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Physicochemical Analysis of Untreated Municipal Wastewater for Irrigation Purposes in Chiro Town, West Hararghe, Ethiopia

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ABSTRACT: Reuse of wastewater for irrigation is certainly an effective substitute, especially in developing countries where there is a scarcity of fresh water, depletion of groundwater, the cost of pumping underground water, and the supply of some valuable plant nutrients. Therefore, the objective of this paper was to assess the suitability of untreated municipal wastewater (UMWW) for irrigation purposes in Chiro town, west Hararghe zone, Ethiopia using relevant standard methods. The results obtained show that the average values of hydrogen ion concentration (pH) and electrical conductivity (EC) in the sample were 7.48 and 2.54 dS/m. The average values obtained for the principal cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) and anions (Cl^{-}, CO_3^{2-}, SO_4^{2-}, HCO_3^{-}) were (119.56, 38.10, 13.00, and 58.00) mg/L and (88.75, 0.00, 11.91,705.6) mg/L, respectively. The experimental results obtained for other miscellaneous factors, such as total suspended solids (TSS), total dissolved solids (TDS), and chemical oxygen demand (COD), are 90.0, 695.0, and 136.0 in mg/L. Throughout this study, the salinity hazard was assessed by analyzing the combination of TDS and EC values. The sodium hazard was evaluated by analyzing crucial factors such as sodium adsorption ratio (SAR), soluble sodium percentage (SSP), and residual sodium carbonate (RSC). Finally, the study findings of all relevant quality parameters for irrigation water revealed that the tested UMWW sample can be used in irrigation with a slight to moderate degree of restriction of use.

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Reusing treated sewage or wastewater is an exceptional approach to overcoming the problem of freshwater scarcity (Adams, 2017). Almost 80-92% of irrigation water in the world is used for crop production, and nearly 70% of the water is taken from freshwater (Ofori *et al*., 2021). The United Nations (UN) has set the application of wastewater reuse in the world as one of the main goals of sustainable development because upcycling wastewater for irrigation purposes could encourage crops, prevent wastewater pollution in the environment, and reduce concerns about freshwater scarcity (Wennersten and Qie, 2018). Additionally, wastewater irrigation benefits in maintaining essential nutrients in the soil and crops (Ofori *et al*., 2021). On the other hand, the scarcity of fresh irrigation water and the rigorous production of fruits and vegetables in developing countries have drawn attention to the use of untreated wastewater for irrigation (Egbueri *et al*., 2023; Ungureanu *et al*., 2020). Although the possibility of

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reusing wastewater in irrigation could be used instead of freshwater irrigation; evaluation of its quality parameters and necessary measurements should be taken to reduce associated problems in soils, plants, animals, and humans after the consumption of the crop products (WHO, 2006).

Water dissolves the salt components into cations and anions when it comes into contact with the salt-containing substances in rocks and soils such as gypsum salt ($CaSO_4.2H_2O$), Epsom salt ($MgSO_4.7H_2O$), Glauber salt ($Na_2SO_4.10H_2O$), baking soda ($NaHCO_3$), and table salt (NaCl) (Greene *et al*., 2016). It is also suggested that the primary cations and anions present in irrigation water are Calcium (Ca^{2+}), Magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+), and carbonate (CO_3^{2-}), bicarbonates (HCO_3^-), sulfates (SO_4^{2-}), chlorides (Cl^-), and nitrates NO_3^-), respectively (Jampani *et al*., 2020).

The quality characteristics of the water for irrigation use depend on the type and amount of dissolved salts in it (Arshad and Shakoor, 2017). The salinity problem and sodium hazard are the two most important quality characteristics of wastewater to evaluate before use in irrigation (Fianko and Korankye, 2020). The dissolved salt content of a body of water (*salinity*) can be evaluated depending on the conductivity value of the water and classified as low salinity (C_1) when; EC = 0 to 250 mho/cm, medium salinity (C_2) when; EC = 250 to 750 mho/cm, high salinity (C_3) when; EC = 750 to 2,250 mho/cm, very high salinity (C_4), when; EC = 2,250 to 5000 mho/cm.

Low-salinity water (C_1) can be used for irrigation with most crops on most soils, and medium-salinity water, C_2, can be used if leaching is applied. However, high-salinity water (C_3) and very high-salinity water (C_4) is not suitable for irrigation under normal irrigation practices (Shammi *et al*., 2016). Similarly, sodium classification can be low-sodium water (S_1), medium-sodium water (S_2), high-sodium water (S_3), and very high-sodium water (S_4) by analyzing the necessary factors such as SSR, SSP, RSC, and/or analyzing the combination effects of TDS and EC of the water sample.

The maximum concentration level of sodium ions in irrigation water Na^+, tends to be absorbed by clay particles, displacing Ca^{2+} and Mg^{2+} ions. This phenomenon reduces soil permeability and ends with poor soil internal drainage. S_1 can be used for irrigation in almost all soils except for sodium-sensitive crops, such as avocados, while, S_2 can be used on sand or organic soils that take water well. However, S_3 may cause troublesome sodium problems if special management such as good drainage, high leaching, and addition of organic matter is not performed. S_4 is generally not suitable for irrigation (Gautam *et al*., 2023). Additionally, low-quality irrigation water can cause soil infertility, low-quality fruits and vegetables, low crop yield, and adverse health effects for end-product consumers.

Sufficient management of irrigation water quality is necessary to improve the agricultural productivity of products (Zhang and Shen, 2019). The necessary management and soil amendments can be applicable and useful after the analysis of the physiochemical properties of the wastewater, which helps to suggest its suitability for irrigation (Racar *et al*., 2020).

Therefore, the objective of this paper was to assess the suitability of untreated municipal wastewater (UMWW) for irrigation purposes in Chiro town, west Hararghe zone, Ethiopia.

MATERIALS AND METHODS

Study Area: Chiro town, the capital of the West Hararghe zone, is semi-arid with a latitude and longitude of 9º05′N 40º52′E and an average altitude of 1826 m above sea level. The town is located about 326 km from Addis Ababa, the capital of Ethiopia. The relative location of the Chiro district in west Hararghe, Oromia region is shown in Figure 1 (Amare and Getachew, 2019). According to statistical data from Chiro municipality for 2022, approximately 69,793 people live in the town with an annual population change of about 5%. In this area, the municipal wastewater generated during different human activities such as washing clothes and dishes, cleaning floors, septic tank leakages, etc., is disposed of in the environment without any treatment. According to some survey data, 41% of wastewater is stored in an open field, 35% is flown in an open ditch, 20% is released directly into a river across the town and only about 4% is collected in the septic tank (Fekadu *et al*., 2023).

Sampling Methods and Analysis: An untreated municipal wastewater (UMWW) sample was collected from the Oda Bultum University wastewater treatment site. The samples were collected at room temperature and stored in polyethylene bottles that were washed several times with the sample itself before filling them to the required volume. The samples were then brought to the *JIJE analytical service laboratory* and stored at a temperature below 4℃ before analysis.

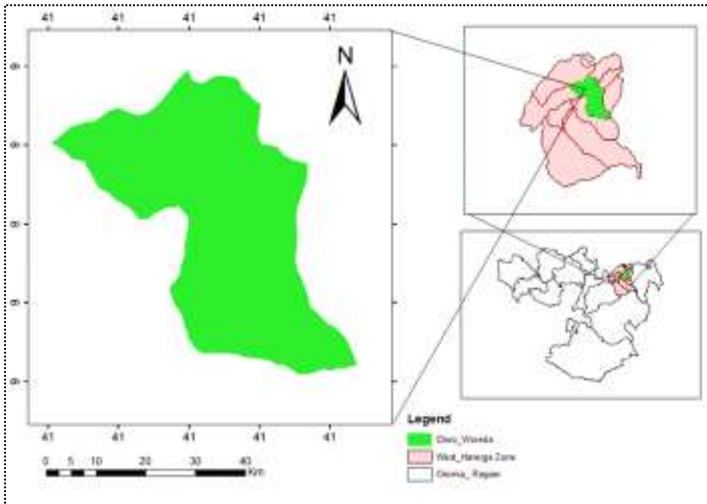

Fig 1: Relative location of the study area

The quality parameters were conducted following the methodologies given by (Rice *et al*., 2012). Calibration for different chemical constituents was done by preparing low-level standard solutions using laboratory-grade chemicals. Throughout this study, the principal cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined using standard EDTA titrimetric method, while sodium (Na^{+}) and potassium (K^{+}) were measured by flame photometry. The carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) anions were determined by titration with HCl, and sulfate (SO_4^{2-}) ions were evaluated by employing a turbidimetric method. Chloride (Cl^{-}) was determined by standard $AgNO_3$ titration. Furthermore, miscellaneous factors such as total suspended solids (TSS) and total dissolved solids (TDS) were determined by gravimetric method dried at 103℃-105℃ and 180ºC, respectively. The chemical oxygen demand (COD) was determined by the standard open reflux method. Other tests, such as the electrical conductivity of the sample (EC) and the hydrogen concentration ion (pH) were measured directly using potentiometric and conductometric measuring devices, respectively.

Table 1: Guidelines for salinity hazard, soil water infiltration, specific ion toxicity, and miscellaneous effects (Zaman *et al*., 2018)

Salinity Hazard			
Parameters	Degree of restriction on use		
	None	Slight to Moderate	Severe
EC (dS/m)	< 0.7	0.7-3.0	> 3.0
TDS (mg/L)	< 450	450-2000	> 2000
Soil Water Infiltration (Evaluate using EC and SAR together)			
Parameters	Degree of restriction on use		
EC (dS/m) & SAR	None	Slight to Moderate	Severe
If SAR 0 – 3 & EC =	< 0.7	0.7 – 3.0	> 3.0
If SAR 3 – 6 & EC =	< 0.2	0.2 – 0.3	> 3.0
If SAR 6 – 12 &EC =	< 1.9	1.9 – 0.5	< 0.5
If SAR 12 – 20 &EC	< 2.9	2.9 – 1.5	< 1.3
If SAR 20 – 40 & EC =	< 5.0	5.0 – 2.9	< 1.3
Specific Ion Toxicity			
Parameters	Degree of restriction on use		
	None	Slight to Moderate	Severe
Na^{+} (mg/L)	< 100	> 100	> 100
Na^{+} (SAR)	< 3	3 – 9	> 9
Cl^{-} (mEq/L)	< 4	4 – 10	> 4
Miscellaneous Effects			
Parameters	Degree of restriction on use		
	None	Slight to Moderate	Severe
pH (standard unit)	Normal range: 6.5 – 8.4		
Nitrogen (NO_3^{-}), mg/L	< 5	5 – 30	> 30
Bicarbonate (HCO_3^{-}), mEq/L	< 1.5	1.5 – 8.5	> 8.5

Water Quality Standards for Indirect Wastewater Reuse: The standards mentioned in Table 1 were used for detailed discussions on the suitability of the UMWW sample for irrigation purposes.

Assessment of Irrigation Water Quality Parameters: The study used the following equations (Equation (1) – (6)) to assess the concentration levels of ions (in *milliequivalents per liter*, mEq/L), and other quality parameters that offer evidence of the suitability of water for irrigation use (Panneerselvam *et al*., 2020).

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (1)$$

$$SSP = \frac{(Na^{+} * 100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \quad (2)$$

$$MH = \frac{Mg^{2+} * 100}{(Ca^{2+} + Mg^{2+})} \quad (3)$$

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{(Ca^{2+} + Mg^{2+} + Na^{+})} * 100 \quad (4)$$

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (5)$$

$$\frac{mEq}{L} = \frac{\frac{mg}{L} * \text{Valence}}{\text{Atomic, formula, or molecular weight}} \quad (6)$$

Formula Keys: ***SAR****: Sodium adsorption ratio,* ***SSP****: Soluble Sodium Percentage,* ***MH****: Magnesium Hazard,* ***PI****: Permeability Index,* ***RSC****: Residual Sodium Carbonate,* ***mEq/L****: milliequivalents per liter*

RESULTS AND DISCUSSION

Hydrogen Ion Activity (pH): The evaluation of hydrogen ion concentration provides quick information on the suitability of wastewater for irrigation use (Chhabra and Chhabra, 2021). The normal pH value of irrigation water ranges from 6.5 to 8.4 (Bortolini *et al*., 2018; Zaman *et al*., 2018). In this study, the average pH value of untreated municipal wastewater samples was determined to be 7.48, which indicates that the wastewater sample is alkaline in nature. The pH value of the sample of 7.48 makes it suitable for irrigation.

Table 2: Evaluated physiochemical properties of the untreated municipal wastewater (UMWW) sample.

Sr. No	Tested Quality Parameters	Experimental Results (average values)	Unit			
	pH ***(@ 25ºC)***	7.48	Standard units			
	Electrical Conductivity (EC)	2.54	dS/m			
		(mg/L)	**Valence**	**Atomic or Formula Weight**	**Equivalent Weight**	**mEq/L**
	Chemical oxygen demand (COD)	136.08	-	-	-	-
	Total dissolved solids (TDS)	695.00	-	-	-	-
	Total suspended solids (TSS)	90.00	-	-	-	-
Cations						
	Calcium (Ca^{2+})	**119.56**	2	40	20	**5.966**
	Magnesium (Mg^{2+})	38.10	2	24	12	3.135
	Potassium (K^{+})	13.00	1	39	39	0.333
	Sodium (Na^{+})	58.00	1	23	23	2.523
Anions						
	Bicarbonate alkalinity (HCO_3^{-})	**705.6**	1	61	61	**11.57**
	Carbonate alkalinity (CO_3^{2-})	ND	2	60	30	ND
	Chloride (Cl^{-})	88.75	1	35.5	35.5	2.304
	Sulfate (SO_4^{2-})	11.91	2	96	48	0.248

Salinity Hazard: The salinization process occurs when water dissolves salts into cations and anions. Salinity has been considered the most important factor in determining the suitability of water for irrigation because high salinity can create unfavorable conditions for the crop to absorb nutrients and result in low yield (Shammi *et al*., 2016; Zaman *et al*., 2018). Electrical conductivity (EC) is the most essential factor in determining the quality of water for irrigation and is a good measurement of the salinity hazard to the crop as it reflects a TDS in wastewater (Chhabra *et al*., 2021). A study by Rebello *et al*., (2020) suggested that if the EC value range of wastewater is 0.7dS/m ≤ EC ≤ 3dS/m, and the TDS value is 450 mg/L ≤ TDS ≤ 2000 mg/L; the wastewater is suitable for irrigation purposes with a slight to moderate degree of restriction on use. In this study, the determined average EC value of the sample was 2.54dS/m while the TDS was 695 mg/L, which indicates that the degree of restriction on the use of this wastewater for irrigation is slight to moderate.

Sodium Hazard: A high level of sodium concentration in irrigation water leads to low soil permeability (Kaboosi, 2017; Zaman *et al*., 2018). Sodium is absorbed into plant roots and transported to leaves where it accumulates and causes plant damage (Gautam *et al*., 2023; Qadir *et al*., 2021). In the present study, the average sodium concentration level was 58 mg/L, indicating that the wastewater sample can be used for irrigation without any restriction of use. In addition, sodium hazards are usually expressed in terms of sodium absorption ratio (SAR), which is a relative amount of Na^+ to the combined amount of Ca^{2+} and Mg^{2+} ions in water, and it can be estimated using Equation (1) (Panneerselvam *et al*., 2020). Irrigation water with a maximum value of SAR can cause plant toxicity and calcium deficiency and as a result, reduces soil fertility and decreases crop productivity.

In this study, the average SAR value is 0.848. Based on the guidelines mentioned in Table 1, the determined average value of SAR together with its EC indicates that the wastewater sample can be used for irrigation with a slight to moderate degree of restriction of use.

Soluble Sodium Percentage (SSP): SSP is also used to predict sodium hazard and can be estimated from Equation (2). Water with SSP greater than 60% can cause sodium accumulation that will result in a breakdown of the soil's physical properties (Rahimi *et al*., 2018). In this study, the average value of SSP is estimated to be 21.33%, indicating that the wastewater sample can be used in irrigation with a slight degree of restriction on use.

Chloride: The most common ion toxicity in irrigation water is from chloride (Cl^-) ions. Cl^- is taken up directly by crops, moves in the transpiration stream, and accumulates in leaves. If the Cl^- concentration is not within an acceptable limit for the crop, it damages the leaf and causes the drying of the leaf tissues (Egbueri *et al*., 2023; Ibrahim *et al*., 2019). The average value of Cl^- in this study is 2.304 mEq/L, which indicates that the wastewater sample can be suitable for irrigation without any restriction on use.

Magnesium and Calcium: Magnesium (Mg^{2+}) and Calcium (Ca^{2+}) ions are plant nutrients, however, excessive amounts of these cations in irrigation water can increase soil pH, resulting in minimizing the availability of phosphorous (Adams, 2017; Chhabra, 2021). Water containing Mg^{2+} and Ca^{2+} greater than 10 mEq/L cannot be used in irrigation (Singh *et al*., 2020). In this study, the average values of Mg^{2+} and Ca^{2+} are 3.135 and 5.966 mEq/L, respectively, indicating that the wastewater sample can be suitable for irrigation. On the other hand, the magnesium hazard (MH) can be determined from Equation (3) to evaluate the safety of the water. If the magnesium hazard is less than 50%, the water is safe and suitable for irrigation (Farhadkhani *et al*., 2018). The average value of MH in this study is estimated to be 34.5%, which indicates that the wastewater sample is safe and suitable for irrigation.

Permeability Index: The permeability index was determined to assess the risk of soil permeability (Badr *et al*., 2023). Throughout the study, an average value of PI was determined using Equation (4) and was found to be 51%, indicating that the wastewater sample is significant for continuous irrigation.

Residual Sodium Carbonate (RSC): The high amount of the sum of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) over the sum of Mg^{2+} and Ca^{2+} in wastewater indicates the water is not suitable for irrigation. Water with the maximum RSC has the maximum pH and the land irrigated by such waters becomes infertile (Egbueri *et al*., 2023; Panneerselvam *et al*., 2020). According to the study by Batarseh *et al*., (2021), if the result of residual sodium bicarbonate result is found between 0 and 1.25 mEq/L, the water is probably safe for irrigation, and if $1.25 < RSC < 2.50$ the water is of permissible quality but requires good management and proper use of soil modifications. Usually, water with $RSC < 0$ is preferable for irrigation, and if $RSC > 2.50$ mEq/L the water is not suitable for irrigation purposes. In this study, the average RSC value is estimated using Equation (5), and determined to be 2.47 mEq/L, which indicates that the wastewater is of permissible quality and can be used in irrigation if good management and soil modification are applied.

Other Related Characteristics: The evaluation of oxygen demand arises from the biochemical degradation of organic materials and the oxidation of inorganic materials such as sulfides and ferrous materials suggested to further evaluate the quality of water in irrigation (Asami *et al*., 2021). The determined values of TDS, COD, and TSS for the sample were 695 mg/L, 136.08 mg/L, and 90 mg/L, respectively. With few exceptions, the wastewater in this study area displayed moderate values of TDS, COD, and TSS. These results provided that the wastewater sample can be suitable for irrigation with a slight to moderate degree of restriction of use.

Piper plots: A Piper diagram (see Figure 2) was plotted for the UMWW sample using the analytical data obtained from the chemical compositional analysis. The Piper diagram was one of the most commonly used graphical procedures for understanding water chemistry and was effectively used to separate relevant analytical data to know the sources of the dissolved constituents in the water sample (Singh *et al*., 2020). It was presumed that the most abundant cations in the water sample are two alkaline earth calcium (Ca^{2+}) and magnesium (Mg^{2+}) and one ''Alkali'' sodium (Na^+). The most common anions are one "weak acid" bicarbonate (HCO_3^-) and two "strong acids" sulfate (SO_4^{2-}) and chloride (Cl^-). The result indicates that the sample does not present a dominant cation type, it corresponds with the bicarbonate type and can be a magnesium bicarbonate type. In addition, the sample exhibits that weak acids exceed strong acids. Besides, as can be seen from the diagram the alkaline earths exceed the alkalies in this sample.

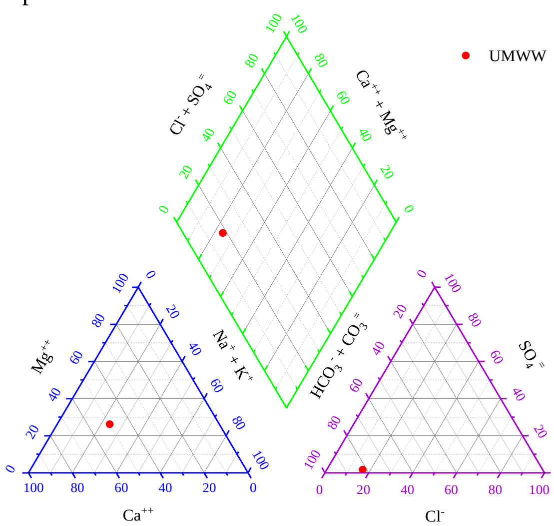

Fig 2: Piper diagram of water chemistry for untreated municipal wastewater in the study area.

Conclusion: In this study, the suitability of untreated municipal wastewater (UMWW) samples for irrigation was determined by analyzing relevant irrigation water quality parameters such as soil-water infiltration, specific ion toxicity, salinity hazard, sodium hazard, magnesium hazard, and other miscellaneous factors. This study's finding revealed that the reuse of wastewater for irrigation is certainly an effective substitute for freshwater and it could also be significant to the supply of some valuable plant nutrients. In general, all tested physiochemical properties of the UMWW sample evaluated in this study revealed that the sample can be suitable for irrigation with a slight to moderate degree of restriction of use.

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