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Investigating suitability of treated wastewater for agriculture in Hawassa, Sidama region, Ethiopia

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ABSTRACT

This study is based on the quality of wastewater from Hawassa University surroundings, which was assessed to determine its suitability for irrigation purposes during 2019. Grab samples of influent and the treated water were taken for assessing for quality parameters. The study revealed that the treated water could be used for irrigation purpose with some moderate restrictions. Even though Electrical Conductivity (EC) and Total Dissolved Solids (TDS) permit to irrigate fruit trees and fodder crops, there is a risk of soil degradation due to high value of Sodium Adsorption Ratio (SAR). Results also indicated that carbonate, potassium and phosphate exceeded the specified limits for wastewater reuse in agriculture. Despite increased nutritive elements, continuous use of treated sewage water for irrigation will make the soil acidic. Analysis of soil parameters indicated that there is an increase in nitrogen, phosphate and potassium nutrient levels considerably to benefit crop production but increase in soil EC is a serious concern.

Keywords: Crop water, Irrigation demand, Pollutants, Sewage water, Water treatment.

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Introduction

Water, a prime nutrient, which sustains life and it is the most important compound to the ecosystem and is often the limiting factor for successful crop production. Irrigated agriculture is dependent on adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available (Shamsad and Islam, 2005; Islam and Shamsad, 2010). This situation is now changing in many areas around the world. Intensive use of nearly all good quality supplies means that new irrigation projects, and old projects seeking new or supplemental supplies, must rely on lower quality and less desirable sources (Cuena, 1989).

In order to sustain irrigation, large amounts of water are withdrawn from rivers, lakes, reservoirs, and groundwater, together making up about 70% of global water withdrawals (Famiglietti, 2011). The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot, 1985). In this respect, the reuse of sewage effluent for irrigation purpose seems to be the most promising method to reduce dependability to other water resources and reduce environmental degradation. In many studies worldwide the use of treated sewage effluents (TSE) as water and nutrient sources in agricultural irrigation have been introduced as a viable alternative for wastewater destination in the environment. Various studies have revealed that the nutrient supply only by TSE irrigation was not sufficient to meet plant nutrient requirements resulting in yield decreases. Sewage, often untreated, is used to irrigate 10% of the world's crops, according to the first over global survey of wastewater irrigation (Scott *et al.*, 2004). Globally, around 20 million hectares of land are irrigated with wastewater and this figure is likely to increase during the next few decades (Hamilton *et al.*, 2007). Availability of plant essential nutrients from the biodegradable constituents of wastewater attracts farmers to use it for agriculture. In that sense, it enables farmers to reduce the expenditures on fertilizer and better production can be achieved. In some cases up to 37% increase in harvest is possible when raw wastewater is applied compared to freshwater irrigation with chemical fertilizer (Martijn and Redwood, 2005).

During dry spells, supplemental irrigation is must for annual crops like banana/sugarcane to boost yield and coping uncertainty of rainfall due to climate change. At present, the treated water from the system is disposed to underground by seepage and percolation. To make use of this water for irrigation purpose, it is necessary to study its quality parameters and suitability for irrigation. For this purpose, research was conducted in wastewater from Hawassa University surroundings during 2019 dealing with how best the pollutants are treated and the unutilized resource of sewage water can be utilized productively.

Materials and Methods

Description of the study area

Hawassa city is the capital of Sidama regional state. It is located at a distance of 273 km South of Addis Ababa. The geographic coordinates of the town are approximately 7°03' latitude North and 38°29' longitudes East. Sewage water from the student's hostel buildings in the main campus is first diverted to septic tanks to remove the solids and then diverted to stabilization pond and a series of oxidation and polishing ponds. There is a possibility for utilizing the treated sewage water for irrigation purpose in the nearby hill side lands. Based on physical observation, soils on adjacent hillside land is generally sandy loam with low humus and are more permeable. They dry fast even after a heavy rain. The cultivated crops are maize, onion, tomato, potato and sugarcane under rainfed and irrigated conditions.

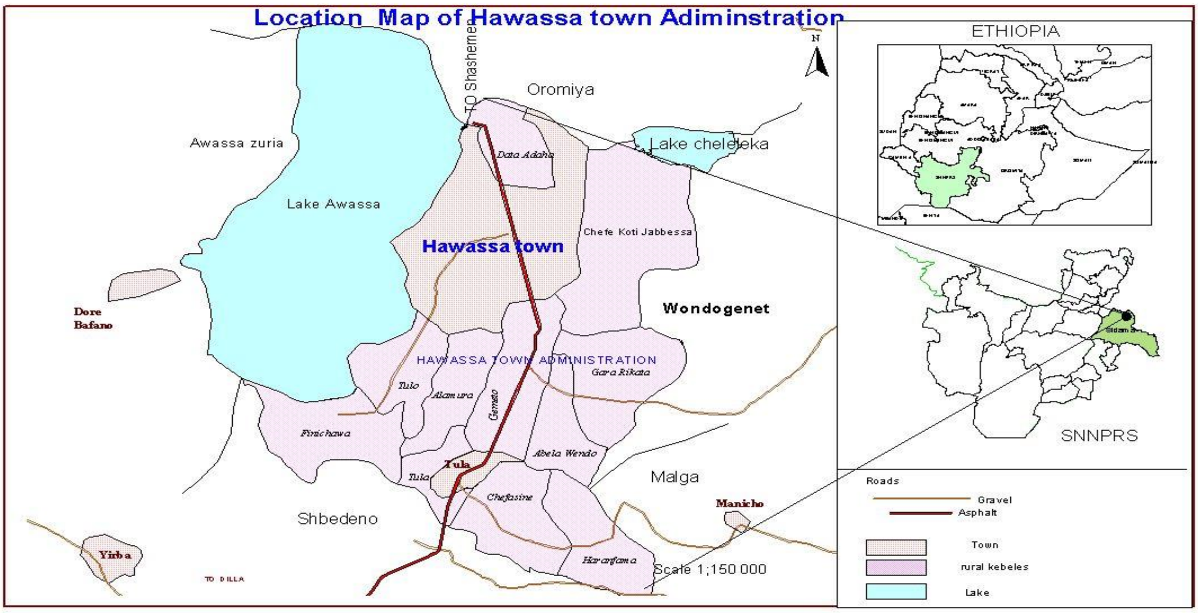

Fig. 1. Location map of Hawassa University main campus.

Hawassa has warm temperature, which varies between 10°C in winter and 30°C in summer. The mean annual precipitation is 958 mm. The average elevation at is 1700 m and that of the lake surface is 1680 m. Rain is more intensive during the four rainy months of June to September such that more than 80% of the rain falls during this period.

Sewage treatment system

Ponds and tanks are one of storage options and combinations that can be considered for managing increasing water resources variability (McCartney and Smakhtin, 2010). From the student's hostel buildings, which accommodate more than 10,000 students, average sewage discharge of 5.8 to 8.1 (500 to 700 m^3/d) litres per second was estimated (Directorate of constructions, Hawassa University). This water is collected by many septic tanks constructed as part of primary anaerobic treatment removing macro particles. The effluent from these septic tanks is collected and delivered to sewage treatment plant (STP) Line 1 and 2 located at a distance of around 1.0 km. The STP comprises of a series of lined earthen tanks of different capacities starting from equalization pond followed by oxidation and polishing ponds. The sewage water is treated both by physical and biological treatment to reduce the suspended solids and biochemical oxygen demand to the acceptable levels.

Crop water requirement

To estimate the crop water requirements and irrigation water requirement of selected crop, CROPWAT software for windows was used. The input climate parameters i.e. rainfall, temperature, humidity, solar radiation, wind velocity and pan evaporation data obtained from Meteorological station of Hawassa were used for the research. Climate data was analyzed to estimate the peak crop water demand of sugarcane plant and observations were also made on soil quality parameters to find the impact using treated sewage water if used for irrigation on soil parameters. Treated sewage water quality has been compared with standard water quality requirements for irrigation.

Water sampling and analysis

Grab water samples were collected from STP during peak functioning month of the university. Raw and treated effluent samples were collected and analyzed for the water quality parameters. Samples for Biological Oxygen Demand (BOD), Nitrogen, Phosphorus, Chlorides and Solids etc. were analyzed in accordance with the procedure laid down in Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Total Suspended Solid (TSS) and Total Dissolved Solid (TDS) were determined by gravimetric method (dried at 103°C). Biological Oxygen Demand (BOD) was determined by the 5 Day BOD test. Other tests such as Conductivity (EC) and pH were directly measured in-situ using portable measuring devices (HANNA instruments, HI 9811, portable pH-EC-TDS Meter). Note that before each measurement, the pH meter was calibrated with reference buffer solution. Each analysis was carried out in triplicate and then the mean value was taken.

All samples were collected and transported within ice box and analyzed within 6 hours of collection for chemical examinations. Soil samples from sewage disposal land and nearby cultivated land were also analyzed. Soil sample were taken at 30 to 60 cm depth in three different locations. Totally six samples were collected and tested for Na^{++}, K^{+}, Sodium Adsorption Ratio (SAR), pH, EC, Total Organic Carbon (TOC), available phosphorous and Total nitrogen. Organic carbon was determined using the Walkley-Black method. Phosphorus (P) content determination was done using the colorimeter method using sodium hydrogen carbonate extract (Adepetu *et al.*, 2000). Exchangeable bases were extracted by the ammonium acetate extraction technique and determined by flame photometry (Adepetu *et al.*, 2000). The total nitrogen was determined using Kjeldal method while pH was determined using 1:2.5 $CaCl_2$ dilution method (Adepetu *et al.*, 2000).

Results and Discussion

Rainfall and crop water demand

Annual average rainfall considering 5, 10 and 20 years data shows a decreasing trend due to impact of climate change. The rate of decrease in rainfall is 1.76% and 8.9% based on 10 and 5 years average. This implies that the rate of decrease is increasing year by year resulting severe impact on agriculture and land management practices. To cope with this decline in rainfall, suitable strategies should be followed in crop scheduling and water management. Owing to increasing population and food demand new water resources and appropriate water application methods need to be evolved.

Considering a long duration crop (Sugarcane), it needs total crop water demand of 1400 mm for Hawassa climate conditions. Twenty (20) years average monthly rainfall data are analyzed to estimate effective rainfall and irrigation demand (Fig. 2). Considering medium sandy loam soil, the net irrigation water to be applied in the root zone to replenish 30% depletion is calculated as 48.6mm. For 90% irrigation efficiency, gross irrigation depth of 54mm is to be applied. Peak irrigation demand of 2.7 mm/day is observed for 20 years average data with planting date in January whereas 4.6 mm/day is observed when planting is in June.

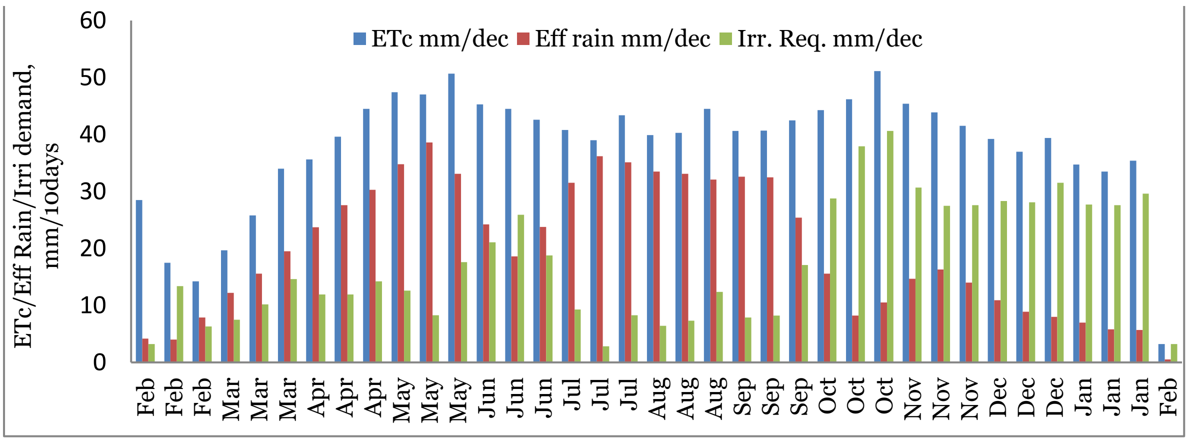

Fig. 2. Monthly crop water and irrigation demand.

Sewage water quality for irrigation

The average value of pH was 7.8, which indicate that the treated sewage water is slightly alkaline in nature. The normal pH range for irrigation water is from 6.5 to 8.4. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion (Ayers and Westcot, 1985; Pescod, 1985).

Electrical conductivity (EC) is the most important parameter in determining the suitability of water for irrigation use and it is a good measurement of salinity hazard to crop as it reflects the TDS in wastewater. The most important negative effect on the environment caused by agricultural wastewater is the increases in soil salinity, which if not controlled, can decrease productivity in long term (WHO, 2005). EC values of treated wastewater varied from 1100 to 1300 μScm^{-1} (mean value = 1200 μScm^{-1}) while TDS values varied from 545 to 675 mgL^{-1} (mean value = 610 mgL^{-1}) indicating slight to moderate degree of restriction on the use of this wastewater in irrigation due to salt build-up in soils and its adverse effects on plant growth (Ayers and Westcost, 1985). Furthermore, the results indicted also that this type of water can be used on the soils with restricted drainage. Special salinity control management with selection of good salt tolerant plants is required. However, irrigation water with conductivity in the range of 750-2250 μScm^{-1} is permissible for irrigation and widely used. It is necessary to combine the use of wastewater with practices to control salinization, such as soil washing and appropriate soil drainage (WHO, 2005). The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Tatawat and Singh, 2008).

The SAR and EC values (Fig. 3) of the treated wastewater reflect that it should be severely restricted for surface irrigation system since it reduces the infiltration rate of the soil. Highly efficient irrigation systems are recommended if the treated sewage water needs to be used for irrigation to avoid soil degradation. The effects of the high SAR percentages are that the soil hydraulic system is affected, as aggregates will begin to break down resulting in poor soil structure. This will make the soils less productive as they will be sticky when wet and crusty when dry making tillage operations very difficult (Ayers and Westcot, 1985; Affullo, 2009).

The obtained Cl^- ion concentration of the samples varied from 130 to 224 mgL^{-1} representing slight to moderate degree of restriction on the use of this wastewater in irrigation (Ayers and Westcot, 1985). While, according to USSL classification of irrigation water, the effluent samples can be used for moderately tolerant plants (WHO, 2005). The most common toxicity is from chloride (Cl^-) in the irrigation water. Cl^- is not adsorbed or held back by soils, therefore it moves readily with the soil-water, is taken up by the crop, moves in the transpiration stream, and accumulates in the leaves. If the Cl^- concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Normally, plant injury occurs first at the leaf tips (which is common for chloride toxicity), and progresses from the tip back along the edges as severity increases. Excessive necrosis (dead tissue) is often accompanied by early leaf drop or defoliation (Pescod, 1985). Except SAR and Chloride (Fig. 3), all other parameters are well within the permissible limits recommended for irrigation water.

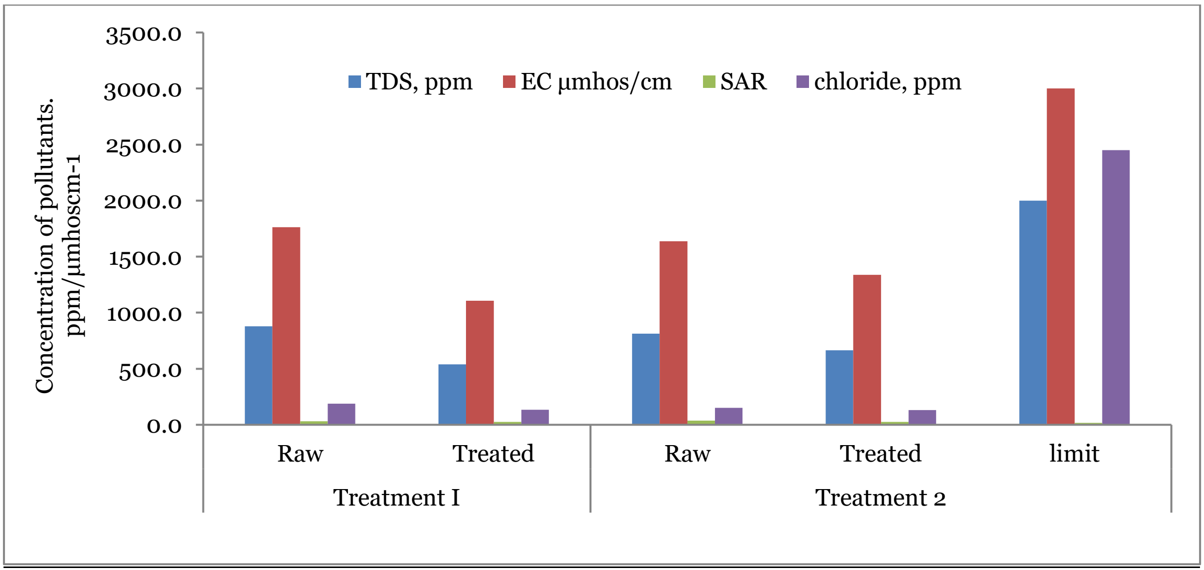

Fig. 3. Treated water quality parameters against permissible limit for irrigation.

According to the guidelines of Pescod (1992), BOD and Suspended Solids (SS) (Fig. 4) also favor possibility of using the treated sewage water for irrigating fruit trees and fodder crops. For other crops, BOD and SS should be less than 20ppm, which is the requirement for irrigating vegetable crops. Moreover, it should be noted that BOD meets the standard requirement for treated sewage water whereas suspended solids do not so as such the treated wastewater cannot be disposed into natural water bodies. This indicates that the performance of the treatment system in the university campus needs to be improved in terms of operational efficiency despite having adequate capacity of the ponds system.

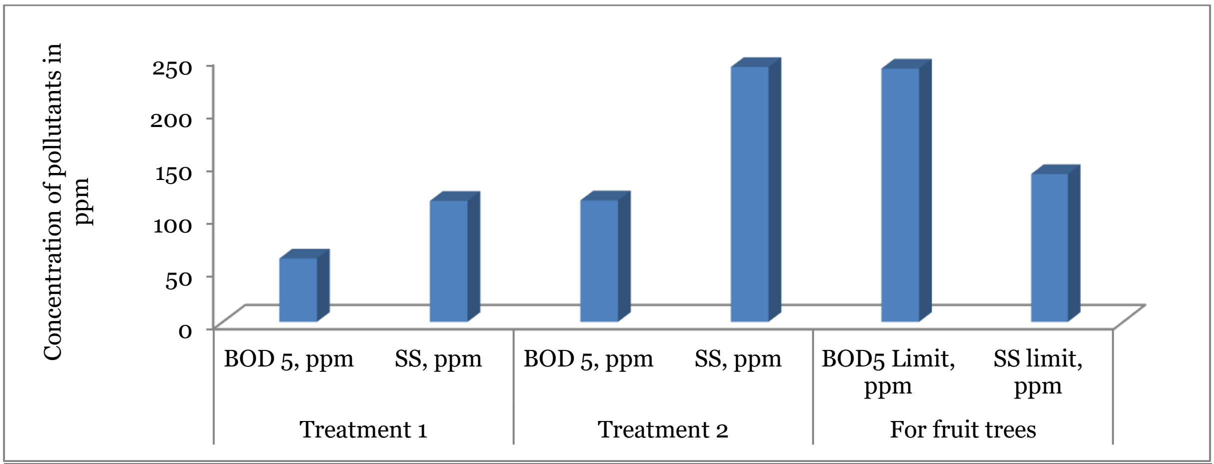

Fig. 4. Permissible Limits of BOD and SS for fruit trees.

Total cation and anion concentration

The principal cations present in irrigation water are calcium, magnesium and sodium with a small amount of potassium. Use of bad quality water create imbalance in the concentration of different cations in water. If the proportion of sodium is high the alkali hazard is high and conversely, if the calcium and magnesium predominate, the hazard is low. Mean concentration of calcium ion and magnesium ions are 48 mgL^{-1} (2.4 me/l) at the entrance, 51 mgL^{-1} (2.55 me/l) in the outlet and 13.5 mgL^{-1} (1.11 me/l), 11.5 mgL^{-1} (0.95 me/l), respectively.

According to FAO (1985), the Calcium and Magnesium ion concentration of wastewater to be available for irrigation should be within the range of 0-20 me/l and 0-5 me/l, respectively. Also the normal range of Ca^{2+} in irrigation water should be 0–20 cmol/l, while that of Mg^{2+} should be between 0–5 cmol/l (Christensen *et al.*, 1977). To convert mg/l to me/l multiply by 0.0499 for calcium ions and 0.0823 for magnesium (Bauder *et al.*, 2007). The mean result of the concentration of calcium and magnesium ions of the sample area obtained is within the ranges of the standards, therefore it is suitable for irrigation. In waters containing high concentration of bicarbonate ions, there is tendency for calcium and magnesium to precipitate as carbonate and the soil solution becomes more concentrated. Carbonate ions are also similarly harmful; however, they are seldom present in waters in significant quantities. Bicarbonate ions, in general, represent an appreciable proportion of the total anions present in irrigation water.

The mean carbonates concentration detected in the irrigation water was ranges from 40 mgL^{-1} (0.668 me/l) to 70 mgL^{-1} (1.17 me/l) as we go from the inlet to the outlet of the septic tanks respectively, while the mean bicarbonate content ranged from 395 mgL^{-1} (6.44 me/l) to 457.5 mgL^{-1} (7.4 me/l). The normal safe ranking for carbonate (CO_3^{2-}) and bicarbonates (HCO_3^-) are 0-0.1 me/l and 0-10 me/l, respectively (FAO, 1989). By this criteria therefore, the irrigation water in the sample area is assessed in terms of carbonates as it is out of the ranges, it could be described as being at less severe risk concerning carbonates. But, in the case of bicarbonates, it is the normal range so it can be used for irrigation purpose.

Sulphate (SO_4^-)

Mean values of sulphate ranged from 2.3 to 6.5 mgL^{-1}, respectively. If sulphate is present in more quantity in water then it creates serious problem for crop growth and affect the quality of soil. As described in (FAO, 1985), for crop production, it should contain a sulphate content ranges from 0-20 me/l and therefore, the treated wastewater is within the range as described by the standards of less than 10 ppm SO_4^- in irrigation water (Mass, 1990).

Ammonium and Nitrate–Nitrogen contents (NH_4 –N and NO_3 – N)

Mean values of NH_4–N ranged from 0.005 to 0.01 mgL^{-1}, respectively. This finding is probably attributed to oxidation of the NH_4^+ to NO_3^- by the action of the microorganisms previously activated due to aeration such as some kinds of bacteria i.e. Nitrosomonas and Nitrobacter. NO_3-N content took an opposite trend to that of NH_4^+, where its concentration values were lower at outlets than the corresponding concentration values at the inlets. Oxidation of NH_4^+ at the aeration basin may account for such increases in NO_3^-. The normal safe ranking water quality for irrigation purpose in terms of ammonia-nitrogen (NH_4 –N) and nitrate- nitrogen (NO_3 – N) contents are 0-5 mgL^{-1} and 0-10 mgL^{-1}, respectively (FAO,1985). This infers the wastewater can be used for irrigation purpose even if it has less content of the above nutrients.

Phosphate-phosphorus (PO_4-P) and potassium (K^+)

In normal case, higher quantity of K^+ is expected in sewage water due to the entrance of leached fertilizers from the surrounding agriculture lands and amount of urine and other human waste from the student residential buildings. Moreover, the higher concentration in the STP also indicates intensive agriculture activities prevailing in the surrounding area. Content of both phosphate – phosphorous and potassium are much greater in the inlet as well as in the outlet at different depths. Normally, FAO (1985) describes the best ranges of both the above described nutrients to be within in the range from 0-2 mgL^{-1}. Based on these results that proper management of wastewater irrigation and periodic monitoring of quality parameters are required to ensure successful, safe and long term reuse of wastewater for irrigation.

Conclusion

Comparison of the water quality parameters with the permissible limit of the FAO guideline values were made regarding with safe and acceptable level of irrigation water quality. The present sewage treatment system was introduced so that pollution load can be minimized and the water can be used for beneficial purposes. Interpretation of physical and chemical analysis revealed that the treated wastewater is slightly alkaline in nature. In present conditions, the treated water can be used for irrigation purpose with some restrictions. Even though EC and TDS permit to irrigate fruit trees and fodder crops, there is a risk of soil degradation due to high value of SAR. In such cases, high efficiency irrigation systems are recommended rather than flood irrigation. Continuous use of treated sewage water for irrigation will make the soil acidic. Analysis of other soil parameters indicates that there is an increase in nitrogen, phosphate and organic carbon nutrient levels considerably to benefit crop production but increase in soil EC is a serious concern demanding soil reclamation by leaching the accumulated salts when it goes beyond the limit. Therefore, the sustainable use of treated wastewater in agriculture can be beneficial to the environment in such a way that minimizes the side effects on the quality of downstream water resources, but it requires the control of soil salinity at the field level. It is recommended as a matter of high priority that treated wastewater is considered and made a reliable alternative source in water resources management. Agricultural wastewater reuse can effectively contribute to fill the increasing gap between water demand and water availability particularly in semi-arid areas.

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