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FULL LENGTH ARTICLE

Environmental and health risks associated with reuse of wastewater for irrigation

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KEYWORDS

Al-Rustamia WWTP;
Irrigation;
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Abstract The present study focuses on the environmental and health risks associated with the use of treated wastewater produced from Al-Rustamia third extension plant for irrigation. The measured data are used to evaluate comprehensive pollution index (CPI) and organic pollution index (OPI). The average CPI was found as 0.69 which indicated to be slightly polluted for all seasons and a similar result was also obtained with OPI, which is found to slightly vary in the range 1.29–1.60 which indicates as being to be contaminated. Also to evaluate its suitability for irrigation purposes, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Residual Sodium Carbonate (RSC) were calculated following standard equations and found experimentally as (8.70), (74.76) and (2.68) respectively. Irrigation water classes are used for Salinity hazard (EC) and Sodium hazard (SAR) to assess water suitability for irrigation, and it is found that samples in summer and autumn in the class of C3-S1, indicate high salinity and low sodium water, while in spring and winter in the class of C4-S1, they indicate very high-salinity. Furthermore, the data indicate a slight to moderate degree of restriction on the use of this treated wastewater in irrigation due to chloride hazard. RSC value is more than 1.25 at all seasons, indicating that samples in summer and autumn are doubtful for irrigation purposes, while the samples in spring and winter are unsuitable for irrigation.

1. Introduction

Wastewater reuse is an integral part of water demand management, promoting the protection of high quality fresh water and reducing both environmental pollution and overall supply costs. Recent developments in technology and changes in attitudes toward wastewater reuse suggest that there is a potential for Wastewater reuse in the developing world [1,2]. The amount of collected and treated wastewater is likely to increase considerably with population growth, rapid urbanization, and improvement of sanitation service coverage [3–6]. Wastewater generates from domestic, commercial, and industrial sources. In many networks the domestic component is the largest, accounting for as much as 50–80% of the total water use [7,8]. Irrigation with treated wastewater has potential for both positive and negative environmental impacts [9] and with careful planning and management, the use of treated wastewater

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in agriculture can be beneficial to the environment. However, the direct and indirect uses of untreated wastewater in irrigation are increasing as a result of increasing global water scarcity, insufficient and inappropriate wastewater treatment and disposal and escalating fertilizer costs [10–12]. Wastewater is a source of plant nutrients and organic matter [13]. Nevertheless, it may contain undesirable chemical constituents and pathogens that pose environmental and health risks [14]. At the same time, a number of risk factors have been identified in reuse of wastewater; some of them are short term impacts (e.g., microbial pathogens) whereas others have longer-term impacts that increase with the continued use of wastewater (e.g., salinity effects on soil) [15]. The use of treated wastewater for irrigation is one of the methods which are currently widely used [16]. Reuse of treated wastewater helps to alleviate the pressure on traditional water resources by using part of treated wastewater for irrigation and industry. The nutrients in these waters can help plant growth rather than be contaminated as it occurs in the case of discharge into river, as well as the fact that the agricultural sector is the largest consumer of water, consuming about 92% of the amount of water available in Iraq at 1992 after it was 78% at 1980 due to the increase and expansion of agricultural land significantly [17]. Although irrigation with treated wastewater can reduce the utilization of natural water resources, it may also result in environmental problems [18,19]. The Iraqi capital, Baghdad city, has the highest level of sanitation provision with about 80% of the population connected to sewer treatment facilities. The sewerage network that was established between 1960 and 1980 worked on the basis of the separate system, but a combined system has been adopted since 1980. Basic stage was created, which call zero phase (Stage 0), at 1960 with a design capacity (40,000 m^3/day); only 24% of Baghdad's population were served by full sewage treatment. In 1974 was added the first expansion (Stage 1), which partly merge with the basic stage with a design capacity (45,000 m^3/day) and finally, was added second expansion (Stage 2) at 1981 with a design capacity (90,000 m^3/day) and thus became the total capacity of the project (175,000 m^3/day); which serve the East Bank of Tigris River south of the Army Canal. Al-Rustamia plant Stage 3 was operated in 1985 as part of the major expansion of sewage treatment capacity that led to 80% of Baghdad population. Now this stage serves the East Bank of Tigris River north of the Army canal. It was designed to serve a total population equivalent of 1,500,000 [9,20]. The objective of this research focused on the environmental and health risks associated with the use of treated wastewater produced from Al-Rustamia wastewater treatment plant (WWTP) for irrigation and to evaluate its suitability for irrigation purposes as non-conventional water resources.

2. Materials and methods

2.1. Site description

Baghdad city is about 900 km^2 and the approximation number of population for the year 2011 was 7.2 million people. It is a very large city and it is divided by Tigris River to two main parts: the east side (Rusafa) and the western side (Karkh). The city includes 457 sectors where about 82% of the sectors are served by sewerage systems. The Al-Rustamia wastewater treatment plant is located on the Diyala River to the south of Baghdad city at Rusafa Side. Al-Rustamia Project is the oldest sewerage network in Iraq, which provision of services to a third of the population of Baghdad. After treatment, the effluent is discharged into Diyala river and thus into the Tigris River. Al-Rustamia wastewater treatment plants are illustrated in Fig. 1.

2.2. Analysis and data collection

The data used in this study were provided by Al-Rustamia WWTP-Extension3 during 2002. Samples were seasonally collected (twice each season) using clean polyethylene containers before they are thrown to the river. Samples of treated wastewater were analyzed for chemical and physical properties after collection. Procedures followed for analysis have been in accordance with the Standard Method for Examination of Water and Wastewater [21] parameters are electrical conductivity (EC), pH, total dissolved solid (TDS), total suspended solid (TSS), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO_3-N), nitrite (NO_2-N), ammonia (NH_4), phosphate (PO_4^{2-}), sulfate (SO_4^{2-}), boron (B), iron (Fe), and chromium (Cr). The seasonal mean values of parameters are presented in Table 1.

2.3. Assessment methods

The data obtained during laboratory analysis were used in the evaluation of different indices to classify wastewater pollution and to evaluate its suitability for irrigation purposes, the indices are:

2.3.1. Comprehensive pollution index (CPI)

CPI evaluated by using measured concentration of parameters with respect to their permissible limit in irrigation wastewater quality prescribed by Iraqi Fact standard [33], to classify the wastewater quality status and its suitability for irrigation and human use.

$$\mathrm{CPI} = \frac{1}{n}\sum_{i=1}^{n}\mathrm{PI} \quad (1)$$

$$\mathrm{PI} = \frac{\text{measured concentration of individual parameter}}{\text{standard permissible concentration of parameter}} \quad (2)$$

where n: parameters number.

The water quality is ranked in the following categories: clean: (values 0–0.2), sub clean: (values 0.21–0.4), slightly polluted: (values 0.41–1.0), moderately polluted: (values 1.01–2.0), and severally polluted: (values $\geqslant$ 2.01) [22].

2.3.2. Organic pollution index (OPI)

The measured concentration of BOD, COD, Nitrate, and Phosphate is used to evaluate OPI with respect to their permissible limit in irrigation wastewater quality prescribed by Iraqi Fact standard [31], to classify the organic pollution due to organic compounds in the treated wastewater.

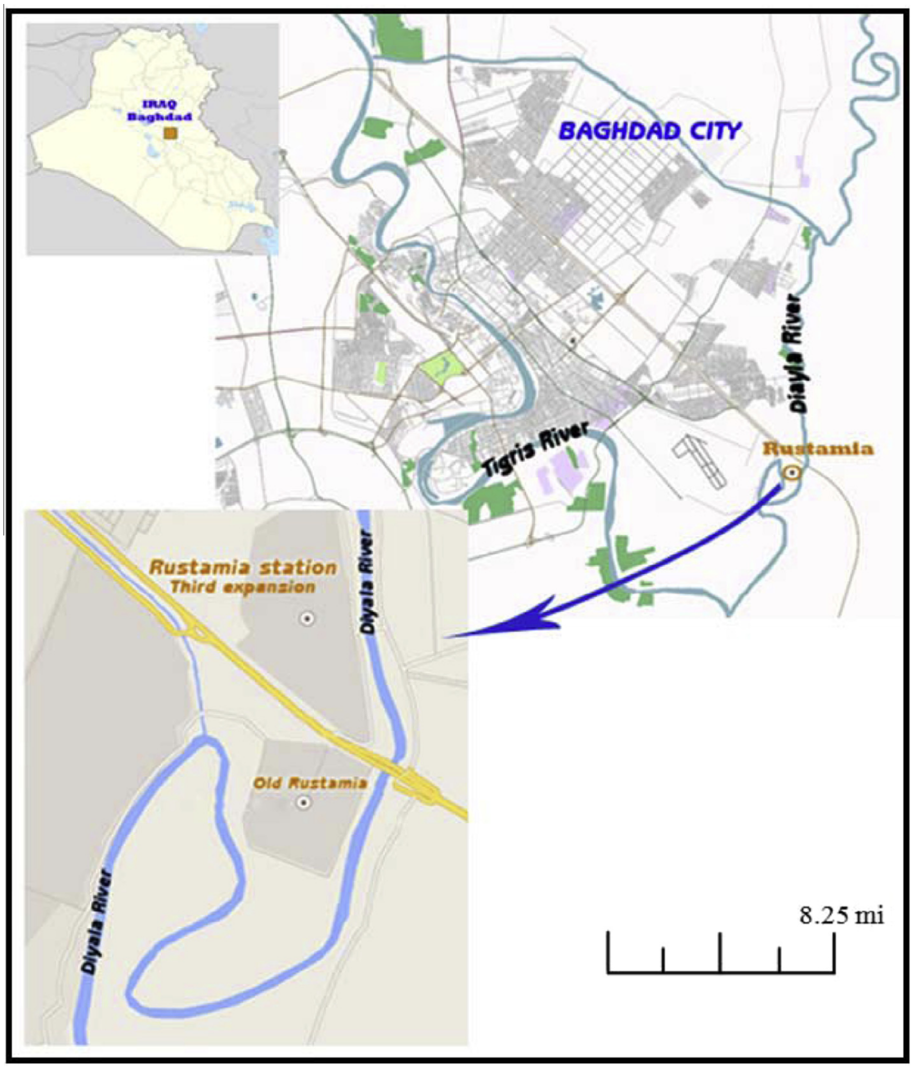

Figure 1 Map of Al-Rustamia WWTP in Baghdad city.

$$OPI = \frac{BOD}{BOD_s} + \frac{COD}{COD_s} + \frac{Nitrate}{Nitrate_s} + \frac{Phosphate}{Phosphate_s} \quad (3)$$

The water quality is ranked in the following categories: excellent: (OPI values <0), good: (OPI values 0–1), being to be contaminated: (OPI values 1–2), lightly polluted: (OPI values 2–3), moderately polluted: (OPI values 3–4), and heavily polluted: (OPI values 4–5) [23].

2.3.3. Application of the irrigation data hazardous

Numerous water quality guidelines have been developed by many researchers for using water in irrigation under different conditions. However, the classification of US Salinity Laboratory (USSL) is used most commonly. Parameters such as electrical conductivity (EC), total dissolved solid (TDS), sodium (Na^+), Sodium Adsorption Ratio (SAR), Soluble Sodium Percent (SSP), Residual Sodium Carbonate (RSC), and chloride (Cl^-) were used to assess the suitability of wastewater for irrigation purposes.

3. Results and discussion

The risks involved in using treated wastewater are of two types: Public Health and Environment. The following is a brief description of the possible risks.

3.1. Human health risks

The health effects of irrigating with wastewater can be both positive and negative. The positive effects are related to food security in poor areas. Wastewater is possible (and commonly the only way) to produce food and increase income in poor areas, thus also increasing nutrition and the quality of life. Negative effects are due to the presence of pathogens and toxic chemical compounds in wastewater [24]. Irrigation with treated wastewater poses a number of potential risks to human health via consumption or exposure to pathogenic microorganisms, heavy metals, harmful organic chemicals.

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Table 1 The seasonally mean values of parameters.

Parameters	Unit	Spring	Summer	Autumn	Winter	Objective values [33]
EC	μm/cm	2300	2200	2100	2300	–
pH	–	7.72	8.3	7.75	7.85	4–8.6
TDS	mg/L	1472	1480	1344	1472	2500
TSS	mg/L	38	40	22	23	40
Na^{+}	mg/L	285.00	285	215	262	250
Ca^{2+}	mg/L	168	78	139	157	450
Mg^{2+}	mg/L	94.00	92	73	83.5	80
K^{+}	mg/L	12.90	19.4	12.6	12.1	100
Cl^{-}	mg/L	357	300	243	289	–
CO_3^{2-}	mg/L	9.6	4.9	4.8	0.0	–
HCO_3^{-}	mg/L	398	293	314	410	–
BOD	mg/L	43	41	44	66	40
COD	mg/L	10	7.6	12.4	10	100
NO_3-N	mg/L	0.85	0.0	0.55	2.94	50
NH_4	mg/L	17.2	20.3	0.02	22.6	5
PO_4^{2-}	mg/L	10.15	4.72	4.99	10.97	25
B	mg/L	0.34	0.22	0.38	0.45	0.75
Fe	mg/L	0.0	0.0	0.0	0.04	5
Cr	mg/L	0.0	0.0	0.0	0.01	0.1

Four groups are at risk: (1) agricultural workers and their families; (2) crop handlers; (3) consumers of crops, meat, and milk; and (4) those living near the areas irrigated with wastewater, particularly children, and the elderly. Wastewater contains a variety of excreted organisms, and the types and concentrations vary depending upon the background levels of disease in the population. Many pathogens can survive for long enough periods of time in soil or on crop surfaces and thus be transmitted to humans or animals [25]. Therefore, pathogenic microorganisms are generally considered to pose the greatest threat to human health. Household sewage contains a high percentage of organic materials and pathogenic microorganisms, including bacteria, viruses, and protozoan. The diseases associated with such infections are also diverse and include typhoid, dysentery, diarrhea, vomiting, and malabsorption. Any human contact with the treated wastewater might be hazardous [26].

The process at the treatment plants reduces the pathogenic micro-organism content, but it does not eliminate it completely. This problem can be solved by desalination of the treated wastewater, but this is an expensive process and is usually not required from the aspect of agricultural use.

Different crops that are irrigated by treated wastewater pose various threats to human health. There are crops with pathogenic microorganisms' contamination that do not seem to pose any health risk:

– Industrial crops such as cotton or fodder.
– Fruits that are dried in the sun for at least 60 days after last irrigation.
– Watermelons grown for edible grains or for seeds that are irrigated only before blooming.
– Groves or flora, without human access [17].

Regarding chemical compounds in wastewater, the major health concern is due to metals. Many of them are biologically beneficial in small quantities but become harmful at high levels of exposure. Cobalt, zinc, and copper are not considered here because plants are not likely to absorb them in sufficient quantities to prove harmful to consumers and are toxic to plants far before reaching a content that is toxic to humans [27]. There is a limit for hexavalent chromium, however, because it is rapidly reduced to trivalent chromium, which forms a less soluble solid phase in wastewater or soils. Cadmium is the metal that causes the largest risk. Its uptake can increase with time, depending on soil concentration, and is toxic to humans and animals in doses much lower than those that visibly affect plants [28].

Wastewater contains a wide variety of organic compounds, some of them toxic or causing cancer or embryo/fetal effects. The specific effect depends on the type of compound, its concentration, and the route and duration of exposure. Normally, the effects are long term. Therefore, to assess the human health risk and wastewater pollution, the measured data of parameters were used to evaluate comprehensive pollution index (CPI) and organic pollution index (OPI). The result of these indices at all seasons is shown in Fig. 2. The CPI results were found to vary in the range 0.43–0.83, whereas the average CPI was found as 0.69 which indicated to slightly pollute: (CPI values 0.41–1.0) for all seasons. The variation of the PI value

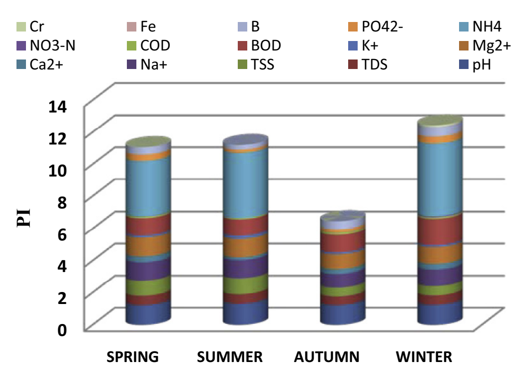

Figure 2 PI values of water quality parameters.

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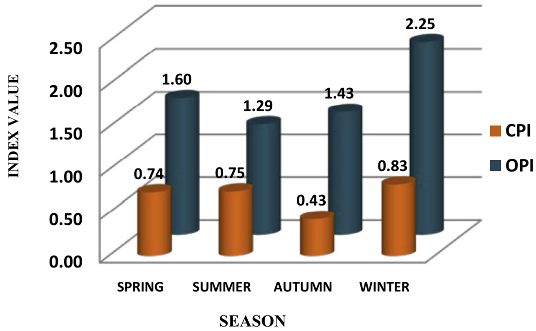

Figure 3 Variations of pollution indices at various seasons.

of all parameters considered is shown in Fig. 3. A similar result was also obtained with OPI in Winter season, this is found slightly polluted (OPI values 2–3),while for the other seasons OPI vary in the range 1.29–1.60 which indicated as being to be contaminated (OPI values 1–2).

An additional potential health threat might happen if a cross connection between the effluent and the fresh water piping systems occurs. This situation poses a risk of a massive disease outburst, because it could insert the microbiological contamination directly into the fresh water piping system. It appears that there are unknown risks where the treated wastewater quality is unsuitable. It is not always possible to solve such a condition except with substantial means, financial or others [29].

3.2. Environmental risks

Irrigation with treated wastewater might add certain contaminates, such as chlorides, to the groundwater [30]. This risk has an accumulative nature as the contaminate appear in the water supply systems; flow to the treatment plants and back to the aquifer. The risks in this respect have a long-term influence and are difficult to evaluate. According to the health regulation, treated wastewater irrigation is prohibited in the vicinity of drinking water wells (except for effluent that does not pose any risk). Irrigation above fresh water pipes can be approved, only if the treated wastewater is at the needed quality level, if the water pipe is in good condition and there is no risk of under pressure in the pipe.

In addition to microorganisms, household sewage also contains substantial salt additions [26]. Irrigation with treated wastewater causes land salinity, also causes land sealing and sodium accumulation, which could cause increased run off and land erosion. One particular concern of the environmental problems is long-term sustainability issue (e.g. the increase of salinity and sodium content in soil). High values of soil salinity and SAR cause soil structure deteriorations, decrease of soil permeability and reduction of crop yields due to toxic and osmotic effects [31]. The criteria used to evaluate quality of wastewater for use in irrigation are listed in Table 2.

An explanation of the observed characteristics follows in the following sections:

3.2.1. Salinity hazard

Salinity is the result of all dissolved anions and cations in water. It cause increase of the osmotic pressure of soil solutions, harming the ability of plants to absorb water and nutrients [34]. It is the most important parameter in determining the suitability of water for irrigation use, and generally measured as the electrical conductivity (EC) of water or the concentration of total dissolved solid (TDS).

Electrical conductivity (EC) is a good measure of salinity and it is the most significant issue in determining the suitability of water for irrigation. The most important negative effect on the environment caused by irrigation with wastewater is the increases in soil salinity, which can decrease productivity in the long term [35]. EC values of experimental samples varied from 2100 to 2300 μS/cm (mean value = 2225 μS/cm) while TDS values varied from 1344 to 1480 mg/L (mean value = 1442 mg/L) indicating a slight to moderate degree of restriction on the use of this wastewater in irrigation. However, irrigation water with conductivity in the range of 750–2250 μS/cm is permissible for irrigation and widely used. The concentration of TDS permissible limit of the treated wastewater for irrigation is about 2500 mg/L [33]. It is clear that irrigation using saline water can add salt concentration to the soils and a problem may be occurring due to the increase in concentration that is harmful to the crop or landscape. Therefore it is necessary to control the salinity when using treated wastewater for irrigation.

Table 2 Degree of restriction on use for agriculture irrigation.

Degree of restriction on use [32]			
Parameters	None	Slight to moderate	Sever
EC, μS/cm	< 700	700–3000	> 3000
TDS, mg/L	< 450	450–2000	> 2000
Na^+, mg/L	< 100	> 100	> 100
SAR, meq/L	< 3	3–9	> 9
	No problem	Increasing problem	Sever problem
Cl^-, mg/L	< 4	4–10	> 10

3.2.2. Sodium hazard

Sodium content is an important factor in irrigation water quality evaluation and Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reducing soil permeability [36]. The concentration of the sodium permissible limit of the treated wastewater for irrigation is about 10.87 meq/L (250 mg/L) [33]. Sodium concentrations in the samples varied from 215 to 285 mg/L (mean value = 261.75 mg/L), indicating a slight to moderate to high degree of restriction on the use of this wastewater in irrigation [32].

Sodium hazard is usually expressed in terms of Sodium Adsorption Ratio (SAR) and it can be calculated from the ratio of sodium to calcium and magnesium. SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the Sodium hazard [37]. The permissible limit of Sodium Adsorption Ratio (SAR) of the treated wastewater for irrigation is about 6–7 mg/L [33]. The SAR value of the samples ranges from 7.35 to 10.34 meq/L (mean value = 8.70 meq/L), which is out of the permissible limit. It has been calculated as follows:

$$SAR = Na/\sqrt{(Ca + Mg)/2} \quad (4)$$

where Na^+, Ca^{2+} and Mg^{2+} are in meq/L.

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Soil permeability is reduced by irrigation with water high in sodium; therefore, the best measure of a water likely effect on soil permeability is the water SAR considered together with its EC. In this respect, Table 3 which is based on the integrated effect of EC (Salinity hazard) and SAR (Sodium hazard), has been used to assess the water suitability for irrigation [38]. It is found that samples in summer and autumn in the class C3-S1, indicate high salinity and low sodium water, which can be used for irrigation on almost all types of soil except for those crops which are highly sensitive to Sodium, while in spring and winter in the class C4-S1, they indicate very high-salinity water is not suitable for irrigation under normal conditions. This type of water can be suitable for plants having good salt tolerance, but restricts its suitability for irrigation, especially in soils with restricted drainage [38].

The Soluble Sodium Percentage (SSP) was calculated by the following equation:

$$SSP = (Na * 100)/(Ca + Mg + Na + K) \quad (5)$$

where all the ions are expressed in meq/L.

The standard value of SSP is 40–60% recommended by US Salinity Laboratory [40]. The classification of irrigation water according to the SSP values is presented in Table 3. Water with high percent of SSP may result in sodium accumulations that will cause a breakdown of the soil's physical properties [41]. The SSP values of the samples range from 72.4% to 78.6%. The calculated SSP values for all seasons show that samples are doubtful for irrigation purposes.

Residual Sodium Carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose [41]. The excess sum of CO_3^{2-} and HCO_3^- in wastewater over the sum of Ca^{2+} and Mg^{2+} influences the unsuitability of wastewater for irrigation. It has been determined by the formula:

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad (6)$$

where all the ionic concentration was reported in meq/L.

The classification of irrigation water according to the RSC values is presented in Table 4. According to the US Department of Agriculture [38], water having more than 2.5 meq/L of RSC is not suitable for irrigation purposes while those having 1.25–2.5 meq/L are marginally suitable and those with less than 1.25 meq/L are safe for irrigation. The RSC value of the samples ranges from (2.21 to 3.38) meq/L. The calculated RSC values show that samples in summer and autumn are doubtful for irrigation purposes, while the samples in spring and winter are unsuitable for irrigation.

3.2.3. Chloride hazardous

The most common toxicity is from chloride (Cl^-) in the irrigation water. Cl^- is not adsorbed or held back by soils, therefore it moves readily with the soil–water, is taken up by the crop, moves in the transpiration stream, and accumulates in the leaves [42]. The obtained Cl^- ion concentration of the samples varied from 243 to 357 mg/L (mean value = 297.25 mg/L = 8.38 meq/L) representing a slight to moderate degree of

Table 3 Irrigation water classes for Salinity hazard and Sodium hazard [39].

Salinity hazard class	EC, μS/cm	TDS, mg/L	Irrigation water classification	Characteristics
C1	0–250	< 200	Excellent	Low-salinity water can be used for irrigation on most soil with minimal likelihood that soil salinity will develop
C2	251–750	200–500	Good	Medium-salinity water can be used for irrigation if a moderate amount of drainage occurs
C3	751–2250	501–1500	Permissible	High-salinity water is not suitable for use on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required
C4	> 2250	1501–3000	Unsuitable	Very high-salinity water is not suitable for irrigation under normal conditions
Sodium hazard class	**SAR meq/L**	**Water-suitability for irrigation**	**Characteristics**	
S1	0–10	Low	Suitable for all types of soils except for those crops which are highly sensitive to Sodium	
S2	10–18	Medium	Suitable for coarse textured or organic soil with good permeability. Relatively unsuitable in fine textured soil	
S3	18–26	High	Harmful for almost all types of soils. Requires good drainage, high leaching, and gypsum addition	
S4	> 26	Very high	Unsuitable for irrigation	

Table 4 Irrigation water quality based on SSP and RSC [40].

Water-suitability for irrigation	Excellent	Good	Permissible	Doubtful	Unsuitable
SSP meq/L	< 20%	20%-40%	40–60%	60–80%	> 80%
RSC meq/L	–	< 1.25	–	1.25–2.5	> 2.5

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restriction on the use of this wastewater in irrigation [32]. While, the samples can be used for moderately tolerant plants, according to USSL classification of irrigation water [38]. Crop tolerances to chloride are not so good as crop tolerances to salinity [32].

Other potential environmental effects:

– Poor quality treated wastewater, or treated wastewater that is being sucked from anaerobic layers of the treatment plant's reservoir could cause a strong odor nuisances.
– Irrigation with treated wastewater, if not properly controlled, could cause a decrease in yield, as well as in the quality of the crops.

4. Conclusion

- The average CPI indicates slight pollution for all seasons.
- The average OPI indicates slight pollution in Winter season, while for the other seasons indicated as being to be contaminated.
- The irrigation water classes for Salinity hazard and Sodium hazard found that samples in summer and autumn in the class of C3-S1, indicate high salinity and low sodium water, while in spring and winter in the class of C4-S1, they indicate very high-salinity.
- Data obtained indicate a slight to moderate degree of restriction on the use of this treated wastewater in irrigation due to chloride hazard.
- Due to RSC value, data indicate doubtful for irrigation purposes in summer and autumn, while unsuitable for irrigation in spring and winter.

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