Heliyon 10 (2024) e24913

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessment of irrigation water quality for vegetable farming in peri-urban Kumasi

Winfred Bediakoh Ashie [a], Jonathan Awewomom [b,*], Emil Nana Yaw Osei Ettey [a], Francis Opoku [a], Osei Akoto [a,**]

[a] Faculty of Physical and Computational sciences,Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[b] College of Natural Sciences, Department of Earth and Environmental Sciences, Michigan State University, East Lansing, USA

ARTICLE INFO

Keywords:
Sodium absorption potential
Quality
Irrigation
Water
Discharge

ABSTRACT

Polluted water contains a variety of toxic compounds that tend to affect human health. Farmers have recently looked at runoff wastewater as a source of irrigation water because it comes at no cost and is a more efficient alternative to potable water due to the high demand but limited supply. This present study assesses the quality and suitability of water sources used for irrigation at the Kwame Nkrumah University of Science and Technology vegetable farmlands. The study specifically investigated the quality of water used for irrigation with the following parameters: pH, turbidity, total dissolved solids, total suspended solids, chloride, chemical oxygen demand, biological oxygen demand, oil and grease, fluoride, nitrate, nitrite, sulphate, sodium, calcium, magnesium, sodium adsorption potential, alkalinity, conductivity, phosphate, *Escherichia coli*, fecal and total coliforms. The results revealed that the water contained moderate levels of chloride and could be good for plant growth. The total coliform counts range from 2.1×10^6 to 4.15×10^7 MPN/100 mL, suggesting a relatively high microbial load in the irrigation water. The results also suggested that the sodium absorption ratio was very low and may not affect the quality of water for irrigation purposes. Fe levels far exceed the 5 mg/L maximum acceptable limits recommended by the WHO and FAO for the irrigation of vegetables. The high Fe concentration could discolor the leaves of some plants, especially foliage leaves. However, the levels of Cd were within the WHO maximum permissible limit of 0.01 mg/L.

1. Introduction

Irrigation water quality plays a crucial role in determining the health and productivity of vegetable crops, especially in peri-urban areas where farming activities coexist with urban development. Ensuring the safety and suitability of irrigation water is essential to prevent the contamination of vegetables with potentially harmful substances. Although Africa is often associated with the abundance of rich water resources and great biodiversity [1], the quantity and quality of water are of great importance to the ecosystem and human survival [2]. Unfortunately, Africa, of which Ghana is a part, is plagued with rapid population growth, urbanization and poor economy [2] alongside insufficient treatment of water and wastewater making renewable water scarce.

Farmers have recently looked at runoff wastewater as a source of irrigation water because it comes at no cost and is a more efficient

* Corresponding author.
** Corresponding author.
E-mail addresses: jonathankeinzie8a154@gmail.com (J. Awewomom), wofakmann@yahoo.com (O. Akoto).

https://doi.org/10.1016/j.heliyon.2024.e24913
Received 27 August 2023; Received in revised form 8 January 2024; Accepted 17 January 2024
Available online 1 February 2024
2405-8440/

alternative to potable water due to the high demand but limited supply. Polluted water contains a variety of toxic compounds that tend to affect human health. Water is considered polluted when it contains enough contaminants to make it unfit for a specific use, such as drinking, swimming, or fishing. Although natural factors have an impact on water quality, pollution is frequently used to refer to contamination caused by human activity, therefore, water pollution is primarily caused by the discharge of contaminated water into surface or groundwater [3].

In most metropolitan locations in Ghana, lettuce, cabbage, green pepper, and spring onions are regularly produced vegetables that are consumed raw as salads in fast-food restaurants. Water cans were commonly employed by vegetable producers for irrigation, which can infect vegetables when water is poured directly to the leaves. However, if the water is applied to the soil surface, the pollution may be lessened.

According to Keraita, Jimenez [4] Irrigation with wastewater has a centuries-long history. Prehistoric civilizations such as the ancient Egyptians, the Mesopotamians, the Minoans, and Indus Valley societies practised it. Water scarcity prompted its use, and it was initially used for irrigation to ensure the nutrient benefits of yields. The Romans used polluted water, and contaminated irrigation farms were established as early as 1531 in Germany and 1650 in Scotland in modern times [5]. In 2021, Hashem and Qi [6] reported that the potassium content of soils increased when wastewater meant for irrigation was treated before use. When treated polluted water is used for irrigation, it improves plant nutrition, soil properties and fertility [5]. Xu, Wu [7] also reported a total increase in nitrogen concentration in the top layer of soils when irrigated with effluents for a long time with similar patterns observed in the availability of potassium and phosphorous. However, Baveye [8] found no significant increase in the concentrations of nitrogen, phosphorus and potassium in the soil after short-term irrigation with treated contaminated water. These contradictory results could be attributed to nutrient concentrations in treated taint water or the duration of the irrigation [9].

The quality of wastewater is determined by a series of laboratory tests to determine the appropriateness of wastewater for disposal, treatment, or reuse. The tests used depend on the intended application or discharge location. Physical, chemical, and biological aspects of wastewater are measured using tests. Temperature, turbidity, total suspended solids and total dissolved solids are examples of physical qualities. pH value, dissolved oxygen concentrations, biochemical oxygen demand (BOD) and chemical oxygen demand (COD), nitrogen, phosphorus, and chlorine are all chemical properties [10]. Bioassays and aquatic toxicity tests are used to determine biological properties, both the BOD and COD tests assess a waste contaminant's relative oxygen-depletion effect. Both have become frequently used as indicators of pollution impact. Any oxidizable substance in an aerobic natural waterway or industrial effluent will be oxidized by both biochemical (bacterial) and chemical mechanisms. As a result, the oxygen concentration of the water will be reduced [10].

Heavy metals are significant environmental contaminants, and their toxicity is a growing concern [11]. The heavy metals most commonly found in polluted and wastewater are arsenic, cadmium, chromium, copper, lead, nickel, and zinc, these could all be harmful to the health of humans and pose risks to the environment [12]. Chauhan and Chauhan [13], Balkhair and Ashraf [14] and Alghobar and Suresha [15] reported that heavy metals accumulated in plants is as a result of irrigation with wastewater with potential health risk to human health. Heavy metals, toxic organic compounds and salts, which are primarily found in industrial discharges and domestic effluents are difficult to remove from wastewater, so it is cheaper, easier, and safer to prevent them from entering the sewage system in the first place, this is critical to promote cleaner industrial production processes in order to avoid the use and discharge of toxic compounds, as well as to educate society about the dangers of improper discharge of domestic liquid waste. Water storage as part of an irrigation system improves its quality by lowering the content of pathogens and pollutants associated with suspended solids. As a result, when designing wastewater irrigation systems, it is critical to maximize storage time.

Phytoremediation in conjunction with microbial remediation of wastewater can be employed as a more sustainable and cost-effective technique to conventional treatment techniques to improve the quality of wastewater used for irrigation [16]. Indian mustard (*Brassica juncea*), Willow (*Salix species*), Poplar tree (*Populus deltoides*), Indian grass (*Sorghastrum nutans*), and Sunflower (*Helianthus Annuus*) are some examples of plants that can be used for phytoremediation in and on the banks of wastewater ponds or collecting systems [17]. Rhizospheric bacteria, endophytes, and algae are some microbial pollutant removers and could be used by farmers to minimize microbial growth and presence in produced crops [18]. Farmers have recently resorted to polluted water as a source of irrigation because it comes at no cost and is a more efficient alternative to potable water due to the high demand but limited supply. The issue is, contaminated water may include nutrients and components that are important for plant growth, but may also contain contaminants consisting of a variety of dangerous compounds that when consumed by humans, can result in health complications without an identifiable root cause.

This current study seeks to evaluate the quality of the Wiwi River, which is use for irrigating vegetable farms in peri-urban areas, specifically within the vicinity of Kwame Nkrumah University of Science and Technology (KNUST). The study aims to assess the specific characteristics and potential risks associated with the irrigation water in this peri-urban region, considering the unique challenges stemming from the interface between agriculture and urban influences, such as industrialization, pollution, and population density. Understanding the specific characteristics and potential risks associated with irrigation water in these areas is essential for promoting sustainable and safe vegetable farming practices. According to Extension [19], the quality of water used for irrigation should first be tested before use to maximize crop yield and to avoid issues of toxicity in plants. The vegetable farm under this present study is a major source of common vegetables such as carrots, lettuce, onion, pepper, tomatoes cabbage etc. for the university community, Kumasi metropolitan and the nation at large, it is therefore empirical to assess the current state and quality of water used for irrigation at the farmlands.

2. Materials and methods

2.1. Study area

The water samples were taken along the Wiwi River at locations coded as L1, L2, L3, L4 and L5 as shown in Fig. 1. This part of the Wiwi River is used for irrigation of vegetable farms cultivated along the river course. Untreated wastewater from residents and run-offs from commercial areas and small skill industries such as auto mechanics and car wash in communities along the river are channelled into the river. These can affect the quality of the stream water used for irrigation.

2.2. Sampling and sample analysis

The water samples were sampled directly from the irrigation source with a pre-cleaned fluoropolymer bottles by submerging the bottles below the water surface whilst avoiding any contact with the inside. The bottles were properly labelled with the date, time and location of the sampling and transported to the Laboratory in a cool temperature with a container with ice for analysis. Laboratory analysis and sampling were done according to the procedures outlined in the methods of physical analysis, chemical analysis and biological analysis for the examination of wastewater with slight modifications [20,21]. To achieve a more representative sampling, sequential composite sampling was used. pH and conductivity were determined on-site with portable pH and conductivity meters respectively. The pH meter was standardized using a two-point calibration with two buffers. The conductivity meter was standardized with a 0.1 M KCL solution at 25 °C [22]. Total dissolved solids (TDS) and turbidity were also determined by the multimeter and an LP2000 turbidity meter, respectively. Calcium, magnesium and total hardness were determined by ethylenediaminetetraacetic (EDTA) titration. Fluoride, alkalinity, phosphate, sulphate, nitrate, chemical oxygen demand (COD) and nitrite were determined with the Prime lab 1.0 photometer with the prescribed water testing tablets according to the standard methods [23,24]. Biochemical chemical demand (BOD) was determined according to the methods prescribed by Rice, Bridgewater [25]. The sodium adsorption ratio (SAR) was determined using equation (2), all concentrations were converted to milliequivalents (mEq) which is a measure of the chemical activity of an electrolyte, the unit conversion was done using Equation (1) [26,82].

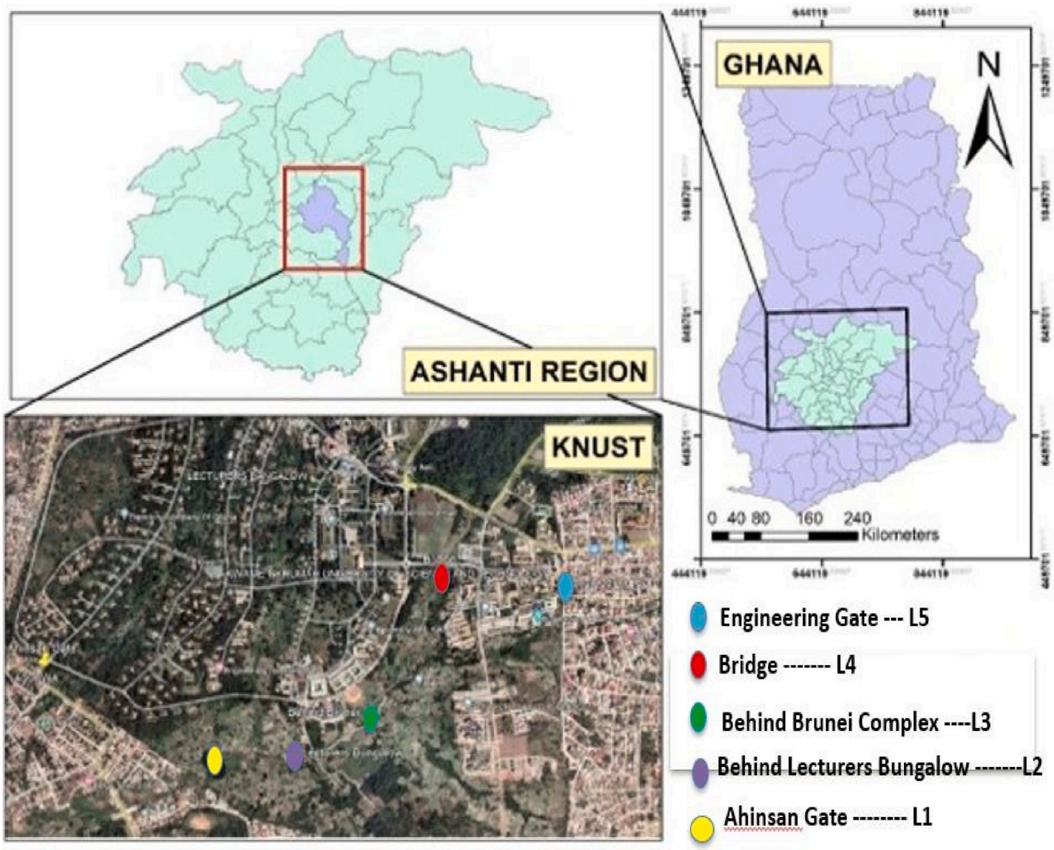

Fig. 1. Map of the study area showing all the sampling sites.

$$\mathrm{mEq} = \frac{\frac{\mathrm{mg}}{\mathrm{L}} \times \mathrm{valence}}{\mathrm{atomic\ weight}} \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

2.2.1. Total and faecal coliforms

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in samples. Serial dilution of 10^{-1} to 10 were prepared by picking 1 mL of the sample into 9 mL sterile distilled water. 1 mL aliquots from each of the dilutions were inoculated into a 5 mL of MacConkey Broth and incubated at 37 °C for total coliform and 44 °C faecal coliforms for 24 h. Tubes showing a colour change from purple to yellow after 24 h were identified as positive for both total and faecal coliforms. Counts per 100 mL were calculated from the Most Probable Number (MPN).

2.2.2. E. coli

From each of the positive tubes identified from the analysis of faecal coliforms, a drop of the sample was transferred into a 5 ml test tube of tryptone water and incubated at 44 °C for 24 h. A drop of Kovacs, Reagent was then added to the tube of tryptone water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and were recorded as presumptive for thermotolerant coliforms (*Escherichia coli*). Counts per 100 mL were calculated from Most Probable Number (MPN) tables.

2.2.3. Determination of heavy metals

The water samples were prepared for heavy metal analysis by acid digestion. 50 mL of each water sample was measured into a labelled digestion tube and 10 mL of nitric acid, 3 mL of perchloric acid and 3 mL of sulfuric acid were added. The digestion tubes were placed into digestion blocks, 5 mL of nitric acid was then added to each digestion tube and heated for about 1 h. The heating continued until digestion was completed and a clear digest was observed. Digests were left to cool, filtered with a Whatman No.4 filter paper into 50 mL falcon tubes and topped up with deionized water to the mark for metal analysis. A blank solution was prepared in a similar procedure. The concentrations of heavy metals were determined with the analytic Jena NOVAA 400 P Model Atomic Absorption Spectrophotometer (AAS) at the Central Laboratory of the Kwame Nkrumah University of Science and Technology.

2.3. Quality assurance

Analytical grade chemicals were used for the acid digestion of samples. Prior to the metal analysis, the AAS was calibrated with a set of standards to ensure the accuracy and reliability of measurements, a blank solution, made up of a similar matrix as the sample without the analyte was used to check interferences and contaminations from the reagents. The analysis was performed in replicates to ensure reproducibility and precision of the analysis results. Analysis of certified reference materials and spike recovery were all performed to ensure the accuracy of results. Accuracy of results for physical parameters was assured by standardizing the measuring instruments such as the pH and conductivity meters to ensure the validity of the results, pH and conductivity were also determined on-site.

2.4. Data analysis

Microsoft Excel and the IBM Statistical Package for Social Science (SPSS) were employed for data analysis. Descriptive statistics which helped to interpret the analysis results was performed to ensure data visualization, comparison and summarization.

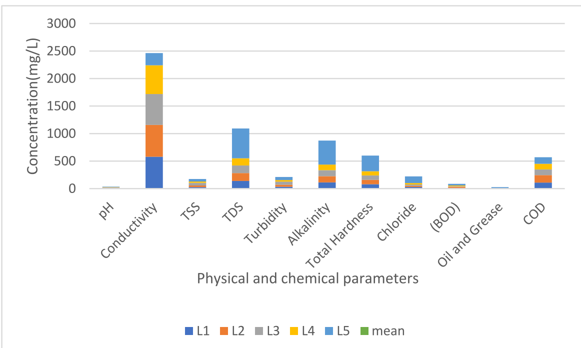

Fig. 2. Physical and chemical properties characterizing water quality for irrigation.

3. Results and discussion

3.1. Physicochemical parameters

Fig. 2 shows the results of physicochemical parameters characterizing the quality of water for irrigation in this study. Total suspended solids (TSS) in the samples ranged from 22 mg/l at location L1 to 49 mg/l at location L3 with a mean concentration of 35 ± 5.46 mg/L as shown in Fig. 2. In another study, Aliyu, Balogun [27] reported a TSS level ranging 10.3–90.6 mg/L from Kwara state in Nigeria in water used for irrigation, this is higher than the levels recorded in this study in Ghana. A high TSS can influence the level of water turbidity directly, affect soil structure by increasing soil density and reducing soil porosity, as a result of this, percolation and infiltration rates of soil are reduced which significantly reduces the uptake of water by plants [28,29]. TSS can also affect the movement of water from the soil to the root of plants (osmotic potential) in soil, this occurs by causing a clogging in the roots of plants [30]. TDS ranged from 130 mg/L at location L4 to 541 mg/L at L5 with a mean concentration of 218.4 ± 80.67 mg/L. The highest level of dissolved solids (541 mg/L) was detected in L5, the Bridge, this exceeds the 426.5 mg/L reported by Abdallah and Mourad [31] in a similar study conducted in Tamale, Ghana on water used for irrigation of vegetable cultivation. High levels of dissolved solids can affect the osmotic potential of crops resulting in an interruption of smooth water uptake by plants [27], the TDS recorded in this study are considered to be unacceptable and far above the 30 mg/L maximum recommended limit of the Food and Agriculture Organization (FAO) and the 50 mg/L of the WHO for irrigation water [32]. The high TSS from this study could affect the uptake of water by plants, osmosis and photosynthesis by reducing the amount of light that reaches the leaves of plants. The elevated TDS and TSS can be attributed to various sources of contamination, including urban runoff, soil erosion, and industrial discharges, it is therefore essential to implement best management practices, such as sedimentation basins, vegetative buffers, and erosion control measures [30].

The pH ranged from 6.22 for location L4 - 7.29 for L5 with an average of 6.92 ± 0.18 this is well within the FAO standard permissible limits of 6.50–8.40 for water used for irrigation. Purposes [33]. Metals such as Pb, Hg, Cu, and As are more soluble at lower pH levels, as a result, higher concentrations of metals can be absorbed into plant tissues and taken by consumers through the food chain [34]. pH of irrigation water can also affect the availability of nutrients and soil structure, reduce plant growth and yield through the unavailability of nutrients and alteration of microbial activity which is crucial in decomposition and nutrient cycling [35]. Results from the study depicted slightly acidic pH, this effect could be due to the effluents channeled into the water from residential and commercial facilities scattered along the course of the river [26]. Results showed that the alkalinity levels of the water used for irrigation ranged from 103 mg/L for location L3 to 436 mg/L with a mean concentration of 174.6 ± 65.37 mg/L, the highest level of alkalinity (436 mg/L) was detected at L5 and is above the WHO maximum limit of 120 mg/L set for irrigation water [36]. According to Ogedengbe and Akinbile [37], these high levels of alkalinity in this study could arise as a result of effluents with high contents of carbonates and bicarbonates, wastewater and the use of pesticides and fertilizer by farmers could also account for the high level of alkalinity recorded in this study [38]. When the alkalinity level in irrigation water exceeds 150 mg/L, it can increase the pH levels of the soil, which can, in turn, affect the availability of essential plant nutrients such as Ca and Fe. The alkalinity of 436 mg/L recorded at location L5 of this study could therefore accumulate in soils and affect the quality of plant nutrients. Promoting responsible pesticide and fertilizer use among farmers can contribute to reducing pH-altering substances in the water, and implementing soil amendments and pH adjustment techniques, such as liming, can help maintain the pH balance in irrigation water [19].

Irrigating vegetable farms with turbid water may affect the quality of the vegetables because bacteria and viruses may attach and migrate to the vegetables via solid particles in the water [39]. When Irrigating with turbid water, the suspended particles can also physically damage the surface of the plant, causing scarring or abrasions or can clog the stomata of the leaves, which are tiny pores that allow for the exchange of gases. When stomata are blocked, the plant may not be able to photosynthesize properly, leading to reduced growth and productivity [40]. The level of turbidity ranged from 28 to 57 NTU with an average of 42.2 ± 5.98 NTU, this varied similarly to the 5.0–49.3 NTU reported in Nigeria by Akpan-Idiok, Ibrahim [41]. The results for turbidity reported in this study far exceed the 5.0 NTU recommended limit by the WHO [42] and could therefore introduce several pathogens to the vegetables through irrigation, this could negatively affect the health of consumers [43], the high turbidity could be caused by decayed organic matter and effluents of households channelled into the water [44]. Electrical conductivity is a measure of the dissolved soluble salts in water [45], the conductivity of the sampling points L1 to L5 ranged from 222.2 to 521.8 μS/cm, the EC of water recorded from L1 to L5 were all lower than the maximum limit of 1000 μS/cm set by the FAO and as such, may not be a threat to the growth of the vegetables [26]. High levels of dissolved solids in wastewater could increase the conductivity of soil at waste water-irrigated sites and this increases the mobility of heavy metals in the soil [46].

The hardness ranged from 76.6 to 284 mg/L with a mean concentration of 120 ± 41.00 mg/L, the sample from L5 recorded the highest hardness concentration of 284 mg/L whilst location L4 recorded the lowest hardness level of 76.6 mg/L. The United States Department of Agriculture (USDA) has established the following guidelines for hardness in irrigation water based on the calcium carbonate equivalent (CCE): soft water: less than 60 mg/L, moderately hard water between 60 and 120 mg/L, hard water: between 120 and 180 mg/L and very hard water greater than 180 mg/L [47], based on this criteria, the water used for irrigation sampled from L1 to L4 in this study can be said to be moderately hard, however, Sample L5 could be categorized as very hard as it recorded a high value of 284 mg/L. Hard water can lead to soil compaction, which can reduce the pore space in the soil and limit the availability of oxygen and water to plant roots. This can negatively affect plant growth and yield [48], very hard water causes a layer of salt and calcium carbonate to form on the roots and soil eventually affecting water uptake through repulsion, water is considered to be very hard when its hardness exceeds 300 mg/L. Remedial measures such as soil amendments should be implemented to counteract excessive hardness and mitigate its impact on soil structure and plant growth [49]. In this study, chloride ranged from 22.1 to 121 mg/L with an average of 44.26 ± 19.21 mg/L, chlorides are required for plant growth, but in high concentrations, they can inhibit plant growth and become toxic to some sensitive plants [50]. Chlorides are very stable in water because they are usually not affected by processes which are physical, chemical and biochemical in nature [51]. When the right irrigation practices are used, water with a chloride concentration of 150 mg/L and below is safe and essential for the health of crops, careful monitoring and targeted irrigation practices can maintain chloride levels at levels that are both safe and beneficial for crop health [27]. The 44.26 ± 19.21 mg/L of chloride recorded from this study, therefore, suggest the water contained moderate levels of chloride and was good for plants.

The oil and grease content of the water under study ranged from 1 mg/L to 20 mg/L at L5 with a mean concentration of 5.50 ± 3.64 mg/L. Oil and grease can have negative effects on plants and soil in water used for irrigation. When oil and grease are present in irrigation water, they can form a film on the surface of the soil that reduces soil aeration and water infiltration. This can lead to reduced plant growth and yield, as well as increased susceptibility to disease and pests [52]. Oil and grease in water used for irrigation decreases the capillary action of water in the soil and reduces the soil's ability to significantly transmit water to the roots of plants [53]. Oil and grease can directly harm plants by blocking stomata, the small openings on the surface of leaves that are responsible for gas exchange. When stomata are blocked, plants cannot take in the carbon dioxide they need for photosynthesis and release the oxygen they produce, this can cause reduced growth and even death of plants, the use of oil-water separators and filtration systems in industrial processes could address this menace [54]. There are so far no maximum guideline limits set by regulatory agencies such as the FAO for oil and grease in irrigation water. However, the levels of oil and grease recorded in this study could have toxic effects on soil microorganisms that are important for nutrient cycling. These microorganisms can be killed or their populations reduced when exposed to oil and grease in irrigation water, leading to decreased soil fertility and plant growth [55].

BOD ranged from 9.73 to 29.8 mg/L with an average of 17.27 ± 3.56 mg/L in this current study, the highest BOD concentration of 29.8 mg/L was recorded at sampling point L5. High levels of BOD in irrigation water can lead to oxygen depletion in soil and water, which can negatively affect the growth of plants and soil microorganisms. When plants are irrigated with water which has high BOD levels, their growth can be stunted, and may also exhibit signs of nutrient deficiencies [39]. The mean BODs (17.27 ± 3.56 mg/L) recorded in this study exceeded the USEPA recommended limit of 10 mg/L [56], this suggests the water may be polluted, this agrees with a similar study conducted by Aliyu, Balogun [27]. A study by Adebayo and Usman [57] on water used for irrigation in Ilorin-Nigeria reported 17.27–3.56 mg/L of BOD, which is similar to the ranges recorded in this present study. COD concentrations in this study ranged from 101 to 136 mg/L with an average concentration of 114.20 ± 6.43 mg/L. These far exceeded the 20 mg/L maximum limits recommended for water bodies [58]. COD is a measure of the amount of oxygen required to oxidize all organic and inorganic compounds in water. High levels of COD in irrigation water is an indicator of the presence of pollutants and toxic substances, which can also negatively affect plant growth and soil health. When plants are irrigated with water containing high COD levels, they may exhibit stunted growth, reduced yield, and increased susceptibility to diseases and pests. The high COD values recorded in this study suggests a possible pollution of the water used for vegetable irrigation in the farmlands in this study. Effective pollution control measures, including proper wastewater treatment and industrial effluent regulation are essential to mitigate BOD and COD contamination [27].

3.2. Nutrients

The concentrations of nutrients recorded in study are shown in Fig. 3. The recorded levels of nitrate (NO_3^-) and nitrite (NO_2^-) ranged from 0.103 to 0.684 mg/L and 0.08–0.22 mg/L, with average concentrations of 0.55 ± 0.11 mg/L and 0.17 ± 0.02 mg/L, respectively. These were within the FAO maximum recommended standard of 50 mg/L on water quality for irrigation [59]. Nitrate is a key nutrient for plant growth, but excessive amounts of nitrate in irrigation water can lead to nitrogen pollution and eutrophication in water bodies. When plants are irrigated with water containing high levels of nitrate, they may exhibit reduced growth, as well as increased susceptibility to pests and diseases [60]. A mean nitrite concentration of 0.17 ± 0.02 mg/L was recorded in this study, The European Union, the Water Framework Directive (WFD) sets maximum allowable limits of 50 mg/L for nitrate and 0.1 mg/L for nitrite in irrigation water. The WFD aims to ensure a good ecological status of all water bodies, including those used for irrigation, by reducing

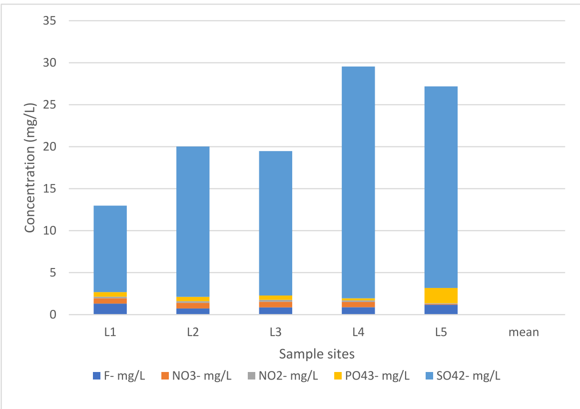

Fig. 3. Level of nutrients in irrigation water.

the level of pollutants and contaminants in water [61]. Nitrite is toxic to plants and can inhibit plant growth and development. When plants are exposed to high levels of nitrite in irrigation water, they may exhibit stunted growth, yellowing of leaves, and reduced yields. Additionally, high levels of nitrite in irrigation water can lead to soil degradation and reduced soil fertility, which can further impact plant growth and yield [62]. The nitrite concentration in the water under this present study exceeded the 0.1 mg/L maximum allowable limit according to the WFD of the European Union and as such could be toxic to plants, this could inhibit the growth of the vegetables in irrigated farmlands [61,62]. Nitrogen is usually present in water as nitrate and has proven to stimulates the growth of plants, however excess nitrogen supply to plants through irrigated water may result in a reduction in crop yield and nutrient quality as well as an impact on soil microbial communities [63,64].

Levels of sulphates ranged from 10.3 to 27.6 mg/L with L4 recording the highest sulphate concentration of 27.6 mg/L. Salinity of water is largely influenced by sulphate ions, high levels of sulphates in irrigation water could interfere with the uptake of vital nutrients in the soil [65]. Sulphate can be beneficial for plant growth in moderate levels, but excessive sulphate in irrigation water can lead to soil salinity, alkalinity, and toxicity. When plants are irrigated with water containing high levels of sulphate, they may exhibit reduced growth and yield, as well as increased susceptibility to drought and pests. The recorded levels of sulphates in this study were well within the 250 mg/L maximum limit set by the FAO [66], this could be due to a decreased used of fertilizer by the farmers and absence of major industrial activities around the farms which could have introduced high amounts of sulphates into the water used for irrigation Aliyu, Balogun [27]. Levels of phosphates in the irrigation water ranged of 0.25–1.82 mg/L with the highest concentration of 1.82 mg/L at sampling point L5. Phosphate is also an essential nutrient for plant growth, but high levels of phosphate in irrigation water can lead to eutrophication in water bodies and can negatively impact plant growth and soil health. When plants are exposed to high levels of phosphate in irrigation water, they may exhibit reduced growth and yield [67].

A mean concentration of 0.99 ± 0.11 mg/L of fluoride was recorded in this study, this is well within the 2.0 mg/L recommended limit for fluoride in irrigation water by the USEPA [56]. Fluoride is an essential micronutrient for plants, excessive levels of fluoride in irrigation water can accumulate in soil leading to the development of fluoride-rich soils that are unsuitable for agriculture. Also, accumulation of fluoride in plant tissues, which can interfere with several metabolic processes and disrupt the uptake of other essential nutrients, such as phosphorus. Limiting the use of phosphate-containing products such as fertilizer can help manage phosphate levels. Additionally, regular monitoring and adoption of water purification technologies can help maintain safe levels of fluoride, ensuring minimal interference with plant metabolic processes and nutrient uptake [68].

3.3. Minerals and heavy metals

Magnesium levels in the irrigation water ranged from 6.93 to 15.37 mg/L with an average value of 9.10 ± 1.59 mg/L. Mg is very essential for the growth of plants acting as an integral component of chlorophyll and an agent for activation of enzymes [69]. The water used for irrigation in this study contains significant levels of Mg needed for plant growth and development. Pb and Cr were below detection limits in the irrigation water samples, however the levels of some of the assessed metals were in the order Fe $<$ Ni $<$ Cr $<$ As. Prolonged use of waste water for irrigation could lead to the accumulation of heavy metals in plants and agricultural soils, this threatens the health of consumers [70]. The mean levels of Fe, Ni, As and Cd in this current study were 25.68 ± 5.31, 0.28 ± 0.02, 0.001 ± 0.0002 and 0.002 ± 0.0004 mg/L respectively. The USEPA recommends that irrigation water should not contain excessive levels of iron that can cause clogging of irrigation systems or negatively impact plant growth and soil health. For irrigation of vegetables, the high Fe concentration in this study could discolor the leaves of some plants especially foliage leaves [27]. Though the levels of Cd in this study were very low, Cd is toxic to plants at low concentrations and can accumulate in plant tissues, leading to reduced growth and yield, chlorosis, necrosis, and alterations in the physiological processes of the plant. Cadmium can also negatively impact soil microbial activity, nutrient cycling, and soil fertility [71], to enhance soil health and diminish the movement of cadmium within the soil in this current study area, it's crucial to invest in alternative source of quality water for irrigation [42]. The concentration of Na in the irrigation water from this study ranged from 9.40 to 23.10 mg/L with a mean concentration of 15.68 ± 2.42 mg/L as shown in Fig. 4. The recorded levels of Na ions in the irrigation water could be toxic to sensitive plants and may constrain vital nutrients such as nitrogen, zinc and phosphorus in plants [72,73]. The concentration of Ca ranged from 22.8 to 111 mg/L with a mean concentration of

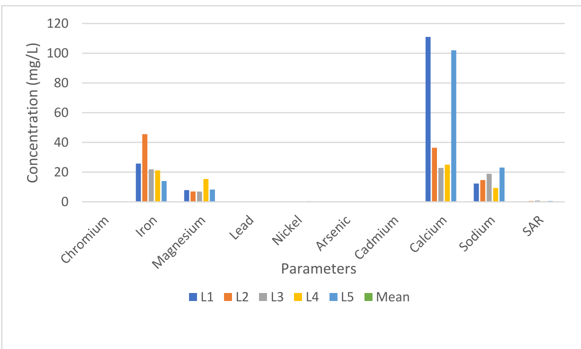

Fig. 4. Concentration of heavy metals in water for irrigation.

59.44 ± 19.40 mg/L. Ca is an essential nutrient for plant growth and development, and its presence in irrigation water can have positive impacts on plants and soil, when Ca is present in irrigation water, it can help to reduce the negative impacts of other contaminants such as Na, Cl^-, and heavy metals. Ca competes with these contaminants for uptake by the plant and can help to reduce their accumulation in plant tissues. In addition, Ca can help to improve soil structure and water-holding capacity, which can improve soil fertility and reduce the risk of soil erosion [74] and as such, the 59.44 ± 19.40 mg/kg of calcium recorded in this study could be a vital mineral in the irrigation water for vegetable farming.

3.4. Sodium adsorption ratio (SAR)

SAR is a vital parameter for irrigation water quality which measures the relative levels of sodium to calcium and magnesium to provide estimations on the degree of sodium absorption by the soil [75]. The effects of SAR on soil depends on the soil type, texture and the drainage capacity. A high SAR in irrigation water results in accumulation of Na in soil which hardens and compacts the soil, expose soil to erosion, lowers soil permeability and the rates of infiltration of both air and water [75]. Irrigation water with excellent quality should have an SAR of not more than 10, an SAR between 10 and 18 is considered as good water, 18 to 26 represents doubtful water quality and SAR above 26 indicates that the water is not good for irrigation [26]. The calculated SAR from this study ranged from 0.303 to 0.886 with an average of 0.544 ± 0.102 as shown in Fig. 4. Results from this study suggests the SAR was very low and as such considered acceptable for most crops and indicates an unlikely potential risk of soil degradation.

3.5. Microbial loads of irrigation water

Coliform bacteria have been utilized as a sign of the overall bacterial quality of water and the potential presence of human infections. Coliform bacteria are always found in high concentrations in the intestinal tract, and millions of them are expelled in faeces. The range of total coliform counts reported in this research, from 2.1×10^6 to 4.15×10^7 MPN/100 mL as shown in Table 1, suggests a relatively high microbial load in the irrigation water. Total coliforms encompass a broad group of bacteria, including both fecal and non-fecal species. While some coliforms may be harmless, their presence can indicate potential fecal contamination and the possible presence of pathogens [76]. The vegetables irrigated with the water in this study containing high levels of coliform bacteria, including fecal coliforms, can become contaminated. If these vegetables are consumed raw or insufficiently cooked, there is an increased risk of foodborne illnesses. Fecal coliform counts in the irrigation water range from 2.35×10^6 to 4.15×10^5 MPN/100 mL. Fecal coliforms specifically indicate the presence of bacteria originating from the intestines of warm-blooded animals, including humans and animals [77]. The high counts reported suggest a significant level of fecal contamination in the irrigation water. The use of this irrigation water could introduce bacteria and their associated pathogens into the soil. Over time, this can contribute to the build-up of harmful bacteria in the soil, potentially posing long-term risks to crop production and soil health [78]. Jamieson, Gordon [79] reported that faecal coliform above 100 CFU/100 mL in irrigation water is beyond the acceptable limits. Brandt, Johnson [80] reported that if coliform bacteria are found but no *E. coli*, the contamination is probably due to soil or vegetation, or it may serve as a warning that more dangerous contamination may occur. The total and faecal coliforms recorded in this study could contaminate the vegetables produced in the KNUST farms with potential effects on the health of consumers, this could make it unwholesome for consumption [81]. Vegetables from these areas should therefore be washed properly before use. To mitigate these risks, it is important to ensure the use of irrigation water that meets appropriate quality standards. Treatment or remediation measures, such as filtration, disinfection, or alternative water sources, may be necessary to reduce microbial contamination levels and safeguard plant and food safety.

4. Conclusion

From the study results, the water used for irrigation contains elevated levels of contaminants, including faecal and total coliforms. This finding suggests a potential health risk to consumers of vegetables grown with this water. Contaminated produce could lead to foodborne illnesses and other health issues, emphasizing the importance of thorough washing and cooking of vegetable. The study area, KNUST vegetable farmlands, serves a significant portion of the Ghanaian population with vegetables. Any decline in crop quality and yield due to water contamination could have economic ramifications, affecting both farmers and consumers.Vegetables from these areas should therefore be washed properly before use. The KNUST farmlands serves the vast majority of Ghanaians with vegetables and as such strict attention is needed to regulate the activities of residents and farmers along the irrigation source, proper waste disposal, efficient disposal and treatment of domestic effluents, and education on the impact of the negligence and ignorance from society that contributes to pollution of the water source is highly recommended. It is therefore prudent to implement regular water testing and monitoring programs to assess the quality of irrigation water in Peri urban Kumasi and provide training and awareness programs for farmers on best agricultural practices. This will help identify potential contaminants and enable timely intervention measures.

Table 1
Levels of microbial loads in waste water for irrigation.

Parameters	Units	L1	L2	L3	L4	L5
Total Coliform	MPN/100 mL	4.15×10^7	9.15×10^6	2.35×10^7	2.35×10^7	2.1×10^6
Faecal Coliform	MPN/100 mL	2.35×10^6	4.15×10^5	2.3×10^5	9.15×10^5	4.15×10^5
E. coli	MPN/100 mL	NIL	NIL	NIL	NIL	NIL

Limitations and future perspectives

This investigation was primarily centered on a particular geographical area, potentially constraining the applicability of our findings to broader regions. To address this limitation, forthcoming research could encompass multi-site studies spanning diverse environments. Moreover, this study predominantly made use of conventional techniques for assessing water quality, which, while providing valuable insights, might benefit from the integration of advanced technologies to enhance the precision and timeliness of evaluations. Additionally, this study's temporal scope was confined to a specific timeframe, and future endeavours could delve into long-term trends and the influence of seasonal variations on irrigation water quality. Finally, it is significant to involve stakeholders and employing community-based participatory research approaches to gain a deeper understanding of local concerns and foster sustainable water management practices.

Data availability

Data will be made available on request.

Funding statement

The authors did not receive any funding for this project.

CRediT authorship contribution statement

Winfred Bediakoh Ashie: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jonathan Awewomom:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Emil Nana Yaw Osei Ettey:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Francis Opoku:** Writing – review & editing, Supervision, Formal analysis, Data curation. **Osei Akoto:** Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] United Nations, Africa water atlas, in: Environment Programme. Division of Early Warning Assessment, UNEP/Earthprint, 2010.
[2] C. Mafuta, Green Hills, Blue Cities: an Ecosystems Approach to Water Resources Management for African Cities, 2011.
[3] R. Najjar, S. Heidari, M. Tazerout, Formulation of an economical microemulsion of diesel/colza oil fuel and investigation of some physical parameters for its stability, Environ. Prog. Sustain. Energy 37 (5) (2018) 1762–1769, https://doi.org/10.1002/ep.12820.
[4] B. Keraita, B. Jimenez, P. Drechsel, Extent and Implications of Agricultural Reuse of Untreated, Partly Treated and Diluted Wastewater in Developing Countries, vol. 2008, CABI Reviews, 2008, p. 15, https://doi.org/10.1079/PAVSNNR20083058.
[5] A.N. Angelakis, S.A. Snyder, Wastewater Treatment and Reuse: Past, Present, and Future, MDPI, 2015, pp. 4887–4895, https://doi.org/10.3390/w7094887.
[6] M. Hashem, X. Qi, Treated Wastewater Irrigation-A Review. Water 13 (2021) 1527, https://doi.org/10.3390/w13111527.
[7] J. Xu, et al., Impact of long-term reclaimed wastewater irrigation on agricultural soils: a preliminary assessment, J. Hazard Mater. 183 (1–3) (2010) 780–786, https://doi.org/10.1016/j.jhazmat.2010.07.094.
[8] P. Baveye, A future for soil science, J. Soil Water Conserv. 61 (5) (2006) 148A–151A.
[9] A. Kapoor, A.D. Ghare, A.M. Badar, Closure to "cylindrical central baffle Flume for flow Measurement in open channels" by aniruddha D. Ghare, ankur kapoor, and avinash M. Badar, J. Irrigat. Drain. Eng. 147 (7) (2021) 07021013.
[10] WHO. *Wastewater Quality Indicators*, 2023 [cited 2023 5th January, 2023]; Available from: https://en.wikipedia.org/wiki/Wastewater_quality_indicators.
[11] P.C. Nagajyoti, K.D. Lee, T. Sreekanth, Heavy metals, occurrence and toxicity for plants: a review, Environ. Chem. Lett. 8 (2010) 199–216.
[12] M. Lambert, B. Leven, R. Green, New methods of cleaning up heavy metal in soils and water, Environmental science and technology briefs for citizens 7 (4) (2000) 133–163.
[13] G. Chauhan, U. Chauhan, Human health risk assessment of heavy metals via dietary intake of vegetables grown in wastewater irrigated area of Rewa, India, International journal of scientific and research publications 4 (9) (2014) 1–9.
[14] K.S. Balkhair, M.A. Ashraf, Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia, Saudi J. Biol. Sci. 23 (1) (2016) S32–S44.
[15] M.A. Alghobar, S. Suresha, Evaluation of metal accumulation in soil and tomatoes irrigated with sewage water from Mysore city, Karnataka, India, Journal of the Saudi Society of Agricultural Sciences 16 (1) (2017) 49–59.
[16] H.M. Mustafa, G. Hayder, Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: a review article, Ain Shams Eng. J. 12 (1) (2021) 355–365.
[17] Nieto, E.G. 5 Best Plants For Phytoremediation. [cited 2023 6th January,2023]; Available from: https://land8.com/5-best-plants-for-phytoremediation/.
[18] M.J. Shahid, et al., Role of microorganisms in the remediation of wastewater in floating treatment wetlands: a review, Sustainability 12 (14) (2020) 5559.
[19] P. Extension, Interpreting Irrigation Water Tests, 2016. https://extension.psu.edu/interpreting-irrigation-water-tests.
[20] M.K. Mensah, Assessment of Drinking Water Quality in Ehi Community in the Ketu-North District of the Volta Region of Ghana, 2011.
[21] A.P.H. Association, in: A.E. Greenberg, L.S. Clesceri, A.D. Eaton (Eds.), *American Public Health Association (APHA). Standard Methods for the Examination of Water and Wastewater.* Apha, WEF and AWWA, 1992, p. 1134.
[22] D. Vidyasagar, Y. Vidyasagar, Simple Procedures to Prepare Conductivity Cell and pH Solution & Measure Conductivity AQC Solution, 2019.
[23] A. Greenberg, , et al.Apha, Awwa, Wpcf, Standard Methods for the Examination of Water and Wastewaters, APHA, Washington, 1985.
[24] K. Prakash, R. Somashekar, Groundwater quality- assessment on anekal taluk, Bangalore urban district, India, J. Environ. Biol. 27 (4) (2006) 633–637.

[25] E.W. Rice, L. Bridgewater, A.P.H. Association, Standard Methods for the Examination of Water and Wastewater, vol. 10, American public health association, Washington, DC, 2012.
[26] D. Kadyampakeni, et al., Analysis of water quality of selected irrigation water sources in northern Ghana, Water Sci. Technol. Water Supply 18 (4) (2018) 1308–1317.
[27] T. Aliyu, et al., Assessment of the Presence of Metals and Quality of Water Used for Irrigation in Kwara State, 2017. Nigeria.
[28] D.H. Wilber, D.G. Clarke, Biological effects of suspended sediments: a review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries, N. Am. J. Fish. Manag. 21 (4) (2001) 855–875.
[29] M.J. Malakooti, M.S. Tabrizi, Effect of suspended solids on soil infiltration and water retention properties, Iranian Journal of Soil Research 26 (3) (2012) 263–269.
[30] A. Mahajan, R.K. Gupta, Impact of suspended solids on plant growth and development, J. Environ. Sci. Eng. 53 (2) (2014) 121–127.
[31] C.K. Abdallah, K.A. Mourad, Assessing the quality of water used for vegetable irrigation in Tamale Metropolis, Ghana, Sci. Rep. 11 (1) (2021) 5314.
[32] Nations, F.a.A.O.o.t.U, Irrigation Water Quality, 2002. http://www.fao.org/3/y4773e/y4773e06.htm.
[33] FAO, Water Quality for Agriculture, Irrigation and Drainage. http://www.fao.org/3/t0234e/T0234E00.htm: p. 29.
[34] A. Hayes, C.F. Mancino, I. Pepper, Irrigation of turfgrass with secondary sewage effluent: I. Soil and leachate water quality, Agron. J. 82 (5) (1990) 939–943.
[35] X. Li, C. Ding, T. Zhang, X. Wang, H. Chen, Oil microbial community response to pH and plant growth-promoting Rhizobacteria (PGPR) in different soils, J. Basic Microbiol. 58 (10) (2018) 872–882.
[36] W.H. Organization, Prevention of Mental Disorders: Effective Interventions and Policy Options: Summary Report, 2004.
[37] K. Ogedengbe, C. Akinbile, Impact of industrial pollutants on quality of ground and surface waters at Oluyole industrial estate, Ibadan, Nigeria, Niger. J. Technol. Dev. 4 (2) (2004) 139–144.
[38] U.S. Department of Agriculture, N.R.C.S., Water Quality: Irrigation Water Quality Criteria, 2014. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf.
[39] H. Jeong, H. Kim, T. Jang, Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea, Water 8 (4) (2016) 169.
[40] V.D. Taffouo, T.F. Noubissié, D.O. Ndoumou, D. Ndongo, N.Y. Njintang, Effects of irrigation water turbidity on growth and yield of Solanum melongena L, Am. J. Plant Sci. 7 (11) (2016) 1571–1578, https://doi.org/10.4236/ajps.2016.711145.
[41] A. Akpan-Idiok, A. Ibrahim, I. Udo, Water quality assessment of okpauku river for drinking and irrigation uses in Yala, Cross river state, Nigeria, Res. J. Environ. Sci. 6 (6) (2012) 210.
[42] Who, Guidelines for the Safe Use of Wastewater, Excreta and Greywater, vol. 2, 2006. https://www.who.int/water_sanitation_health/publications/gsuweg4/en/.
[43] Agency, U.S.E.P. and U, *Wade Able Streams Assessment.* EPA/841-B-06-002, vol. 2004, U.S. Environmental Protection Agency, Washington, DC, 2004. Office of Water.
[44] O. Adefemi, S. Asaolu, O. Olaofe, Assessment of the physico-chemical status of water samples from major dams in Ekiti State, Nigeria, Pakistan J. Nutr. 6 (6) (2007) 657–659.
[45] N.J. Warrence, J.W. Bauder, K.E. Pearson, Basics of Salinity and Sodicity Effects on Soil Physical Properties, vol. 129, Departement of Land Resources and Environmental Sciences, Montana State University-Bozeman, MT, 2002, pp. 1–29.
[46] M.J. Mohammad, N. Mazahreh, Changes in soil fertility parameters in response to irrigation of forage crops with secondary treated wastewater, Commun. Soil Sci. Plant Anal. 34 (9–10) (2003) 1281–1294.
[47] USDA, Irrigation water quality standards and salinity management strategies, in: Agriculture Information Bulletin, 1999.
[48] R. Ali, R. Khalid, T. Hussain, Impact of hard water on soil and plants, Int. J. Agric. Biol. 17 (2) (2015) 361–366, https://doi.org/10.17957/ijab/17.2.361.366.
[49] C.N. Sawyer, P.L. McCarty, G.F. Parkin, Chemistry for Environmental Engineering and Science, McGraw-Hill, 2003.
[50] M. Zaman, S.A. Shahid, L. Heng, Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques, Springer Nature, 2018.
[51] M. Aremu, G. Ozonyia, P. Ikokoh, Physicochemical properties of well, borehole and stream waters in Kubwa, Bwari Area Council, FCT, Nigeria, Electron. J. Environ. Agric. Food Chem. 10 (6) (2011) 2296–2304.
[52] Z.Y. Hseu, C.H. Chen, The Effects of Wastewater Irrigation on Soil and Crop Quality in Agricultural Research Updates, Nova Science Publishers, Inc., 2012, pp. 99–124.
[53] M.J. Travis, N. Weisbrod, A. Gross, Accumulation of oil and grease in soils irrigated with greywater and their potential role in soil water repellency, Sci. Total Environ. 394 (1) (2008) 68–74.
[54] M.S. Islam, M.K. Ahmed, M. Habibullah-Al-Mamun, S. Masunaga, Impacts of industrial effluents on vegetables and soils in the surrounding areas of Dhaka Export Processing Zone, Bangladesh, J. Environ. Manag. (2015) 276–283.
[55] F. Jiang, H. Li, Q. Li, Z. Li, X. Li, Y. Li, W. Liang, Ecological effects of wastewater irrigation: soil enzyme activity, microbial biomass, and community structure, Environ. Sci. Pollut. Control Ser. 24 (28) (2017) 22103–22111.
[56] USEPA, National Recommended Water Quality Criteria, Office of Water, Washington, DC, 2002.
[57] S. Adebayo, L. Usman, Levels of Ammonia-Nitrogen, Carbo Dioxide, Dissolved Oxygen, and Biochemical Oxygen Demand in Asa River, Ilorin, Nigeria, 2009.
[58] O.M. Kolawole, et al., Assessment of water quality in Asa River (Nigeria) and its indigenous Clarias gariepinus fish, Int. J. Environ. Res. Publ. Health 8 (11) (2011) 4332–4352.
[59] R.S. Ayers, D.W. Westcot, Water Quality for Agriculture, vol. 29, Food and Agriculture Organization of the United Nations Rome, 1985.
[60] H. Zhang, W. Davison, W. Huang, Effects of nitrogen sources and loading rates on nitrate contamination in groundwater under intensive vegetable cultivation, Environ. Sci. Pollut. Control Ser. 21 (1) (2014) 363–371.
[61] E. Union, Official Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, Journal of the European Communities (2000) 1–72.
[62] X. Dong, Y. Wang, X. Zeng, J. Yang, J. Liu, Effects of nitrate contamination in irrigation water on vegetable growth and quality: a review, J. Agric. Sci. 11 (9) (2019) 249–257.
[63] M. Qadir, C.A. Scott, Non-pathogenic trade-offs of wastewater irrigation, in: Wastewater Irrigation and Health, Routledge, 2009, pp. 127–152.
[64] C. Becerra-Castro, et al., Wastewater reuse in irrigation: a microbiological perspective on implications in soil fertility and human and environmental health, Environ. Int. 75 (2015) 117–135.
[65] M.I. Yesilnacar, M.S. Gulluoglu, Hydrochemical characteristics and the effects of irrigation on groundwater quality in Harran Plain, GAP Project, Turkey, Environ. Geol. 54 (1) (2008) 183–196.
[66] Food and Agriculture Organization of the United Nations, https://www.fao.org/food-agriculture-statistics/en/, 2023.
[67] S. Ali, M. Rizwan, A. Hussain, S. Mehmood, Effect of high phosphate-containing irrigation water on soil health and plant productivity, J. Plant Nutr. Soil Sci. 43 (7) (2020) 1003–1019.
[68] S. Khan, S. Ullah, I.U. Din, A. Khan, S. Khan, The effects of fluoride on plants, with emphasis on its uptake, translocation, accumulation and use efficiency, J. Plant Nutr. 41 (13) (2018) 1705–1715.
[69] M. Qadir, et al., High-magnesium waters and soils: emerging environmental and food security constraints, Sci. Total Environ. 642 (2018) 1108–1117.
[70] S. Chaoua, et al., Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco, Journal of the Saudi Society of Agricultural Sciences 18 (4) (2019) 429–436.
[71] B.J. Alloway, Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability, third ed., Springer, 2013.
[72] G. Ahmed, et al., Distribution of trace metal pollutants in surface water system connected to effluent disposal points of Dhaka Export Processing Zone (DEPZ), Bangladesh: a statistical approach, J. Nat. Sci. Sustain. Technol. 3 (2009) 293–304.

[73] R.K. Sharma, M. Agrawal, F.M. Marshall, Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: a case study in Varanasi, Environ. Pollut. 154 (2) (2008) 254–263.
[74] R. Ragab, C. Prudhomme, Soil and water: management, conservation and effects of climate change, Phil. Trans. Math. Phys. Eng. Sci. 360 (1796) (2002) 1921–1937, 2002.
[75] K. Wisialowski, Sodium Adsorption Ratio, Irrigation, and Soil Health, 2019. https://mytapscore.com/blogs/tips-for-taps/sodium-adsorption-ratio-irrigation-and-soil-health.
[76] J. Monaghan, M. Hutchison, Distribution and decline of human pathogenic bacteria in soil after application in irrigation water and the potential for soil-splash-mediated dispersal onto fresh produce, J. Appl. Microbiol. 112 (5) (2012) 1007–1019.
[77] A.M. Paruch, T. Mæhlum, Specific features of Escherichia coli that distinguish it from coliform and thermotolerant coliform bacteria and define it as the most accurate indicator of faecal contamination in the environment, Ecol. Indicat. 23 (2012) 140–142.
[78] M. Uyttendaele, et al., Microbial hazards in irrigation water: standards, norms, and testing to manage use of water in fresh produce primary production, Compr. Rev. Food Sci. Food Saf. 14 (4) (2015) 336–356.
[79] T. Jamieson, et al., What You Should Know about Irrigation Water Quality Safety, 2002.
[80] M.J. Brandt, et al., Twort's Water Supply, Butterworth-Heinemann, 2016.
[81] E.E.Y. Amuah, P. Amanin-Ennin, K. Antwi, Irrigation water quality in Ghana and associated implications on vegetables and public health. A systematic review, J. Hydrol. 604 (2022) 127211.
[82] S. Lesch, D. Suarez, A short note on calculating the adjusted SAR index, Transactions of the ASABE 52 (2) (2009) 493–496.