Heliyon 7 (2021) e07129

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Evaluation of irrigation suitability potential of brewery effluent post treated in a pilot horizontal subsurface flow constructed wetland system: implications for sustainable urban agriculture

Ermias Alayu[a,b], Seyoum Leta[a,*]

[a] Center for Environmental Science, College of Natural and Computational Sciences, Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia
[b] Department of Chemistry, College of Natural and Computational Sciences, Assosa University, P. O. Box 18, Assosa, Ethiopia

ARTICLE INFO

Keywords:
Anaerobic digestion brewery effluent
Constructed wetland post-treatment
Irrigation suitability for urban agriculture

ABSTRACT

The use of untreated or partially treated wastewater reuse for urban and peri-urban agricultural irrigation is a common practice in developing countries like Ethiopia. Such practices, however, pose significant environmental and public health risks. The objective of this study was to evaluate the irrigation suitability of anaerobic digestion brewery effluent (ADBE) and two-stage horizontal subsurface constructed wetland post-treated ADBE (CWPBE). A series of pot experiments were conducted in a plastic - greenhouse system arranged in three sets of irrigation schemes: Treatment Group1 (TG1): municipal pipe tap water (MPTW) irrigated pots; Treatment Group2 (TG2): ADBE irrigated pots, and Treatment Group3 (TG3): CWPBE irrigated pots. Pots packed with the same amount of sandy clay loam soil and local tomato seeds sown were irrigated following an updated tomato irrigation schedule derived from the FAO CROPWAT stimulation model for 120 days. The findings from key irrigation water quality parameters showed that the CWPBE achieved the prescribed irrigation water standards with values of pH (7.4 $\pm$ 0.15), electrical conductivity (1.9 $\pm$ 0.11 dS.m^{-1}), total suspended solids (25 $\pm$ 4.17 mgL^{-1}), chemical oxygen demand (185.1 $\pm$ 1.66 mgL^{-1}), total nitrogen (17.4 $\pm$ 0.7 mgL^{-1}), total phosphorous (8.8 $\pm$ 0.26 mgkg^{-1}), calcium (10.5 $\pm$ 3.6 mgkg^{-1}), magnesium (4.9 $\pm$ 0.98 mgkg^{-1}), sodium (4.4 $\pm$ 1.51 mgkg^{-1}), potassium (2.3 $\pm$ 1.15 mgkg^{-1}), sodium adsorption ratio (1.6 $\pm$ 0.34), and total coliform (8 $\pm$ 0.16$\times$10^{-5} CFU/100 mL). Moreover, tomato plants grown in TG3 attained higher growth such as number of leaves (85.6 $\pm$ 4.68), plant height (92.2 $\pm$ 1.29 cm), stem diameter (13.1 $\pm$ 2.35 cm) and leaf area (35.5 $\pm$ 1.03 cm^2) as well as higher biomass (61.2 $\pm$ 1.33 kgm^{-2}) and fruit (46.4 $\pm$ 3.51 kgm^{-2}) yields over other treatment groups. The results revealed that irrigation waters significantly improved both growth and yield parameters of tomato plants with the ascending order of TG1 $<$ TG2 $<$ TG3. Moreover, CWPBE showed minima short-term residual effect on soil physicochemical properties as compared to ADBE, and thus, it has potential suitability for agricultural irrigation reuse.

1. Introduction

The increasing scarcity of freshwater resources in developing countries and dry eco-regions have prompted communities to recycle wastewater for agriculture and other domestic purposes especially in urban and peri-urban settings (Gatta et al., 2015; Jones and Power, 2016; Balkhair, 2016). Recent research reports indicated that 40% of the population will face water scarcity problems, especially half of them will be under high stress around the world, including Ethiopia by 2030 (Almuktar et al., 2018). Under these situations, the reuse of large quantities of wastewater generated from different agro-process industries such as brewery factories can complement the use of freshwater resources and mitigate local irrigation water deficits. Breweries generate a huge volume of wastewater, approximately 3–10 liters of wastewater is produced per liter of beer production (Simate et al., 2011), which can be reused with proper treatment practices. In Ethiopia, there are over twelve breweries that use between 9 and 22 m^3 of water per m^3 of beer produced. This accounts for 70% of the water used as effluent discharge putting considerable strain on the water supply and wastewater management systems (Worku et al., 2018). These brewery industries are concentrated in urban and rural areas; all discharge their untreated or partially treated wastewaters into the environment and cause severe environmental pollution (Oljira et al., 2018; Kitaw et al., 2018). A safe way of recycling wastewater from these brewery industries is essential to overcome water

* Corresponding author.
E-mail addresses: seyoum.leta@aau.edu.et, letaseyoum@yahoo.com (S. Leta).

https://doi.org/10.1016/j.heliyon.2021.e07129
Received 1 February 2021; Received in revised form 9 February 2021; Accepted 19 May 2021

scarcity problem and for sustainable reuse to improve physicochemical characteristics, fertility, and soil microbial communities of the soil (Singh and Agrawal, 2012; Tarantino et al., 2017) as well as increased plant growth and crop yield (Kumar et al., 2010). Although, reuse of wastewater for irrigation offers many advantages; its reuse without proper treatment practices may impair soil functions by changing soil physicochemical properties, reducing the crop production, and overall result in both human and environmental health threat problems worldwide including Ethiopia (Zinabu et al., 2010; Abegunrin et al., 2016; Shakir et al., 2017).

Research findings have also shown that reuse of poor quality brewery effluent for irrigation raises some harmful effects like inhibition of seed germination, plant growth, and yield reduction (Bahri et al., 2015) and low soil quality (Abd-Elwahed, 2019) due to the presence of high chemical oxygen demand (COD), pH, salts, pathogens (Masto et al., 2009; Bahri et al., 2015), protein, fat, fiber, carbohydrates, yeast and hop residues, ethanol, volatile fatty acids, and total suspended solids (TSS) (Simate et al., 2011; Eyvaz, 2016; Bakare et al., 2017). Besides, its higher suspended solids can affect soil porosity and hydrological properties (Ghanem et al., 2017). Similarly, high loads of nutrients have also major effects on soil physicochemical and biological properties (Jueschke et al., 2008). High concentrations of salts increase soil electrical conductivity (EC) and soil salinity, which causes soil dispersion, decreases soil hydraulic conductivity (Muyen et al., 2011). In addition, it causes soil nutrient and microbial community imbalance (Sousa et al., 2012), reduce plant growth and crop productivity (Oo et al., 2015), and potential threats to animals and human beings (Gatta et al., 2015; Eyvaz, 2016). Hence, quality irrigation water is needed for safe reuse (Jeong et al., 2016). In Ethiopia, urban and peri-urban agriculture is commonly practiced with the use of river water receiving untreated and or partially treated wastewaters. Hence, reusing agro-process industrial wastewater is a plausible strategy to mitigate water stress and expand urban agriculture. In the Kombolcha areas (Northern Ethiopia), the study site, wastewater from the Kombolcha brewery factory is routinely used as one of the potential alternative irrigation water sources, though, local farmers raise complaints about its quality. To reduce this problem, the factory treat its wastewater using an up-flow anaerobic sludge blanket (UASB) reactor, a common biological wastewater treatment technology aiming at reducing organics and production of biogas (methane), but the resultant effluent often does not meet irrigation standards and or environmental discharge requirements (EEPA, 2003). Though many researchers have also indicated that several aspects of brewery wastewater treatment options are available (Simate et al., 2011; Worku et al., 2018), most developing countries are unable to treat their wastewaters to the required level due to high operation and maintenance costs (Almuktar et al., 2018).

Integrating constructed wetland (CW) system with an anaerobic treatment system is reported as a viable wastewater treatment option for sustainable reuse at low maintenance and operation costs. Anaerobic reactors are efficient in the removal of organic matter from different types of wastewater (Yasar and Tabinda, 2010; Caliskan et al., 2014), and convert it into a high-grade biogas energy source (Karina et al., 2017). While, the CW system provides many benefits through holding and treating variable volumes of wastewater (Tazkiaturrizki et al., 2018) and recommended as a sound-polishing choice for anaerobic reactor effluents to meet the irrigation reuse standards (El-Khateeb and El-Bahrawy, 2013; Almuktar et al., 2018). Among the CW systems, the horizontal subsurface flow constructed wetland (HSSFCW) system is commonly used for the tertiary level treatment of various types of wastewater (de la Varga et al., 2013; Zeb et al., 2013). Similarly, in Ethiopia, the HSSFCW was tested for the treatment of different types of agro-process industrial wastewater and showed good output efficiency (Kenatu, 2011; Terfie and Asfaw, 2015). But its performance is affected by local climatic conditions, macrophytes and substrate media used, wetland design, and other operations. Similarly, Vymazal (2005) reported that treatment of high-strength agro-process industrial wastewater using a single macrophyte planted HSSFCW system is difficult. So, for effective treatment and sustainable reuse, Merino-solís et al. (2015) and Cheng et al. (2010) recommended various series connected HSSFCW systems planted with different macrophytes to regulate pollutant load variations and consistently met the irrigation water quality standards (Alemu et al., 2019). Reuse of treated wastewater for irrigation is an "end of pipe" solution to managing irrigation water supplies. However, its use sometimes cause a substantial impact on soil properties (Jaramillo and Restrepo, 2017). Similarly, use of untreated or partially treated wastewater reuse for urban and peri-urban agricultural irrigation is a common practice in developing countries like Ethiopia. Such practices, however, pose a significant environmental and public health risks. In general, lack of proper wastewater management in Ethiopia, wastewater application for crop production becomes a critical problem (Zinabu et al., 2010). Therefore, this study assessed the suitability of low-cost CW post-treated anaerobic digestion reactor brewery effluent for irrigation potential in urban and peri-urban setting.

2. Materials and methods

2.1. Experimental location and treatment plant description

A horizontal subsurface flow constructed wetland (HSSFCW) pilot plant was connected with the existing up-flow anaerobic sludge blanket (UASB) treatment plant in an industrial zone of Kombolcha town, Northern Ethiopia, located at 11° 04′42.43″N 39° 43′34.45″ E and 1833 m above sea level (Figure 1) for effluent reuse, an area with annual average minimum and maximum temperatures varying between 6.1–15.2 °C and 24.7–30.4 °C, respectively, and mean annual rainfall of 255.7 mm.

The design and construction of the HSSFCW system (Figure 2) was done as described in detail in our previous published work (Alayu and Leta, 2021). Substrate media used in the system include a clay rock media with a scale of 15–25 mm that contains 13.69% w/w Al_2O_3, 4.24% w/w Fe_2O_3, and 1.52% w/w CaO. Two selected macrophytes, as indicated in Figure 2, Umbrella Grass (*Cyperus alternifolius*) was planted in the first cell because of its high pH resistance (Miyazaki et al., 2004), high productivity, relatively strong root system, ease of adaptation to organic load changes, salinity tolerance, and high nutrient absorption potential (Bilgin et al., 2014) followed by cattail *(Typha latifolia)* due to its short root length (Bonanno and Cirelli, 2017), less salinity tolerance, and ability to mitigate nutrient-rich wastewater (Mollard et al., 2013). The macrophytes were continuously acclimatized using diluted wastewater. Following acclimatization, the two-stage HSSFCW system was operated

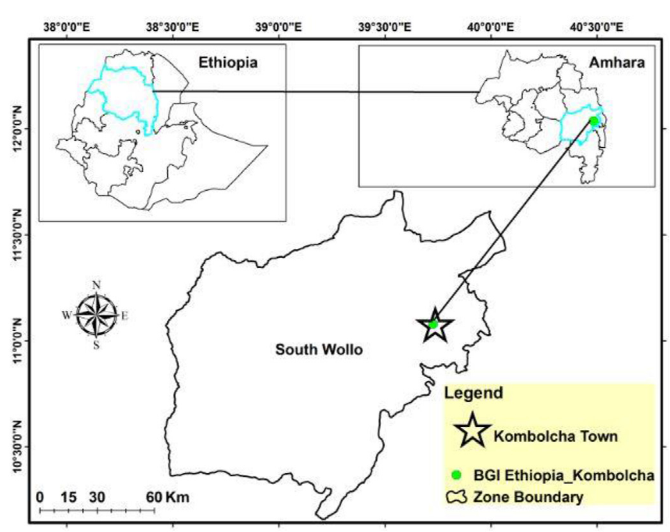

Figure 1. Map of experimental location.

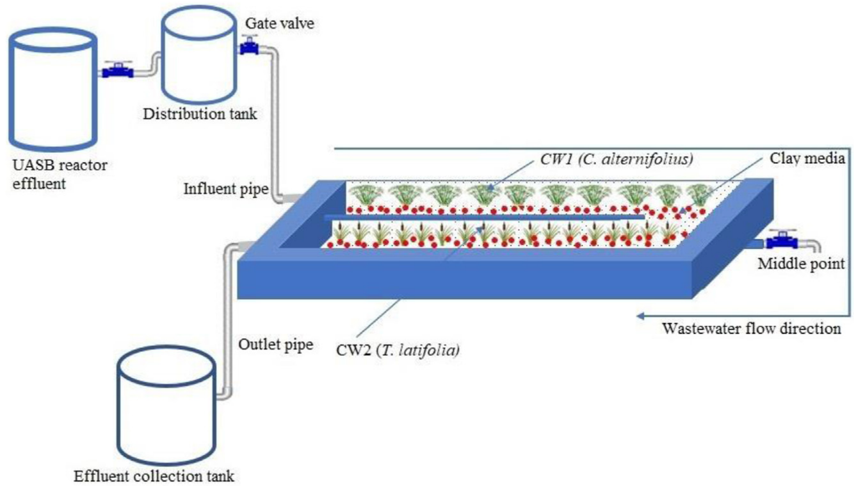

Figure 2. Schematic diagram of the experimental setup of the two-stage HSSFCW system.

by continuously feeding ADBE from the distribution tank, which was monitored by a 2-inch gate valve at the CW's inlet.

The main characteristics of the HSSFCW system is provided in Table 1.

2.2. HSSFCW water budget

The HSSFCW water budget or change in storage in the form of hydraulic loading (HLR) was 0.2373 md^{-1} which was determined by the following Eq. (1) (Ayub et al., 2010):

$$\text{HSSFCW water budget } (md^{-1}) = P + Q_i - ET - Q_o \quad (1)$$

But, the rate of evapotranspiration (ET) is 0.2492 md^{-1}, which was determined based on the Eq. (2) (Leto et al., 2013):

$$Q_o = Q_i + (P - ET)A_s \quad (2)$$

where Q_i (0.698 m^3d^{-1}) and Q_o (0.549 m^3d^{-1}) are the inflow and outflow rates respectively, P is the rate of precipitation (0.2557 md^{-1}), and A_s is the HSSFCW surface area (22.98 m^2).

2.3. Experimental design for effluent irrigation suitability assessment

Pot (volume and length of 0.678 m^3 and 0.6 m) experiments were conducted under plastic – greenhouse systems to evaluate the two-stage constructed wetland post-treated ADBE effluent (CWPBE) irrigation suitability compared to anaerobic digestion brewery effluent (ADBE), and Municipal Pipe Tap Water (MPTW). Figure 3 shows the three sets of irrigation schemes (i.e., Treatment Group 1 (TG1): MPTW irrigated pots as control, Treatment Group 2 (TG2): ADBE-irrigated pots, and Treatment Group 3 (TG3): CWPBE irrigated pots.

Table 1. Design characteristics and operating parameters of each series-connected HSSFCW unit.

Design parameters	Values of each series individual unit
Number of series-connected HSSFCW units	2
Length (m)	7.56
Width (m)	1.52
Unit surface area (m^2)	11.49
Volume (m^3)	5.17
Gravel depth (m)	0.45
the porosity of the media	0.27
Macrophyte types	Umbrella Grass and cattail
Operational parameters	
Hydraulic loading rate (md^{-1})	0.06
Daily hydraulic flow rate (m^3d^{-1})	0.698
HRT (day)	2

2.4. Description of the CROPWAT Window 8.0 model

The FAO created CROPWAT Window 8.0 is a computer program that calculates the reference evapotranspiration (ET0) and climate data. This software makes it simple to measure crop water needs in irrigated fields (FAO, 2009). In a greenhouse system, effective irrigation scheduling is needed to save irrigation water and increase crop yield and quality (Nikolaou et al., 2019). As a result, tomato crop water requirement (CWR) and irrigation schedule were estimated following FAO CROPWAT 8.0 simulation software and the CLIMWAT 2.0 tool attached to it (FAO, 2009).

2.4.1. Input data requirement for CROPWAT modeling

Rainfall, climatic, soil, and crop data are the four types of data required to use the CROPWAT program (FAO, 1998). Climatic data for the study area (Figure 4) were collected from the CLIMWAT 2.0 database, which can be used to estimate the irrigation water requirement for various crops. CLIMWAT includes thirty years of monthly climatic parameters as well as the location's coordinates and altitude. Monthly

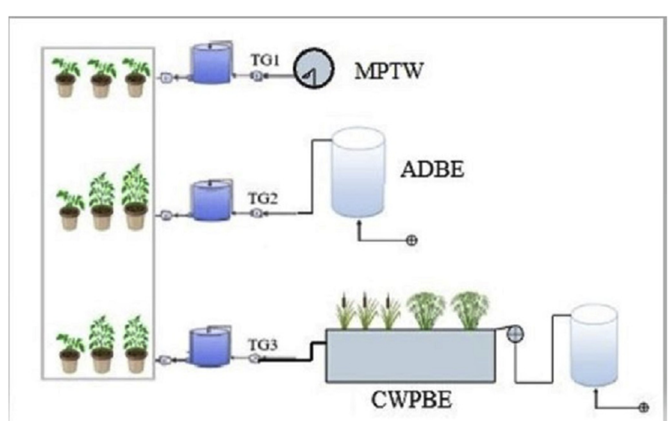

Figure 3. The layout of the experimental irrigation system.

maximum and minimum temperatures (degrees Celsius), wind speed (kilometers per hour), mean relative humidity (percentage), sunshine hours (h), rainfall data (mm), and efficient rainfall (mm) are the variables used in CLIMWAT (FAO 2009).

2.4.2. Reference evapotranspiration

Transpiration (water loss from the plant surface) and evaporation (water loss from the soil surface) both occur at the same time are referred to as evapotranspiration (ET). The rate of ET obtained from a full ground cover of grass is called the reference evapotranspiration. Based on FAO irrigation and drainage paper 56, the ET0 was determined using the FAO Penman-Monteith method and the Windows CROPWAT model (FAO, 1998). The computed solar radiation and reference evapotranspiration (ET0) are shown in Figure 4.

2.4.3. Crop water requirement and irrigation schedule

For crop water requirement (CWR) computation, the FAO CROPWAT software (FAO 2009) was used. A dimensionless Kc is the ratio of crop evapotranspiration (ETc) to reference crop evapotranspiration (ET0), and it reflects an aggregation of the effects of four important qualities that distinguish the crop from the reference grass, including crop soil surface reflectance, crop height, canopy resistance, and soil evapotranspiration. The Kc for the crop will vary over the growing period due to ETc variations during the growth stages (FAO, 1998). Irrigation scheduling determines the required amount of water to irrigate a crop and when to water it (Allen et al., 2005). The crop data for tomatoes were collected from the CLIMWAT 2.0 database and entered into the CROPWAT program for ET0 computation. The crop coefficient (Kc), computed ET0, zero rainfall data, planting date, 80% irrigation efficiency, initial background soil particle size indicated in Table 2, and its corresponding sandy clay loam (classified according to USDA textural triangle) were updated as a set in the CROPWAT 8.0 window software for CWR computation. The CWR is the amount of water needed to replace the water lost by evapotranspiration (ETc) from a cultivated field, expressed in millimeters per day. CWR or ETc can be determined using the flowing Eq. (3) (FAO 1998):

$$CWR = ETc = K_c\, ET0 \tag{3}$$

Before beginning the experiment, the physico-chemical characteristics of the experimental soil was determined, as shown in Table 2.

2.5. Experimental operation

The initial experimental soil sample was collected from the uncontaminated area of 20 cm layer depth, and a 20-kg soil was filled into nine pots and allowed for 15 days for settling time. Local tomato variety, *Lycopersicon esculentum mill* was selected, and each pot was seeded with nine tomato seeds on September 14, 2019. Initially, 17% of the total CWR or 33.4 liter of irrigation water at transplant was used to moisten each potting soil before seed germination. After this initial distribution, each treatment group was irrigated using a spray bucket following the tomato crop irrigation schedule (Table 3) from 8:00 a.m. to 9:00 a.m. throughout the study periods. The harvesting date was extended up to January 16, 2019. After germination, three healthy tomato plants out of the nine were later retained in every pot. Normal tomato crop agronomic practices such as watering, pruning, nipping, trimming leaves, tying up or staking tomato plants with wood stakes, and weed control were performed during the cropping period.

2.6. Water, soil, and fruit sample collection and analysis

2.6.1. Irrigation water quality analysis

Irrigation waters were collected during the cropping cycle from the anaerobic digestion reactor outlet (influent of the two-stage HSSFCW unit), the outlet of the two-stage HSSFCW unit, and household municipal pipe using a 1-liter sterile glass bottle and transported to the laboratory for immediate analysis in refrigerated bags. Irrigation water pH and EC were measured on-site using a handheld IntelliCAL™ pH/temperature digital probe (HACH® HD30d Flexi, Loveland, USA), and a conductivity meter (Cyberscan 100/LFA/78, EUTECH, USA), respectively. Whereas, TSS, COD, TN, and total coliform (TC) were measured offsite using oven-dry method, closed reflux method, persulfate digestion method, and membrane filter technique, respectively (APHA, 1998). TP and exchangeable cations such as Na^+, K^+, Ca^{2+}, and Mg^{2+} were determined using inductively coupled plasma (ICP - OES, Arcos spectrophotometer, Germany) following the APHA method (1985). SAR was computed using Eq. (4) (Richards, 1954).

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}} \tag{4}$$

2.6.2. Measurement of tomato biomass and yield biometric parameters

The tomato agronomic parameters such as the number of leaves, plant height, biomass, and the number of fruits were determined following standard methods; the height of the tomato plant (PH) was measured in centimeter (cm) starting from the base to top, while the tomato plant stem diameter (SD) was measured in centimeter (cm) at the base. The number of leaves (NL) per plant for each pot was also counted. The tomato leaf area (*LA*) was calculated using Eq. (5) (Blanco and Folegatti, 2003), its length is the distance between the insertions of the first leaflet to the distal end; and the maximum width was measured with a ruler.

$$LA\left(cm^2\right) = 0.85(L\,x\,W) \tag{5}$$

where L stands for leaf length (cm) and W stands for the leaf's widest middle portion (cm) with the width corrected to 0.85.

At the end of the experiment, the tomato biomass yield (BY) of the three treatment groups was determined in kilograms per square meter (kgm^{-2}) by harvesting the above-ground parts and drying them in an oven at 70 °C for 3 days (Ismail et al., 2007). Similarly, the healthy and matured tomato fruit yield (FY) on each of the three treatment groups was measured in kilograms per square meter (kgm^{-2}). Tomato fruit was collected using UV - sterile plastic bags and taken to the laboratory for immediate TC analysis following a serial dilution method (Shenge et al., 2015).

2.7. Soil sample collection and analysis

The initial background soil sample before the experiment and irrigated pot soils after harvest were collected, air-dried, and powdered into <2 mm size using an electric grinder and stored in plastic bottles for laboratory analysis. The background soil particle size distribution was measured using the hydrometer method (Gee and Bauder, 1986). Next, both background and irrigated soils pH and EC were measured in a 1:5 (soil: water) suspension using pH meter (HACH® HQ440d, Loveland, USA) and conductivity meter (Orion, EA 940 USA) respectively (Pawar and Shah, 2009). Soil OC was determined using Walkely and Black method (Nelson and Sommers, 1996), and OM was also estimated from OC by multiplying with a 1.724 conversion factor. Whereas, TN was measured using the Kjeldahl method (Bremner and Mulvaney, 1982). Soil TP and exchangeable cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) were determined by the Mehlich-3 extraction method (Mehlich, 1978) using inductively coupled plasma (ICP - OES, Arcos spectrophotometer, Germany). The soil SAR was computed using Eq. (5) suggested by Richards (1954).

2.8. Statistical analyses

One-way ANOVA was performed with Shapiro-Wilk normalized data at $p = 0.05$, followed by post hoc analysis to look for differences between

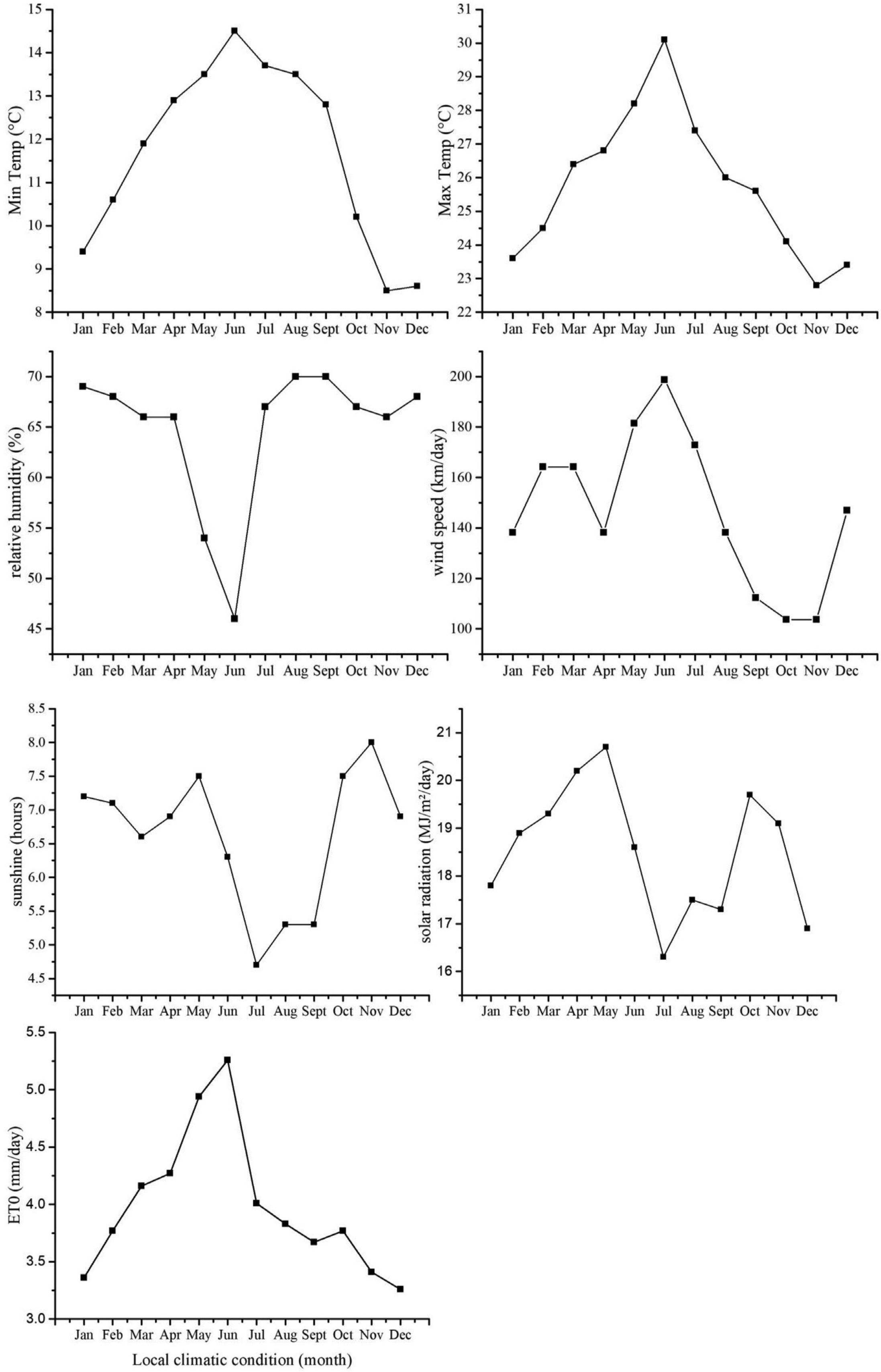

Figure 4. Representative climatic conditions of Kombolcha town.

Table 2. Initial Physico-chemical characteristics of experimental soil.

Parameters	Mean ± SD
Soil texture	
Sandy	51.2 ± 4.15%
Silt	15 ± 6.93%
Clay	33.8 ± 4.15%
pH	7.87 ± 0.12
EC ($dS.m^{-1}$)	0.8 ± 0.03
Sodium adsorption ratio (SAR)	3.95 ± 0.29
Organic carbon (OC) (%)	5.6 ± 0.1
Organic matter (OM) (%)	9.65 ± 0.17
Total Nitrogen (TN) (%)	1.55 ± 0.11
Total phosphorous (TP) ($mgkg^{-1}$)	7.93 ± 0.93
Calcium (Ca^{2+}) ($mgkg^{-1}$)	363.4 ± 41.97
Magnesium (Mg^{2+}) ($mgkg^{-1}$)	162.64 ± 12.29
Potassium (K^{+}) ($mgkg^{-1}$)	112.79 ± 1.61
Sodium (Na^{+}) ($mgkg^{-1}$)	63.84 ± 1.24

means compared using a Turkey's test at a 5% level of significance using Origin® Pro 2017 software (OriginLab Cooperation, Northampton, MA, USA). Principal components analysis (PCA) was conducted using PAST software version 4.0) (Hammer et al., 2001) to understand the data structure and minimize the number of variables to a manageable number of independent principal components). To avoid misclassification due to large differences in data dimensionality, data was normalized (log x; x = mean value) in PCA. After applying the Scree test and considering principal components with eigenvalues >1, the principal components were maintained. The factor loadings were graded as “strong”, “moderate,” and “weak,” corresponding to absolute loading values of >0.75, 0.75–0.50, and 0.50–0.30, respectively (Tomaz et al., 2020). The results were expressed in terms of mean and standard deviation values. Results were presented using graphs and tables.

3. Results and discussion

3.1. Characteristics of irrigation waters

The mean ± SD values of the physicochemical and biological characteristics of the ADBE, CWPBE, and MPTW are summarized in Table 4. The pH of the three-irrigation water showed significant ($p < 0.05$) variations with lower values found in the ADBE followed by CWPBE. This is due to certain pH adjustments taken in the anaerobic reactor pretreatment stage for the proper function of microbial communities in the anaerobic reactor and phytoremediation of ionic substances in the constructed wetland unit. The mean pH values of ADBE, CWPBE, and MPTW provided in Table 4 met the Food and Agriculture Organization of the United Nations (FAO) standard (i.e., 6.5 to 8.4) for the agricultural reuse of treated water; pH values outside of this range indicate that the water is of poor quality (Ayers and Westcot, 1985). Research findings showed that irrigation water pH < 6.5 promotes leaching of exchangeable cations. Whereas pH > 11, causes soil microorganism's death and inactive movement of ions. Overall, irrigation water pH values outside the standard range cause a nutritional imbalance and plant growth restriction (Mutengu et al., 2007). Similarly, analysis of the three irrigation water EC values showed significant variation with maximum value occurred in ADBE (Table 4), which might be due to the presence of mineral ions. But its value falls within FAO standard limits 0–3 $dS.m^{-1}$ (Ayers and Westcot, 1985). EC of the ADBE showed a 34.5% decline after its further treatment with a two-stage HSSFCW system planted with Umbrella Grass and cattail due to direct macrophytes uptake or sedimentation and precipitation in the wetland sludge (Zurita and White, 2014). Whereas the MPTW mean EC content was found below the unrestricted reuse (EC < 0.7 $dS.m^{-1}$) (Ayers and Westcot, 1985). The FAO guidelines focused on Ayers and Westcot (1985) quality principles, which consider a "potential issue" approach with three levels of restriction on uses: none (EC < 0.7 $dS.m^{-1}$), mild to moderate (0.7 < EC < 3 $dS.m^{-1}$), and severe (>3 $dS.m^{-1}$). The effect of EC on tomato plant growth, water transport, and nutrient uptake potential was studied by Heinen et al. (2001). The authors concluded that higher EC (>4 $dS.m^{-1}$) resulted in reduced tomato plant growth due to less water uptake or low osmotic capacity. Additionally, higher irrigation water EC may cause soil structure clump and reduce the absorptivity of irrigated soil (Abd-Elwahed, 2019), and may also result in soil and plant toxicity; depending on the irrigation period and soil nature (Mutengu et al., 2007; Samia et al., 2013). Generally, both ADBE and CWPBE EC values were fall within the slight to moderate degree of reuse restriction due to the accumulation of total dissolved salts, but its gradual increase, particularly ADBE may reduce the yield content of a crop, and hence, care should be taken in the selection of crop and management if full yield potential is to be achieved (Ayers and Westcot, 1985).

Analyses of irrigation water TSS and COD content also showed significant variations ($p < 0.05$) with the maximum value recorded in the ADBE followed by CWPBE, and MPTW (Table 4). Among the irrigation waters, the ADBE TSS value exceeded the FAO treated effluent irrigation quality standards of <30 mgL^{-1}, while there are no standards for COD in WHO (Jeong et al., 2016), and thus, the most strict water quality

Table 3. Tomato CWR and irrigation schedule of each pot.

Month	Decade	Stage	Kc coeff	ETc (Ld^{-1})	ETc (Ld^{-1}) for 2 days irrigation interval	Total ETc (Ld^{-1})
Sep	2	Init	0.4	0.98	1.95	5.85
Sep	3	Init	0.4	0.84	1.68	8.38
Oct	1	Deve	0.46	0.98	1.95	9.75
Oct	2	Deve	0.67	1.43	2.85	14.25
Oct	3	Deve	0.9	2.04	4.08	20.38
Nov	1	Mid	1.05	2.09	4.18	20.88
Nov	2	Mid	1.05	2.01	4.03	20.13
Nov	3	Mid	1.05	1.99	3.98	19.88
Dec	1	Mid	1.05	1.96	3.93	19.63
Dec	2	Late	1	1.85	3.7	18.5
Dec	3	Late	0.87	1.78	3.55	17.75
Jan	1	Late	0.74	1.39	2.78	13.88
Jan	2	Late	0.64	1.81	3.63	7.25
Total CWR for one-pot during the entire monitoring period						196.48

Where Init: initial stage; Dev: developmental stage; Mid: middle stage.

Table 4. The physicochemical and biological characteristics of irrigation waters.

Characteristics	Irrigation water type			
	MPTW	ADBE	CWPBE	*p-value
pH	8.4 ± 0.1	7.7 ± 0.08	7.4 ± 0.15	1.4E-4
EC ($ds.m^{-1}$)	0.6 ± 0.01	2.9 ± 0.1	1.9 ± 0.11	1.6E-7
TSS (mgL^{-1})	6.2 ± 0.12	189.3 ± 10.1	25 ± 4.17	7.2E-8
COD (mgL^{-1})	9.2 ± 0.45	381.4 ± 11.3	185.1 ± 1.66	1.9E-9
TN (mgL^{-1})	4.2 ± 0.25	51.2 ± 1.87	17.4 ± 0.7	1.2E-8
TP ($mgkg^{-1}$)	0.29 ± 0.01	22.5 ± 0.21	8.8 ± 0.26	2.7E-11
Ca^{2+} ($mgkg^{-1}$)	50 ± 0.42	21.6 ± 3.8	10.5 ± 3.6	1.0E-5
Mg^{2+}($mgkg^{-1}$)	21.9 ± 0.08	15 ± 1.8	4.9 ± 0.98	6.9–6
Na^{+} ($mgkg^{-1}$)	13.4 ± 0.72	21.3 ± 2.1	4.4 ± 1.51	3.3E-5
K^{+} ($mgkg^{-1}$)	0.12 ± 0.01	6.3 ± 2.0	2.3 ± 1.15	0.003
SAR	2.2 ± 0.15	5 ± 0.1	1.6 ± 0.34	3.0E-6
TC (CFU/100 mL)	0	$1.4 \pm 0.2\times10^{-4}$	$8 \pm 0.16\times10^{-5}$	4.0E-5

* Significant test at $\alpha = 0.05$ significant level.

standards of Alberta Environment (2000) have been used; with treated effluent irrigation quality standards of 150 mgL^{-1}. These variations are due to the relatively higher fraction of solids and organic matter mainly associated with the presence of greatly variable pollutants such as carbohydrates, alcohols, suspended solids, and yeast (Mohan et al., 2018); proteins, ethanol, and volatile fatty acids (Raposo et al., 2010). Yasar and Tabinda (2010) have also indicated that anaerobically treated effluents had high levels of residual organics and nutrients. Whereas further treatment of ADBE with two–stage phytoremediation process showed a promising reduction of these pollutants below the above-mentioned standards. Because the restricted TSS and promising COD removal of anaerobic digestion reactor could be compensated by high efficiency in the two-stage HSSFCW system; Umbrella Grass planted bed removed 68%TSS and 74%COD. Further treatment with cattail planted bed removed 67%TSS and 70%COD (Alayu and Leta, 2021). Studies on the individual evaluation of treatment efficiency of Umbrella Grass and cattail in wastewater treatment revealed high organic matter and nutrient removals. For example, Umbrella Grass planted HSSFCW removed 93% TSS and 95% COD (Sa'at et al., 2017), while cattail removed 92% TSS, and 79% COD (Ciria et al., 2005). But, the use of both macrophytes in a two-stage HSSFCW system removed 89% TSS and 92% COD (Alayu and Leta, 2021). According to Carballeira et al. (2016), macrophytes play a significant role in TSS and COD removal efficiencies. Likewise, in this study, the enhanced TSS and COD removal efficiencies could be due to better contact of anaerobic digestion reactor effluent with a network of aerobic, anoxic, and anaerobic zones of the two-stage HSSFCW macrophytes that leak oxygen to the media, and removed pollutants by the synergies of the physical, chemical, and biological processes in the CW system (UN-HABITAT, 2008). Since macrophytes root mat enhances more solid particles adhering, filtration, and sedimentation; and organic matters biodegradation, and consumption by attached anaerobic-aerobic bacteria (Theophile et al., 2011; Aziz et al., 2015). A high level of suspended solids can affect the performance of the irrigation facility and can lower the hydraulic conductivity of the soil, and in turn pollute the soil surface through surface flow.

Concerning the TN and TP content, a relatively high nutrient content was found in the ADBE compared to the CWPBE and MPTW irrigation waters. The ADBE showed almost triple increases in TN and TP compared to the CWPBE TN and TP concentrations (Table 4), which may be due to the high nutrient content of ADBE, primarily derived from malts, yeast cells, and sanitizing chemical agents used in the cleaning in place (Worku et al., 2018), and further mineralization of nutrients in the anaerobic reactor from complex organic matters (Moawad et al., 2009). However, in our previous report, further treatment of nutrient-rich ADBE with a two-stage HSSFCW system showed promising TN and TP removal efficiencies across the treatment stages; i.e., Umbrella Grass planted bed removed 56%TN and 41%TP, while treatment with the cattail planted bed resulted in mean removal efficiencies of 63%TN and 58%TP (Alayu and Leta, 2021). A previous study by Leto et al. (2013) and El-Khateeb and El-Bahrawy (2013) also showed that 65%TN and 75%TN removal efficiencies, respectively, using Umbrella Grass and cattail from raw and anaerobically treated domestic wastewater. Whereas, Da Motta Marques et al. (2001) and Cheng et al. (2010) reported 93%TP and 75%TP of phosphorous removal, respectively, using a *Z. bonorriensis;* and *T. subalata* and *P. australis* and *P. stratiotes* planted HSSFCW units from anaerobic reactor municipal wastewater and a mixture of sewage and swine wastewater. Analogously, in this study, treatment of anaerobic digestion reactor brewery effluent with two-stage HSSFCW system removed 66%TN and 61%TP with residual concentrations indicated in Table 4. This better achievement is due to the good nutrient uptake potential of both macrophytes (Alayu and Leta, 2021), and the combined effect of macrophytes through physicochemical and biological processes (Vymazal, 2007) and via media absorption, as well as plant uptake and absorption (Badejo et al., 2014).

The presence of nutrients (N and P) in the effluent is most likely to be used by plants. Plant nutrients in wastewater, on the other hand, are available in large quantities that aren't always suitable for direct crop production, and these proportions are difficult to adjust to meet crop nutrient requirements. When one nutrient requirement is met, it is common for another nutrient level to become unbalanced. As a result, nutrient deficiency or oversupply can cause toxicity and have negative effects on crop yield; additionally, depending on the crop, excess nutrients can reduce productivity. To avoid crop yield loss due to excess nutrients in wastewater, careful nutrient management is required (Hanjra et al., 2012). Similarly, the high nutrient content of ADBE can provide an essential source of soil fertility, plant growth, and yield (Gatta et al., 2015). Furthermore, organic nitrogen nutrition can affect the quality of the plant product as well as the plant's metabolism (Jaramillo and Restrepo, 2017). For example, sensitive crops like beets can be influenced by excess nitrogen exceeding 5 mgL^{-1}, while almost all other crops are comparatively unaffected until its concentration exceeds 30 mgL^{-1}. Hence, nitrogen concentration level in the treated effluent wastewater should not go beyond 30 mgL^{-1} to alkaline soils (Mutengu et al., 2007). However, if total nitrogen delivered by wastewater irrigation exceeds the recommended dose for the crop, it can stimulate vegetative growth but delay ripening and maturity, possibly resulting in yield losses (Hanjra et al., 2012). Furthermore, excessive nitrogen application can cause vegetables to accumulate high levels of nitrate, which, may cause serious health problems when consumed by living things and impede soil carbon biodegradation (Jaramillo and Restrepo, 2017). Comparing to the above limits, the ADBE nitrogen concentration exceeded (51.2 ± 1.87), and may cause the above effects. Phosphorous is also an essential nutrient for an organism's metabolic processes and plant health by resisting certain diseases (Mutengu et al., 2007). The concentrations of phosphorus in the effluent are usually about 10 mgL^{-1}, which is beneficial to plant development (Hanjra et al., 2012). In contrast, its continuous application for irrigation can change soil phosphorous behavior and become another environmental concern from agricultural runoff (Liu et al., 2017). Additionally, phosphorus can cause eutrophication or toxicity in other habitats (Jaramillo and Restrepo, 2017).

The three irrigation waters also contain exchangeable cations such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}. The presence of these higher exchangeable cations Ca^{2+}, Mg^{2+}, and K^{+} in treated wastewater is also very interesting from an agronomic point of view since they represent important nutrients for improving soil fertility, plant growth, and crop yield (Gatta et al., 2015). Whereas, the presence of Na^{+} in irrigated wastewater can promote soil salinization or sodification, which is easily concentrated in the root zone, and causing osmotic stress of plants to absorb water and nutrients (Jaramillo and Restrepo, 2017). In this study, the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) concentration in the ADBE, CWBE, and MPTW are provided in Table 4. In the CWPBE, the Ca^{2+} and K^{+} showed a two-fold decrease while Mg^{2+} and Na^{+} decreased threefold and five-fold from the ADBE, respectively (Table 4). However, the Ca^{2+} and Mg^{2+} were relatively higher in the MPTW. Whereas, the ADBE effluent Na^{+} concentration was 4.8 and 1.6 times higher than the CWPBE and MPTW, respectively (Table 4). The European Catchment Management Agencies have the strictest quality standards for exchangeable cations in wastewater for agricultural reuse. Hence, the concentration of the exchangeable cations determined in this study were compared with these standards. The values of exchangeable cations concentrations in this study were below the European Catchment Management Agencies recommended standards of 150 mgL^{-1}, 12 mgL^{-1}, 50 mgL^{-1}, and 50 mgL^{-1}, respectively, for Na^{+}, K^{+}, Mg^{2+}, and Ca^{2+}, which don't cause substantial effects on both soil physicochemical properties and crop production (Abd-Elwahed, 2019). But, measures should be taken for long-term application of Na^{+}, since it adversely affects the soil structure and reduces the permeability of irrigated soil and crop production restriction (Leal et al., 2009).

Excess Na^{+} accumulation is linked to SAR, which is a useful indicator for predicting the negative effect of excess Na^{+}on soil physical properties (Ayers and Westcot, 1985). In this analysis, SAR measurements were found to be higher in the ADBE (5 ± 0.1) (Table 4), which met the FAO threshold limit of 3–9, which is considered a potential problem due to its usage restrictions. Further treatment of ADBE with a two-stage HSSFCW system, on the other hand, reduced the SAR value (1.6 ± 0.34) to levels below the FAO guidelines for non-restricted reuse; i.e., SAR< 3 (Ayers and Westcot, 1985). Long-term use of sodium-rich wastewater can cause soil sodicity, destroy soil structure, reduce water penetration, increase compaction, and alter soil microbial community structure and activity. Soil sodicity can be caused by irrigation water with a SAR of 3. When irrigation water has a SAR of more than 6, it can cause permeability and aeration issues. Wastewater-mediated salinity can decrease crop production through nutritional imbalance, and growth inhibition by toxic ions. Cucumbers, for example, are more sensitive than tomatoes. Hence, for efficient and long-lasting effluent irrigation, periodic monitoring of soil salt concentration is needed for adequate management using leaching or green manure or gypsum application (Hanjra et al., 2012). Table 4 shows the microbiological properties of the three irrigation water sources (ADBE, CWBE, and MPTW). TC content differed significantly among the three irrigation waters, with the ADBE having the highest level ($1.4 \pm 0.2 \times 10^{-4}$), followed by the CWPBE ($8 \pm 0.16 \times 10^{-5}$) (Table 4). TC content was higher in ADBE than in CWPBE, but it was still below the WHO (2006) recommended guideline of 10^{3} CFU/100 mL, even for the strictest standards for unrestricted irrigation. This may be due to the thermalization of untreated brewery wastewater. Its subsequent treatment with two-stage HSSFCW units resulted in a significantly lower TC concentration, which may be attributed to natural die-off in two-stage HSSFCW units.

3.2. Effect of irrigation waters on tomato growth, biomass and fruit yields

Data reported in Table 5 shows the average quantitative changes of tomato plant growth component parameters (NL, PH, SD, and LA) characteristics observed over the entire growing season under the three different treatment groups. As indicated in Table 5, TG3 attained the higher tomato growth component. Results from the study showed significant ($p < 0.05$) differences in NL, PH, and LA between the treatment groups grown in three studied irrigation waters. But, post hoc analysis between the means of TG2 and TG3 for SD showed insignificant ($p = 0.931$) variation. Tomato plants grown in TG3 with the application of CWPBE increased the NL, PH, and SD by 13.3%, 9%, and 4.8%, respectively, over tomato plants grown in TG2 with applications of ADBE; and it also increased the NL, PH, and SD by 30%, 25.3%, and 46.1% over to tomato plants grown in TG1 with MPTW (Table 5). These findings correspond with the results of Khan et al. (2011) who reported that the application wastewater increased the growth component parameters of tomato plants. A similar finding was reported by El-Tohamy et al. (2006), an increase in plant height could be attributed to the better availability of soil nutrients that enhance the growth of plants by increasing cell division and elongation in the growing area. Another study reported by Omotade (2019), reported a significantly higher NL and SD of the tomato plants under CW treated wastewater irrigation practice due to the removals of toxic nutrients, which could have limited the plant growth. Likewise, the good performance response of tomato plants NL, PH, and SD in TG3 is associated with the sufficient supply of nutrients, and reduced contents of soluble salts in the CWPBE (Table 4), which may enhance the growth of the local tomato variety used to grow tomatoes in the study. Rhoades et al. (1992) identified possible tomato yield reductions at levels of water EC greater than 2.5 $dS.m^{-1}$. The local tomato plant variety is sensitive, hence, the observed relative growth component parameters reduction in TG2 may be linked to its higher salinity limit greater than 2.5 $dS.m^{-1}$ Because of the slight shift in irrigation waters physicochemical properties (Table 4), causes less essential nutrient supply and water stress (Heinen et al., 2001), which can impede the local tomato plant growth development and yield production via causing crop physiological disorders (Ahmed et al., 2017). The irrigation waters also showed a significant impact on the LA of the tomato plant (Table 5). The CWPBE treated pot raised the LA by 32.7% and 61.4% respectively, as compared to the ADBE and MPIW treated pots. In consistent with the current study, Omotade (2019) also found that hot pepper plants irrigated with treated wastewater treatment had substantially higher LA due to enhancement of photosynthesis thereby leading to a high yield of plants (Liu et al., 2008). Whereas, the decline in LA under ADBE treated pot may be due to the exhaustion of required nutrients for plant growth. Similarly, Vieira et al. (2016) reported irrigation water excess ions to trigger nutritional imbalance decreases stomatal conductance, transpiration, and photosynthesis, and thus tends to inhibit plant growth. da Silva et al. (2008) also found that increasing irrigation water salinity caused the reduction of plant growth due to excess salts concentrations around the plant root zone. Another study found that increasing irrigation water salinity from 0.5 to 6.0 $dS.m^{-1}$ in EC causes a decrease in plant LA, which could be linked to reducing water availability and absorption, which affects cell division and elongation (Vieira et al., 2016), decrease in the root's osmotic potential, and thus contributes to a decrease in the number of cells, depletion of leaf nutrient content, and decreased leaf elongation (Ouansafi et al., 2019).

Similarly, as indicated in Table 5, the measurement of the yield component parameters (BY (dry weight) and FY (fresh weight) showed relatively higher in TG3 (61.2 ± 1.33 kgm^{-2} for BY, and 46.4 ± 3.51 kgm^{-2}) followed by TG2 (52.4 ± 1.72 kgm^{-2} for BY, and 28.1 ± 6.38 kgm^{-2}) and TG1 (41 ± 3 kgm^{-2} for BY, and 17.3 ± 4.13 kgm^{-2}), respectively, with respective irrigation waters of CWPBE, ADBE, and MPTW. The irrigation waters property difference produced higher variability in tomato BY and FY due to the significant ($p < 0.05$) difference in

Table 5. Effect of irrigation waters on growth and yield component of tomato.

Treatment groups	Tomato growth component parameters				Tomato yield components	
	NL	PH (cm)	SD (cm)	LA (cm^2)	BY (kgm^{-2})	FY (kgm^{-2})
TG1	59.9 ± 2.05	68.9 ± 2.97	7.1 ± 2.57	13.7 ± 1.51	41 ± 3	17.3 ± 4.13
TG2	74.2 ± 2.36	83.9 ± 1.87	12.5 ± 1.25	23.1 ± 3.11	52.4 ± 1.72	28.1 ± 6.38
TG3	85.6 ± 4.68	92.2 ± 1.98	13.1 ± 2.35	35.6 ± 1.03	61.2 ± 1.33	46.4 ± 3.51
*p-value	2.1E-4	5.2E-5	0.025	0.001	7.8E-5	9.2E-4

* Significant test at $\alpha = 0.05$ significant level.

nutrient composition indicated in Table 4. In TG3, the BY was increased significantly by 33% over TG1 and 14.4% over TG2 While, FY was increased significantly by 62.7% over TG1 and 39.2% over TG2 (Table 5). The post hoc analysis between the means of TG1 and TG2 showed insignificant variation ($p = 0.075$), which may be due to the sensitivity of the local tomato variety to the relatively higher salinity of ADBE, which may affect its productivity through inhibiting nutrient absorption capacity. The higher variability in tomato biomass found in this study has concurred with Khan et al. (2011), who found a substantially higher biomass yield under plots receiving wastewater than tap water treated due to the addition of an important plant nutrient (both macro and micronutrients). Segura et al. (2004) studied wastewater reuse in arid and semiarid regions around the world. They found that irrigating greenhouse crops with effluents resulted in significantly higher tomato yields due to the significantly higher levels of N, P, and K in the effluents. Another study carried out by Khan Jadoon et al. (2013) also argued that the irrigation of different vegetables with different industrial effluents improved the seeding and root lengths of various vegetables, but, the high concentration of numerous effluents decreased the seed germination and growth of vegetables. Recent studies have also indicated that irrigation with treated wastewater enhanced the yield of lettuce by 50% (Vergine et al., 2017). Tomato is a moderately salt-tolerant crop, but higher EC of ADBE in TG2 may influence the tomato plant yield components which may be due to its salinity tolerance limit is ranged from 2 to 3 $dS.m^{-1}$ (FAO Regional Office for the Near East Cairo, 2003). The tomato PH was significantly influenced by the irrigation water's salinity; i.e., a decreased PH was observed under the increasing level of salinity due to the change of soil physicochemical properties, which hinder plant growth and yield production (Ahmed et al., 2017). Another study report conducted by Castro et al. (2011) indicated that treated wastewater reuse for irrigation significantly increased the vegetative weight and yield, but, numerous crops may be affected by wastewater irrigation because of the higher Na^+ content. In addition, wastewater reuse may raise biological traits to crops. However, in this study, assessment of such threats to tomato fruit was not observed due to the very low TC contents of the irrigation waters that meet the unrestricted reuse for irrigation. In the same regard, research findings reported by Vergine et al. (2017) showed that agro-industrial effluents may be considered for reuse due to limited microbiological contamination.

3.3. Short – term residual effect of irrigation waters on soil properties

The physicochemical characteristics of the soil before and after treating with irrigation waters are indicated in Figure 5 For each treatment group, the background soil pH was 7.87. After, the application of the ADBE, soil pH was increased to 9.23 in TG2. Whereas, the application of MPTW and CWPBE raises this background pH value to 8.15 and 8.03, respectively, in TG1 and TG3 treatments (Figure 5 (a)). Among the treatment groups, only TG2 soil irrigated with ADBE recorded a significant increment to alkaline conditions as compared to the background, TG1, and TG3 treatments, which may be associated with the relatively higher mineral contents found in ADBE. In agreement with this result, Disciglio et al. (2015) observed an increased soil pH under wastewater irrigation due to the accumulation of high content of exchangeable cations (La Bella et al., 2016), and release OH^+ ions through ligand exchange from high organic matters exist in wastewater (Abd-Elwahed, 2019). According to Libutti et al. (2018), the presence of high content of exchangeable cations in the irrigation wastewater raised soil pH due to reservation of basic cations in the soil particle. Irrigation with ADBE caused a 1.13 and 1.15 unit rise in soil pH over CWPBE and MPTW irrigations. In the literature, a 0.8 unit increase in soil pH was observed under irrigation with treated wastewater (Libutti et al. (2018).

Similarly, in treatment groups, soil EC was also influenced by irrigation waters. EC of the background soil was 0.8 $dS.m^{-1}$, but after irrigation with ADBE and CWPBE, its average value was shifted to be 4.75 and 2.31 $dS.m^{-1}$, respectively, for TG2 and TG3; whereas, in TG1, it was found to be 0.94 $dS.m^{-1}$ (Figure 5 (a)). In TG2, application of ADBE significantly increased the soil EC value by fivefold over TG1 and twofold over TG3, which increase can be assigned to high suspended solids and salt quantities dissolved in ADBE as shown in water EC values in Table 4. The soil EC difference values in the three wastewater irrigated pots (Figure 5 (a)) indicate a radical soil EC increase in TG2 is the most influenced pot followed by TG3. In argument to this study, Singh and Agrawal (2012) also reported that the addition of wastewater increases the EC of soil due to a higher concentration of total dissolved solids. According to Libutti et al. (2018), the rise in EC in wastewater-irrigated soil was primarily attributed to the higher initial concentration of cations such as Na^+ and K^+. However, application of further treated ADBE in TG3 showed minimal shifts from the background and other treatment group soil EC values due to the removal of solids and salts. Morugan-Coronado et al. (2013) have also reported that two years of treated wastewater application does not affect soil EC. Compared to the recommended threshold EC value of 4 $dS.m^{-1}$ (Abegunrin, 2013), the MPTW and CWPBE treated pot soils EC value was classified as not posing any threat. Whereas, the ADBE irrigated pot soil EC value was exceeded the above salinity threshold limit. This indicates that ADBE application does not only influence the soil-EC but also affects soil structure, organic matter content, and permeability (Libutti et al., 2018). In addition, it also affects the activity of soil microorganisms, plant growth, and soil productivity due to high salt accumulation (Castro et al., 2011).

Soil OM is essential for the formation and stabilization of soil structure, and increase soil water-holding capacity. It is also a reservoir of nutrients such as nitrogen, phosphorous, and sulfur, all are important for plant growth, and maintain soil fertility (Becerra-Castro et al., 2015). Analyses of soil OC and OM contents showed considerable increases from the background value in TG2 followed by TG3. Background soil OC and OM contents were 5.6% and 9.65%, but after irrigation with ADBE and CWPBE, these mineral contents were raised to 24.63% and 42.47% for TG2, and 9.9% and 17.07% for TG3, respectively, for OC and OM. Whereas in TG1, both OC and OM values were found to be 6.27% and 10.8%, respectively (Figure 5 (b)). ADBE application showed a 4.4 fold significant shift in OC and OM from background value, while CWPBE increased the background soil OC and OM by 1.8 fold. But, a minimal change of 1.2 fold increment in OC and OM from the background was observed in TG1. The increase of soil OC and OM can be assigned to the high suspended solids and organic matter contents particularly in ADBE and CWPBE application as shown in water OC and OM values indicated in Table 4. Similarly, several studies reported results to indicate that the

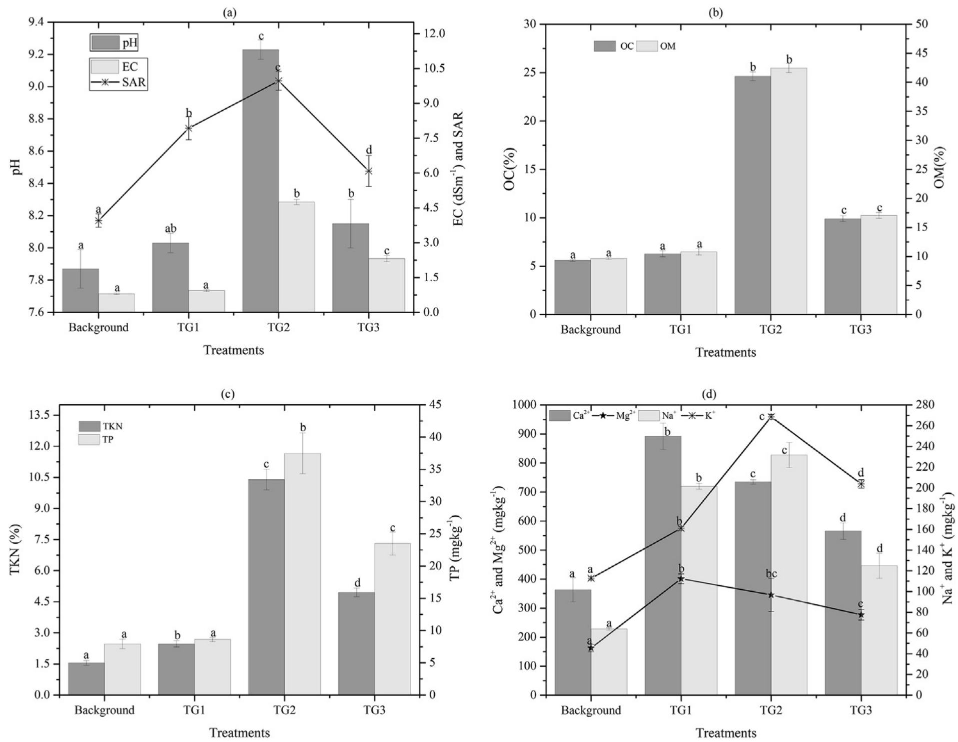

Figure 5. Effect of irrigation water on background soil (a) pH, EC, SAR, (b) OC and OM, (c) TKN and TP and (d) exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}); different letters in each graph indicate significant difference at $p < 0.05$.

use of wastewater for irrigation improves soil OM content due to its high biodegradable substances (Abd-Elwahed, 2019; Ahmad et al., 2019). Another study report conducted by Singh and Agrawal (2012) also showed a 2.5 times increase in soil OM in an untreated sewage wastewater-irrigated plot. The presence of OC and OM in irrigation waters contributed to an improved soil organic matter increment and microbial activity (Abegunrin et al., 2016). Moreover, the soil OM content was also significantly enhanced through irrigation with wastewater and can be considered a positive change in soil quality (Abd-Elwahed, 2019). However, the addition of organic matter by wastewater irrigation will affect soil microbial activity, soil biomass carbon, and enzymatic processes (Lal et al., 2015). Regarding soil TN and TP contents, the background soil TN and TP were 1.55% and 7.93 $mgkg^{-1}$. However, after irrigation, an encouraging shift was observed in ADBE application followed by CWPBE treated pot soils with respective average values of 10.4% and 37.48 $mgkg^{-1}$ in TG2; 4.95% and 23.48 $mgkg^{-1}$ respectively for TN and TP in TG3. Whereas in TG1, these values were found to be 2.47% and 8.61 $mgkg^{-1}$, respectively, for TN and TP (Figure 5 (c)). Substantial increments of TN and TP were observed in TG2 followed by TG3 soil samples compared to TG1. Application of ADBE showed 6.7 and 4.7 fold shifts in TN and TP respectively, from background values for TG2, while 3.2 and 2.9 fold increments in TN and TP, respectively was observed in TG3, respectively, due to their relatively high nutrient content loads. But, minimal change of TN (i.e., 1.6 fold increase) and TP (i.e., 1.1-fold increase) from the background was observed in TG1. In general, the application of both ADBE and CWPBE for agricultural irrigation boosts essential nutrients (i.e., nitrogen and phosphorous) in the soil and are more important for crop growth and productivity (Abegunrin et al., 2016). In agreement with this study, Onweremadu (2008) reported that TN ad TP increment under wastewater-irrigated soil compared with pure water-irrigated soil. Likewise, Masto et al. (2009) have also reported that 18.2% Total Kjeldahl Nitrogen (TKN) and 240.67%PO_4^{3-} increases in the soil irrigated by treated sewage wastewater (Singh and Agrawal, 2012).

Wastewater reuse can also have another benefit in contributing macro-nutrient (i.e., Ca^{2+} and Mg^{2+}) and micronutrients (i.e., K^{+}) (Becerra-Castro et al., 2015). Analysis of soil exchangeable cations such as Ca^{2+} Mg^{2+}, K^{+}, and Na^{+} concentrations between treatment groups indicated a significant variation. TG1 had considerably higher levels of Ca^{2+} and Mg^{2+} concentration followed by TG2 and TG3, which is associated with the high content of Ca^{2+} and Mg^{2+} concentrations of MPTW (Table 4). Whereas, relatively higher concentrations of Na^{+} and K^{+} occurred in TG2. As indicated in Figure 5 (d), the maximum Ca^{2+} and Mg^{2+} contents in the background soil were 363.4 $mgkg^{-1}$ and 162.64 $mgkg^{-1}$, respectively, but after irrigation with MPTW, these cation concentrations were increased from 363.4 to 892.41 $mgkg^{-1}$ and 162.64 to 401.25 $mgkg^{-1}$, respectively, followed by ADBE irrigated TG2 pot soil, which increased from 363.4 to 734.91 $mgkg^{-1}$, and 162.64 to 345.65 $mgkg^{-1}$ for Ca^{2+} and Mg^{2+}, respectively. The minimum concentration changes in Ca^{2+} and Mg^{2+} ranged from 363.4 to 565.62 $mgkg^{-1}$ and 162.64 to 277.1 $mgkg^{-1}$ was found in TG3, respectively. For K^{+} and Na^{+}, relatively higher change in K^{+} (268.6 $mgkg^{-1}$) and Na^{+} (231.78 $mgkg^{-1}$) was found in TG2. Whereas, the lower change of 203.87 $mgkg^{-1}$ and 161.03 $mgkg^{-1}$ for K^{+} and 124.9 $mgkg^{-1}$ and 201.6 $mgkg^{-1}$ for Na^{+} were found in TG3 and TG1, respectively (Figure 5 (d)). The substantial decrease in exchangeable cations concentration in TG3 is due to their removals in CW. Research investigation has also indicated that lower concentrations of exchangeable Ca^{2+} and K^{+} were found in treated textile mill wastewater (Singh and Agrawal, 2012). The application of Na^{+} rich wastewater in the soil can prevent the absorption of essential elements in plant growth, reduce the nutritional imbalance in the soil, affects the availability of crop water, and causes soil physicochemical changes, particularly decrease to soil water holding capacity, and adversely affect the plant growth (Leal et al., 2009; Castro et al., 2011).

It must be noted that the study soils, because of the alkaline condition of the soil, higher values for exchangeable cations were found in each treatment group soil, despite the higher irrigation waters cations supply (Table 4). Wastewater reuse for irrigation caused a notable increase in SAR. An increase of two-fold from a background in TG2 was found in SAR values, which can cause a threat on the soil that needs more consideration before it affects the other soil properties (e.g., pH and permeability) and soil suffer sodicity problems (Libutti et al., 2018). A high increase in SAR was found under ADBE irrigation compared to TG1 and TG3. Salinity hazard is linked with SAR; hence, the evaluation of irrigation soil SAR value indicates that the application of ADBE brought a higher SAR value of 9.97 in TG2 followed by T'G1 with SAR value of 7.93 in MPTW irrigated pot soil. Soil irrigated with CWPBE gave the minimum SAR value of 6.09 (Figure 5a). This irrigation water application showed a significant change from background values with 2, 2.5, and 1.5 folds increment, respectively, for TG1, TG2, and TG3. Globally, SAR 6 is accepted as a level above which soil permeability and structural stability may be affected, while SAR 8 was suggested as the higher limit for irrigation of non – tolerant plants (Al-Hamaiedeh and Bino, 2010). A comparison of this study's SAR value with the above-recommended threshold limits, the TG3 soil SAR meets the accepted standard of 6, whereas TG1 SAR meet the higher limit of 8. But, the TG2 SAR exceeded both limits. Compared to CWPBE and MPTW, the higher Na^+ concentration in ADBE resulted in a slightly higher Na^+ concentration in SAR soil, most likely due to its accumulation in the root zone. High levels of Na^+ in ADBE may cause other cations in the soil to be substituted. This substitution leads to decrease soil hydraulic conductivity, increased soil compressibility, decrease crop growth and productivity due to toxic and osmotic effects cause (Becerra-Castro et al., 2015). According to Ayers

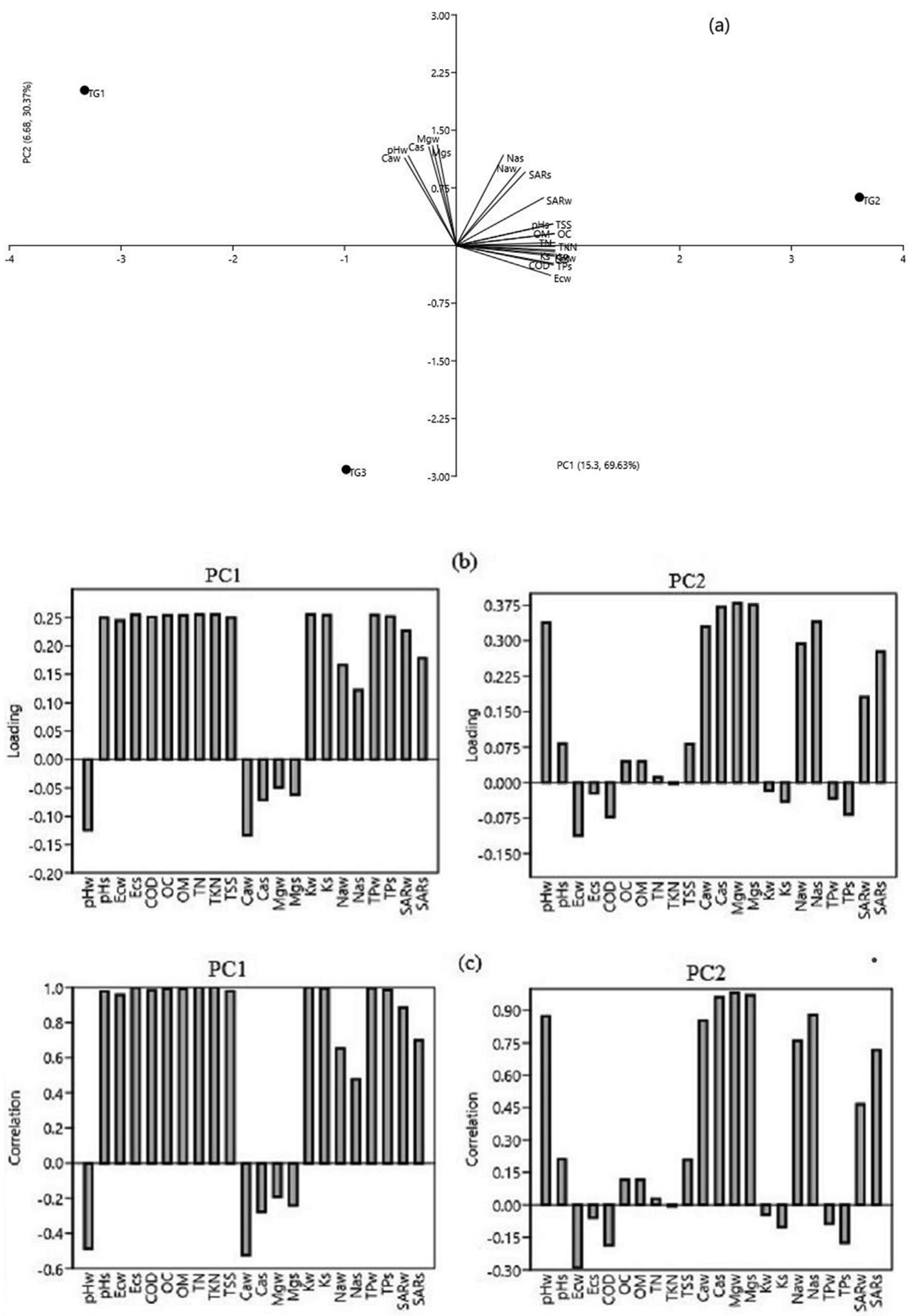

Figure 6. (a) PCA of irrigation water and irrigated soil physicochemical parameters, (b) loading plot of the variables and PCA scores, and (c) correlation plot; 'w' and 's' indicates water and soil parameter.

and Westcot (1985), when SAR exceeds 15, arise serious problems, such as the soil being hard and crusting badly, leading to plants having trouble absorbing water. In addition, damage to the physical characteristics of the soil can occur when SAR is in the 12–15 range (Libutti et al., 2018).

3.4. PCA and Pearson's correlation of irrigation water and irrigated soil parameters

Overall, the PCA produced a strong correlation in two dimensions, one with ADBE and soil physicochemical parameters considered in TG2 in the PC1 dimension and the other with MPTW and TG1 soil physicochemical parameters in the PC2 dimension (Figure 6a). As indicated in Figure 6a, Eigen-values, and percentage of total variation accounted for the PC1 dimension were 15.3 and 69.63%, respectively with positive loading of all parameters except water pH, Ca^{2+} Mg^{2+}, and soil Ca^{2+}, and Mg^{2+} in TG2 observation. Whereas, PC2 showed major positive loading of water pH, Ca^{2+}, Mg^{2+}, Na^{+}, and SAR along with soil Ca^{2+}, Mg^{2+}, Na^{+}, and SAR. But, irrigation water TSS and soil OC and OM showed minor positive loading in TG1 with an Eigen-value of 6.68 and a total percentage variance of 30.37% (Figure 6a). In the PC2 direction, a strong correlation was observed between MPTW pH with soil exchangeable cations of Ca^{2+} ($r = 0.974$) and Mg^{2+}($r = 0.965$), but weak correlation was found between MPTW and soil Na^{+} ($r = 0.498$) and SAR ($r = 0.284$); Ca^{2+} of MPTW with soil exchangeable cations of Ca^{2+} ($r = 0.964$) and Mg^{2+} ($r = 0.953$), moderately correlated with MPTW and soil Na^{+} cation with Pearson r-value of 0.547. Similarly, MPTW Mg^{2+} is strongly correlated with soil Mg^{2+} content of soil ($r = 0.999$), but moderately correlated with a MPTW and soil Na^{+} content with respective Pearson r values of 0.619 and 0.771; while it showed a weakly correlation with MPTW TSS ($r = 0.017$) and soil pH ($r = 0.019$) and soil SAR ($r = 0.238$) (Figure 6c). Analogously, in the PC1 direction, a strong linear correlation was observed between ADBE irrigation water and its pot soil parameters. Among these, the ADBE EC, COD, TN, TSS, K^{+}, Na^{+}, and TP contents were linearly correlated with soil pH, EC, OC, OM, TN, TP, and K^{+} with $r \geq 0.9$. While ADBE Na^{+} and SAR were linearly correlated with soil Na^{+} and SAR $0.5 \leq r \leq 0.9$. But, ADBE Ca^{2+} and Mg^{2+} were negatively correlated with soil Ca^{2+} and Mg^{2+}. Overall, major positive loading was observed in TG2 with a strong positive correlation between ADBE and soil parameters (Figure 6c).

Similarly, Mandal et al. (2008) used PCA to examine the effect of irrigation water quality on soil and found that the fifteen variables resulted in relationships in three principal axes with an 81% cumulative variance. Positive loading was observed in PCA1 for stability ration (SR), exchangeable potassium, TN, available phosphorous, hydraulic conductivity, fluorescein dilacerate enzymatic activity (FDA), organic carbon, and pH. For PCA2 and PCA3, however, only boron had a positive loading effect. FDA had the highest factor loading for the minimum data collection, according to Pearson correlation analysis for each strongly weighted variable in PC1 (MDS). With an $r = 0.94$, exchangeable sodium had the next highest association with MDS. The least correlated variables were EC and hydraulic conductivity (Mandal et al., 2008). Another study by Tomaz et al. (2020) explained 73.9% of the total variance in three PCA axes. In PCA1, salinity showed the highest correlation while nutrient contents were highly associated with PCA2. Sodium and magnesium showed the most influence cations in the Alqueva water sample and increase the salinity parameters of SAR and EC. Liu et al. (2003) explained 44.6% of the total variance, which strongly correlated with Na^{+}, Mg^{2+}, EC, and SAR and moderately correlated with Ca^{2+}, SO_4^{2-}, K^{+}, pH and Cl^{-1} with 17% of the total variance.

4. Conclusion

The findings from the present study indicated that further treatment of ADBE with two-stage horizontal subsurface flow constructed wetland produced quality effluent, which can be reused as a potential source of irrigation water for tomatoes grown in a pot experimental system. The laboratory-scale and short-term experiment indicated that the CWPBE application significantly enhanced the growth and yield biometric parameters of tomato crop plants. This may be due to its sufficient micro – and macro-nutrient characteristics and reduced content of suspended solids, pathogens, and salts, which improved the nutrient uptake potential of tomato plants. On the other hand, the ADBE application for pot tomato irrigation showed a reduced growth and yield of tomato which may be due to the relatively increased salt content, which reduced the nutrient uptake and water stress of the tomato plant. PCA of irrigation water and soil physicochemical association indicated that the majority (68.68%) of the parameters showed a positive response to the ADBE-treated group (TG2). While 28.32% of the parameters (i.e., pH, Ca^{2+}, and Mg^{2+}) showed a positive correlation with an MPTW group (TG1). The short – term residual effect analysis of the irrigation waters on the background soil also indicated that a relatively higher pH, EC, SAR, TN, TP, OC, OM, and exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) changes were observed in TG2 pot soil with ADBE application. ADBE application also significantly increased soil EC, SAR, and Na^{+} concentrations compared to the background and other treatment group soils, and thus, attempts should be made to identify the sensitive crop species and soil indicators under its irrigation reuse. On the other hand, CWPBE in TG3 contributed a minimum residual effect on soil basic properties as compared to ADBE, and thus, its irrigation application is promising for enhancing soil physicochemical properties and increasing crop productivity. However, comprehensive long-term monitoring of the effect of both treatment effluents should be investigated to avoid the development of soil salinity beyond the prescribed limit to effectively address future irrigation challenges.

Declarations

Author contribution statement

Ermias Alayu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Seyoum Leta: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors would like to acknowledge Addis Ababa University for financial support through its thematic research project (Project No. TR/012/2016). The authors would like also to thank Kombolcha brewery factory for providing the necessary equipment and laboratory facilities.

References

Abd-Elwahed, M.S., 2019. Effect of long-term wastewater irrigation on the quality of alluvial soil for agricultural sustainability. Ann. Agric. Sci. 64 (2), 151–160.

Abegunrin, A., 2013. Effect of kitchen wastewater irrigation on soil properties and growth of cucumber (Cucumis sativus). J. Soil Sci. Environ. Manag. 4 (7), 139–145.
Abegunrin, T.P., Awe, G.O., Idowu, D.O., Adejumobi, M.A., 2016. Impact of wastewater irrigation on soil physico-chemical properties, growth and water use pattern of two indigenous vegetables in southwest Nigeria. Catena 139, 167–178.
Ahmad, K., Wajid, K., Khan, Z.I., Ugulu, I., Memoona, H., Sana, M., Sher, M., 2019. Evaluation of potential toxic metals accumulation in wheat irrigated with wastewater. Bull. Environ. Contam. Toxicol. 102 (6), 822–828.
Ahmed, N.U., Mahmud, N.U., Zaman, M.A., Ferdous, Z., Halder, S.C., 2017. Effect of different salinity level on tomato (Lycopersicon esculentum) production under climate change condition in Bangladesh. Ann. Res. Rev. Biol. 13 (3), 1–9.
Al-Hamaiedeh, H., Bino, M., 2010. Effect of treated grey water reuse in irrigation on soil and plants. Desalination 256 (1–3), 115–119.
Alayu, E., Leta, S., 2021. Post treatment of anaerobically treated brewery effluent using pilot scale horizontal subsurface flow constructed wetland system. Bioresources Bioprocess. 8 (1), 1–19.
Alberta Environment, 2000. Guidelines for Municipal Wastewater Irrigation. Municipal Program Development Branch Environmental Sciences Division Environmental Service.
Alemu, T., Mekonnen, A., Leta, S., 2019. Integrated tannery wastewater treatment for effluent reuse for irrigation: encouraging water efficiency and sustainable development in developing countries. J. Water Process Eng. 30, 100514.
Allen, R.G., Pereira, L.S., Smith, M., Raes, D., Wright, J.L., 2005. FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. J. Irrigat. Drain. Eng. 131, 2–13.
Almuktar, S.A.A.A.N., Abed, S.N., Scholz, M., 2018. Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. Environ. Sci. Pollut. Control Ser. 25, 23595–23623.
APHA, 1985. Standard Method for the Examination of Water and Wastewater, sixteenth ed. American Public Health Association, Washington DC.
APHA, 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association. Inc., Washington, DC.
Ayers, R.S., Westcot, D.W., 1985. Water Quality Ofagriculture. FAO Irrigation and Drainage Paper No. 29, Revision 1. Food and agriculture Organization of the United Nations, Rome.
Ayub, K.R., Zakaria, N.A., Abdullah, R., Ramli, R., 2010. Water balance: case study of a constructed wetland as part of the bio-ecological drainage system (BIOECODS). Water Sci. Technol. 62 (8), 1931–1936.
Aziz, S., Ali, M., Asghar, S., Ahmed, S., 2015. Comparative analysis of Ranunculus muricatus and Typha latifolia as wetland plants applied for domestic wastewater treatment in a Mesocosm scale study. Int. J. Biol. Biomol. Agric. Food Biotechnol. Eng. 9 (1), 110–118.
Badejo, A.A.A., Ndambuki, J., Kupolati, W.K., 2014. Performance of Anaerobic Digester-Constructed Wetlands System for Brewery Wastewater Treatment.
Bahri, A., Drechsel, P., Brissaud, F., 2015. Water Reuse in Africa : Challenges and Opportunities Water Reuse in Africa: Challenges and Opportunities.
Bakare, B.F., Shabangu, K., Chetty, M., 2017. Brewery wastewater treatment using laboratory scale aerobic sequencing batch reactor. S. Afr. J. Chem. Eng. 24, 128–134.
Balkhair, K.S., 2016. Microbial contamination of vegetable crop and soil profile in arid regions under controlled application of domestic wastewater. Saudi J. Biol. Sci. 23 (1), S83–S92.
Becerra-Castro, C., Lopes, A.R., Vaz-Moreira, I., Silva, E.F., Manaia, C.M., Nunes, O.C., 2015. Wastewater reuse in irrigation: a microbiological perspective on implications in soil fertility and human and environmental health. Environ. Int. 75, 117–135.
Bilgin, M., Simsek, I., Tulun, S., 2014. Treatment of domestic wastewater using a lab-scale activated sludge/vertical flow subsurface constructed wetlands by using Cyperus alternifolius. Ecol. Eng. 70362–70365.
Blanco, F.F., Folegatti, M.V., 2003. A new method for estimating the leaf area index of cucumber and tomato plants. Hortic. Bras. 2 (4), 666–669.
Bonanno, G., Cirelli, G.L., 2017. Comparative analysis of element concentrations and translocation in three wetland congener plants: Typha domingensis, Typha latifolia, and Typha angustifolia. Ecotoxicol. Environ. Saf. 143, 92–101.
Bremner, J.M., Mulvaney, C.S., 1982. Nitrogen—total. In: Page, A.L., et al. (Eds.), Methods of Soil Analysis: Part 2, second ed. American Society of Agronomy, Madison, pp. 595–624.
Caliskan, G., Giray, G., Gundogdu, T.K., Azbar, N., 2014. Anaerobic biodegradation of beer production wastewater at a field scale and explotation of bioenergy potential of other solid wastes from beer production. Int. J. Renew. Energy Biofuels 2014, h1–15.
Carballeira, T., Ruiz, I., Soto, M., 2016. Effect of plants and surface loading rate on the treatment efficiency of shallow subsurface constructed wetlands. Ecol. Eng. 90, 203–214.
Castro, E., Mañas, M.P., De Las Heras, J., 2011. Effects of wastewater irrigation on soil properties and turfgrass growth. Water Sci. Technol. 63 (8), 1678–1688.
Cheng, L., Lee, H., Lin, J., Chou, M., 2010. Treatment of mixture of sewage and partially treated swine wastewater by a combination of UASB and constructed wetlands. Pract. Period. Hazard. Toxic, Radioact. Waste Manag. 14, 234–239.
Ciria, M.P., Solano, M.L., Soriano, P., 2005. Role of macrophyte Typha latifolia in a constructed wetland for wastewater treatment and assessment of its potential as a biomass fuel. Biosyst. Eng. 92 (4), 535–544.
Da Motta Marques, D.M.L., Leite, G.R., Giovannini, S.G.T., 2001. Performance of two macrophyte species in experimental wetlands receiving variable loads of anaerobically treated municipal wastewater. Water Sci. Technol. 44 (11–12), 311–316.
da Silva, E.C., Nogueira, R.J.M.C., de Araújo, F.P., de Melo, N.F., de Azevedo Neto, A.D., 2008. Physiological responses to salt stress in young umbu plants. Environ. Exp. Bot. 63 (1-3), 147–157.
de la Varga, D., Díaz, M.A., Ruiz, I., Soto, M., 2013. Heavy metal removal in a UASB-CW system treating municipal wastewater. Chemosphere 93, 1317–1323.
Disciglio, G., Gatta, G., Libutti, A., Gagliardi, A., Carlucci, A., Lops, F., et al., 2015. Effects of irrigation with treated agro-industrial wastewater on soil chemical characteristics and fungal populations during processing tomato crop cycle. J. Soil Sci. Plant Nutr. 15 (3), 765–780.
El-Khateeb, M.A., El-Bahrawy, A.Z., 2013. Extensive post treatment using constructed wetland. Life Sci. J. 10 (2), 560–568.
El-Tohamy, W.A., Ghoname, A.A., Abou-Hussein, S.D., 2006. Improvement of pepper growth and productivity in sandy soil by different fertilization treatments under protected cultivation. J. Appl. Sci. Res. 2 (1), 8–12.
Ethiopian Environmental Protection Authority (EEPA), 2003. Provisional Standards for Industrial Pollution Control in Ethiopia, Prepared under the Ecologically Sustainable Development (ESID) Project–US. ETH/99/068/Ehiopia. EPA/UNIDO, Addis Ababa.
Eyvaz, M., 2016. Treatment of brewery wastewater with electrocoagulation: improving the process performance by using alternating pulse current. Int. J. Electrochem. Sci. 11 (6), 4988–5008.
FAO, 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO irrigation and drainage paper 56. Rome, Italy.
FAO, 2009. Cropwat 8.0 for Windows User Guide. Rome, Italy.
FAO Regional Office for the Near East Cairo, 2003. USERS MANUAL for IRRIGATION WITH TREATED WASTEWATER. Cairo, Egypt. n. pag. Print.
Gatta, G., Libutti, A., Gagliardi, A., Beneduce, L., Brusetti, L., Borruso, L., Tarantino, E., 2015. Treated agro-industrial wastewater irrigation of tomato crop: effects on qualitative/quantitative characteristics of production and microbiological properties of the soil. Agric. Water Manag. 149, 33–43.
Gee, G.W., Bauder, J.W., 1986. Particle size analysis. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Physical and Minerological Methods. Agron. Monogr. 9, second ed. ASA and SSSA, Madison, WI, pp. 404–408.
Ghanem, N.K., Mohammed, K., Mohammed, E.H.E.O., 2017. Interaction between soil physicochemical parameters and earthworm communities in irrigated areas with natural water and wastewaters. Appl. Environ. Soil Sci. 2017.
Hammer, Ø., Harper, D.A., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol. Electron. 4 (1), 9.
Hanjra, M.A., Blackwell, J., Carr, G., Zhang, F., Jackson, T.M., 2012. Wastewater irrigation and environmental health: implications for water governance and public policy. Int. J. Hyg Environ. Health 215 (3), 255–269.
Heinen, M., Marcelis, l.F.M., Elingus, A., Figueroa, R., 2001. Effects of EC and fertigation strategy on water and nutrient uptake of tomato plants. In: IV International Symposium on Models for Plant Groeth and Control in Greenhouses: Modeling for the 21st Century – Agronomic, vol. 593, pp. 101–107.
Ismail, S.M., Ozawa, K., Khondaker, N.A., 2007. Effect of Irrigation Frequency and Timing on Tomato Yield, Soil Water Dynamics and Water Use Efficiency under Drip Irrigation. Eleventh International Water Technology Conference, IWTC11, pp. 69–84. Retrieved from. https://www.kau.edu.sa/Files/155/Researches/60190_32090.pdf%0Ahttp://www.iwtc.info/2007_pdf/1-4.pdf.
Jaramillo, M.F., Restrepo, I., 2017. Wastewater reuse in agriculture: a review about its limitations and benefits. Sustainability 9, 1734.
Jeong, H., Kim, H., Jang, T., 2016. Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainablewastewater reuse in South Korea. Water 8 (4).
Jones, C.L.W., Power, S.D., 2016. Anaerobically digested brewery effluent as a medium for hydroponic crop production - the influence of algal ponds and pH. J. Clean. Prod. 139, 167–174.
Jueschke, E., Marschner, B., Tarchitzky, J., Chen, Y., 2008. Effects of treated wastewater irrigation on the dissolved and soil organic carbon in Israeli soils. Water Sci. Technol. 57 (5), 727–733.
Karina, M., Jos, H., Sequinel, R., Pioneiro, R., 2017. Treatment of brewery wastewater and its use for biological production of methane and hydrogen. Int. J. Hydrogen Energy 42, 26243–26256.
Kenatu, A., 2011. Evaluation of the Performance of Constructed Wetland System for Treatment of Brewery Wastewater. Master's thesis. Addis Ababa Institute of Technology University, Addis Ababa.
Khan, M.J., Jan, M.T., Farhatullah, Khan, N.U., Arif, M., Perveen, S., Jan, A.U., 2011. The effect of using waste water for tomato. Pakistan J. Bot. 43 (2), 1033–1044.
Khan Jadoon, I.B., Ali, S., Jadoon, Q.B.K., Shakoor, M.B., Bharwana, S.A., Farooq, M.A., 2013. Effects of irrigation with waste water from different industries on vegetables grown in vicinity of Faisalabad, Pakistan. Int. Res. J. Pharmaceut. Sci. 4 (6), 144–148.
Kitaw, G., Tamir, B., Assefa, G., Animut, G., 2018. Production , preservation , and utilization patterns of brewery spent grain in Ethiopia aside from enhancing household livelihoods, improving the animal productivity, 28 (3), 1–17.
Kumar, V., Chopra, A.K., Pathak, C., Pathak, S., 2010. Agro-potentiality of paper mill effluent on the characteristics of Trigonella foenum-graecum L. (Fenugreek). New York Sci. J. 33 (55), 68–77.
La Bella, S., Tuttolomondo, T., Leto, C., Leone, R., Virga, G., Licata, M., Licata, M., 2016. Pollutant removal efficiency of a pilot-scale Horizontal Subsurface Flow in Sicily (Italy) planted with Cyperus alternifolius L. and Typha latifolia L. and reuse of treated wastewater for irrigation of Arundo donax L. for pellet production—results of two-year tests under Mediterranean climatic conditions. Desalination Water Treat. 57 (48-49), 22743–22763.
Lal, K., Minhas, P.S., Yadav, R.K., 2015. Long-term impact of wastewater irrigation and nutrient rates II. Nutrient balance, nitrate leaching and soil properties under peri-urban cropping systems. Agric. Water Manag. 156, 110–117.
Leal, R.M.P., Firme, L.P., Montes, C.R., Melfi, A.J., Piedade, S.M.D.S., 2009. Soil exchangeable cations, sugarcane production and nutrient uptake after wastewater irrigation. Sci. Agric. 66 (2), 242–249.

Leto, C., Tuttolomondo, T., La Bella, S.L., Leone, R., Licata, M., 2013. Effects of plant species in a horizontal subsurface flow constructed wetland – phytoremediation of treated urban wastewater with Cyperus alternifolius L . and Typha latifolia L . in the West of Sicily (Italy). Ecol. Eng. 61, 282–291.

Libutti, A., Gatta, G., Gagliardi, A., Vergine, P., Pollice, A., Beneduce, L., Tarantino, E., 2018. Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. Agric. Water Manag. 196, 1–14.

Liu, C.W., Lin, K.H., Kuo, Y.M., 2003. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Sci. Total Environ. 313 (1-3), 77–89.

Liu, B., Gumpertz, M.L., Hu, S., Ristaino, J.B., 2008. Effect of prior tillage and soil fertility amendments on dispersal of Phytophthora capsici and infection of pepper. Eur. J. Plant Pathol. 120 (3), 273–287.

Liu, C., Dang, X., Mayes, M.A., Chen, L., Zhang, Y., 2017. Effect of long-term irrigation patterns on phosphorus forms and distribution in the brown soil zone. PloS One 12 (11), 1–16 e0188361.

Mandal, U.K., Warrington, D.N., Bhardwaj, A.K., Bar-Tal, A., Kautsky, L., Minz, D., Levy, G.J., 2008. Evaluating impact of irrigation water quality on a calcareous clay soil using principal component analysis. Geoderma 144 (1-2), 189–197.

Masto, R.E., Chhonkar, P.K., Singh, D., Patra, A.K., 2009. Changes in soil quality indicators under long-term sewage irrigation in a sub-tropical environment. Environ. Geol. 56 (6), 1237–1243.

Mehlich, A., 1978. New extractant for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, Manganese, and Zinc. Commun. Soil Sci. Plant Anal. 9 (6), 477–492.

Merino-solís, M.L., Villegas, E., Anda, J. De, López-lópez, A., 2015. The Effect of the Hydraulic Retention Time on the Performance of an Ecological Wastewater Treatment System: an Anaerobic Filter with a Constructed Wetland, pp. 1149–1163.

Miyazaki, A., Takeuchi, T., Nakamura, H., Yamamoto, Y., 2004. Soil Science and Plant Nutrition Characteristics of nutrient absorption and water purification in some plant species grown by floating culture system. Soil Sci. Plant Nutr. 50 (3), 357–363.

Moawad, A., Mahmoud, U.F., El-Khateeb, M.A., El-Molla, E., 2009. Coupling of sequencing batch reactor and UASB reactor for domestic wastewater treatment. Desalination 242, 325–335.

Mohan, S., Vivekanandhan, V., Sivakumar, R., 2018. Performance of an up-flow anaerobic sludge blanket reactor (Uasbr) in the treatment of brewery effluent. Am. J. Eng. Res. (AJER) (5), 351–356.

Mollard, F.P.O., Roy, M., Foote, A.L., 2013. Typha latifolia plant performance and stand biomass in wetlands affected by surface oil sands mining. Ecol. Eng. 58, 26–34.

Morugán-Coronado, A., Arcenegui, V., García-Orenes, F., Mataix-Solera, J., Mataix-Beneyto, J., 2013. Application of soil quality indices to assess the status of agricultural soils irrigated with treated wastewater. Solid Earth 4 (1), 119–127.

Mutengu, S., Hoko, Z., Makoni, F.S., 2007. An assessment of the public health hazard potential of wastewater reuse for crop production. A case of Bulawayo city, Zimbabwe. Phys. Chem. Earth 32 (15–18), 1195–1203.

Muyen, Z., Moore, G.A., Wrigley, R.J., 2011. Soil salinity and sodicity effects of wastewater irrigation in South East Australia. Agric. Water Manag. 99 (1), 33–41.

Nelson, D.W., Sommers, L.E., 1996. Total carbon, organic carbon, and organic matter. Methods Soil Analysis: Part 3 Chem. methods 5, 961–1010.

Nikolaou, G., Neocleous, D., Katsoulas, N., Kittas, C., 2019. Irrigation of greenhouse crops. Horticulturae 5 (1), 7.

Oljira, T., Muleta, D., Jida, M., 2018. Potential applications of some indigenous bacteria isolated from polluted areas in the treatment of brewery effluents. Biotechnol. Res. Int. 2018.

Omotade, I.F., 2019. Growth and yield performance of hot pepper using aquaculture wastewater. Agric. Eng. Int.: CIGR J. 21 (2), 18–25.

Onweremadu, E.U., 2008. Physico-chemical characterization of a farmland affected by wastewater in relation to heavy metals. J. Zhejiang Univ. – Sci. 9 (3), 366–372.

Oo, A.N., Iwai, C.B., Saenjan, P., 2015. Soil properties and maize growth in saline and nonsaline soils using cassava-industrial waste compost and vermicompost with or without earthworms. Land Degrad. Dev. 310, 300–310.

Ouansafi, S., Abdelilah, F., Kabine, M., Maaghloud, H., Bellali, F., El Bouqdaoui, K., 2019. The effects of soil proprieties on the yield and the growth of tomato plants and fruits irrigated by treated wastewater. AIMS Agric. Food 4 (4), 921–938.

Pawar, D.R., Shah, K.M., 2009. Laboratory Testing Procedure for Soil and Water Sample Analysis. Government of Maharashtra Water Resources Department, Directorate of Irrigation Research and Development. Pune.Pescod, M.B., 1992. Wastewater Treatment and Use in Agriculture. F.A.O of the United States, Rome 1992- F.A.O Irrigation Drainage Paper 47.

Raposo, M.F.D.J., Oliveira, S.E., Castro, P.M., Bandarra, N.M., Morais, R.M., 2010. On the utilization of microalgae for brewery effluent treatment and possible applications of the produced biomass. J. Inst. Brew. 116 (3), 285–292.

Rhoades, J.D., Kandiah, A., Mashali, A.M., 1992. The use of saline waters for crop production. Food and Agriculture Organization of the United Nations. FAO Irrigation and Drainage Paper 48. Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Richards, L.A., 1954. Diagnosis and improvement of saline and alkali soils. USDA and IBH Pub, Coy Ltd., New Delhi, India. Agric. Handb. 60, 98–99.

Sa'at, S.K., Zaman, N.Q., Yusoff, S.M., Ismail, H.A., 2017. Investigation of the potential of *Cyperus alternifolius* in the phytoremediation of palm oil mill effluent. AIP Conf. Proc. 1892 (1), 040009.

Samia, K., Abdelkarim, C., Yassin, H., Teruo, H., 2013. The effect of long-term soil irrigation by wastewater on organic matter, polycyclic aromatic hydrocarbons, and heavy metals evolution: case study of Zaouit Sousse (Tunisia). Arab. J. Geosci. 6 (11), 4337–4346.

Segura, M.L., Granados, M.R., Moreno, J., Urrestarazu, M., 2004. Response of greenhouse melon and tomato crops to wastewater fertirrigation. In: XXVI International Horticultural Congress: Protected Cultivation 2002: in Search of Structures. Systems and Plant Materials Fo, vol. 633, pp. 391–396.

Shakir, E., Zahraw, Z., Al-Obaidy, A.H.M.J., 2017. Environmental and health risks associated with reuse of wastewater for irrigation. Egypt. J. Petrol. 26 (1), 95–102.

Shenge, K.C., Whong, C.M., Yakubu, L.L., Omolehin, R.A., Erbaugh, J., Miller, S.A., Le Jeune, J.T., 2015. Contamination of tomatoes with coliforms and Escherichia coli on farms and in markets of northwest Nigeria. J. Food Protect. 78 (1), 57–64.

Simate, G.S., Iyuke, S.E., Cluett, J., Iyuke, S.E., Musapatika, E.T., Ndlovu, S., Alvarez, A.E., 2011. The treatment of brewery wastewater for reuse: state of the art the treatment of brewery wastewater for reuse: state of the art. DES 273 (2–3), 235–247.

Singh, A., Agrawal, M., 2012. Effects of waste water irrigation on physical and biochemical characteristics of soil and metal partitioning in beta vulgaris L. Agric. Res. 1 (4), 379–391.

Sousa, J. T. De, Cássia, R. De, Alves, V., Lopes, S., 2012. Domestic wastewater treated for agricultural reuse. Afr. J. Biotechnol. 11 (100), 16560–16567.

Tazkiaturrizki, T., Soewondo, P., Handajani, M., 2018. Nitrogen removal on recycling water process of wastewater treatment plant effluent using subsurface horizontal wetland with continuous feed Nitrogen removal on recycling water process of wastewater treatment plant effluent using subsurface horizontal wetl. IOP Conf. Ser. Earth Environ. Sci. 106.

Terfie, T.A., Asfaw, S.L., 2015. Evaluation of selected wetland plants for removal of chromium from tannery wastewater in constructed wetlands, Ethiopia. Afr. J. Environ. Sci. Technol. 9, 420–427.

Theophile, F., Sako, I.B., Martin, L., Fabrice, M.T., Akoa, A., 2011. Potential of Cyperus papyrus in yard-scale horizontal flow constructed wetlands for wastewater treatment in Cameroon. Univers. J. Environ. Res. Technol. 1 (2).

Tomaz, A., Palma, P., Fialho, S., Lima, A., Alvarenga, P., Potes, M., Salgado, R., 2020. Spatial and temporal dynamics of irrigation water quality under drought conditions in a large reservoir in Southern Portugal. Environ. Monit. Assess. 192 (2), 1–17.

Tarantino, E., Disciglio, G., Gatta, G., Libutti, A., Frabboni, L., Frabboni, A., Tarantino, A., 2017. Agro-industrial treated wastewater reuse for crop irrigation: implication in soil fertility. Chem. Eng. Trans. 58, 679–684.

UN-HABITAT, 2008. *Constructed Wetlands Manual*. UN-HABITAT Water for Asian Cities Programme Nepal, Kathmandu.

Vergine, P., Salerno, C., Libutti, A., Beneduce, L., Gatta, G., Berardi, G., Pollice, A., 2017. Closing the water cycle in the agro-industrial sector by reusing treated wastewater for irrigation. J. Clean. Prod. 164, 587–596.

Vieira, I.G., Nobre, R.G., Dias, A.S., Pinheiro, F.W., 2016. Cultivation of cherry tomato under irrigation with saline water and nitrogen fertilization. Rev. Bras. Eng. Agrícola Ambient. 20 (1), 55–61.

Vymazal, J., 2005. Horizontal subsurface flow and hybrid constructed wetlands systems for wastewater treatment. Ecol. Eng. 25, 478–490.

Vymazal, J., 2007. Review: removal of nutrients in various types of constructed wetlands. Sci. Total Environ. 380, 48–65.

WHO, 2006. Guidelines for the Safe Use of Wastewater. Excreta and Greywater, Geneva, Switzerland.

Worku, A., Tefera, N., Kloos, H., Benor, S., 2018. Bioremediation of brewery wastewater using hydroponics planted with vetiver grass in Addis Ababa, Ethiopia. Bioresources Bioprocess. 5 (1), 39.

Yasar, A., Tabinda, A.B., 2010. Anaerobic treatment of industrial wastewater by UASB reactor integrated with chemical oxidation processes; an overview. Pol. J. Environ. Stud. 19 (5), 1051–1061.

Zeb, B.S., Mahmood, Q., Jadoon, S., Pervez, A., Irshad, M., Bilal, M., Bhatti, Z.A., 2013. Combined industrial wastewater treatment in anaerobic bioreactor post-treated in constructed wetland. BioMed Res. Int. 2013.

Zinabu, E., Yazew, E., Haile, M., 2010. Assessment of the impact of industrial effluents on the quality of irrigation water and changes on soil characteristics (A case of Kombolcha town) location of study area. In: Fourteenth International Water Technology Conference, IWTC 14 2010, Cairo, Egypt, pp. 711–727.

Zurita, F., White, J.R., 2014. Comparative study of three two-Stage hybrid ecological wastewater treatment systems for producing high nutrient, reclaimed water for irrigation reuse in developing countries. Water 6 (2), 213–228.