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TREATED MUNICIPAL WASTEWATER REUSE IN VEGETABLE PRODUCTION IN INDIA: A REVIEW

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ABSTRACT: Lead, copper, zinc, boron, cobalt, chromium, arsenic, molybdenum, and manganese are just a few of the essential and non-essential metal pollutants that can be found in municipal wastewater-irrigated areas.The amount of treated wastewater used for irrigation had an impact on the growth of several plants. In comparison to plants irrigated with 0, 25, 50, and 75% of treated wastewater, it was shown that plants irrigated with 100% treated wastewater experienced the greatest growth. It was also discovered that the weight of the plant roots and leaves increased throughout the course of a 60-day period. Vegetable development is also aided by the presence of potassium, phosphorus, and nitrogen. In the current investigation, it was discovered that vegetable plants grew enormously because there was a suitable quantity of potassium in both the soil and the treated wastewater. The rate of growth, the size of the cells, and the water content of the tissues may all be affected by a lower potassium concentration. Another macronutrient, Ca, which is present in treated wastewater, plays a crucial function in the composition, permeability, and cell division, fostering growth. All vegetable plants had greater Ni concentrations in their leaves, ranging from 100 to 545 mg g^{-1}. Mn levels in all vegetable plants were determined to be between 106.5 and 429 mg g^{-1}, which is below the hazardous level. Zn and Pb concentrations varied between 152 and 259 mg/kg and 72.5 and 346 mg kg^{-1}, respectively. Data analysis of the translocation factor revealed that heavy metal accumulation is more pronounced in plant shoots than in roots. Ganjia, which receives continuous sewage water for irrigation and is situated close to the sewage disposal site, has the highest concentration of Mn^{2+}, Zn^{2+}, and Fe^{2+} in vegetables, followed by Arail and Dandi. Due to the higher concentration of micronutrients in sewage water, Mn^{2+}, Zn^{2+}, and Fe^{2+} levels in the vegetables cultivated have significantly increased.

Key words: Fresh water, treated municipal wastewater, agriculture, macro and micronutrient, India.

INTRODUCTION

India is a large tropical nation with a wide range of climatic characteristics, from humid, dry tropical climate in the south to temperate alpine climate in the Himalayan north. Despite having water on three sides, the Indian subcontinent has a continually increasing need for freshwater. Due to population growth, fast urbanization, variable precipitation, and intense use for agricultural activity, both surface and groundwater levels have been declining for the past few decades (**Sahoo *et al.*, 2021**). Many industries face significant obstacles as a result of the restricted supply of freshwater resources, especially in the agriculture and related industries.

In India, agriculture is the main means of subsistence. According to the Food and Agriculture Organization (India), more than half of the rural population depends on agriculture for a living. It significantly influences India's economic growth rate (20.2%). Over 70% of the freshwater that is available in India is used for agriculture, which accounts for the majority of water withdrawals (**World Bank, 2020**). Today's agriculture is competitive, driving farmers to

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produce higher yields with the limited water supply. To maintain sustainability, it is essential to look for and prioritize alternative resources as well as manage the current water resources appropriately (**Hamdan *et al.*, 2021**). To satisfy the rising demand for water, a number of techniques have been developed, including interstate water transfer, desalinization, efficient water usage technologies such micro-irrigation, and water reuse (**Haghi *et al.*, 2020**).

Even in dry periods, water reuse can be regarded as one of the reliable alternative water sources. It offers sustainability in resource management and can lessen the unrelenting pressure on the limited resources (**Garcia and Pargament, 2015**). It minimizes pollution discharge into aquatic bodies as well as the demand for freshwater. It has the ability to offset the water demand over the course of the hydrological year.Reusing treated wastewater (TWW) can prevent the negative impacts that can result from reusing untreated wastewater in cultivable land (**Liang *et al.*, 2014**). Water for irrigation can be supplemented by using wastewater that has been properly treated (**Leonel and Tonetti, 2021**). However, the TWW must meet the irrigation water quality requirements, and the successful execution of water reuse projects depends on a well-planned water supply system. Due of its inherent nutrient value, the TWW can also serve as a supplement to fertilizers (**Dare and Mohtar, 2018**).

In India, only cities create roughly 62,000 mld (million liters per day) of wastewater, of which only 27% are handled in treatment facilities and 70% are disposed of in water bodies (**CPCB, 2009**). Wastewater is used to irrigate roughly 73000 acres of land in India (**Singh *et al.*, 2022**). Around 40,000 acres of farmland were irrigated utilizing diluted sewage and fresh water from the Musi River, which flows through Hyderabad city, according to a study by **Surinaidu *et al.* (2023**). India produces 13,468 MLD of industrial wastewater in addition to sewage, but only 60% of it gets treated. In order to safely reuse wastewaters in agriculture, decentralized wastewater treatment solutions that are both environmentally sound and economically viable will be required by the year 2051, when it is predicted that India's wastewater generation will almost double to about 132,000 million liters per day (**Kaur, 2020**).

The 2030 Agenda for Sustainable Development **UN Nations** (**2015**) calls for the employment of innovative wastewater treatment and reuse technologies to help improve urban sanitation and increase water security. The benefits of wastewater treatment and reuse technologies are widely established, but their application in the municipal wastewater management sector is still in its infancy, particularly in low- and middle-income nations like India (**Otoo and Drechsel, 2018**).

Engineers and political figures alike want centralized sewage treatment technologies. There are only a few centralized programs that recycle water. There are formal water reuse programs for horticulture and agriculture, such as in Kanpur, Uttar Pradesh (**WSP and IWMI, 2016**), as well as for some sectors needing cooling, including in Nagpur, Maharashtra, and Chennai, Tamil Nadu (**PwC, 2016**). Given the lack of a freshwater alternative and the fertilizing characteristics of sewage, partially treated and untreated sewage are frequently used for irrigation, such as in Hyderabad, Telangana (**Kumar and Tortjada, 2020**).

Methodology

The study is based on basic historical, objective, description, and analytical research principles because it is a theoretical study with a literary focus. By using these techniques in the research, it is possible to view scientific knowledge as a cohesive system in which each prior strategy had an indirect or direct impact on the following one. All of these factors worked together to enable the methodical collection of scientific and theoretical calculations on the topic at hand. The opinions of the authors are discussed regardless of their ethnic backgrounds and political leanings, which calls for a full comparison of the facts and phenomena as a whole, or a thorough examination of the issue. The report also employs a systematic method that considers both the characteristics of the research items themselves and the variables that affect these characteristics. Such methods make it possible to find not only gaps in the subject being examined but also specific facets of the issue that the researchers may not have been aware of for a variety of reasons. In general, this offers the chance to analyze these features objectively and, based on their comparison, identify the possibilities for more study.

Information Related to the Utilization of Freshwater and Treated Wastewater

Rapidly depleting and elevating the level of freshwater demand, though wastewater reclamation or reuse is one of the most important necessities of the current scenario. Total water consumption worldwide for agriculture accounts 92% (**Hoekstra and Mekonnen, 2012**). Out of which about 70% of freshwater is used for irrigation (**WRI, 2020**), which comes from the rivers and underground water sources (**Pedrero *et al.*, 2010**). The statistics shows serious concern for the countries facing water crisis. **Shen *et al.* (2014)** reported that 40% of the global population is situated in heavy water–stressed basins, which represents the water crisis for irrigation. Therefore, wastewater reuse in agriculture is an ideal resource to replace freshwater use in agriculture (**Contreras *et al.*, 2017**). Treated wastewater is generally applied for non-potable purposes, like agriculture, land, irrigation, groundwater recharge, golf course irrigation, vehicle washing, toilet flushes, firefighting, and building construction activities. It can also be used for cooling purposes in thermal power plants (**Yang *et al.*, 2017**). At global level, treated wastewater irrigation supports agricultural yield and the livelihoods of millions of smallholder farmers (**Sato *et al.*, 2013**). Global reuse of treated wastewater for agricultural purposes shows wide variability ranging from 1.5 to 6.6% (**Ungureanu *et al.*, 2018**). More than 10% of the global population consumes agriculture-based products, which are cultivated by wastewater irrigation (**WHO, 2006**). Treated wastewater reuse has experienced very rapid growth and the volumes have been increased ~10 to 29% per year in Europe, the USA, China, and up to 41% in Australia (**Aziz and Farissi, 2014**).

China stands out as the leading country in Asia for the reuse of wastewater with an estimated 1.3 M ha area including Vietnam, India, and Pakistan (**Zhang and Shen, 2017**). Presently, it has been estimated that, only 37.6% of the urban wastewater in India is getting treated (**Singh *et al.*, 2019**). The detail information related to the utilization of freshwater and treated wastewater is compiled in Table 1.

Effect of Reuse Treated Wastewater on Growth Parameters of the Vegetables (Spinach, Radish and Carrot) In India

The opening and closing of stomata, which is essential for gaseous exchange and boosting photosynthesis, is a function of micronutrients like Cl. Additionally, it is necessary for the cell division of leaves and shoots. Iron, which plants typically have in concentrations between 50 and 250 mg L^{-1}, is another crucial micronutrient.

Additionally, Cu functions as an electron transporter and is a component of plastocyanin, which is crucial for photosynthesis and the buildup of dry matter. It is generally known that Mn plays a role in the development of oxygen during photosynthesis. Zinc levels in plants should be between 25 and 150 mg/L, and deficiencies have a negative impact on leaf development because deformed leaf margins are common (**Marschner, 2002**).

It was observed that the growth of various vegetables was assessed based on the plant's overall weight, the size of its root, the breadth of its leaves, and the length of its shoots in terms of the plant's height, the number of its leaves, and the diameter of its roots. Table 2 is a summary of the data for the same. The concentration of treated wastewater used for irrigation had an impact on the development of plants. As compared to plants that were irrigated with 0, 25, 50, and 75% of treated wastewater, plants that were irrigated with 100% of the wastewater were shown to grow at the highest rates (**Hussain *et al.*, 2019**).

It was discovered that during the course of 60 days, the weight of the plant's roots and leaves increased with respect to time. Vegetable development is also aided by the presence of potassium, phosphorus, and nitrogen. In the current investigation, it was discovered that vegetable plants grew enormously because there was an adequate quantity of potassium in both the soil and the treated wastewater. The rate of growth, the size of the cells, and the water content of the tissues may all be affected by a lower potassium concentration. Another macronutrient, Ca, which is present in treated wastewater, is crucial for the composition, permeability, and cell division of membranes, all of which contribute to growth.

Table 1. Freshwater and treated wastewater utilization status in different countries

Country	Water utilizing sectors		Status of water reuse (major sectors reusing water)	
Europe			Landscape irrigation	20%
	Agriculture	44%	Groundwater Recharge	2.2%
			Recreational	6.8%
			Non-potable urban uses	8.3%
	Industry and energy production	40%	Indirect potable uses	2.3%
			Agriculture irrigation	32%
			Industrial	19.3%
	Public water supply	16%	Environmental Enhancement	8%
			Other	1.5%
South Africa	Agriculture	60%	Landscape and sports field irrigation	9%
	Domestic	27%		
	Industrial	3%	Industry	48%
	Power	4%		
	Mining	3%	Agriculture	43%
	Other	3%		
USA	Freshwater thermoelectric plants	41%	Agricultural irrigation	37%
	Agricultural irrigation	37%	Geothermal energy	2%
	Industries	6%	Golf course irrigation	7%
	Domestic	14%	Landscape irrigation	17%
	Livestock and aquaculture	3%	Groundwater recharge	12%
			Seawater intrusion barrier	7%
			Recreational impoundment	4%
			Wetlands, wildlife habitat	4%
			Industrial and commercial	8%
			Other	2%
India	Agriculture	87%	Agricultural irrigation	78%
	Industrial	7%	Industrial use	12%
	Domestic	4%	Thermal power plant	4%
	Energy	2%	Groundwater recharge and artificial lakes	6%
Greece	Irrigation	83%	Agricultural irrigation	58.38%
	Animal husbandry	1.3%	Irrigation of forested land and firefighting	17.7%
	Industry	2.2%	Landscape irrigation	23.92%
	Public use (potable)	13%		
	Other	1.2%		

Source: (**Kesari *et al.*, 2021**)

Table 2. Growth parameters of the vegetables (Spinach, Radish and Carrot) in India

Concentration (%)		No. of crops	No of leaves	Weight of plant (gm)	Size of leave (cm)	Width of leave (cm)	Width of root (mm)	Length ofroot (cm)	Total height of plant (cm)
Tap water	**Treated waste water**								
				Spinach					
100	**0**	1.	12	5.9	8–13.5	4.2	1	9.3	23
		2.	11	5.5	7–12	4.2	1	8.5	20.8
75	**25**	3.	16	11.86	8–15	5	1.5	17	27.3
		4.	12	8.4	7–14	4.3	2	14	29.8
50	**50**	5.	24	44.6	16–26	9	3	14	40
		6.	23	11.39	9–15	5.8	1.5	13	50
25	**75**	7.	23	35.5	9–17.8	5.5	2.5	11	28.5
		8.	17	6.48	6–11.5	4.5	1.5	8	19
0	**100**	9.	18	25.4	9–17	5.5	3	21	43
		10.	35	16.5	9–18	6	3.1	11	29.7
				Radish					
100	**0**	1.	8	5.3	5–9	3.3	2	9	18
		2.	11	4.38	6–9.8	4	1	10.6	19
75	**25**	3.	12	14	10–13.3	5	1.6	10	24
		4.	6	5.87	6–8	4	2.1	12	20
50	**50**	5.	7	3.5	6–9	3.5	0.5	7	16
		6.	7	3.22	5–7.5	3.9	1	10	16.3
25	**75**	7.	8	3.62	5–8.5	3	1.1	11	19
		8.	9	3.33	5–7	3	0.7	8	15
0	**100**	9.	12	11	8–11	5	2	11	22
		10.	13	7.4	5.5–9	3.4	0.9	10.5	19
				Carrot physical measurement					
100	**0**	1.	6	3.1	–	–	0.7	4	10
75	**25**	2.	8	3.62	–	–	0.92	3.8	11.8
50	**50**	3.	10	5.2	–	–	1	5	12.7
25	**75**	4.	7	4.1	–	–	0.98	3.7	9.4
0	**100**	5.	9	3.3	–	–	0.88	5	10.9

Source: (**Hussain *et al.*, 2019**)

Heavy Metal Accumulation and Translocation Ratio in some Vegetable Plants

In Northern India, **Ghosh *et al.* (2012)** found that TSW irrigation of vegetables increased both the amount of heavy metal contamination and the amount of metal that the crops absorbed, raising health concerns. In comparison to GW irrigated soils, the content of heavy metals (Cd, Cr, and Ni) in the dry matter of several vegetables grown on TSW irrigated soils was found to be considerably greater (data not shown).

This is in line with research indicating that vegetables grown in sewage water irrigation fields have greater levels of heavy metals than those grown in tube well irrigation fields. Based on their overall Cd, Cr, and Ni absorption, vegetables can be divided into three groups (Fig. 1). Radish, cabbage, and spinach are high in heavy metals in the first group, while coriander, beans, tomatoes, turnips, and carrots accumulate them at a moderate rate. The least amount of heavy metals were found in potato, brinjal, and cauliflower edible components.

The concentration of heavy metals was consistently higher in leaves than in storage organs, and the ratio of leaf to storage organ heavy metal content ranged from 2.4 to 3.8. Heavy metals can be passively carried from the root to the shoot through the xylem vessels, according to studies on heavy metal intake by plants (**Krijger *et al.*, 1999**), but redistribution into the storage organs is mostly dependent on phloem, and heavy metals have little mobility in the phloem. Heavy metal contamination of the human food chain typically occurs through the direct eating of vegetable edible components (**Arora *et al.*, 2008**). However, this does not rule out the possibility of metals entering the food chain since the leaves are typically fed to stray milk cows that are idling and loitering, and heavy metals can re-enter the human food chain by intake of the milk from these cows. In the study area, general bioaccumulation behavior has been seen in the plants. Radishes and turnips, which have edible roots, gathered more Cd and Cr than spinach, coriander, and cabbage, which have edible leaves. Brinjal and cauliflower, which have edible fruits or curds, came in second and third. In contrast, leafy vegetables tend to accumulate more metals than root crops (**Puschenreiter *et al.*, 2005**), according to general findings. It has been discovered that cabbage accumulates more Ni than other vegetables grown in soil with a similar Ni level.

In radish, spinach, and carrot cultivated over a 60-day period, the heavy metals were found in the leaves and roots. The concentration of each heavy metal in various areas of various vegetable plants is listed in Table 3. While Ni content was found to range between 100 and 545 mg/g, Cd concentration ranged from 20.5 to 39.5 mg g^{-1}. Cu concentrations were found to be between 22 and 324 mg g^{-1}, whereas Zn concentrations were found to be between 152 and 259 mg g^{-1}. Mn concentrations were found to be between 106.5 and 429 mg g^{-1}, whereas Pb concentrations were found to be between 72.5 and 346 mg g^{-1}. According to (**Hussain *et al.*, 2019)**, the content of Cr was determined to be between 84 and 441 mg $g^{-1}$and the concentration of Co to be between 12 and 77 mg g^{-1}.

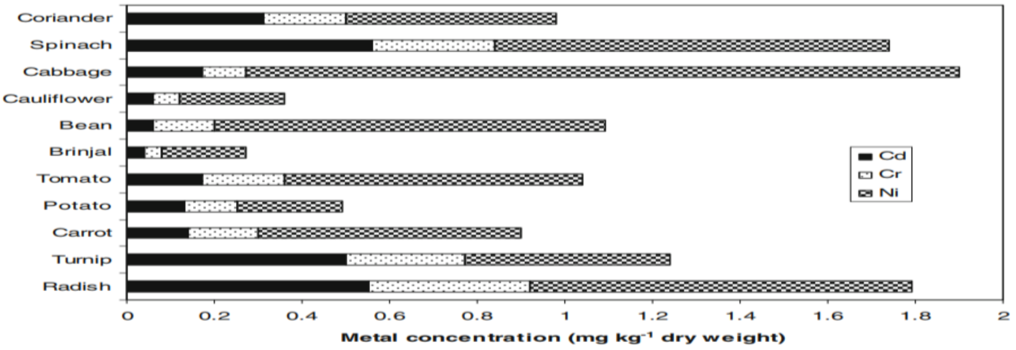

Fig.1. Heavy metal accumulation and translocation ratio in some vegetable plants

Source: (**Ghosh *et al.*, 2012**)

Table 3. Concentration of heavy metals in several vegetable plant parts in India (including radish, spinach, and carrot)

Concentration (%)		Part of plant	Concentration of heavy metals in radish (mg g^{-1})							
Tap water	**Treated wastewater**		**Cd**	**Ni**	**Cu**	**Zn**	**Mn**	**Pb**	**Cr**	**Co**
100	**0**	Root	0.033	0.062	0.05	0.302	0.106	0.092	0.1	0.002
		Leaf	0.039	0.138	0.07	0.256	0.148	0.12	0.068	0.046
75	**25**	Root	0.034	0.071	0.075	0.214	0.103	0.025	0.058	0.03
		Leaf	0.04	0.152	0.07	0.2	0.131	0.177	0.181	0.015
50	**50**	Root	0.037	0.094	0.108	0.226	0.063	0.098	0.221	0.023
		Leaf	0.039	0.184	0.05	0.225	0.15	0.161	0.207	0.001
25	**75**	Root	0.033	0.1	0.023	0.07	0.102	0.005	0.212	0.001
		Leaf	0.04	0.133	0.021	0.322	0.147	0.14	0.157	0.039
0	**100**	Root	0.038	0.093	0.054	0.3	0.1	0.117	0.065	0.039
		Leaf	0.041	0.125	0.101	0.243	0.173	0.15	0.134	0.035

Concentration (%)		Part of plant	Concentration of heavy metals in spinach (mg g^{-1})							
Tap water	**Treated wastewater**		**Cd**	**Ni**	**Cu**	**Zn**	**Mn**	**Pb**	**Cr**	**Co**
100	**0**	Root	0.042	0.18	0.01	0.237	0.15	0.176	0.223	0.028
		Leaf	0.02	0.197	0.129	0.318	0.195	0.234	0.275	0.087
75	**25**	Root	0.04	0.148	0.049	0.256	0.145	0.164	0.147	0.042
		Leaf	0.023	0.235	0.09	0.327	0.235	0.269	0.261	0.096
50	**50**	Root	0.043	0.17	0.076	0.246	0.145	0.264	0.338	0.029
		Leaf	0.02	0.204	0.071	0.213	0.299	0.174	0.092	0.045
25	**75**	Root	0.036	0.204	0.088	0.221	0.146	0.184	0.198	0.043
		Leaf	0.022	0.215	0.095	0.326	0.261	0.181	0.197	0.071
0	**100**	Root	0.017	0.213	0.112	0.213	0.14	0.21	0.36	0.001
		Leaf	0.024	0.218	0.058	0.227	0.126	0.112	0.209	0.005

Concentration (%)		Part of plant	Concentration of heavy metals in carrot (mg g^{-1})							
Tap water	**Treated wastewater**		**Cd**	**Ni**	**Cu**	**Zn**	**Mn**	**Pb**	**Cr**	**Co**
100	**0**	Root	0.021	0.225	0.066	0.152	0.273	0.104	0.283	0.077
		Leaf	0.019	0.235	0.067	0.234	0.235	0.112	0.208	0.086
75	**25**	Root	0.023	0.23	0.162	0.197	0.429	0.128	0.282	0.083
		Leaf	0.034	0.232	0.177	0.212	0.411	0.137	0.105	0.055
50	**50**	Root	0.024	0.228	0.085	0.215	0.198	0.234	0.235	0.083
		Leaf	0.027	0.219	0.105	0.238	0.217	0.256	0.229	0.088
25	**75**	Root	0.027	0.545	0.145	0.265	0.145	0.202	0.357	0.064
		Leaf	0.034	0.435	0.211	0.355	0.245	0.241	0.249	0.088
0	**100**	Root	0.026	0.465	0.324	0.259	0.163	0.346	0.441	0.052
		Leaf	0.031	0.343	0.298	0.287	0.137	0.424	0.398	0.055

Source: (**Hussain *et al.*, 2019**)

According to study findings, Cd, Co, and Pb concentrations in root sample concentrations were determined to be below the dangerous level. The sequence in which the concentration of heavy metals decreased in leaves was Zn>Ni> Cr>Pb> Mn>Cu>Co>Cd, whereas in roots it was Zn>Ni>Cr>Pb>Mn> Cu>Co >Cd. Plant samples that had been watered with tap water had a greater Zn concentration than other plant samples. Additionally, it was found that the Zn concentration was higher in the roots than in the leaves and that it declined over time as the plant reached its full development. The physicochemical makeup of the soil and the plant's ability to absorb each metal account for the difference in metal content in these veggies. It is affected by a number of things, including the plant's nature, the environment, and human involvement.

Concentration of Zn was found to be higher in plant samples irrigated with tap water. Also, the concentration of Zn was observed to be high in the roots than in the leaves, and it decreased with respect to time as the plant attained growth. The variation in concentration of metals in these vegetables depends on physicochemical nature of the soil and absorption capacity for each metal by the plant. It is afected by the various factors like environmental condition, human interference and the nature of the plant.

In comparison to other heavy metals, Cd and Co were shown to be present in lower concentrations among the eight heavy metals. This could be as a result of their great reliance on soil pH and solubility. The findings of the current study showed that the concentration of heavy metal is higher in the leaves and roots of plants that are watered with 25%, 50%, and 75% of treated wastewater as compared to plants that are irrigated with 100% treated wastewater. The fact that the metal uptake may vary depending on the plant's genotype and external concentration made it less astonishing.

Additionally, it should be noted that plant heavy metal uptake is not linearly related to the concentration of treated effluent. After 60 days, it was discovered that spinach watered with 25% treated wastewater and radish irrigated with 75% treated wastewater had the highest concentrations of Zn.

The study's result also shows that Zn content is highest in leaves as opposed to roots. With more plant growth, the concentration was observed to typically decrease in the roots. According to research by **Demirezen and Aksoy (2004)**, the content of Cd was shown to be higher in spinach roots than in leaves.

Between 20.5 and 39.5 mg/g of Cd were discovered in the current investigation. Fig. 2 shows that the concentration of Cd, Co, and Cu in the leaves and roots of all vegetables is low and below dangerous values. All of the plants had a Cu content ranging from 22 to 324 mg/g. Cr and Co concentrations varied from 84 to 441 mg/g and 12 to 77 mg g^{-1}, respectively. The spinach and carrot leaves have a greater concentration of Cr. However, in radish, the concentration was higher in the roots than the leaves.

All vegetable plants had greater Ni concentrations in their leaves, ranging from 100 to 545 mg g^{-1}. Mn levels in all vegetable plants were determined to be between 106.5 and 429 mg g^{-1}, which is below the hazardous level. Zn and Pb concentrations varied between 152 and 259 mg kg^{-1} and 72.5 and 346 mg kg^{-1}, respectively. Data analysis of the translocation factor revealed that heavy metal accumulation is more pronounced in plant shoots than in roots.

Percentage of Macronutrient and Micronutrient Content in the Vegetables From Different Sites In India

The highest value was found in the potato and the lowest in the carrot when the mean percentage values for N, P, and K were recorded in carrot, radish, spinach, cauliflower, and potato. The highest levels of N, P, and K were found in the vegetables grown in Ganjia soils, followed by Arail and Dandi. The mean N content of carrot, radish, spinach, cauliflower, and potato was 4.03 percent at Ganjia, 4.43 percent at Arail, and 4.40 percent at Dandi, respectively. It was 3.16 percent at Ganjia, 3.16 percent at Arail, and 3.83 percent at Dandi. At Ganjia, the amounts of phosphorus found in carrot, radish, spinach, cauliflower, and potatoes were 0.31, 0.55, 0.73, 0.51, and 0.83 percent; at Arail, they were 0.24, 0.40, 0.61, 0.37 percent; and at Dandi, they were 0.22, 0.32, 0.51, 0.30, and 0.55 percent, respectively. The percentage of

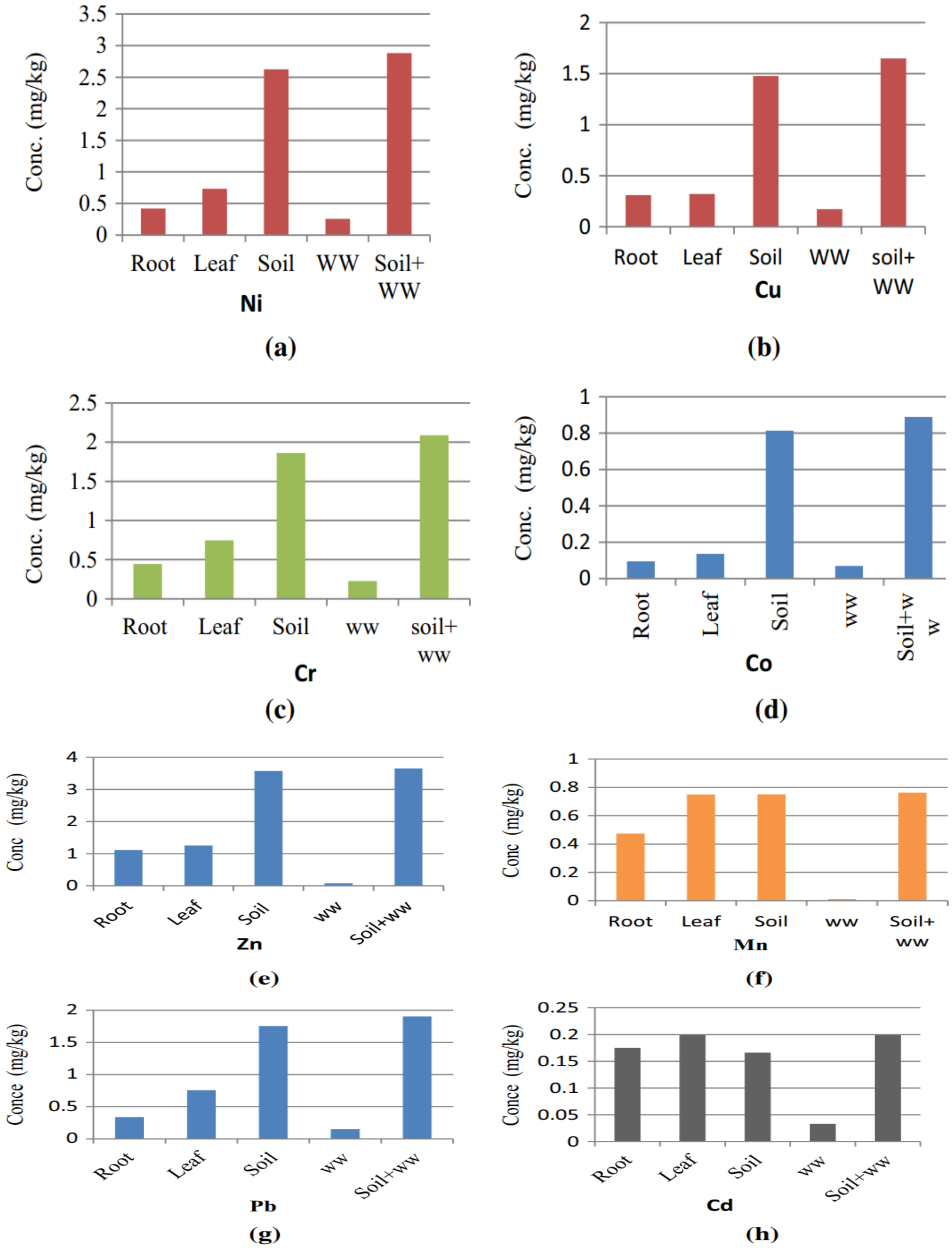

Fig. 2. Variation in concentration of heavy metals in various parts of radish a Ni b Cu c Cr d Co e Zn f Mn g Pb h Cd

Source: (Hussain *et al.*, 2019)

potassium showed a similar pattern, with values of 3.10, 3.33, 3.80, 3.10 and 4.33 percent at Ganjia, 2.50, 2.70, 3.20, 2.53 and 3.76 percent at Arail, and 2.03, 2.20, 2.70, 2.03 and 3.03 percent at Dandi, respectively, in the cases of carrot, radish, spinach, cauliflower, and potato (Table 4).

According to **Jones *et al.* (1991)**, the typical limits for NPK in plants are reported to be between 4 and 5 percent for N, 0.30 to 0.70 percent for P, and 3.00 to 4.50 percent for K. According to a N assessment, the range of values for potatoes is normal, however the N levels for all other vegetables are below average. Only the carrot displays P values below the normal range in this instance; all other veggies fall within the normal range. When K levels are assessed, readings for potatoes and spinach are at normal levels, but all other vegetables have values that are below normal.

Overall analysis of our results suggests that this may be because soils at Ganjia are situated close to the sewage discharge point after Arail and Dandi and get continuous sewage water for irrigation for extended periods of time. The percentages of N, P, and K in vegetable crops significantly rise when sewage water is used since it includes larger levels of these nutrients as well as other nutrients. **Mitra and Gupta** (**1999**) reported findings that were comparable.

Vegetables produced in various locations, such as carrot, radish, spinach, cauliflower, and potatoes, are significantly impacted by sewage waters. For Mn^{2+} (mg kg^{-1}), the mean values are as follows: spinach> carrot> radish> cauliflower > potato; for Zn^{2+} (mg kg^{-1}), the mean values are as follows: spinach > radish > carrot > potato > cauliflower; and for Fe^{2+} (mg kg^{-1}) the mean values are as follows: carrot > spinach > radish > potato > cauliflower in all three sites. The average amounts of Mn^{2+} in carrot, radish, spinach, cauliflower, and potatoes were 25.76, 23.70, 32.40, 18.80, and 15.10 mg kg^{-1} in Ganjia, 18.36, 16.96, 28.26, 12.83, and 13.00 mg kg^{-1} in Arail, and 11.23, 10.16, 20.43, 9.63, and 8.66 mg kg^{-1} in Dandi, respectively. Zn^{2+} concentrations in carrot, radish, spinach, cauliflower, and potatoes were 249.40 mg kg^{-1} at Ganjia, 210.76 mg kg^{-1} at Arail, and 185.33 mg kg^{-1} at Dandi, respectively. Zn^{2+} concentrations in other vegetables were also measured, and they were 210.76 mg kg^{-1} at Ganjia, 230.33 mg kg^{-1} at Arail, and 105.70 mg kg^{-1} at Dandi. In carrot, radish, spinach, cauliflower, and potato, the mean values of Fe^{2+} were 316.20, 221.03, 213.80, 153.30, and 140.63 mg kg^{-1} at Ganjia, 299.36, 180.80, 151.30, 110.46, and 114.70 mg kg^{-1} at Arail, and 249.90, 110.23, 100.50, 70.30, and 81.20 mg kg^{-1} at Dandi (Table 5).

The safety of vegetables is a problem for human health and has drawn increased attention because agricultural plants typically use up a lot of critical nutrients and trace elements in a short period of time. Heavy metals including copper, cadmium, lead, zinc, and manganese can be easily absorbed by some vegetables like spinach, radish, and carrot in their tissue. When plants are grown on polluted soils, their absorption by plants often increases (**Khan *et al.*, 2015**). According to reports, the usual limits for manganese and zinc concentrations in plants are 20–400 ppm and 20–100 ppm, respectively (**Blum *et al.*, 2012**). Iron levels should not exceed 220–1200 ppm in normal circumstances, according to **Ozturk *et al.* (2015 and 2017)**. In light of these studies, manganese levels were within acceptable norms in spinach, but they were below normal in all other vegetables in our samples. Carrots have iron levels that are within acceptable limits, but all other vegetables have readings that are below normal. In all veggies, zinc levels have been shown to be significantly higher than average.

The fact that Ganjia receives the most Mn^{2+}, Zn^{2+}, and Fe^{2+} accumulation in its vegetables—along with the fact that it is the closest to the sewage discharge point after Arail and Dandi—may be responsible. Increases in Mn^{2+}, Zn^{2+}, and Fe^{2+} are shown in the vegetables grown because sewage water contains a higher concentration of micronutrients. **Gupta *et al.* (2008)** reported findings that are comparable to these. Sewage-amended plants typically have elevated amounts of micronutrients; these nutrients may build up to a point where they become harmful to living things. According to **Patel *et al.*** (**2004**), diverse vegetable crops always acquire large levels of micronutrients, regardless of the type of effluents or water used for irrigation. This indicates that crop species, cultivar, and element selectivity all affect uptake.

Table 4. Percentage of macronutrient content in some vegetables from different sites in India

Sites	Carrot	Radish	Spinach	Cauliflower	Potato	Mean
Nitrogen						
Site-I (Ganjia)	4.03	4.43	4.56	4.40	4.96	4.48
Site-II (Arail)	3.16	3.83	3.96	3.73	4.13	3.76
Site-III (Dandi)	2.90	2.53	3.46	3.07	3.56	3.10
Mean	3.36	3.60	3.99	3.73	4.22	
$p<0.05$	Vegetables	0.28				
	sites	0.28				
Phosphorus						
Site-I (Ganjia)	0.31	0.55	0.73	0.51	0.83	0.59
Site-II (Arail)	0.24	0.40	0.61.	0.37	0.67	0.46
Site-III (Dandi)	0.22	0.32	0.51	0.30	0.55	0.38
Mean	0.26	0.42	0.62	0.39	0.68	
$p<0.05$	Vegetables	0.05				
	sites	0.05				
Potassium						
Site-I (Ganjia)	3.10	3.33	3.80	3.10	4.33	3.53
Site-II (Arail)	2.50	2.70	3.20	2.53	3.76	2.94
Site-III (Dandi)	2.03	2.20	2.70	2.03	3.03	2.40
Mean	2.54	2.74	3.23	2.55	3.71	
$p<0.05$	Vegetables	0.08				
	sites	0.08				

Source: (**Haq *et al.*, 2021**)

Table 5. Micronutrient content (mg kg^{-1}) in some vegetables cultivated at different sites in India

Sites	Carrot	Radish	Spinach	Cauliflower	Potato	Mean
Manganese						
Site-I (Ganjia)	25.36	23.70	32.40	18.80	15.10	23.07
Site-II (Arail)	18.36	16.96	28.26	12.83	13.00	17.88
Site-III (Dandi)	11.23	10.16	20.43	9.63	8.66	12.02
Mean	18.32	16.94	27.03	13.75	12.25	
$p<0.05$	Vegetables	2.30				
	Sites	2.30				
Zinc						
Site-I (Ganjia)	249.90	282.30	296.80	179.30	170.03	235.67
Site-II (Arail)	210.76	230.33	251.08	120.30	141.33	190.76
Site-III (Dandi)	185.33	200.70	220.90	105.70	100.13	162.55
Mean	215.33	237.78	256.26	135.10	137.16	
$p<0.05$	Vegetables	8.78				
	Sites	8.78				
Iron						
Site-I (Ganjia)	316.20	221.03	213.80	153.30	140.63	208.99
Site-II (Arail)	299.36	180.80	151.30	110.46	114.70	171.32
Site-III (Dandi)	249.90	110.23	100.50	70.30	81.20	102.43
Mean	288.49	137.35	155.20	111.35	112.18	
$p<0.05$	Vegetables	17.90				
	Sites	17.90				

Source: (**Haq *et al.*, 2021**)

The majority of urban farmers in India already use wastewater rich in heavy metals as cadmium, chromium, iron, nickel, manganese, lead, and zinc for crop cultivation in response to the restricted supply of fresh water for agriculture. As a result, growing wastewater volumes will increasingly serve as the primary source of new irrigation water supplies for agricultural in water-scarce nations like India (**Kumar *et al.*, 2015**).

Use of Wastewater in Vegetable Production in India

Large amounts of wastewater are routinely produced by homes, businesses, and agriculture. According to **Hussain *et al.* (2019)**, wastewater accounts for 50– 80% of domestic household water use, and according to **Zhang *et al.* (2017)**, worldwide wastewater discharge is expected to be 400 billion m^3/year, contaminating around 5500 billion m^3 of water. According to **Hanjra *et al.* (2012)**, wastewater typically has 99% water and 1% suspended, colloidal, and dissolved particles. Depending on the source, wastewater is known to contain pathogenic microorganisms such as bacteria, viruses, protozoans, and parasitic worms, as well as organic matter, suspended solids, nutrients (primarily nitrogen and phosphorus), heavy metals, and emerging contaminants such as antibiotic-resistant bacteria and genes, hormones, personal care products, pesticides, hormones, and hormone-like substances. Due to its high nutritional concentration and ability to supply plants with organic carbon, nutrients (NPK), and inorganic micronutrients, wastewater has a significant potential for application in agricultural irrigation (**Alcalde-Sanz and Gawik, 2017**).

Through the collection of nutrients from reclaimed water and the application of those nutrients to crops using a variety of irrigation techniques, wastewater reuse for agricultural crop irrigation is a market-driven action based on the needs of the agricultural sector. This practice can support the circular economy. According to **Bedbabis *et al.* (2014)**, reuse of wastewater for irrigation of agriculture is primarily carried out in low-income, arid and semi-arid nations where evapo-transpiration outpaces precipitation for the majority of the year. Due to the proximity of nearby communities' wastewater treatment facilities, farmers' crop selections are increased. According to the literature review (Table 6), wastewater has been successfully used to irrigate a range of vegetable crops.

The various benefits of this practice are causing it to become more and more popular throughout the world. The older population is still unwilling to eat food cultivated with wastewater, despite the young generation having access to quality education and information about the advantages of recycling wastewater as irrigation water (**Anastasiadis *et al.*, 2014**). Some advantages of using wastewater (treated, partially treated, or diluted) in agriculture include the following: availability of large amounts of water throughout the year without being impacted by environmental conditions; high nutrient content that can reduce the use of chemical fertilisers; raising productivity on less fertile lands; minimizing the loss to freshwater ecosystems caused by eutrophication and algal blooms; and so forth (**Ungureanu *et al.*, 2020**). Although there are many benefits to using wastewater in agriculture, there are also a number of disadvantages, including a variety of illnesses in farmers and consumers of food from wastewater-irrigated crops; accumulation of heavy metals, salts, antibiotics, growth hormones, and other hazardous substances in the soil; low hydraulic conductivity because soil pores are clogged with wastewater suspended solids; and decreased quality of agricultural crops because of contaminated soil. According to benefits shown by higher agricultural productivity as a result of the high nutritional content of these waters, several studies emphasize the use of wastewater and treated water in particular for crop irrigation. According to studies **Jang *et al.*** (**2013**), wastewater irrigation increased tomato production by 14.9% while rice output increased by 15%. A recent study **Chojnacka *et al.*** (**2020**) found that the nutrient concentration of treated urban wastewater allowed it to be reused in nations like Brazil, Poland, and Saudi Arabia, where it would completely satisfy the phosphorus and potassium needs of maize crops.

In order to ensure compliance with country-specific criteria (if any) or WHO minimum standards, another measure is to continuously monitor the quality of the effluent or wastewater to be reused. Wastewater should be treated by sedimentation and/or filtration in the absence of

Table 6: Use of wastewater in vegetable production in India

Sr. No.	Crops	Type of wastewater used in production
1	Lettuce	Both untreated and treated municipal wastewater
2	Tomatoes	untreated wastewater
3	Potatoes	untreated wastewater
4	Carrots	untreated wastewater
5	Radishes	Both untreated and treated municipal wastewater
6	Cucumbers	untreated wastewater
7	Spinach	untreated wastewater
8	Onions	Both untreated and treated municipal wastewater
9	Fennel	Both untreated and treated municipal wastewater
10	Asparagus	untreated municipal wastewater
11	Broccoli	untreated municipal wastewater
12	Cabbage	Treated and untreated municipal wastewater
13	Eggplant	Treated wastewater
14	Kidney beans	Untreated wastewater
15	Lady’s fingers	Untreated wastewater
16	Turnips	Treated and untreated municipal wastewater
17	Zucchini	Treated and untreated municipal wastewater

Source: (**Brar and Rawat, 2022**)

a complete treatment technology to reduce clogging of soil pores and irrigation emitters. Farmers and agricultural workers in some areas run the risk of pollution and health issues because there aren't any sanitation facilities in place. They must therefore avoid handling wastewater irrigation goods directly and wash their hands thoroughly after coming into contact with wastewater or wastewater irrigation products. Avoid irrigation of vegetable crops if wastewater treatment is not possible.

Applications of Treated Wastewater in Crop Irrigation

The effects of the reuse of recycled/treated wastewater in significant sectors have been evaluated by a number of researches.

These include toilet flushing, dust control, landscaping, irrigation for golf courses, cooling water for power plants and oil refineries, processing water for mills and plants, public parks, landscaping, toilet flushing, and concrete mixing and artificial lakes (Table 7). Although the level of heavy metals in the effluent after secondary treatment makes it suitable for reuse **Ayers and Westcot** (**1985**), experimental data have been found and evaluated the effects of irrigation with treated wastewater on soil fertility and chemical characteristics, where it has been concluded that secondary treated wastewater can improve soil fertility parameters.

This has been changed in the suggested model by advancing it with UV and ozone therapy. According to a recent study **Bhatnagar *et al.*** (**2016**), the treated water passed quality tests appropriate for agriculture irrigation.

Table 7. Applications, methods and health concerns of treated or untreated wastewater for irrigation in India

Approach	Experimental details	Results and remarks
Groundwater, secondary (SW) and tertiary wastewater (TW)	Tomato and broccoli was irrigated with agro-industrial treated wastewater	No significant effects neither on marketable yield nor on the qualitative traits of tomato and broccoli crops. Treated wastewater has been found more effective for irrigation and to cope with the agricultural water shortage
Irrigation with groundwater (GW) and treated agro-industrial wastewater (TW)	Physico-chemical characteristics of the irrigation waters. Monitoring of fruit quality parameters, E. coli, fecal Enterococci, and Salmonella spp.	No significant effects on yields quantitative traits in an irrigated water, although marketable fruit yield was higher in GW than with TW GW
Surface water, groundwater and wastewater	Water samples were analyzed for E. coli using the most probable number method	The incidence of diarrhea in the groundwater area was 7.92 episodes/1000 person-weeks, while the wastewater and surface water group had incidences of 13.1 and 13.4 episodes/ 1000 person-weeks. The average treatment effect of wastewater quality obtained was 2.73
Simulated sugar effluent (lab-made)	Treated with batch electrochemical reactor where current density was varied from 1 to 5 A/dm^2	The percentage removal of COD was 80.74% at 5 A/dm^2 (current density) and 5 g/L of electrolyte concentration
Raw sewage from WWTP	Irrigated water, soil and vegetable samples for Zn, Cu, Pb and Cd concentrations and transfer factor from soils to plants (TF) were analyzed. Health risk index was also calculated	The irrigated soil was contaminated and trend of heavy metals concentrations was Zn > Pb > Cu > Cd. Health risk index was >1 for Cd and Pb. Study indicates potential health risk the human and animal populations
Wastewater treatment plant/treated wastewater	Pollution load indexes (PLI), enrichment factor (EF) and contamination factor (CF) of metals were calculated	Ni, Pb, Cd and Cr concentrations in the edible portions were above the safe limit in 90%, 28%, 83%, and 63% of the samples, respectively. The health risk index (HRI) was >1 indicating a potential health risk and suggests that wastewater irrigation is not safe for human health
Raw sugarcane wastewater	Wastewater treated with UMAS (10 kHz, 7 days incubation) and membrane anaerobic system	More than 90% (>90%) of removal efficiency (BOD, COD, and TSS), and reduced flux decline was achieved by using UAMS
Raw sugarcane wastewater	Wastewater treated with ultrasonic membrane anaerobic system (UMAS), 25 kHz after 28 days experiment	After 28 days, the COD removal efficiency obtained was 97 %, and the methane gas composition nearly reached 79 %. The TSS and VSS removal efficiency also reached 99 % of removal
Municipal wastewater (MWW)	Ultrasonication at 20 kHz, for 15, 30, and 45 min	High bacterial densities were employed, percentages of inactivation > 99% were reached at 45 min

Source: (**Kesari *et al.*, 2021**)

Lead, copper, zinc, boron, cobalt, chromium, arsenic, molybdenum, and manganese are just a few of the essential and non-essential metal pollutants that can be found in wastewater-irrigated fields. Some of these are necessary for crops, but the others are hazardous to humans, animals, and plants and are not necessary. Heavy metal concentrations in plants grown in wastewater-irrigated soils were found to be substantially greater than in plants cultivated in the reference soil in the study, according to (**Kanwar and Sandha, 2000**). According to **Yaqub *et al.* (2012**), using US to remove hazardous or heavy metals and organic contaminants from industrial wastewater is quite successful. However, it has also been noted that metals were effectively eliminated when UV radiation and ozone were mixed (**Samarghandi *et al.*, 2007**). As previously documented **Park *et al.*** (**2008**), ozone exposure is a powerful approach for the removal of metal or hazardous chemicals from wastewater. When US, UV, and O_3 are used together, reactive oxygen species (ROS) are created. ROS oxidize some organic materials, metal ions, and pathogens. According to **Oturan and Aaron (2014)**, the advanced oxidizing process (AOP) relies primarily on oxidants to generate highly reactive free radicals (such as OH) for the breakdown of organic materials. The ozone oxidization process is more successful and promising than the other AOPs for the breakdown of complex organic pollutants (**Xu *et al.*, 2020**). Heavy metals are oxidized by ozone to their higher oxidation state, where they typically form limited soluble oxides and precipitate, making them simple to filter using the filtration process. According to **Upadhyay and Srivastava (2005)**, ozone oxidization is effective at removing heavy metals from water sources including cadmium, chromium, cobalt, copper, lead, manganese, nickel, and zinc. In treated wastewater, sludge treated with ultrasound causes biological cells to break down and bacteria to perish. It has been discovered that a treatment regimen combining ultrasound and nanoparticles is more successful. The physical effects of cavitation caused by ultrasonication inactivate and lyse germs. Particularly during ultrasound irradiation, the produced effects of US, US, or ozone may kill pathogens by attacking free radicals, hydroxyl radicals, and physically rupturing cell membranes (**Kesari *et al.*, 2011a**).

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إعادة استخدام مياه الصرف الصحي البلدية المعالجة في إنتاج بعض الخضروات في الهند: دراسة مرجعية

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يعتبر الحقل المروي بمياه الصرف الصحي مصدراً رئيسياً لملوثات المعادن الأساسية وغير الأساسية مثل الرصاص والنحاس والزنك والبورون والكوبالت والكروم والزرنيخ والموليبدينوم والمنجنيز. وكان لكمية مياة الصرف الصحي المعالجة المستخدمة في الري تأثير علي نمو العديد من النباتات. بالمقارنة مع النباتات التي تم ريها بمياه الصرف الصحي المعالجة بنسب صفر، 25، 50 و 75%، فقد تبين أن نمو النباتات المروية بالمياه المعالجة بنسبة 100% كان نموها أفضل. وجد أن وزن جذور وأوراق النبات ازداد خلال مرور 60 يوماً. كما يعزز وجود النيتروجين والفوسفور إلى جانب البوتاسيوم من نمو الخضروات. تشير الدراسة الحالية إلي أن نظرًا لوجود تركيز كاف من البوتاسيوم في مياه الصرف الصحي المعالجة وكذلك في التربة ، فقد نمت نباتات الخضراوات بشكل جيد . قد يتأثر معدل النمو وحجم الخلايا والمحتوى المائي للأنسجة بانخفاض تركيز البوتاسيوم. تلعب العناصر الغذائية الكبري الأخرى مثل الكالسيوم والموجودة في مياه الصرف الصحي المعالجة ، وظيفة رئيسية في تركيب والنفاذية وانقسام الخلايا ، مما يعزز النمو. تحتوي جميع نباتات الخضروات على تركيزات مرتفعة من النيكل في أوراقها تتراوح من 100 إلى 545 مجم/ جم . وجد أن تركيز المنجنيز في جميع نباتات الخضروات يتراوح من 106.5 إلى 429 مجم/جم وهو أقل من المستوى السام. تراوح تركيز الزنك والرصاص من 152 إلى 259 مجم/كجم ومن 72.5 إلى 346 مجم/كجم على التوالي. تم تحليل عامل النقل ، ووجد أن المعادن الثقيلة تتراكم في براعم النباتات أكثر من الجذور. يرجع تراكم المنجنيز، الزنك، الحديد في خضروات Ganjia بتركيزات مرتفعة إلى أنها تستخدم مياه الصرف الصحي بصفة مستمرة للري وتقع أيضًا بالقرب من نقطة تصريف مياه الصرف الصحي تليها Arail و Dandi. نظراً لأن مياه الصرف الصحي تحتوي على كمية أكبر من العناصر الغذائية الدقيقة ، فإنها تؤدي إلى زيادة معنوية في محتوي الخضراوات من كل من المنجنيز، الزنك والحديد.

الكلمات الإسترشادية: المياه العذبة، إعادة استخدام مياه الصرف الصحي البلدية المعالجة ، الزراعة ، المغذيات-الكبري والدقيقة ، الهند.

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