Environment, Development and Sustainability
https://doi.org/10.1007/s10668-022-02365-9

REVIEW

Reuse of poor-quality water for sustainable crop production in the changing scenario of climate

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Received: 28 July 2020 / Accepted: 9 April 2022

Abstract
The availability of freshwater is limited for agriculture systems across the globe. A fast-growing population demands need to enhance the food grain production from a limited natural resources. Therefore, researchers and policymakers have been emphasized on the production potential of agricultural crops in a sustainable manner. On the challenging side, freshwater bodies are shrinking with the pace of time further limiting crop production. Poor-quality water may be a good alternative for fresh water in water scarce areas. It should not contain toxic pollutants beyond certain critical levels. Unfortunately, such critical limits for different pollutants as well as permissible quality parameters for different wastewater types are lacking or poorly addressed. Marginal quality water and industrial effluent used in crop production should be treated prior to application in crop field. Hence, safe reuse of wastewater for cultivation of food material is necessary to fulfil the demands of growing population across the globe in the changing scenario of climate.

Keywords Climate change · Crop quality · Heavy metals · Plant nutrients · Wastewater reusing

1 Introduction

Water is an essential for human civilization and is being used mostly for agricultural activities, industrial uses, household requirement, and landscape management, etc. The agriculture sector is one of the major consumers of freshwater (Mahmoud et al., 2020; Mahmoud, 2020, 2020b). Whenever freshwater is limited, poor-quality water has been considered as an alternative for irrigation water in agriculture (Dotaniya et al., 2020). The anticipated

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drop in good-quality water available to the agriculture sector in the twenty-first century is pushing farmers to use marginal quality water for irrigation. More than 97.5 percent of the world's water is saline and unfit for human consumption, while only 2.5 percent of the world's water is fresh. Water is a renewable resource, but declining availability and increased wastewater generation are restricting freshwater replenishment (FAO, 2011). Nowadays, water scarcity is a major threat faced by both developing and developed countries. In addition, groundwater (GW) resources are dwindling across the World. It is at an alarming rate and probably may not fulfil the ever-increasing demands of agriculture and the industrial sector in the future (Meena et al., 2020). Decreasing in GW levels up to 200 m observed due to over-exploitation (Toze, 2006). In most locations in India, water level has been declined at the rate of 1 m per year (CGWB, 2011). Groundwater accounts for more than 65% of irrigation water and 85% of the drinking water supply reached in a critical state. Cities in some of the states like Rajasthan, Uttar Pradesh, Madhya Pradesh, and Maharashtra face a crisis in the availability of fresh water. As a result, people have to reuse poor-quality water for drinking and the growing of crops (Dotaniya et al., 2020).

Most of the farmers in the urban/peri-urban areas forced to use poor-quality or recycled wastewater (WW) for agricultural purposes and found it could be an alternative at cheaper cost when WW is well treated (Ghimire, 1994). With that poor-quality water utilization for crop production is an economical alternative that could supply plant nutrient (Chaw and Reeves, 2001; Rusan et al., 2007) and meet the water requirements during peak season. Crop productivity increases by 10–36 percent when diluted or undiluted wastewater is reused, yet production sustainability is dependent on soil type, climatic circumstances, crop cultivated, irrigation practises, and socio-political issues (Minhas et al., 2021). Research across the globe has indicated that use of these WW is a value to irrigation in developing countries and enhanced the economic return from agricultural lands. Dotaniya et al. (2017) reported that use of sewage for crop production has been enhanced soil organic carbon and inorganic matter in soil and also supported plant growth. However, the accumulation of various pollutants in soil causes a decline in its health in terms of a reduced infiltration rate, a decline in the soil's organic matter decomposition rate, microbial population, and diversity, which leads to a poor crop yield (Mahmoud et al., 2018a; Srikanth et al., 2020; Ziarati et al., 2019). On the basis of estimates by various agencies that 70% of the sewage comes from mega- and larger cities, and there will be a capacity to grow about 21,000 ha of crop land or alternatively with reference to 7.8 M ha yearly (Minhas & Samra, 2004). Long-term consumption of heavy metal-contaminated foods accumulates in living organisms and eventually reaches the human body via the food chain (Dotaniya, Dotaniya, et al., 2020; Khan et al., 2021b; Meena, Dotaniya, et al., 2020). In Australia, over-exploitation of fresh water for the intensive cultivation of crops and allied activities almost 33% of the land are risking poor-quality soil due to salinization (Farber et al., 2004). Furthermore, Saudi Arabia is a country facing the poor-quality water and environmental threats due to mismanagement of GW resources (Bushnak, 2002).

The global climate change is also affecting the hydrological cycle and mediated the amount of precipitation of its distribution in various parts of the world. Increasing global temperature is enhancing the evaporation rate as well as water stress in crop plants (Mansoor et al., 2022). It can lower the plant nutrient uptake pattern and crop yield (Meena et al., 2019). Climate change could also increase the demand for farm irrigation, garden sprinklers, and perhaps even swimming pools. Increasing needs may be met by compromising freshwater resources or by reusing poor-quality water (Dotaniya et al., 2018). Water management for the sustainable utilization is a need of today's agriculture at a regional as well as at an international level (Mahmoud et al., 2021; Mahmoud et al., 2020; Mahmoud et al., 2020; Mahmoud, 2020, 2020b). In 2025, water shortages may be faced by developing countries like India, Bangladesh, Pakistan, and Sri Lanka. Where the population growth rate is more and the natural resources are limited with respect to time, *i.e.* the Middle East, Africa, and parts of Asia. Most of the natural water bodies receive the industrial and sewage, which is affecting the quality of irrigation water. During the COVID-19 lockdown period, water samples revealed that sewage discharge without or with poor treatment is a major source of water pollution in the groundwater-fed river Gomti (Khan et al., 2021a, 2021b, 2021) as well as in other countries reported in Gwenzi et al., (2022). With the pace of time growing population and modern technological development, peoples are needed more water for mitigating their daily needs.

In this review paper, poor-quality water is described as any type of WW and sewage effluents released from industrial and municipal activities (Fig. 1). Our main aim is to highlight the utilization of domestic/industrial wastewater and their potential use in agricultural crop production in areas of freshwater scarcity because most of the developing countries are struggling to secure freshwater just for drinking purpose. However, marginal quality water may be used for agricultural activities as per international water quality standard. Our specific aim is the safe use of wastewater for the cultivation of farm crops to fulfil food security for the globe's growing population.

Fig. 1 Sources of poor-quality water in India

2 Status of freshwater availability for agricultural activities

In coming years, freshwater for drinking purpose may be one of the costliest commodities in a hugely populated country like India. Apart from water scarcity, the growing population requires a large amount of food, so the last option is to use of the treated sewage water for farming activities and to save fresh water for drinking purposes. As an example, in India, surface water is mostly contributed by the Indus, Ganges, Brahmaputra, Krishna, Godavari, Mahanadi, Sabarmati, Tapi, Brahmani-Baitarani, Narmada, Pennar, and Mahi Rivers. Mean annual flow in these river basins is estimated to be 1869 km^3 (Dotaniya et al., 2016h). Among the potential rivers, the Ganga river makes a major contribution followed by Godavari and Brahmaputra to the replenishment of surface water. Most of the freshwater (89% and 92% of total surface water and groundwater, respectively) is consumed by the agriculture crop production sector in India.

The average annual precipitation rate on land is approximately 110,000 km^3. On an average 56% of precipitation is evapo-transpired by vegetation into the atmosphere and a significant amount approximately 5% by rainfed agriculture. The remaining amount (39% or 43,000 km^3 annually) passes through the different natural water bodies as well as feeding aquifers. This part is reducing with time and the dryness of natural aquifers is more in the present situation. A percentage of this available fresh water is also utilized for the construction or extracting more volume of water with high mechanization known as withdrawal. These problems are only likely to get worse in the coming years (AQUASTAT–FAO, 2015).

The freshwater withdrawal across the globe is 69, 12, and 19%, for agricultural activities, municipal use, and industrial purpose, respectively (Fig. 2). The above share can be further categorized mostly as crop production (27%) particularly wheat, paddy, and maize; meat and meat products using 22% and approximately 6–7% by dairy activities. As per the projection approximately 70 percent of water is used for crop cultivation as irrigation, whereas 15–35% water is not utilized properly.

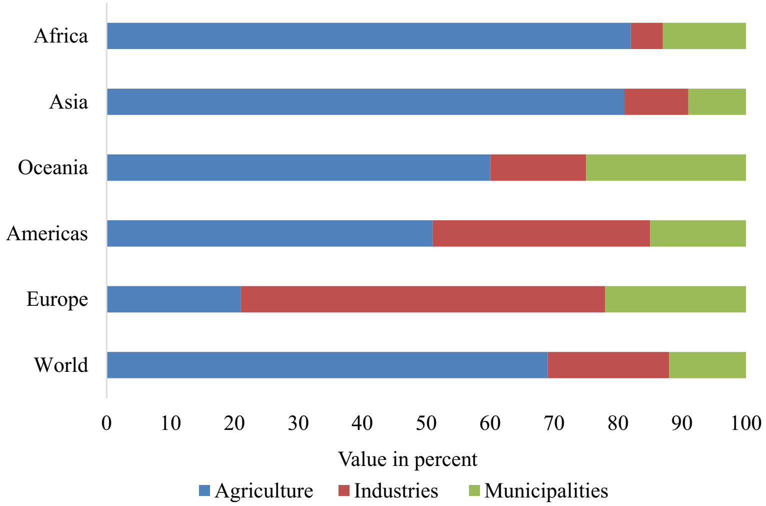

Fig. 2 Freshwater withdrawal ratios by continent. Source: modified from AQUASTAT–FAO (2015)

The crop production potential is also affected by fresh water availability for irrigation. In this context, increasing pulse production across the world meets the protein requirement of the growing population is a big challenge to researchers. Increasing pulse production with existing natural resources (water, soil) is limited for mitigating the demand of pulses (Simon, 1990). Increasing concentration of heavy metal(s) through long- term WW irrigation reduced the microbial population and diversity. It affected the nutrient transformation in soil and reduced the essential plant nutrient uptake to pulse crop (Dotaniya et al., 2016f; Smejkalova et al., 2003). However, the choice of crops, modern water management, and increasing soil health parameters are necessary into the periodic evaluation of marginal water use. Proper agronomic management can be enhanced the production upto a degree. However, this production line is not sufficient and is promoted to utilize barren land and poor-quality resources in resource-limited areas.

The desert part of India uses irrigation water for multi-pulse crops, whereas coastal areas limit pulse production due to poor physico-chemical properties. The first situation is the safe use of marginal water in pulse production with periodic monitoring of soil and crop quality; the second situation opens the door to the identification of best agronomic crop management practices for sustainable crop production.

3 Why do we need to use poor-quality water?

Scarcity of fresh water forced people to use marginal quality water for agricultural activities. Most of the peri-urban areas are cultivating vegetable by using the raw/treated sewage. Poor-quality water contains a significant amount of organic matter and plant nutrients. As for the farmers' view, if a farmer is using 4–5 irrigation with sewage, it cuts down 50 percent of recommended dose of fertilizer for a crop (Dotaniya, Rajendiran, et al., 2020). The dual purpose of using sewage for irrigation promotes sewage farming in peri-urban areas. Researchers have measured the yearly production of WW as more than thirty million tons across the globe (Minhas & Samra, 2004; Roy, 2020). In details, metropolitan cities are generated huge volume of waste and increasing the per capita per day load on waste channels. Only 15–24% of fresh water is properly utilized and the rest enters city hydrological cycle. It means almost 75–85% of the water supplied for domestic use and comes out as a WW (Qadir et al., 2010). In worldwide, more than 800 million farmers are engaged in urban agriculture. Of this group, about 200 million are using marginal water in absence of good-quality water (Qadir et al., 2010). It needs better management of water scarcity in coming years with cheap and durable technologies in combination with better execution with respect to human and environmental risk associated with use of WW (Mishra et al., 2022; Qadir et al., 2007).

Utilization of WW in agriculture sectors is common and farmers are using it for cultivation of multiple crops in freshwater scarce areas. However, the actual estimates are not reliable. Some of the researchers, policy makers, and environmentalists are not including the contribution of sewage or WW in crop production. Their argument is that it is a small part of total fresh water which is converted to waste. However, in a modern lifestyle scenario, it is the total opposite of earlier utilization patterns of fresh water. The study conducted to quantify the potential of WW found that use of untreated as well as partially treated WW can irrigate at least 3.5 M ha across the globe (IWMI, 2006; Jimenez & Asano, 2004). An experiment was implanted by Wim van der Hoek (2002) and found more than 20 M ha cropland can be irrigated with WW generated by urban population, which is a key boost for the agricultural production.

Use of sewage mixed wastewater contributed the significant amount of plant nutrients like N and P as well as micronutrients. According to typical estimations, sewage water supplies 25–50 percent of the crop's necessary nitrogen and phosphorus. In a projection of crop yield, it is increased almost 15–30% in various crops over the tubewell-irrigated crops. Most of the peri-urban farmers are using poor-quality water by choice or by the need for multi-crop production. The cropping intensity is higher (300–400%) in these areas, and the economical returns are also more than 3–4 times than land cultivated by underground water (Minhas & Samra, 2004). Apart from agricultural activities, poor-quality water is utilized in cultivation of aquatic animals and other industrial use in African and Asian countries. In India, almost every state is using contaminated water for agricultural crop production (Minhas et al., 2004; SIA, 2016). In many areas, poor-quality water is being used for forestry or fodder crops for wild animals and re-creation of degraded and wetlands. Most of the peri-urban areas are growing vegetables with WW, and estimates are measured by the researcher Raschid-Sally and Jayakody (2007) mentioned that 32% and 27% in vegetables and cereals crops are produced through irrigation of poor-quality water.

4 Types of poor-quality water

The availability of WW is dependent on its source. Poor quality of the water is much more dependent on the presence of cations and anions, biological load, and organic matter. Some of the metals are more important for plant growth and soil health, but other harmful loads are causing the deterioration of the chemical, biological, and physical health of the soil. On the basis of source of origin and physico-chemical properties of poor-quality water, it is mainly described as:

4.1 Saline and alkaline water

Across the globe, most of the African and Asian countries have salinity and alkalinity problems in groundwater and such water resources are being used for crop production in fresh water scarce areas. In India, large areas are using saline water for agricultural crop production systems. The amount of salt concentration has affected crop performance in these areas. When the concentration of the salts is low, they are not harmful for plant growth. However, long-term use of these water accumulated significant amount of salt content in soil upto high levels, plant growth, and productivity are adversely affected which in turn lower agricultural productivity. In areas of high temperature and low rainfall there are higher amount of salts, and the annual rainfall is not sufficient to leach salts down to deeper layers of the soil. High evaporation in these areas, therefore, results in the accumulation of larger amounts of salts in the plant root zone. The intensity of soil salinization increases with the increase in dryness of the climate. On the basis of electrical conductivity (EC), sodium absorption ratio (SAR) and residual sodium carbonate (RSC) are categorized into saline or alkaline water.

In many regions in the present day, salt-affected soils are developed due to man's erroneous economic activities. Anthropogenic activities, such as fertilizer imbalance and overuse, insufficient sewage treatment facilities, and incorrect management of industrial waste, are the primary causes of NO_3^-, Cl^-, Na^+, and K^+ sources in groundwater according to the multivariate statistical analysis (Shukla & Saxena, 2021). The introduction of irrigation without provision of adequate drainage results in the disturbance of salt water balance and enhances the concentration of salt in the soil. The pH of irrigation water is > 8.2 and EC > 4 dS m^{-1} known as saline water. There is continuous use of this poor-quality water for farming; it accumulated a huge amount of salt in soil and reduced the soil productivity and crop yield. The saline soils are remediated only by the leaching process. On other side water having pH > 8.5 and EC also less than 4 dS m^{-1} are categorized under alkaline water. In this water the higher amount of sodium (Na) and their carbonates are converted the soil marginally suitable for pulse crops or required management options. The use of gypsum as a soil amendment for the reclamation of alkaline soil is popular across the world. Other than these some acid-forming substances are also used for the reclamation of alkaline soils. The identification of poor-quality saline and alkaline water-contaminated agricultural soil can be identified with the help of below formulas:

(A) *Sodium absorption ratio (SAR):* it is the indicator of Na amount or amount of Na relative to other cations present in agricultural field.

$$\mathrm{SAR} = [\mathrm{Na}^{+}]/\sqrt{[\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}]/2}$$

(B) *Exchangeable sodium percent (ESP):* amount of exchangeable Na in soil with respect to other cations.

$$\mathrm{ESP} = 100[(\text{Exchangeable Na}^{+}\text{ions})/(\mathrm{CEC})]$$
$$(\text{All cations and CEC in}\,m\text{Mol}\,(+)/\text{kg soil})$$

(C) Total salt concentration is based on electrical conductivity (EC) categorized into two groups.

(i) For soil solutions having EC ranging from 0.1 to 5 dS m^{-1}

$$\text{Entire dissolved solids}\left(\text{mg L}^{-1}\right) = \text{EC}\left(\text{dS m}^{-1}\right) \times 640$$

(ii) For soil solutions with EC ranging from 3 to 30 dS m^{-1}

$$\text{Osmotic pressure (bars)} = \text{EC}\left(\text{dS m}^{-1}\right) \times (-0.36)$$

4.2 Industrial wastewater

a. *Tannery industries:* consume huge volumes of fresh water and dumping off chromium (Cr)-contaminated water into water bodies and open agriculture fields. In most of the cases untreated raw WW is used for the cultivation of crops (Dotaniya et al., 2014). In one way, it is supplying water potential to water shortage areas and an additional few amounts of plant nutrient and larger amount of organic matter.

Most of the surrounding tannery areas, crops are cultivated, which is having harmful microbial load and trace metal, specially Cr (Dotaniya et al., 2017). It categorized as a carcinogenic metal for a human being (Singh et al., 2020), and in plant it is reducing germination (Dotaniya et al., 2014), plant growth and made plants look bushy (Coumar et al., 2016a; Dotaniya et al., 2014). The use of this metal-contaminated water in pulse production reduced the crop germination rate and N fixation capacity of the crop. Other industries are battery and paint contributing lead (Pb) and nickel (Ni), thermal power plant mercury (Hg) and arsenic (As), zinc (Zn) smelter contributed Zn and cadmium (Cd), mining, electroplating supply copper (Cu), etc. (Dotaniya, Aparna, et al., 2019; Mahmoud & Fawzy, 2015; Mahmoud et al., 2016; Rajendiran et al., 2015). The released effluents from various industrial units have a wide range of pH and chemical and biological properties (Mahmoud et al., 2018b). In coarse-textured soil or with low water table areas long-term use of sewage water enhanced the heavy metal concentration in ground water (GW).

In the year of 1997, a measurement was taken by the Central Pollution Control Board (CPCB) on status of GW quality in leather industrial belt of Kanpur, the results were matter of concern that Cr(VI) concentration in the GW was 6.2 mg L^{-1}, whereas India government permissible limit is at 0.05 mg L^{-1} (Down to Earth, 2014). The story does not end here, and many of the farmers of peri-urban areas complained that nobody wants to buy anything that comes from the WW-irrigated villages in Kanpur. The leafy vegetables and root crops accumulate larger amounts of heavy metals than grain crops. For example, spinach can absorb larger amounts of Pb and Cd compared to wheat grains. These metals accumulate in our body upon consumption of contaminated food material and impair the proper functioning of body organs (Dotaniya, Kundu, et al., 2016). So, the safe use of WW for agricultural activities, mainly crop cultivation, is a challenging task for mitigating water scarcity for irrigation and other side safe health of human being and soil ecosystem. The industrial effluent-contaminated areas are identified using various indices (Saha et al., 2017b, d). Among all, with respect to virgin soils, it is used for toxic metal toxicity in sediments (Ball & Izbicki, 2004; Chabukdhara & Nema, 2012), dust (Kong et al., 2011), crop fields (Dotaniya et al., 2016; Wei & Yang, 2010). The I_{geo} was calculated and classified as per formula described by (Muller, 1969).

$$I_{\text{geo}} = \frac{C_n}{1.5B_n}$$

where C_n means soil toxic metal level (mg kg^{-1}) and B_n geochemical baseline. The calculated value should match with given Table 1 for identification of contamination level.

b. *Automobile industries:* these are the backbone of economic growth in a country. It needs larger volumes of fresh water and significant portions are converted to WW. A

Table 1 Geo-accumulation index (I_{geo}) for computing the metal toxicity level with its class (Saha et al., 2017g)

Geo-accumulation index (I_{geo})	Description	Class
≤0	Uncontaminated	First
0–1	Uncontaminated to moderate contaminated	Second
1–2	Moderate contamination	Third
2–3	Moderate to heavily contaminated	Four
3–4	Heavily contaminated	Five
4–5	Heavily to extremely contaminated	Six
>5	Extremely contaminated	Seven

report published by International Car Association showed that during a car washing consumes approximately 115–170 L fresh water (Asha et al., 2015). These figures may be increased when floor washing is added to the car washing. This wastewater contains paint, grease and oil, detergents, battery acids, cyclic C products as well as concentration of trace metals. The content of oil and grease formed an oily layer on the water surface and reduced the gas exchanges from water/soil to atmosphere. This WW pollution caused the death of aquatic animals due to a shortage of oxygen in the water bodies. It is necessary to decompose the oil molecules with the help of biological process. Some of the chemicals like alum, bentonite, and organo clay are used to reduce the oil and turbidity of automobiles WW. Organo clay performed better than alum to reduce the turbidity in water bodies (Patel et al., 2006). In water scarcity areas, these WW can be utilized for crop production after primary and secondary treatments.

c. *Pulp and paper industries:* Indian paper and pulp industries are contributing 3.5 percent of the World industrial production in terms of total 2 percent of the World trade. The demand of the products has increased with time, and approximately 3.7 percent annually was reported. Across the country 700 mills are working and generating huge volume of WW (Saadia & Ashfaq, 2010). It is highly water consuming and one of the most polluting industries discharging huge volume of WW in water bodies or soil surface. Chakrabarti (2006) reported that wooden-based industries are consuming higher freshwater demand than agro-based industries.

   Most of the countries have per capita consumption of paper of 47.7 kg, whereas in the Indian condition it is only 2.3 kg. This WW contains a huge volume of organic matter and essential plant nutrients, which enhance the growth of plants. Its WW contains lots of soluble salts like sodium carbonate, sodium sulphate, chloride, acids, charcoal power, bleaching material, paint, and raw material waste, etc. The chemical and biological oxygen demands are mostly affected by concentration of salts in the WW. However, the higher concentration of soluble salt limits plant biomass by mediating the plant nutrients in soil. Plant nutrient dynamics are highly affected by the soil microbial biomass C and the mineralization kinetics of nutrients.

d. *Textile industries*: This is also an important industry in generating huge volumes of WW containing salt, organic and inorganic dye, paint fractions, polymers, and concentration of trace metals (Mahmoud et al., 2022a, b). Most of the metropolitan cities have textile industries and the effluent is discharged commonly in the city's sewage channels (Mahmoud, 2022). These effluents are used by agricultural activities like vegetable production in the peri-urban lands. Higher concentrations of soluble Na, chloride, and sulphate are affected soil fertility and crop biomass potential during long-term application of these wastes. Uses of different absorbents for removal of soluble salt from textile waste take place in practice prior to discharge into agricultural fields or water bodies (Wang & Chen, 2014).

4.3 Sewage

In the present context, it is popularized in peri-urban areas of mega cities. In the absence of a separate channel for each type of effluent disposal, sewage channels are sinking for all types of WW. It provides a huge amount of organic matter and plant essential macro- and micronutrients to crops. Most of the Indian sewage channels have trace amounts of heavy metal(s) and huge amounts of organic and inorganic load. Organic matter is necessary for maintaining soil health. Healthy soil provides a sound foundation for high agricultural productivity. Soil organic matter (SOM) provides food material for soil biota and also determines chemical, physical, and biological properties of soil. The optimum plant nutrient exchange among SOM, soil water, clay, and other soil constituents' systems is essential for soil fertility also for sustainable crop production. The addition of SOC enhanced the soil aggregate stability, infiltration rate, microbial population and diversity, plant nutrient dynamics, and soil chemical properties.

Long-term application of sewage water accumulated a significant amount of heavy metals in soil. Through food chain contamination, heavy metal reached humans and caused various types of malfunctions in human and other systems. The chemical and biological properties of sewage largely varied; it depends on the generation of sewage and the intermixing of other effluents in this water (Singh et al., 2016). Sewage water has been perceived by farmers as liquid fertilizer because of its higher nutritional value. The nutrient contents are approximately 48, 8, 72, and 35 mg L^{-1} of nitrogen, phosphorus, potassium, and sulphur (S), respectively. Apart from major plant nutrients, it also contains micronutrient in $mgkg^{-1}$ (0.34 for Zn; 10.8 Fe, 0.2 Cu, and 0.36 Mn). If farmers are applying 5 irrigations of 7.5 cm each with sewage WW, it will add N, P, K, and S about 181, 29, 270, and 130 kg ha^{-1}, respectively, which is sufficient to fulfil the fertilizer requirements of a crop (Saha et al., 2010).

Assuming about 70% potential utilization of WW in agriculture sector shows that sewage farming in the country can annually supply N, P, K, and Zn at 380, 60, 520, and 1.4 thousand tons annually, respectively, computed on the basis of average sewage composition which is equivalent to about 1.78 million US $ worth of plant nutrients. It will add plant nutrients for crop production, but the main hurdle is heavy metal concentration. In developing countries, effluents from small-scale industries are often mixed with effluent from urban dwellings in the sewage-carrying channels. Such sewage water carries significant amount of trace metal(s), *i.e.*, Cd, Cr, Ni, Pb, As, Zn, and Cu (Rattan et al., 2005; Dotaniya et al., 2018). Use of various technologies like primary (to remove heavier particles), secondary (to remove smaller and dissolved organic matter), and tertiary (biological load) sewage treatment can minimize the trace metal concentration in sewage water. However, the proper treatment of sewage or poor-quality water prior to use in agricultural purpose requires regular monitoring of wastewater in irrigated fields and public awareness through mass communication. Apart from these, WW may be used for growing non-edible food, fibre, and oil crops like flowers, castor & jatropha crops beneficial for generating revenue.

5 Reusing poor-quality water for sustainable crop production

Irrigation water for sustainable crop production can be classified on the basis of available cations and their concentration. The ions activities are measured with the help of pH and electrical conductivity (EC), whereas Na ions are measured with flame photometer and expressed in terms of adsorption ratio (SAR) and residual sodium carbonate (RSC). However, fresh water used in various types of soils for the cultivation of crops can be categorized into good (A), and two poor group, *i.e.*, saline (B) and alkali/sodic (C). On the basis of other properties of water, it is further categorized into again three subgroups (Table 2).

Guiding norms for assessment of irrigation water qualities are mentioned in Table 2. Most of the guidelines emphasized on the long-term effect of water parameters on crop cultivation and quality, soil properties, and soil health of a farm (Singh, 1998). These norms and guiding principles are practically easy to follow and use for the categorization

Table 2 Categorization of irrigation water

Group	EC_{iw} (dS m^{-1})	SAR_{iw} $(mmol^{-1})^{½}$	RSC (meq L^{-1})
A. Good	<2	<10	<2.5
B. Saline			
i. Marginally saline	2–4	<10	<2.5
ii. Saline	>4	<10	<2.5
iii. High-SAR saline	>4	>10	<2.5
C. Alkali water			
i. Marginal alkali	<4	<10	2.5–4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	variable	>10	>4.0

of irrigation or wastewater during the crop production in an area. These norms based on few assumptions are carefully mentioned in Table 2. The guidelines are the preventive first instance of water quality and need collective principles and measures for utilization of poor-quality water for agricultural use. It requires mass attention to safely use poor-quality water and regular monitoring by the authentic agencies with respect to crop; methods of application, soil to overcome or adapt to them are also needed. Most countries have poor infrastructure and lack modern tool and techniques for treating the poor-quality water prior to discharge in fields. In later headings, a range of viable examples is given to tell how we can use poor-quality water potential for crop production and implemented from grassroots to the larger scale.

Few countries have their own guidelines regarding use of marginal or poor-quality water, but enforcement is not up to the level that the presence of guidelines loses their importance. Some of the freshwater scarcity countries use WW for the growing of non-food crops or after the proper treatment prior to application. In India, WW used in peri-urban areas for vegetable cultivation after primary or secondary treatments. Saline and alkaline GW is used for crop production after passing through gypsum treatment in Haryana and Punjab. Many guidelines have a direct relation with a particular type of pollutant, but in broader sense it is less applicable. The various guidelines have limitations in monitoring the various toxicants in WW and the evaluation reports sometimes do not meet all the quality parameters, *i.e.* residue of agricultural inputs.

6 Methods and timing of irrigation

The direct contact of contaminated water with the crop plant stem reduced crop biological yield. The metal and salt present in poor-quality water are directly absorbed by the plant system. The metal toxicity is much more in direct contact of WW compared to less contact during irrigation. Therefore, the use of surface or sprinkler irrigation methods is recommended in such areas. The surface irrigation method requires more volumes of water and more chances of metal contamination during irrigation. In arid and semi-arid or highly permeable soils, water requirement is much higher than in black soils. The sprinkler method of water application is more beneficial to reduce the harmful effect of poor-quality water. It also enhanced crop yield and the benefit-cost ratio in pulse crops.

Water application in a thirsty crop will require a significant volume of irrigation water, nearly half of the provided and stored water in soil particles. As per the scientific research fifteen per cent of supplied irrigation water percolates into lower layers of soil profile. Water utilization norms are very particular with methods as well as the type of irrigation, *i.e.* surface or subsurface. In saline soils, sufficient irrigation water is required for the desalinization of salt from the root zone of the crop with suitable methods. Identification of suitable method for irrigation with respect to soil and climatic conditions is also valuable for use of poor-quality water in pulse production.

6.1 Water and nutrient uptake by crops

The capacity of water uptake from soil to plant is much affected by plant roots as well as climatic conditions of a particular area. In general, plant roots take water from easily available soil layers or root zone layers with the help of root hairs. As per the various measurements plant take up 40, 30, 20, 10% from upper quarter, second, third, and lowest quarter, respectively. During crop production moisture level is maintained at field capacity for higher yield.

The moisture reduction during flowering or pod formation in crops significantly reduced the crop yield. Lower moisture enhanced the soil salinity intensity and crop much adversely affected as compared to moisture level at field capacity. Frequent irrigation reduces the salinity from root zone to lower zone. Increasing the depth of root zone is also increasing the salinity concentration in well drainage soils. Soil those are having higher salinity almost 3 times than applied irrigation water during crop cultivation. Use of various moisture measurement techniques to identify the irrigation scheduling in pulse crop production plays a vital role for sustainable production. The conditions prevail during irrigation and the amount of the irrigation water is contributed 15–20% as a leaching for the optimum growth of crops. The moisture in root zone maintained by the rainfall or by artificial irrigation is the vital need for the healthy crops. In saline soils, more water is need for the leaching of root zone salts into lower soil profile, where the salts are not affecting the crop yield potential. In this condition, salt balance is more preferring during the cultivation of pulse crops in high salinity areas. The movement of salt below root zone by the application of irrigation water is an important practice in saline sandy soils of Rajasthan, Gujarat, and Haryana.

Nutrient acquisition by plant in land is influenced by soil properties, moisture conditions, trace metal concentration, biomass C, and climatic factors. Long-term use for crop production may lead to accumulation of significant amount of organic matter, plant nutrients as well as toxic metals and metalloids in soil (Dotaniya et al., 2022). Their interactive effect influences soil health and crop performance in a complex way depending upon the chemical composition of irrigation water (Dotaniya et al., 2019). While organic matters built up have positive influence, accumulation of toxic elements and compounds reduce microbial activity, enzyme activities in soil, and slower down mineralization rate of SOM. Acidic wastewater enhances heavy metals availability in soil and adversely affects uptake of P and Mo by plants (Saha et al., 2017c). On the other hand, application of alkaline industrial effluent during crop production leads the deficiency of most of the essential plant nutrients increases the N loss through volatilization. Increasing concentration soluble salts reduces growth of plant root and consequently affects the uptake of water and plant nutrients (Dotaniya et al., 2019c). However, increased organic matter content in soil with long-term use of organic loaded wastewater may reduce the heavy metal activity by formation of metal–organic complexes and metal inorganic ligand complexes (Parker & Pedler, 1997). Moreover, increasing SOM also enhances the soil microbial activities and reduces heavy metal toxicity in plants. It also acts as an adsorbent for soluble salt and modifies the soil chemical environment for enhancing availability of plant nutrients.

7 Restriction on use

The "Restriction on Use" is categorized into three: none, low to moderate, and extreme. These categories may be changed as per the soil and crop varieties. The categorization is on the basis of its utilization and common properties, so it is not having any clear boundary from one divide to another. Most of cases such type of poor-quality water is using for the forest or pastoral raising. The edible part of the plant is not consumed by the mankind or the metal or other toxic substances did not translocate from root to edible part of the plants. This type of WW needs more attention during the use and larger efforts to treat for the cultivation of agricultural crops. In most of the cases these water sources are not commonly practice for the cultivation of crops. The metal and other toxicant present in WW are limiting the potential use of in pulse crops. However, the metal toxicity limits are mentioned by the various environmental and natural resources conservation agencies regarding safe use of WW. The limit may use little bit higher or lower has significant impact on crop yield. Higher metal levels are reduced the soil and crop production potential. These guideline values need to further re-evaluate with respect to crop, soil, and climatic conditions.

8 Long-term application of poor-quality water and their effect on soil health and crop quality

8.1 Effect on soil health

Use of poor-quality water without any treatment is creating soil pollution and deteriorating the quality of crop produce (Dotaniya et al., 2016b; Saha et al., 2017a). The long-term sewage application in agricultural field's accumulated significant amount of heavy metals in soils (Coumar et al., 2016b; Dotaniya & Saha, 2017) is mentioned in Table 3. The number of irrigations, kind of metal, soil organic matter, and biological features of soil all play a role in heavy metal accumulation in soil during crop growth period. The presence of heavy metal in soil reduced the SOM mineralization rate and enzymatic activities in soil (Saha et al., 2017c). Dotaniya et al. (2016f) observed that enhancing the level of Cr through Cr(VI) in soil from 0 to 100 mg kg^{-1} that reduced the activity of dehydrogenase, alkaline phosphatase, and fluorescein diacetate was 70, 63 and 41%, respectively. Among soil enzymes dehydrogenase activity is more sensitive to Cr toxicity than alkaline phosphatase and fluorescein diacetate. The enzymatic activities directly and indirectly related to C mineralization and nutrient transformation in soil. The mechanism of nodule formation in pulse crops was also affected by the fertility level of soil specially concentration of heavy metals, whereas the amount of the micronutrients presents in sewage or in industrial effluent enhanced the growth of pulse crop in nutrient-deficient soils (Meena et al., 2015).

Table 3 The concentration of essential plant nutrient and trace metals (mg kg^{-1}) in soils with wastewater (WWI) vis-a-vis groundwater (GWI) irrigation

Place	Time of study	Wastewater type	Element	Trace metal concentration		Times	Researcher
				WWI	GWI		
Kolkata	50–60	Sewage effluents	Fe	22,120	9090	2.43	Gupta and Mitra (2002)
			Zn	1210	26	46.5	
			Cu	198	52	3.81	
			Mn	382	446	0.86	
			Cd	3.72	0.04	93.0	
			Pb	385	24.2	15.9	
			Co	46.6	12.0	3.88	
			Ni	61.0	25	2.44	
			Cr	164	24.8	6.61	
			Cu	1.8–6.3	1.15	1.57–5.48	
			Cd	0.12–0.20	0.15	0.80–1.33	
Faridabad	20	Sewage water	Fe	2207	966	2.28	APR (2002–03) CSSRI Karnal
			Zn	261	53	4.92	
			Cu	60	23	2.61	
			Mn	241	188	1.28	
			Cd	4.2	1.1	3.82	
			Ni	73	19	3.84	
			Cr	79	23	3.43	
Ludhiana	–	Sewage water	Pb	7.12	3.88	1.84	Dheri et al. (2007)
			Cr	0.71	0.02	35.5	
			Cd	0.18	0.05	3.60	
			Ni	14.3	1.00	14.3	
Kurukshetra	25	Sewage effluents	Zn	2.65	0.99	2.68	Yadav et al. (2002)
			Cu	2.06	1.45	1.42	
			Fe	22.7	17.8	1.28	

Table 3 (continued)

Place	Time of study	Wastewater type	Element	Trace metal concentration		Times	Researcher
				WWI	GWI		
			Mn	7.2	5.8	1.24	
			Pb	1.65	0.99	1.67	
			Ni	3.3	2.4	1.38	
			Cr	6.8	2.2	3.09	
			Cu	17.0	15.5	1.10	
			Pb	16.5	11.0	1.50	
			Cd	40.5	26.5	1.53	
Rohtak	35	Sewage effluents	Fe	11.24	2.48	4.53	Rana et al. (2010)
			Mn	2.04	0.46	4.43	
			Ni	4.28	0.31	13.8	
			Cd	0.61	N.D	-	
			Zn	10.62	2.53	4.19	
			Cu	3.82	0.65	5.87	
			Pb	3.59	1.06	3.38	
Bhopal	5	Sewage effluents	Fe	8.27	7.70	1.07	Saha et al. (2010)
			Mn	9.46	8.35	1.13	
			Zn	0.82	0.58	1.41	
			Cu	1.21	1.13	1.07	
Ahmednagar, Maharashtra	–	Sewage effluents	Fe	4.81–7.26	–	–	Kharche et al. (2011)
			Mn	0.45–1.17	–	–	
			Zn	0.63–2.00	–	–	
			Cu	0.024–1.18	–	–	
Titagarh, WB	-	Wastewater	Pb	130.45	–	–	Gupta et al. (2008)
			Zn	217.08	–	–	

Table 3 (continued)

Place	Time of study	Wastewater type	Element	Trace metal concentration		Times	Researcher
				WWI	GWI		
			Cd	30.72	–	–	
			Cr	148.41	–	–	
			Cu	89.98	–	–	
			Ni	103.67	–	–	
			Zn	95.67	86.75	1.10	
			Fe	171.75	191.75	0.90	
			Cu	26.33	17.08	1.54	
			Cd	2.27	N.D	-	
			Cd	1.00	N.D	-	
Shandong, China	30	Sewage water	Mn	864.04	452.77	1.91	Zhang et al. (2008)
			Zn	107.36	41.85	2.57	
			Cu	34.2	16.7	2.05	
			Cd	0.2	0.13	1.54	
			Cr	87.89	45.19	1.94	
			Pb	51.75	24.67	2.10	
			Ni	43.63	11.47	3.80	
			As	6.37	4.21	1.51	
			Co	15.33	9.06	1.69	
			V	85.56	56.85	1.51	

8.2 Effect on crop quality

Heavy metal-contaminated crop produced from industrial effluent is poor in growth, and high concentration of toxic metals reduced the shelf life of produced (Mahmoud & Fawzy, 2016). Sewage-irrigated crops are more biomass with less economical yield. The growth is very vigorous, due to excessive nitrogen (N) through external application as well as through sewage water (Saha et al., 2017e). The insect-pest attack is more in sewage-irrigated crops than fresh water irrigated. The pathogenic harmful effect is more in sewage-irrigated crops. The biochemical parameters are also poorly reported in industrial effluent-irrigated crops. The taste and other parameters do not extensively studied by the researchers (Saha et al., 2017g). The saline water and industrial effluent-cultivated crops are in lesser yield and decline the value of produce as well as bound the option regarding crop cultivation (Saha et al., 2017j).

9 Role of poor-quality water to combat climate change effect

Climate change is a phenomenon associated with the elevated temperature and level of greenhouse gases (GHGs) and responsible for the abrupt change in drought and excessive precipitation, which are the most relevant issues in Indian agriculture (Dotaniya et al., 2016e). Challenges do not include only management of scarce and diminishing natural wealth in terms of soil and water, but also reducing negative impact on soil, crops, and livestock, etc. (Dotaniya 2015). Agriculture can also play a crucial role as a mitigating option by reducing the net GHGs emission to atmosphere and improving the environmental quality (Kundu et al., 2013; Kushwah et al., 2014).

In the arid or semi-arid regions farmers are using poor-quality water as a source of irrigation for crop cultivation. Peri-urban areas, mostly cultivating the vegetables from sewage or mixing fresh water, are a common practice. These poor-quality water resources are also using for the forestry plants with the help of various agricultural engineering and agronomic interventions. In the arid and semi-arid areas, saline and alkaline water are used for the cultivation of various agricultural crops as well as allied agricultural activities. Safe utilization of poor water quality in water scarcity areas for agricultural activities is the need to reduce the climate change effect.

10 Management strategies for safe use of poor-quality water

Management of poor-quality water is a big challenge nowadays due to more generation of water and less capacity to WW treatment plants. In developed countries the industrial, sewage, and other poor-quality water have different channels for the disposal. However, in developing countries like India, Pakistan, Bangladesh is not having strong separate disposal system. One industrial WW disposes in sewage channel or any other type of marginal water disposing in a common channel. The experiments were conducted at various research stations across the globe for the sustainable application of marginal water for crop production. The use of poor-quality water, especially in pulse crops, needs more attention to reduce the harmful materials load and check it further move to food chain contamination via crop uptake. Several factors affected the management strategies and use of WW in crops like rainfall pattern of the area, water table depth, soil texture, crop varieties, and also crop management practices. In details various management practices are as follows:

10.1 Crop management

a. Selection of crops

The uses of poor-quality water harmful effects are affecting by crop management option/practices. Every crop has its own genetic potential to tolerant the harmful elements present in WW. Hardy crops are more tolerant to the soft stem crops. The lignin content of crop plant wood increased the tolerant potential of the crops (Meena et al., 2013). Most of the legume crop susceptible to toxic metal like Cr, Cd, Ni, Hg as compared to cereal crops. The saline-irrigated water is affecting the pulse crop germination; blackgram, peas, lentil, and pigeon pea are tolerate exchangeable sodium percent (ESP) 10–15, cowpea 20–25, whereas rice and barley crops tolerate higher ESP.

b. Growth stages

Most of the crop growth stages are not equally performed in poor-quality water like saline, alkaline, or heavy metal-contaminated water. The early growth stages are more sensitive than later stages. The application of Cr at 40 mg kg^{-1} soil reduced the germination in pigeon pea (Dotaniya, Meena, et al., 2014). Therefore, application of poor-quality water should not be applied on the germination phase of crops.

c. Cropping sequence

It is one of the important management practices followed to minimize the effect of marginal quality water on crop cultivation. In this system cereal crops are grown in one season, and in next season, pulse crops may be cultivated, *i.e.* pearl millet-gram, mungbean-wheat, etc. The crops irrigated with saline water, presence of various cations and anions affected the growth of pulse crops and finally reduced the crop yield. The chloride ions are more toxic than the sulphate ions, because this application of sulphate ion rich water in mixing is reduced the adverse effect of chloride (Manchanda 1998; Dotaniya et al., 2019b).

d. Use of horti-crop sequence

The effect of salinity and heavy metal(s) is less effective on tree species. Planting of horticultural plants rows is in between the cereal crop fields. In one way it will minimize the adverse effect of metal toxicity, and in other side, it will give the added income to farmers. It acts as crop insurance in adverse climatic conditions. Some of the medicinal plants are well grown in saline water-irrigated fields, *i.e.* isabgol, aloe, kalmegh, etc.

10.2 Farmyard Manure (FYM) application

Poor-quality water affected the nutrient uptake pattern of crops and also reduced the soil fertility levels. The addition of SOC through external application of Farmyard Manure (FYM) in crop field enhanced the crop growth (Dotaniya, 2013). The FYM not only provides the plant nutrient to plant but also structural improvement in soil. Addition of organic matter through crop residue reduced the salinity, trace metal toxicity in crops and improved the soil health (Meena et al., 2022). Application of organic matter increased the soil biodiversity properties, *i.e.* microbial population and types (Dotaniya et al., 2016h). That microbial population are reduced the trace metal effect on the plant by degradation and conversion of toxic metal to non-toxic metal. Different types of microbial biomass released various types of soil enzymes which also helped to reduce the salinity and adverse impact of metal toxicity in soil and plant growth.

The application of FYM in poor-quality irrigated soils, mediated the rhizospheric micro-climate and enhanced the different types of organic acids, which enhanced plant nutrient uptake (Dotaniya & Meena, 2013, Dotaniya et al., 2013a). In response of these effect plant roots also released various types of low molecular organic acid (LMOA) in the soil, which enhanced the soil microbial biomass and nutrient transformation rate. Soils irrigated with high chloride water reduced the P availability to plant and 50% additional application of P is needed. Application of inorganic fertilizers with FYM effectively countered the poor water effect in pulse crops (Dotaniya et al., 2016g). Addition amount of N fertilizers in higher organic matter irrigated soils, promotes higher rate of mineralization and improves the soil mineralization rate and crop yield (Unuofin & Siswana, 2019). Application of biofertilizers with compost also reduces salinity and toxicity of heavy metal under WW-irrigated crop production systems (Sarkar & Chourasia, 2017).

10.3 Soil amendment

Utilization of marginal quality water for crop cultivation regarding its effect on GW or crop is also affected by the soil type and texture. High permeability soils have more chances to contaminate the GW in sewage-irrigated areas. Due to lower organic matter in the soils of sandy or arid regions, there is less binding capacity of metals and they are leached down to a lower profile of the soils. These metals are again pumped out and used for the cultivation of crops and show their harmful effect on crop productivity and quality. Light-texture soils are good in drainage compared to heavy-textured soils. In soils of high clay content there is resistance to metal transfer in the lower zone of soils due to humus metal complex. Apart from this, the chances of moving the metals after few centimetres from soil surface to lower zone are fewer (Patel et al., 2006). An application of high Na containing poor-quality water reduced the soil fertility and soil productivity. After analysis of physico-chemical properties of WW was formed counter-management strategies, the higher concentration of heavy metals in effluent, addition of absorbent in soil, or WW channel reduces the availability of metal in irrigation water. Different types of absorbent are available in the market like bentonite, bioabsorbent, nanoclay, chitosan-based biosorbents (Wang & Chen, 2014). Long-term application of higher Na concentration effluent during crop production causes alkalinity in soil. For this, the use of gypsum in a cultivated field reduced the alkalinity effect, whereas lower pH effluent-irrigated field application of lime improves the crop's germination rate. In sandy soil condition, addition of FYM and organic residues reduces the toxic metal leaching and improves the soil health (Meena et al., 2018). Addition of

MSW compost in soil improves the plant nutrient concentration and labile part of the sulphur (Meena et al., 2021). Microbial population and diversity enhance the secretion of low molecular organic acids in soil and improve the plant nutrient dynamics during crop growth stages. Nanotechnology is a cutting-edge technology for reducing metal toxicity. Different types of nanoparticles are being created and used to remove trace metals from water bodies all over the world. In comparison with traditional treatment procedures, magnetic microparticles provide target selectivity and cost-effectiveness (Shukla et al., 2021). Many other organic soil amendments also reduced the adverse effect of heavy metals in soils (Dotaniya et al., 2016a). Mwangi et al. (2019) formed the hydrogel from animal waste and reduced the salinity or water loss from soil. These results showed that addition of animal waste-formulated hydrogel improves the moisture availability in soil and plant wilting symptoms are appeared on later period. These organic amendments enhanced the plant nutrient concentration in soil. Some of the organic and inorganic amendment listed in Table 4 is used for heavy metal immobilization during the crop cultivation by heavy metals containing effluent or from contaminated soil.

11 Policy guidelines for wastewater reuse

Wastewater reuse in agricultural and other activities should follow the basic guidelines as per described by international or regional agencies (Saha et al. 2017m). These guidelines are formulated after extensive research on soil health, crop quality, and effect on living

Table 4 Inorganic and organic amendments for heavy metal immobilization (modified from Guo et al., 2006; Branzini & Zubillaga, 2012)

Material	Source	Heavy metal immobilization
Inorganic amendments		
Lime (from)	Lime factory	Cd, Cu, Ni, Pb, Zn
Phosphate salt	Fertilizer plant	Pb, Zn, Cu, Cd
Hydroxyapatite	Phosphorite	Zn, Pb, Cu, Cd
Fly ash	Coal power plant	Cd, Pb, Cu, Zn, Cr
Slag	Coal power plant	Cd, Pb, Zn, Cr
Ca-montmorillonite	Mineral	Zn, Pb
Portland cement	Cement industry	Cr, Cu, Zn, Pb
Bentonite	–	Pb
Organic amendments		
Bark saw dust	Timber industry	Cd,Pb, Hg, Cu
Xylogen	Paper mill wastewater	Zn, Pb, Hg
Chitosan	Crab meat canning industry	Cd, Cr, Hg
Bagasse	Sugar industry	Pb
Poultry manure	Poultry farm	Cu, Pb, Zn, Cd
Cattle manure	From cattle	Cd
Rice hulls	Paddy processing	Cd,Cr, Pb
Sewage sludge	–	Cd
Leaves	–	Cr, Cd
Straw	–	Cd, Cr, Pb

beings (Saha et al., 2017f). Most of the countries follow the international agencies guidelines, *i.e.* (World Health Organization) WHO (1989), Food and Agriculture Organization (FAO) (1985), and US EPA (1992). Most of the countries formulated strategies for safe reuse of WW in different use as shown in Table 5.

Few countries like the USA and Spain fixed their own guidelines for WW reuse in agricultural crop production. A very smaller number of European countries have their own standard and guidelines on WW reclamation and reuse, due to less need of reuse water and on the other hand the existing river bodies have sufficient dilution factor. Many developing countries have restrictions on the reuse of WW for vegetable production that can be eaten raw. Such type of restrictions needs regular monitoring of WW channels, treatment process, and harvested produced from poor-quality water, as per the international agencies (WHO, FAO, US EPA) fixed the various values for reuse of WW in agriculture.

World health organization made a few guidelines regarding potential risk related to utilization of WW in agricultural activities. These guidelines help the policymaker to set the legislative permission for the safe reuse of WW. Many countries welcome the WHO guidelines and set their own standard and guidelines. The main guidelines of WHO (1989) are mentioned below:

- Wastewater is a resource and utilized safely.
- The plan of developing WW uses guidelines to guard the exposed population, i.e. farmers, consumers, and populations living near to WW channels.
- For the pathogen indicators *i.e.* faecal coliforms and intestinal nematode eggs.
- Best crop management practices should follow like restriction on crops with WW irrigation; appropriate irrigation method, regular monitoring; precautions on personal hygiene.
- The feasibility of guidelines considered for achieving the health protection.

Food and Agriculture Organization of the United Nations mainly focused on the defence of health issues of humans. FAO developed a crop irrigation guideline for identifying the appropriateness of irrigation water. The criteria are based on the salinity, infiltration rate, particular metal toxicity, intensity of metal species, and their related effects. The rules are important for the agriculture manager and cultivators, consultants, farmers, and researchers for identifying the suitability and monitoring of water quality. Poor-quality water is forcefully used by the farmers in most of the developing countries, where fresh water is limited only for drinking purpose. For safe use of poor-quality water for irrigating the crops certain limits are fixed mentioned in Table 6 and standard related to metal concentration in irrigation water in Table 7.

The US-Environmental protection agency (US EPA) guidelines are much stricter than the WHO. The main focus is on faecal coliforms which are not permitted more than 14 MPN/100 mL in WW samples. Secondary treatment should use filtration and disinfection. These standards also indicated the type of treatment feasible, resultant water quality, and setback distance are also included in US EPA norms (Table 8).

Table 5 Policy/strategies of wastewater uses in different countries

Country	Policy/Strategies	Approach
India	Wastewater reuse for agriculture	Use treated wastewater for agricultural crop production
Mexico	Wastewater reuse for agriculture	Restricted irrigation excludes raw vegetables but health risks
Australia	Environmental awareness Lagoons	Wastewater is a valuable resource; The largest lagoon-based wastewater treatment plant biodiversity
Jordan	Policy effectiveness wastewater reuse	Water conservation recycling initiatives
Singapore	Unique holistic approach	Drinking water can be produced from wastewater using reverse osmosis
South Africa	A human rights-based approach	A better efficiency of water use by new granular sludge technology in module of public–private partnership
Switzerland	New tax for upgrading wastewater treatment plants	Swiss Parliament amended the Water Protection Act
Lausanne	Treatment of micropollutants in municipal wastewater	Initiation of new Federal tax on water bill

Table 6 Guidelines for water quality parameters for irrigation (modified from FAO, 1985)

Probable irrigation limitation		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Salinity (mediate water availability)					
	EC_w	dS m^{-1}	< 0.7	0.7–3.0	> 3.0
	TDS	mg L^{-1}	< 450	450–2000	> 2000
SAR	= 0–3		> 0.7	0.7 – 0.2	< 0.2
	= 3–6		> 1.2	1.2–0.3	< 0.3
	= 6–12		> 1.9	1.9–0.5	< 0.5
	= 12–20		> 2.9	2.9–1.3	< 1.3
	= 20–40		> 5.0	5.0–2.9	< 2.9
Specific ion toxicity (affects sensitive crops)					
	Sodium (Na)				
	Surface irrigation	SAR	< 3	3–9	> 9
	Sprinkler irrigation	mgL^{-1}	< 3	> 3	
	Chloride (Cl)				
	Surface irrigation	mgL^{-1}	< 4	4–10	> 10
	Sprinkler irrigation	mgL^{-1}	< 3	> 3	
	Boron (B)	mgL^{-1}	< 0.7	0.7–3.0	> 3.0
Miscellaneous effects					
	Nitrogen (NO_3—N)	mgL^{-1}	< 5	5–30	> 30
	Bicarbonate (HCO_3)	mgL^{-1}	< 1.5	1.5–8.5	> 8.5
	pH		Normal range 6.5–8.4		

12 Conclusions

Fresh water availability is continuously decreasing and peoples are forced to use marginal or poor-quality water for various agricultural activities. The safe reuse of marginal quality water for the sustainable production of crops is a need of the present time in the scarcity of good-quality water areas. The use of sewage mixed industrial effluents increased the level of SOC and plant nutrient in soil, but on the other hand, they built up a significant amount of toxic heavy metals and harmful microbial biomass in soil. These toxic metals reduced the biochemical process of crops and ultimately decreased the yield of crops. Use of poor-quality water in crops should be well treated prior to application. The application of FYM also reduced the toxicity of heavy metals during pulse production by industrial effluents. Escape initial irrigation requirement in crops with poor-quality water may enhance the germination percent and crop growth. The safe utilization of marginal quality water is a prime necessity in the present context for sustainable crop production. So, the proper treatment of sewage water (through STP), prior to use in agricultural purpose, regular monitoring of wastewater-irrigated fields, public awareness through mass communication. Apart from these, use this WW for growing non-edible food, fibre & oil crops like flowers, castor, and jatropha crops.

Table 7 Recommended maximum concentrations of trace elements in irrigation water (modified from FAO, 1985)

Element	Recommended Maximum Concentration (mgL^{-1})	Remarks
Cd (cadmium)	0.01	Harmful for beans crops, beets and turnips @ 0.1 mgL^{-1} plant nutrient media. It is accumulating in plant part and harmful to human health
Al (aluminium)	5.0	Toxicity prevails in acid soil environment
As (arsenic)	0.10	Harmful range is wider
Be (beryllium)	0.10	Toxicity ranged varied with soil and crop plants
Co (cobalt)	0.05	Showing toxicity in tomato @ 0.1 mgL^{-1} level in growth solution. Less effect in high pH soils
Cr (chromium)	0.10	It is not a plant nutrient and the limits are varying with respect to soil and plant
Cu (copper)	0.20	Ranged 0.1 to 1.0 mgL^{-1} in nutrient solutions
F (fluoride)	1.0	Less toxic in high pH soils
Fe (iron)	5.0	It is an essential plant nutrients, having less toxicity in well drained soils. Higher concentration may reduce the availability of P & Mo in soil
Mn (manganese)	0.20	Harmful effect in acidic environment
Mo (molybdenum)	0.01	It is essential for plant growth and toxicity symptoms rarely observed
Ni (nickel)	0.20	Harmful range vary 0.5- 1.0 mgL^{-1}
Li (lithium)	2.5	Most of the crop can tolerated up to 5 mgL^{-1}; in soil solution. It is behave like boron
Pd (lead)	5.0	Toxic at higher level
Se (selenium)	0.02	Very minute concentration (0.025 mgL^{-1}) toxic for plant and required very low amount for animal health
Ti (titanium)	–	Non-selective absorption by plant in present of higher concentration
V (vanadium)	0.10	Phyto-toxicity occurred at minute level
Zn (zinc)	2.0	It is essential plant nutrient for plants and its toxicity in plant occurred in very high Zn level soils

Table 8 US EPA norms for agricultural uses of WW (modified from EPA, 1992)

Type of reuse	Treatment	Reclaimed water quality	Reclaimed water monitoring
Urban Reuse All types of landscape irrigation (e.g. golf courses, parks, cemeteries)	i. Secondary ii. Filtration iii. Disinfection	pH = 6–9 ≤ 10 mgL^{-1} BOD ≤ 2 NTU No detectable FC/100 ml^{3} 1 mgL^{-1} Cl_2 residual (min.)	pH—weekly BOD—weekly Turbidity—continuous Coliform—daily Cl_2 residual -continuous
Agricultural Reuse –Food Crops Not Commercially Processed Surface or spray irrigation of any food crop, including crops eaten raw	i. Secondary ii. Filtration iii. Disinfection	pH = 6–9 ≤ 10 mgL^{-1} BOD ≤ 2 NTU No detectable FC/100 ml^{3} 1 mg/l Cl_2 residual (min.)	pH—weekly BOD—weekly Turbidity – continuous Coliform—daily Cl_2 residual -continuous
Agricultural Reuse—Food Crops Commercially Processed	i. Secondary ii. Disinfection	pH = 6–9 ≤ 30 mgL^{-1} BOD ≤ 30 mgL^{-1} SS ≤ 200 FC/100 ml^{4} 1 mgL^{-1} Cl_2 residual (min.)	pH–weekly BOD—weekly SS—daily Coliform—daily Cl_2 residual -continuous
Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring
Agricultural Reuse—Non-Food CropsPasture for milking animals; fodder, fibre and seed crops	i. Secondary ii. Disinfection	pH = 6–9 ≤ 30 mgL^{-1} BOD ≤ 30 mgL^{-1} SS ≤ 200 FC/100 ml^{4} 1 mgL^{-1} Cl_2 residual (min.)	pH—weekly BOD—weekly SS – daily Coliform—daily Cl_2 residual -continuous

*SS = suspended solids; FC = faecal coliforms

13 Future thrust of research

- Use of marginal quality water for crop production needs soil type and crop-specific study with respect to regional climate. It also evaluates the soil health and crop yield and quality.
- The toxic metal transfers from soil to the economical part of a plant with respect to the crop varietal level. Trace metal accumulation in a crop is much affected by the genetic potential of crops as well as the stage of growth of the plants.
- Periodic monitoring of sources of poor-quality water channels identify appropriate pre-treatment material for contaminants. The temporal and spatial analysis of soil and poor quality clears the physico-chemical properties and helps to formulate policies related to winter and summer crop irrigation strategies.
- Extensive study on food chain contamination is required. In the last few years, more carcinogenic cases have been reported which is mainly from the consumption of poor-quality foodstuffs produced from marginal wastewater as well as from poor-quality natural resources. It is a pressing need that research policy should be focused on food chain contamination of trace metals.

Acknowledgements Authors are grateful to Dr Kuldeep Kumar, ICAR-Indian Institute of Soil and Water Conservation, Dehradun, India, for the motivation and incorporated suggestion during execution of this review. Also, authors would like to thank Mr. Kevin Harrington, Canada, for the language editing of the manuscript.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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