarcane consumes large quantities of water, the yield in EGP per cubic meter used for irrigation is higher for sugarcane than the other major cash crops selected. Therefore, optimizing water use for sugarcane involves obtaining the maximum value of production with each drop of water consumed. The optimal use of water is the cornerstone of the agricultural development sector because the current available water resources in Egypt are not sufficient for future horizontal agricultural expansion within the scope of current technologies and irrigation practices. Given the emergence of the challenges of the twenty-first century in light of disputes over water quotas in the Nile River, this may lead to the intensification of conflicts over local water resources. Since most of these sites are considered to have high climate risks, there is a need to save irrigation water in this area, and the attempt to continue the policy of agricultural horizontal expansion has become worse.

This clarifies the necessity to achieve the maximum efficiency of water resources in Egypt through some criteria that can be used in achieving the best use of the available water resources in Egypt. As a result, some voices recently called for replacing sugar cane with sugar beet, which requires relatively less amounts of water. Zohry and Ouda (2020) have also shown that modern sugar irrigation systems under dry conditions have given the highest yield and quality of sugar cane. The expectant effects of the expansion of irrigated sugar cane monoculture were replete with serious ecological consequences on soil and water environment. It is therefore vital that national institutions, in collaboration with the private sector, take responsibility to conduct urgent ecosystem recovery for soil and water remediation. From these results, the feasibility of replacing sugar cane cultivation with sugar beet cultivation and its impact on water and soil resources should be singled out for research focus.

Integrated fertilization system.

The sustainable monoculture system of sugarcane is under threat due to intensive irrigation and fertilization along with manual harvesting and pre, post-harvest crop residue burning that degrades soil and natural water resources (Yin et al., 2019; Ouda, 2020; Wu et al., 2020). In Egypt, soils productivity under sugarcane farming systems is declining in some areas and reached a plateau in some other areas due to overexploitation of the natural resources and agrochemicals. Also, poor conservation of fertile soils and fresh water and low efficiency of irrigation and fertilization systems lead to a real burden on the Egyptian available natural resources (Abd El-Azeim et al., 2020). Accordingly, the appropriate management of irrigated sugar cane monoculture and regular monitoring of soil and aquatic quality parameters are mandatory to guarantee secure long-term irrigated sugar cane monoculture (Bünemann et al., 2018).

Besides, sugar cane is a highly extractive crop, amounts of nutrients extracted, however depends on soil nature, intensity of irrigation, fertilizer type and application rate and method and region climate (Yin et al., 2019; Ouda, 2020). Alluvial soils have high soil fertility and highest productivity with respect to other soils in arid areas of upper Egypt due to alluviums by the Nile River. Mechanized harvesting associated with minimum tillage and maintenance of sugar cane straw on soil surface are key-factors to increase soil organic carbon sequestration, nutrient-cycling and enhance soil health in sugar cane farming systems (Cherubin et al., 2015). In addition, fertilization using organic residues from sugar cane industry such as vinasse, bagasse and mud cake could be a feasible alternative to increase soil organic matter and provide nutrients, especially potassium and phosphorus reducing the production costs associated with artificial fertilizers (Cherubin et al., 2015).

Soil organic matter (SOM) is essential for maintaining soil chemical, physical, and biological characteristics. SOM serves many functions, including increasing soil cation exchange capacity, improving water infiltration and holding capacity, and acting as a slow-release reservoir of nutrients, particularly nitrogen, phosphorus, and sulfur. Loss of SOM in sugarcane monoculture occurs due to intensive tillage, which increases aeration of the soil, favors microbial activity, thus accelerating the rate of mineralization of SOM. Moreover, the practice of burning sugarcane trash before and after harvest turns plant organic residues into ash (Weiler et al., 2019). The low and diminishing content of the soil organic matter contributes to the degradation of microorganisms, increased pathogens and deterioration of soil health, a situation exacerbated by conventional tillage, waste burning and intensive surface irrigation of sugarcane monocropping.

The results from these studies clearly showed that the long-term sugar cane monoculture is having an adverse effect on sugar cane productivity due to declining irrigation water quality and soil fertility. In this situation, more attention to soil fertility through breaking the monocultural system is likely to improve productivity and sustainability. Legumes may be planted from January through March as an alternative farming method after the last sugar cane ratoon harvest. This substitutes one year of sugar cane with legumes, simulating the heavy land usage of the succeeding sugar cane system. Another alternative is to transplant sugar cane after leaving fields fallow for three to six months, although this is not feasible in Upper Egypt due to the scarcity of fertile soils and the small size of the land tenure.

Management of different rotation breaks and intercropping systems.

Previous studies assumed that deterioration of soil quality and the aquatic environment is widespread in monoculture soils of sugarcane in tropical and arid regions. As a result of this study, the situation in Egypt was confirmed, and in order to avoid these degrading effects of sugarcane on the soil and the aquatic environment, major changes in the sugarcane monoculture system must be taken into account. The effects of various rotation breaks, such as bare fallow or alternating legume crops, on the makeup of the community of organisms and soil health on soils that had previously been subjected to cane monoculture were evaluated. Every break decreased the numbers of known harmful soil biota and greatly raised the productivity of the subsequent crop of sugar cane. Other management options are no-till techniques, organic conditioners are always suggested, and one other management options are no-till techniques. Other management options are no-till techniques, organic conditioners are always suggested, and one crop of legumes break appears to be sufficient to obtain the majority of these benefits (Marin, et al., 2021).

Abo Shelbaya et al., (2021a and 2021b) discovered that the loss in critical soil biochemical characteristics such as SOM, SOC and CEC over time in alluvial soils under sugar cane monoculture shows that the existing management strategy is unsustainable. This suggests that sustained sugar cane cultivation has adverse consequences on soil health and fertility. The primary causes of the loss of soil organic matter (SOM) in sugar cane fields include excessive tillage, burning the cane fields both before and after harvesting, and the failure to supplement soils with organic matter (Chi et al., 2017; Marin et al., 2021). Previous research looked at the effects of land management practices on soil microbial diversity, soil enzyme activities, and crop productivity. All of these soil characteristics increased more under intercropping systems than under sugarcane monoculture (Yang et al. 2013; Solanki et al., 2020).

Surki et al. (2020) indicated that soils with a high soil organic carbon had a significantly higher soil cation exchange capacity effect, and that nutrient availability and bioavailability were significantly correlated with soil organic carbon (SOC). Results of the present study revealed that SOC pools were found to be lower in the soils under monoculture of sugar cane systems confirming that soil health parameters were influenced significantly by different land uses. By contrast, in Egypt, Abo Shelbaya et al., (2021a) and (2021b) revealed that SOC concentration and pools were higher in the soils under crop rotation systems promising the sustainability and providing the good yield against global climate change under crop rotation systems rather than sugar cane farming systems. Higher rates of SOC may be attributed to higher rates of residues left twice yearly from the crop rotation systems compared to the sugar cane monoculture system where pre- or post-harvest burning straw residues is a common practice.

Mechanized harvesting of sugarcane.

There is a main type of sugar cane farming system in this region of Upper Egypt based on conventional monoculture of sugar cane production with traditional harvesting and burning sugarcane straw residues. Conventional monoculture of sugarcane production includes manual harvesting of burnt trash, application of intensive artificial, organic fertilizers and pesticides and surface irrigated with groundwater. Modern sugar cane production includes green legumes fertilizer and biological pest control, mechanical harvesting of green cane with trash blanketing and drip irrigation system are supposed to eradicate soil and aquatic environmental problems related to sugarcane monoculture agricultural practices. Modern agro-farming systems have agricultural management practices, including routine soil and irrigation water testing, nutrient management strategy, residue management, which is the key to protect the environment, the local community health and generates income for sugarcane farmers and labors.

Sugar cane production expenses comprise fixed costs, raw material costs, interests, management costs, and labor cost. Mechanical harvesting is probably the most critical practice for sugar cane production as this can avoid post and pre-harvest burning of sugar cane and can also address the problem of the labor's dearth, and save cost for hiring the manual harvesting labors (Chaya et al. 2019). However, one of the major disadvantages of switching from traditional harvesting to mechanical harvesting is reducing labor because mechanization will actually reduce the number of job opportunities. This has led farmers to continue the previous practice of burning sugarcane due to the ease of finding labors because mechanization may reduce employment opportunities sharply and contribute to increasing the harvesting total price.

Adoption of sugar cane trash soil blanketing and zero tillage practices.

The quantity of residue of sugarcane straw on the field's soil generally varies from 10 to 20 Mg ha^{-1} dry matter

(Vieira et al., 2020). Studies on the effect of removing different quantities of sugarcane straw for industrial purposes have chiefly been restricted to the impacts on sugar cane yield (Carvalho et al., 2017) or on the biological, chemical or physical soil characteristics (Satiro et al., 2017). Soltangheisi et al., (2021), concluded that sugar cane trash blanketing on the field even at low rates can enhance the proficiency of organic matter and phosphorus cycling and decrease the use of chemical phosphorus fertilizers in sugar cane monoculture. It is reported that long-term sugar cane or maize causes an obvious decline in soil organic carbon and related soil microbial, chemical and physical attributes in the soil surface of 10 cm. Management practices such as straw retaining (rather than burning), no tillage and use of green crops in rotation, should be considered as ways to stop soil health deterioration. For the monoculture of sugar cane to be sustainable, it is essential to conserve and enhance soil organic matter. Implementing green harvesting, trash retaining, no-till, and use of legume crops in rotation are ways to stop soil health degradation (Soltangheisi et al., 2021).

More sustainable solutions comprise the inclusion of crop rotation systems, the widespread application of organic conditioners to the agricultural system and decreased tillage to prevent damage to soil structure and increase water penetration (Bell et al., 2011). Each of these alternatives has the ability to contribute considerably to modifying the physical and chemical qualities of the soil and hence change the balance between helpful and harmful species in the soil. Rotation breaks are often utilized in agricultural systems as a strategy to interrupt disease cycles and to increase overall soil fertility. Harvesting green cane is now practiced on a large scale and this generally results in a return of 10-15 tonnes / ha of sugar cane trash to the soil surface after each harvest. Tilling the soil between sugarcane replanting cycles is a traditional belief that has beneficial effects for arresting root pests and diseases. Whereas there is at present time no indication to support this, the hypothesis is that natural biological control systems will have a greater chance of evolution if tillage is reduced to the minimum setting. The adoption of abridged tillage or zero tillage practices is usually accompanied by an increase in soil microbial biomass activities as well as significant improvement in soil health and structure.

Finally, under arid conditions, groundwater is a very treasured natural asset and extremely significant playing a major role in the sustainability of agriculture in Egypt and many countries around the world. Quality and quantity of groundwater are both extremely important and must be assessed and monitored regularly to ensure the availability of water in acceptable quality for the planned agricultural farming system (Abd El-Azeim et al., 2020; Ouda et al., 2020). It might be identified from this study that salt and heavy metal contamination are the primary impacts on water quality under sugarcane monoculture. In addition, groundwater contamination arises predominantly from point sources such as agricultural operations with parallel repercussions from city effluents. Under the monoculture sugarcane, immediate ecosystem recovery should be done since soil and groundwater resources got ill with salts, pathogens and heavy metals. Therefore, it is of greatest necessity for one or more national foundations to accept responsibility for monitoring and seeking to cure and control the deterioration of soil and groundwater resources in Upper Egypt. In this sense, major financial assistance from the business sector will be essential.

CONCLUSIONS

Salinization and pollution with heavy metals and pathogens constitute the main impacts on water and soil quality due to the implemented long term irrigated sugar cane farming system. The introduction of new integrated management practices in sugarcane fields are essential to achieve greater sustainability in the sugarcane belt of Upper Egypt. Recently, some voices have called for replacing sugar cane with sugar beet, which need comparatively less irrigation water for its life cycle. Breaking the monoculture cycle of sugarcane has the potential to improve productivity and sustainability by supporting soil fertility through different rotation breaks using alternative legumes. Strict application of the national environmental laws can be taken to protect soil and aquatic environment. Immediately, sewage septic tank system in these rural areas should be stopped as it is directly connected to groundwater used for irrigation making it a constant source of contamination for the environment. Under sugar cane monoculture system, urgent ecosystem recovery should be implemented as soil and groundwater resources became sick with pathogens, salinity and heavy metals buildup.

REFERENCES

Abd El-Azeim, M. M., Mohamed W. S. And Hammam A. A. (2016). Soil physiochemical properties in relation to heavy metals status of agricultural soils in el-minia governorate, egypt. J. Soil sci. And agric. Eng., mansoura univ., vol. 7 (6): 423 - 431. Doi: 10.21608/jssae.2016.39676

Abd El-Azeim, M. M., Sherif, M. A., Hussien, M. S., Tantawy, I. A. A. and Bashandy, S. O. (2020). Impacts of nano- and non-nanofertilizers on potato quality and productivity. Acta ecologica sinica. Https://doi.org/10.1016/j.chnaes.2019.12.007

Abd El-Azeim, M.M., Sherif, M.A., Hussien, M.S. and Haddad, S.A., (2020). Temporal impacts of different fertilization systems on soil health under arid conditions of potato monocropping. *Journal of Soil Science and Plant Nutrition*, *20*(2), pp.322-334. https://doi.org/10.1007/s42729-019-00110-2.

Abd El-Azeim, M.M.; Menesi, A.M.; Abd El-Mageed, M.M.; Lemanowicz, J.; Haddad, S.A. (2022). Wheat Crop Yield and Changes in Soil Biological and Heavy Metals Status in a Sandy Soil Amended with Biochar and Irrigated with Drainage Water. Agriculture 2022, 12, 1723. https://doi.org/10.3390/agriculture13081634

Abd El-Azeim, M.M.; Yousef, E.; Hussien, M.; Hamza, A.; Menesi, A.; Youssef, N.; Omar, M.; Lemanowicz, J.; Eldesoky, G.E.; Abdelkarim, N.S.; et al. (2023). Sustainable Solutions for Arid Regions: Harnessing Aquaponics Water to Enhance Soil Quality in Egypt. Agriculture 2023, 13, 1634. https://doi.org/10.3390/agriculture13081634

Abo Shelbaya, M. A.; M. M. Abd El-Azeim; A. M. Menesi1 and M. M. Abd El-Mageed (2021a). Heavy Metals and Microbial Activity in Alluvial Soils Affected by Different Land-Uses. J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 12 (3):165-177.

Abo Shelbaya, M. A.; M. M. Abd El-Azeim; A. M. Menesi1 and M. M. Abd El-Mageed (2021b). Alluvial Soil Quality Indicators as Affected by Different Land-Uses. J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 12 (4):267-277.

Ahmed A.M., Nagwa R. Ahmed and Soha R.A. Khalil (2013). Effect of intercropping wheat on productivity and quality of some promising sugar cane cultivars. Minia j. Agric. Res. Develop., 33 (4): 557 – 583.

Alloway, B. J. (2013). Sources of heavy metals and metalloids in soils. In: Alloway, b. J. (ed.) Heavy metals in soils: trace metals and metalloids in soils and their bioavailability. Dordrecht: springer Netherlands. Environmental pollution 22,

APHA. (2005). Standard methods for the examination of water and wastewater (21st ed.). American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF).

APHA. (2012). Standard methods for the examination of water and wastewater, 22.

Asim, M. and Rao, K.N., (2021). Assessment of heavy metal pollution in Yamuna River, Delhi-NCR, using heavy metal pollution index and GIS. Environmental Monitoring and Assessment, 193(2), pp.1-16. https://doi.org/10.1007/s10661-021-08886-6

Asmoay, A. S., Salman, S. A., El-Gohary, A. M. and Sabet, H. S. (2019). Evaluation of heavy metal mobility in contaminated soils between abu qurqas and dyer mawas area, el minya governorate, upper egypt. Bulletin of the national research centre, 43, 88.

Ayers, R.S. and Westcot, D.W., (1994). Food, agriculture organization of the United Nations (FAO), water quality for agriculture. Irrigation and Drainage, Rome, Paper, 29, pp.77044-2.

Belew, A.A., Besha, A.T. & Belete, A.A. (2024). Determination of heavy metals and health risk assessment in drinking water in Jigjiga City, Ethiopia. Discov Environ 2, 41. https://doi.org/10.1007/s44274-024-00071-z.

Bell, L.W., Kirkegaard, J.A., Swan, A., Hunt, J.R., Huth, N.I. and Fettell, N.A., (2011). Impacts of soil damage by grazing livestock on crop productivity. Soil and Tillage Research, 113(1), pp.19-29. https://doi.org/10.1016 /j.still.2011.02.003

Bengtson, R., Selim, H. and Ricaud, R. (1998). Water quality from sugar cane production on alluvial soils. Transactions of the asae, 41, 1331.

Bordonal, R., Carvalho, J., Lal, R., Figueiredo, E., Oliveira, B. and La Scala Jr, N. (2018). Sustainability of sugar cane production in brazil. A review. Agron sustain dev 38 (2): 13. Doi :10.1007/s13593-018-0490-x

Bünemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P. and Pulleman, M., (2018). Soil quality–A critical review. Soil Biology and Biochemistry, 120, pp.105-125. https://doi.org/ 10.1016/ j.soilbio.2018.01.030

Carvalho, J. L. N., Nogueirol, R. C., Menandro, L. M. S., Bordonal, R. D. O., Borges, C. D., Cantarella, H. and Franco, H. C. J. (2017). Agronomic and environmental implications of sugar cane straw removal: a major review. Gcb bioenergy, 9 (7): 1181-1195. Doi:10.1111/gcbb.12410

Chandra, A., Gaur, V. and Tripathi, P., (2021). Microbiome analysis of rhizospheres of plant and winter-initiated ratoon crops of sugar cane grown in sub-tropical India: utility to improve ratoon crop productivity. 3 Biotech, 11(1), pp.1-11. https://doi.org/10.1007/s13205-020-02603-9

Chaya, W., Bunnag, B. and Gheewala, S.H., (2019). Adoption, cost and livelihood impact of machinery services used in small-scale sugarcane production in Thailand. Sugar Tech, 21(4), pp.543-556. https://doi.org/10.1007/s12355-018-0651-x.

Cherubin, M.R., Franco, A.L.C., Cerri, C.E.P., da Silva Oliveira, D.M., Davies, C.A. and Cerri, C.C., (2015). Sugarcane expansion in Brazilian tropical soils—Effects of land use change on soil chemical attributes. Agriculture, Ecosystems & Environment, 211, pp.173-184. https://doi.org/10.1016/j.agee.2015.06.006.

Chi, T., Zuo, J. and Liu, F. (2017). Performance and mechanism for cadmium and lead adsorption from water and soil by corn straw biochar. Frontiers of environmental science and engineering, 11, 15. https://doi.org/ 10.1016/j.agee.2015.06.006doi 10.1007/978-94- 007 -4470-7_2,

Doneen, L.D., (1964). Notes on water quality in agriculture. Department of Water Science and Engineering, University of California, Davis.

Eaton, F.M., (1950). Significance of carbonates in irrigation waters. Soil science, 69(2), pp.123-134.

Elbana, T., Gaber, H. M. and Kishk, F. M. (2019). Soil chemical pollution and sustainable agriculture. Book chapter in el-ramady et al. (eds.), the soils of egypt, world soils book series, springer. Https://doi.org/10.1007/978-3-319-95516-2_11

El-Ramady, H., Abowaly, M., Elbehiry, F., Omara, A. E.-D., Elsakhawy, T. A., Mohamed, S., Belal, A.-A., Elbasiouny, H. and Abdalla, Z. F. 9 (2019). Stressful environments and sustainable soil management: a case study of kafr el-sheikh, egypt. Environment, biodiversity and soil security, 3, 193-213. DOI: 10.21608/JENVBS.2019.17750.1070

El-Ramady, H., Alshaal, T., Omara, A. E.-D., Elsakhawy, T. A. and Abdalla, Z. F. (2019). Soils and human creation in the holy quran from the point of view of soil science. Environment, biodiversity and soil security, 3, 1-9. DOI: 10.21608/jenvbs.2019.7856.1052

El-Rawy, M., Ismail, E. & Abdalla, O. (2019). Assessment of groundwater quality using GIS, hydrogeochemistry, and factor statistical analysis in Qena Governorate, Egypt. Desalin Water Treat.

FAO (1985). Soil Resources, Management and Conservation Service, 1985. Guidelines: land evaluation for irrigated agriculture (No. 55). Food & Agriculture Org.

FAO (2019). The agricultural production indices. Faostat, food and agricultural organization of the United Nations (fao). Available online: http://faostat.fao.org/ (accessed on september 2019).

Haddad, S.A., Lemanowicz, J. and Abd El-Azeim, M.M., (2019). Cellulose decomposition in clay and sandy soils contaminated with heavy metals. International journal of environmental science and technology, 16(7), pp.3275-3290. https://doi.org/10.1007/s13762-018-1918-1

Hassan, S.F. & Nasr, M.I., (2008). Sugar Industry in Egypt. Sugar Tech, 10(3): 204-209. https://doi.org/10.1007/s12355-008-0038-5

Jadoon, W.A., Abdel-Dayem, S.M.M.A., Saqib, Z., Takeda, K., Sakugawa, H., Hussain, M., Shah, G.M., Rehman, W. and Syed, J.H., (2021). Heavy metals in urban dusts from Alexandria and Kafr El-Sheikh, Egypt: implications for human health. Environmental Science and Pollution Research, 28(2), pp.2007-2018. https://doi.org/10.1007/s11356-020-08786-1

Kelley, W.P., (1951). Alkali soils (Vol. 72, No. 5, p. 403). LWW.

Liu Y, Ma R. (2020). Human health risk assessment of heavy metals in groundwater in the luan river catchment within the North China Plain. Geofluids. 2020:1–7. https://doi.org/10.1155/2020/8391793.

Malik, D.S., Jain, C.K. and Yadav, A.K., (2017). Removal of heavy metals from emerging cellulosic low-cost adsorbents: a review. Applied water science, 7(5), pp.2113-2136.

Marin, F.R., Edreira, J.I.R., Andrade, J.F. and Grassini, P., (2021). Sugar cane Yield and Yield Components as Affected by Harvest Time. Sugar Tech, pp.1-8. https://doi.org/10.1007/s12355-020-00945-5

Martinez, J.L., (2009). Environmental pollution by antibiotics and by antibiotic resistance determinants. Environmental pollution, 157(11), pp.2893-2902. https://doi.org/10.1016/j.envpol.2009.05.051 .

Narsimha, A. and Sudarshan, V., (2013). Hydrogeochemistry of groundwater in Basara area, adilabad district, Andhra Pradesh, India. J Appl Geochem, 15(2), pp.224-237.

Negm AM, Armanuos AM (2017) GIS-based spatial distribution of groundwater quality in the Western Nile Delta, Egypt. In: Negm AM (ed) The Nile Delta, The handbook of environmental chemistry, vol 55. Springer International Publishing, Switzerland, pp 89–120. https://doi.org/10.1007/698_2016_66.

Ouda, O. K. (2016). Treated wastewater use in saudi arabia: challenges and initiatives. International journal of water resources development, 32, 799-809. https://doi.org/10.1080/07900627.2015.1116435

Ouda, S., Zohry, A. E.-H. and Noreldin, T. (2020). Deficit irrigation: a remedy for water scarcity. Springer. pdf. Accessed Dec 2013. https://doi.org/10.1007/978-3-030-35586-9.

Paul, D., (2017). Research on heavy metal pollution of river Ganga: A review. Annals of Agrarian Science, 15(2), pp.278-286. https://doi.org/10.1016/j.aasci.2017.04.001

Richards, L.A., (1954). Diagnosis and improvement of saline and alkali soils (Vol. 78, No. 2, p. 154). LWW.

Said I., Salman A., Samy Y., Awad S., Melegy A. (2019). Environmental factors controlling potentially toxic element behaviour in urban soils, el tebbin, egypt. Environ monit assess 191:267 https://doi.org/10.1007/s10661-019-7388-1.

Satiro LS, Cherubin MR, Safanelli JL, Lisboa IP, Rocha Junior PR da, Cerri CEP and Cerri CC (2017). Sugar cane straw removal effects on ultisols and oxisols in south-central brazil. Geoderma regional, 11: 86-95. Doi:10.1016/j.geodrs.2017.10.005

Schoeller, H., (1967). Geochemistry of groundwater—an international guide for research and practice (Chap. 15, pp. 1–18).

Shamrukh, M. and Abdel-Wahab, A., (2011). Water pollution and riverbank filtration for water supply along river Nile, Egypt. In Riverbank filtration for water security in desert countries (pp. 5-28). Springer, Dordrecht. https://doi.org/10.1007/978-94-007-0026-0_2 .

Solanki, M. K., Wang, F.-Y., Li, C.-N., Wang, Z., Lan, T.-J., Singh, R. K., Singh, P., Yang, L.-T. and Li, Y.-R. (2020). Impact of sugar cane–legume intercropping on diazotrophic microbiome. Sugar tech, 22, 52-64. Sorption/desorption kinetics in different soils. Soil syst. 3, 38; doi:10.3390/soilsystems3020038.

Soltangheisi, A., Haygarth, P.M., Pavinato, P.S., Cherubin, M.R., Teles, A.P.B., de Oliveira Bordonal, R., Carvalho, J.L.N., Withers, P.J. and Martinelli, L.A., (2021). Long term sugarcane straw removal affects soil phosphorus dynamics. Soil and Tillage Research, 208, p.104898. https://doi.org/10.1016/j.still.2020.104898 .

Surki, A.A., Nazari, M., Fallah, S. and Iranipour, R., (2020). Improvement of the soil properties, nutrients, and carbon stocks in different cereal–legume agroforestry systems. International Journal of Environmental Science and Technology, pp.1-8. https://doi.org/10.1007/s13762-020-02823-9

Szabolcs, I. and Darab, K., (1964). Radio-Active technique for examining the improving effect of $CaCO_3$ on alkali (Szik) soils. Acta Agron. Hung, 13, pp.93-101.

Tegegne WA. (2016). Determination of essential and non-essential metals concentration in garlic (Allium sativum L.) bulb and leaf cultivated in Ambo Woreda, Ethiopia. Sci J Anal Chem.4:84. https://doi.org/10.11648/j.sjac.20160406.12.

US Salinity Laboratory Staff (1954) Diagnosis and Improvement of Saline and Alkali Soils USDA Hanbook No. 60 US Government Printing Office, Washington D.C (1954)

USDA Foreign Agricultural Service. (2020). Sugar: world markets and trade. Https://www.fas.usda.gov/search/sugar egypt 02020.

USDA. (2019). Increasing Sugar Supply on Expanded Beet Production April 15,2019 Report Number:EG-19006.

USDA. (2020). Egypt's Sugar Supply Increase Continues on Expanded Beets Production. Global agriculture information network April 15,2020 Report Number: EG2020-0017.

USEPA. (2005). Ecological Soil Screening Levels for Lead, Interim Final. Office of Solid Waste and Emergency Response. OSWER Directive 9285.7-70. 1200 Pennsylvania Ave. N.W. Washington, D.C. 20460.

Vieira, R.F., Ramos, N.P. and Pazianotto, R.A.A., (2020). Different amounts of sugar cane trash left on the soil: Effects on microbial and enzymatic indicators in a short-term experiment. Soil Use and Management. https://doi.org/10.1111/sum.12584

Webster AJ, Bartley R, Armour JD, Brodie JE and Thorburn PJ (2012). Reducing dissolved inorganic nitrogen in surface runoff water from sugar cane production systems. Marine pollution bulletin, 65 (4-9): 128-135. Doi:10.1016/j.marpolbul.2012.02.023.

Weiler, D. A., Moro, V. J., Awe, G. O., Da Silva Oliveira, D. M., Cerri, C. E. P., Reichert, J. M. and Giacomini, S. J. (2019). Carbon balance in sugar cane areas under different tillage systems. Bioenergy research, 12, 778-788. https://doi.org/10.1007/s12155-019-10002-z

Wu, H., Yang, F., Li, H., Li, Q., Zhang, F., Ba, Y., Cui, L., Sun, L., Lv, T. and Wang, N. (2020). Heavy metal pollution and health risk assessment of agricultural soil near a smelter in an industrial city in china. International journal of environmental health research, 30, 174-186. https://doi.org/10.1080/09603123.2019.1584666

Yang YC, Xue MQ, Xu ZM, Huang C (2013) Health risk assessment of heavy metals (Cr, Ni, Cu, Zn, Cd, Pb) in circumjacent soil of a factory for recycling waste electrical and electronic equipment. J Mater Cycles Waste 15:556–563. DOI 10.1007/s10163-013-0120-2

Yin, J., Deng, C.B., Wang, X.F., Chen, G.L., Mihucz, V.G., Xu, G.P. and Deng, Q.C., (2019). Effects of long-term application of vinasse on physicochemical properties, heavy metals content and microbial diversity in sugarcane field soil. Sugar Tech, 21(1), pp.62-70. https://doi.org/10.1007/s12355-018-0630-2

Zohry, A.E.H. and Ouda, S., (2020). Egypt Faces Water Deficiency, and Food Insufficiency. In Deficit Irrigation (pp. 29-58). Springer, Cham. https://doi.org/10.1007/978-3-030-35586-9_3

Zulu, D., Phiri, D. and Chisha–Kasumu, E. (2019). Sustainable agricultural systems in zambia: a case of organic agriculture. Sustainable livelihoods in the green economy, 50.

تأثير الزراعة الأحادية لقصب السكر والمروية بالغمر علي جودة المياه الجوفية في التربة الطمييه النيلية

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الملخص

يهدف هذا البحث الي تقييم تأثير الزراعات الأحادية لقصب السكر على المدى الطويل على بعض الخصائص الفيزيائية والكيميائية والبيولوجية للمياه الجوفية كمؤشرات لجودة المياه. أجريت دراسة حصرية لتغطي منطقة حزام السكر بمحافظة المنيا، مصر. أشارت نتائج هذا البحث إلى أن صلاحية المياه الجوفية للري تقع تحت درجة تقييد الاستخدام "حادة"، وأن الاستخدام المستمر لهذه المياه الجوفية للري قد يزيد من مشكلة الملوحة في التربة الطمييه على المدى الطويل. وكانت المياه الجوفية بالمنطقة ملوثة بشكل كبير بالبكتيريا القولونية و *E. coli* في كل من الزراعة الأحادية لقصب السكر والنظم الزراعية لتناوب المحاصيل (الدورة الزراعية). تراوح إجمالي متوسط عدد المستعمرات للبكتيريا القولونية من 360 إلى 362، لكل 100/مل، وتراوحت المجموعات القولونية البرازية من 212 إلى 215 لكل 100/ مل، وتراوحت مجموعات *E. coli* من 248 إلى 256 لكل 100/مل من المياه الجوفية مع عدم وجود فروق معنوية بين نظام الزراعة الأحادية لقصب السكر ونظام الدورة الزراعية. وكثيراً ما تجاوز متوسط تركيز المعادن الثقيلة المسجلة في عينات المياه الجوفية الحدود المسموح بها لمياه الري التي حددتها منظمة الصحة العالمية. من هذه النتائج، يمكن أن نستنتج أن الزراعة الأحادية لقصب السكر على المدى الطويل قد أدت إلى تدهور كبير في خصائص جودة المياه الجوفية مما يشير إلى الحاجة الملحة لممارسات إدارة أكثر استدامة للحفاظ على جودة المياه الجوفية في مناطق زراعة قصب السكر.

الكلمات الدالة: الزراعة الأحادية لقصب السكر، المعادن الثقيلة، جودة المياه.