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Utilization of Wastewaters in Urban and Peri-urban Agriculture

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Preface

During the first decade of 21st century, urban population of the world exceeded the rural population, and by 2050 it is expected to account for more than two-thirds of the total population. Rapid urbanization, along with climate change, natural resource degradation, increasing reliance on fossil fuels and pesticides, and volatile markets will further compound the problems of food and nutritional insecurity, poverty, and diseases in urban areas. Water availability will also be a key concern; while freshwater availability would be declining, domestic and industrial wastewater will be increasing gradually, most of which is being disposed off currently untreated.

The biggest challenge is the use of untreated municipal wastewater for agriculture as it is loaded with pathogens, heavy metals and chemicals particularly when industrial effluents are discharged into municipal sewers. This has been emphasized in the UN SDG 6.3. These pose a serious hazard to human and livestock health, especially when they are directly exposed to contaminated water and soil. The challenge, thus, is to find low-cost, low-tech, user-friendly methods that prevent any threats to the livelihoods and natural resources. Nonetheless, the forestry/agroforestry, vertical farming and horticulture in urban and peri-urban areas provide an opportunity to use the municipal wastewaters (both sewage and industrial effluents) in an effective way.

The National Academy of Agricultural Sciences organized a brainstorming session on *"Utilization of Wastewaters in Urban and Peri-urban Agriculture"* under the convenorship of Dr J.C. Dagar on 17 November 2020. A number of scientists, administrators and policy makers participated in the discussion. I am grateful to all of them for their valuable inputs.

On behalf of the Academy, I thank Drs J.C. Dagar and R.K. Yadav for synthesising the opinions, comments and suggestions of the participants in the form of this document. My sincere thanks are due to Drs A.K. Singh and S.K. Chaudhari for efficient handling of the discussion and to Drs Kusumakar Sharma, P.S. Birthal and Malavika Dadlani for their editorial support in bringing this document in its present form.

(Trilochan Mohapatra)
President, NAAS

March 2022
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1. INTRODUCTION

According to the United Nations, urban population of the world had exceeded the rural population in 2007, and is projected to be 66% of the total population by 2050 (UN, 2014). Northern America with 82% of urban population is the most urbanized region, and closely followed by Latin America (80%), Europe (74%) and Australia/Oceania (71%). The rate of urbanization is also high in several developing countries. In India, close to 35% of its population is urban and by 2050 about 60% of the population in India will be urbanized. With 1.7 billion people, it will be the most populous country in the world, accounting for about 17.5% of the global population with only 2.4% of land and 4% of water resources. The unplanned urbanization alongwith climate change and natural disasters may cause urban food and health crises, as the cities although covering less than 3% of world's land surface, consume 75% of the natural resources (Borelli et al., 2017). Rapid urbanization is likely to further accelerate the demand for fruits, vegetables, milk, meat and eggs from ever shrinking land and water resources. The per capita availability of freshwater in India has declined substantially, from 5,177 m^3 in 1951 to 1,588 m^3 in 2010, and expected to decline further to 1,140 m^3 by 2050 (CWC, 2010).

At the same time, wastewater disposal is becoming a serious source of land, water, air and food pollution. About 80% of sewage water in the world is currently discharged without treating and the inland towns and cities dispose off about two-thirds of their sewage on land (UN WWAP, 2017). To address this problem, it is necessary to develop sound strategies and policies that enhance multi-functionality of urban and peri-urban green and blue infrastructures. It is, therefore, important to convert the wastewater-threat into an opportunity by utilising it for irrigation and other developmental works. There is a possibility that appropriately treated wastewaters can be used judiciously in innovative agriculture, horticulture, agroforestry, development of lawns/gardens/green-belts/landscapes, growing avenue trees and ornamental plants in open spaces, cultivation of aromatic and ornamental plants, dairy and poultry units in peri-urban areas, vertical farming and development of roof-top vegetable cultivation and aquaculture. Therefore, urban and peri-urban agriculture can play a significant role in managing wastewater related problems after getting proper policy and administrative guidelines. Some of these aspects of urban agriculture along with challenges involved in the management of these wastewaters, and required technical improvements and policy initiatives, are discussed in this paper.

2. PRESENT STATUS OF WASTEWATERS

According to an estimate about 356 km^3 yr^{-1} of wastewater is generated across all the continents; and only 50% of this is treated at primary level (Sato et al., 2013). However, there is a huge difference in the level of treatment in different countries, with 73% in America and 67% in Europe, as compared to 8-32% in developing countries, primarily due to less investment in treatment facilities. In most of the developing countries, 80-90% of the wastewater is estimated to be discharged with little or no treatment into natural water bodies like rivers, lakes, ponds and wetlands.

In India, on an average 61,754 million litres of sewage are generated every day (GoI, 2018), and of this 63% remains untreated and unutilized economically. Further, about one-fourth of this is contributed by 35 metropolitan cities with a population of more than one million. It has been indicated that out of 18.6% total treatment capacity, only 13.5% of sewage is effectively treated (CPCB, 2017). Across states, about half of the sewage is generated in 6 states (Maharashtra 13%, Uttar Pradesh 11.5%, Tamil Nadu 9%, Gujarat 6.7%, Karnataka 6% and Andhra Pradesh 4.6%). Additionally, about 500 million litres of industrial wastewaters are generated, which are loaded with heavy metals, chemicals and other toxic substances. These wastewaters, are a mixture of liquid water discharged from households, farms, institutions, commercial and industrial establishments, which eventually mix with surface waters. Although the composition of wastewater differs due to its origin, it contains a wide range of pathogens such as bacteria, viruses, fungi, algae, protozoa and parasites, and organic and inorganic substances. Overall, about 80% of the pollution is due to sewage and 20% due to industrial effluents and other causes (e.g., burning of crop residues). According to NSSO (2016), about 63% of the rural/peri-urban households do not have the discharge facilities and 31% have open drains, which often lead to mixing of the grey water with faecal matter. As a result, 75% of all surface water bodies in India are contaminated and serve as breeding ground for vector-borne diseases like malaria, polio, dengue, and cholera. It also poses a serious risk of groundwater contamination, particularly in areas with high water tables. Further, half of the country faces high to very-high water stress, and future projections paint an even grimmer water availability scenario (WBSCD, 2019).

3. STATUS OF URBAN AND PERI-URBAN AGRICULTURE

"Peri-urban" can be described as the landscape interface between town and country and is the rural-urban transition zone. Though urban land uses are generally defined, the fringes remain largely open with the majority of the land with agricultural, woodland or other rural uses. Peri-urban agriculture, in turn, is the cultivation undertaken in places on the fringes of urban areas. Lin and Egerer (2018) described **urban agriculture** as the production of different types of food (e.g., vegetables, fruit, mushrooms, spices, eggs, milk, meat, etc) in a variety of urban green spaces (e.g., community or allotment gardens, private gardens, rooftop gardens, orchards, peri-urban areas). Thus, in simple terms, **urban and peri-urban agriculture** (UPA) can simply be defined as the growing of plants/crops and the raising of animals for food and other uses within and around cities and towns, and related activities such as the production and delivery of inputs, processing and marketing of products. UPA often includes food crops, horticulture, livestock production, milk and egg production, fish farming and other enterprises (FAO, 2007).The urban and peri-urban agriculture is a new concept, though the cultivation of avenue trees, plantations and ornamental plants is as old as urban settlements. Agriculture practices within and around cities compete for resources (land, water, energy, labour) that could also serve other purposes to satisfy the requirements of the urban population. First and the foremost role of this mode of agriculture is the production and distribution of food and other agricultural commodities in and around cities, which integrates into the urban economic and ecological systems.

Use of wastewater for irrigation is probably as ancient as agriculture. From the beginning of the Bronze Age (ca. 3200–1100 BC), domestic wastewater (sewage) has been used for irrigation and aquaculture by number of civilizations including those that developed in China and the Orient, Egypt, the Indus Valley, Mesopotamia, and Crete (Angelakis et al., 2018). In the Indus Valley (modern-day Pakistan) advanced sewerage and drainage systems were identified dating back to ca. 2600 BC (Laureano, 2016). In the city of Harappa, every house was connected to the main sewer ensuring the proper removal of the wastes. Local drains were covered and connected to larger sewers used to transport the collected wastewaters for disposal to agricultural lands. Use of human and other wastes for aquaculture were also practiced as early as ca. 1100 BC in various regions in China during the Yin dynasty.

In historic times (ca. 1000 BC−330 AD), wastewater was disposed of or used for irrigation and fertilization purposes by the Greek and later Roman civilizations, especially in areas surrounding important cities (e.g., Athens and Rome). Ancient Greeks were among the first to use wastewater in agriculture (Tolle-Kastenbein, 2005). The earliest documented application of wastewater to the land for agricultural use, occurred in what were known as "sewage farms," first in Bunzlau (modern-day Poland), in 1531 and later in Edinburgh (Scotland) in 1650. In both locations, wastewater was used for beneficial crop production (Tzanakakis et al., 2014). With the rapid growth of cities "sewage farms," involving irrigation and fertilization of agricultural lands, were viewed favourably as an appropriate solution for the disposal of large volumes of wastewater. Large "sewage farms" were established in rapidly growing cities of Europe and the USA at the end of eighteenth century and in Australia in the end of nineteenth century. In Mexico, drainage canals were built around 1890 to collect wastewater from Mexico City and to irrigate and fertilize agricultural lands in the Mezquital Valley. The scheme is now used to irrigate up to 90,000 ha of agricultural cropland and is the largest water reuse scheme in the world (Jimenez and Asano, 2008). The practice of land application of wastewater for disposal and agricultural use was utilized first in European cities and later in USA. Today, water reclamation and reuse projects are being planned and implemented throughout the world. Recycled water is now used for almost any purpose including potable use.

Food, fuel wood and water supply being vital for human needs, domestic wastewater (sewage) has been used traditionally in many countries including Germany, China, India and Southeast Asian countries. However, the large-scale controlled irrigation in established sewage farms in Europe, Australia, India and the United States for prevention of pollution in surface water bodies dates back to the last century only. Pioneering studies on application of treated municipal wastewater on forest lands as a means of purification and groundwater recharge were carried out in central Pennsylvania, USA during 1963 to 1977. The El-Gabal El-Asfar sewage farm in Egypt was established in 1911 to dispose of untreated wastewater of Cairo city. Initially, it covered 200 ha with tree plantations, and gradually expanded to 1,260 ha in mid-1980s with conversion of forest to citrus orchard along with production of cereals and vegetables (Braatz and Kandiah, 1998). Studies examining the effects of wastewater irrigation on tree plantations in Victoria, Australia commenced in 1973, and provided the benchmark potential productivity of wastewater irrigated *Eucalyptus* (CSIRO, 1995). The short-rotation plantation has been found to be a suitable option for wastewater disposal in many countries.

In recent years, the nutrient potential of wastewater and economic gains have also been considered and the nutrient availability in the effluent was found to influence productivity of crops and growth of trees in urban and peri-urban areas (Aghabarati et al., 2008; Deshmukh et al., 2011; Yadav et al., 2016). Angelakis et al. (2018) provided an overview of the evolution of water reuse over the last 5,000 years, along with current practice and recommendations for the future.

Globally, UPA is gaining attention and the organizations like the United Nations Conference on Environment and Development (UNCED), United Nations Centre for Human Settlements (UNCHS), the Food and Agriculture Organization (FAO) and the Consultative Group on International Agricultural Research (CGIAR) – Urban Harvest, are supporting this cause. Since 1999, the FAO has been implementing a global project entitled Growing Greener Cities, with the main objectives of ensuring political and institutional commitment, securing land and water, ensuring product quality while protecting the environment, ensuring participation of all stakeholders, and securing market for the produce (FAO, 2009). In Havana, UPA has covered 12% of the area involving more than 22,000 urban and peri-urban producers resulting in a near elimination of refuse dumps of household waste, accounted for more than 60% of the country's vegetables production, and provided 117 thousand direct and 26 thousand indirect jobs (FAO, 2008). Sahasranaman (2016) discussed and documented several UPA projects from India and other parts of Asia, Africa and Latin America. Roof gardens in Cairo, solar greenhouses in El Alto, Bolivia, micro gardens in slum areas of Bogota and Medellin in Columbia, Edible Landscapes Project in Kampala (Uganda), Backyard Agricultural Programme of Mexico, and Hubli-Dharward Municipal Cooperation urban agriculture practices involving small livestock farming and vegetable cultivation with sewage water, are some examples.

In India, citizens of Mumbai are transforming terraces, balconies and common areas into vegetable gardens. Self-help groups, NGOs and private organizations like City Farming, Earthoholics, Fresh and Local, and Urban Leaves are helping people to grow their own food using treated sewage water by municipalities (Sahasranaman, 2016). In Nagpur and Cuttack, slum dwellers are practicing organic farming on terraces. In Delhi, extensive farming is happening on the banks of river Yamuna, although the farmers have no legal sanction to farm on the river banks. In Hyderabad, farmers along the Musi River use water for urban farming, while in Chennai roof top farming is becoming popular. Government of Tamil Nadu introduced a “Do-it-Yourself” kit under Urban Horticulture Development Scheme in 2014 to enable city dwellers to grow vegetables on open terraces of houses and apartment buildings. The kit is now available in Madurai also. The Department of Horticulture in Karnataka provides support for horticultural activities, and the Horticultural Producers' Co-operative Marketing and Processing Society Ltd was established for marketing of fruits and vegetables covering initially districts of Bengaluru Urban, Bengaluru Rural, Kolar, Ramanagara and Chikkaballapura. The Society obtains horticultural produces directly from its members and supplies fresh produce to rural areas. There is considerable use of wastewater both treated and untreated in urban and peri-urban irrigation in Gujarat. Towards the end of the XI Five Year Plan, a peri-urban vegetable production scheme was launched by the Government of India (DAC, 2011). The Working Group on Horticulture constituted by the Planning Commission for XII Five Year Plan (2012-2017) advocated UPA for provision of environmental services and health care. A National Dialogue organised jointly by the National Horticulture Board and the Indian Institute of Horticultural Research (IIHR) also discussed urban and peri-urban horticulture and advocated land utilisation, interior and exterior landscaping, vertical gardens, and terrace cultivation of fruits and vegetables and mushroom culture (Singh and Malhotra, 2013). Government of India launched Smart Cities Mission (SCM) with an objective to promote sustainable and inclusive cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of smart solutions. The top five development categories - transportation, energy and ecology, water and sanitation, housing and economy – constitute almost 80% of the SCM budget. Atal Mission for Rejuvenation and Urban Transformation (AMRUT) project, one of the flagship programmes of the Ministry of Housing and Urban Affairs in which the laying of storm water drain lines, installation of rainwater harvesting system and intermediate pumping stations are the main components, is under implementation in many cities across the country. All this will help in developing smart agricultural systems in urban and peri-urban areas using wastewaters.

4. UTILIZATION OF WASTEWATERS IN URBAN AND PERI-URBAN AGRICULTURE

4.1 Wastewater Typology and Problems Associated with Use in Agriculture

Based on source of generation, the wastewater can be classified as municipal wastewater, domestic wastewater (i.e., spent water from communities after a variety of uses in domestic houses, commercial buildings and institutions); and industrial wastewater. The primary parameters of the importance for irrigation include total salt concentration, suspended solids, electrical conductivity, hydrogen ion activity (pH), toxic ions (boron, chloride and sodium), trace elements and heavy metals. Different countries base their standards on various characteristics of treated wastewater—although BOD is almost universally used. A snapshot of regulated parameters across countries is illustrated in Figure 1, which also shows that discharge limits are most commonly set on the basis of organic pollutants and nutrients (Schellenberg et al., 2020). Once the desired discharge standard is fixed, the choice of technology is determined by the desired quality of treated wastewater. However, the major concern with wastewater use for irrigation relates to the limits of pathogenic, and organic and inorganic contaminants influencing BOD.

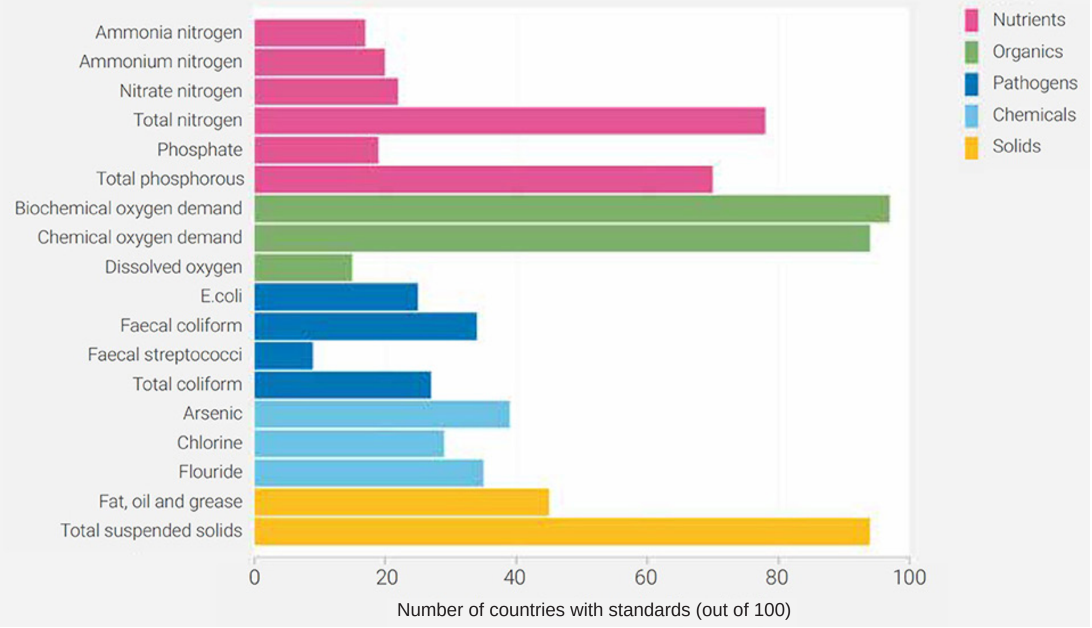

Fig. 1 National discharge standards of 100 countries (WHO, 2017; cited from Schellenberg et al., 2020)

Wastewater contains a range of pathogenic organisms, i.e., bacteria (*faecal streptococci, clostridium*), viruses (enteroviruses, rotaviruses), helminths, parasites, *Salmonella* and intestinal nematodes. These pathogens cause diseases such as diarrhoea, cholera, viral infections and other ailments in human beings and animals. In addition, wastewater also contains organic and inorganic contaminants such as aldrin, benzene, chlordane, chloroform, DDT, hexachlorobenzene, lindane, and tetrachlorethylene; and cadmium, chromium, nickel, arsenic, cyanide, fluoride, lead, mercury, nitrate and selenium are major contaminants of wastewater. The potential contaminants and associated hazards are shown in Table 1.

Table 1. Potential contaminants in wastewater and hazards associated with its use in agriculture

Contaminants	Parameters/ biological organisms	Hazards/concerns
Pathogens	Bacteria (*Escherichia coli*, faecal coliforms, *Salmonella*, *Shigella*, *Vibrio cholera*, *Clostridium*, *Bacillus*), Viruses (polio, hepatitis, cocksakie, rota), helminths (*Ascaris*, *Trichuris*, *Ancylostoma*, *Schistosoma*), protozoa (*Entamoeba, Giardia*), nematodes and parasites	Communicable diseases such as diarrhoea, cholera, typhoid, food poisoning, salmonellosis, dysentery, gastroenteritis, polio, hepatitis, coxsackie infection, ascariasis, trichuriasis, ancylostomiasis, schistosomiasis, amoebiasis, giardiasis, etc.
Biodegradable and stable organics	Biological oxygen demand (BOD), chemical oxygen demand (COD), phenols, pesticides, chlorinated hydrocarbons	Depletion of oxygen demand, development of septic conditions, hindrances in aquatic ecosystem, hazards to habitats, persistent toxicity in environment, hazards for irrigation, etc.
Suspended solids	Volatile compounds, suspended and colloidal impurities	Anaerobic conditions with deposition of sludge, clogging of sprinklers and drippers
Heavy metals	Cd, Cr, Ni, Pb, Zn, As, Hg, etc.	Accumulation in soils, crops, aquatic organisms, ingestion by human and animals, contamination of food chain and environment

Source: Yadav and Dagar (2016)

Although the organic and inorganic constituents of wastewaters are low in concentration, their ingestion over a prolonged period is detrimental to human and animal health. Heavy metals enter and accumulate in human body through food chain (fish, vegetables, fruits, non-vegetarian food, etc) to the extent of non-tolerable limit and occasionally cause untimely mortality. Permissible limits of heavy metals in water, wastewater, agricultural soil and plants (US EPA, 2002; CPCB, 2006; WHO, 2006, 2011) are shown in Table 2.

Table 2. Permissible limits of heavy metals in different resources

Organi-zation/ country	Resource	Recommended/threshold limits (ppm)					*E.coli* (No. per 100 ml)	Nematodes (No L^{-1})	BOD
		Hg^{2+}	Cd^{2+}	Pb^{2+}	*Cr^{6+}	Ni^{2+}			
WHO	Drinking water	0.006	0.005	0.01	0.01	0.07	<1000	< 1	Nil
	Wastewater	0.001	0.003	0.01	0.05	0.02			<30
	Soil (agricul-ture)	0.05	0.003	0.1	0.1	0.05	--	--	<100
	Plants	0.1	0.02	0.1–0.3	1.3	10	--	--	
US EPA	Drinking water	0.002	0.005	0.05	0.1	0.02	--	--	
	Wastewater	0.0003	0.01	0.006	0.05	0.2	--	--	
	Soil (agricul-ture)	1.0	0.5	200	11	72	--	--	
	Plants	0.015	0.2	0.3	2.3	--	--	--	
India CPCB	Surface water	0.01	2.0	0.1	0.1	3.0	--	--	30
	Wastewater	0.01	1.0	1.0	2.0	3.0	--	--	
BIS	Drinking water	0.001	0.003	0.01	0.05	0.02	nil	-	-

*Only hexavalent form of chromium (Cr) is toxic

4.2 Opportunities and Problems of Using Wastewater

Wastewater use in agriculture presents opportunities as well as challenges. Opportunities include low-cost disposal option, reliable source of irrigation, conservation and supplementing supply of water and nutrients for agriculture. However, adoption of more of disposal oriented and unscientific irrigation practices pose health risks to farmers and consumers. The potential problems associated with wastewater use in agriculture are transmission of diseases from excreta related pathogens and vectors, and pollution of environment through accumulation of salts, toxic chemicals and pesticides in soils, surface water bodies and groundwater. Irrigation using raw or partially treated sewage and industrial effluents, is cited as the main reason for accumulation of heavy metals in vegetables. Use of such effluents enhanced availability of metals in agricultural soils; and ultimately leading to significant contribution towards contamination of food chain through their accumulation in vegetables, and other food and fodder crops grown on such soils.

Besides being a source of irrigation water, these wastewaters contain appreciable amounts of plant nutrients and, therefore, higher microbial biomass carbon was recorded in these sewage-treated soils due to the enormous supply of organic matter (Rattan et al., 2001, 2002). Hence, reuse of domestic and industrial waste water in agriculture for irrigating crops appears to be a lucrative option. Hussain et al. (2019) reported that the vegetables when irrigated with treated wastewater brought from a nearby full-scale sewage treatment plant, the concentration levels of the Cd, Co, Cu, Mn and Zn in the leaves were found below toxic limits as prescribed in the literature. Daily intake metals values suggested that the consumption of plants grown in treated wastewater and tap water was nearly free of risks, as the dietary daily intake limits of Cu, Fe, Zn, and Mn in adults can range from 1.2 to 3 mg, 10 to 50 mg, 5 to 22 mg and 2 to 20 mg, respectively. Rattan et al. (2005) assessed the long-term effect of sewage irrigation on heavy metal content in soils, plants and groundwater where various cereals, millets, vegetable and fodder crops were successfully grown. Results indicated that sewage effluents contained much higher amount of P, K, S, Zn, Cu, Fe, Mn and Ni compared to groundwater. While, there was no significant variation in Pb and Cd concentrations in these two sources of irrigation water, and the metel content were within the permissible limits for their use as irrigation water. There was an increase in organic carbon content ranging from 38 to 79% in sewage-irrigated soils as compared to tubewell water-irrigated ones. On an average, the soil pH (alkaline in nature) dropped by 0.4 unit as a result of sewage irrigation. Sewage irrigation for 20 years resulted into significant build-up of DTPA-extractable Zn (208%), Cu (170%), Fe (170%), Ni (63%) and Pb (29%) in sewage-irrigated soils over adjacent tubewell water irrigated soils, whereas Mn was depleted by 31%. Soils receiving sewage irrigation for 10 years exhibited significant increase in Zn, Fe, Ni and Pb, while only Fe in soils was positively affected by sewage irrigation for 5 years. Among these metals, only Zn in some samples exceeded the phytotoxicity limit. Fractionation study indicated relatively higher build-up of Zn, Cu, Fe and Mn in bioavailable pools of sewage-irrigated soils. By and large, tissue metal concentrations in all the crops were below the generalized critical levels of phytotoxicity. Based on the soil to plant transfer ratio (transfer factor) of metals, relative efficiency of some cereals, millet and vegetable crops to absorb metals from sewage and tubewell water-irrigated soils were worked out. Risk assessment in respect of metal contents in some vegetable crops grown on these sewage-irrigated soils indicated that these vegetables can be consumed safely by human.

In well-conducted long-term experiments, Deshmukh et al. (2011, 2015) reported the impact of wastewater irrigation on the dynamics of metal concentration and biological properties in an area where treated sewage water was applied for 20, 10 and 5 years in different villages of the western part of National Capital Territory of New Delhi under Keshopur Effluent Irrigation Scheme. Results indicated that there was significant increase in bacterial and fungal count in sewage-irrigated soils as compared to their respective control (with tubewell water). As high as 31.7%, 27.9% and 20.2% increases in bacterial count were recorded under 20,10- and 5-years sewage-irrigated soils, respectively as compared to controls. The population density of bacteria and fungi in wastewater-irrigated soils increased with the duration of sewage water application and decreased with increasing depth. The bacterial and fungal count was also directly proportional to organic carbon, sand and silt content and negatively correlated to the clay content, electrical conductivity, pH and bulk density of the soil. These microbes can even outnumber the autochthonic soil microorganisms which are native to the soil. The allochthonic microorganisms are generally parasitic and can contaminate the groundwater with the pathogenic bacterial species. The significant increase in the bacterial and fungal population density at the greater depths in sewage-irrigated soils over tubewell water-irrigated ones in the vadose zone is also a precursor of possible pollution of the shallow and deep groundwater of sewage-irrigated areas. The results also indicated that pathogens *Citrobacter freundii* and *Salmonella typhi* were dominant in shallow groundwater, while *E. coli* was dominant in deep groundwater collected from sewage-irrigated field. This implied that *C. freundii* and *Salmonella* could not enter into the deep groundwater under sewage-irrigated field after passing through vadose zone but *E. coli* can also pollute the deeper layers of groundwater.

Although maximum accumulation of metals (depending on metals and species of crops) occurs in roots followed by stalks and leaves; but Pb, Zn, Cd, Cr and Ni in vegetables are at times found beyond the safe limits (Table 3). Ahmed et al. (2019) reported that when crops irrigated with water having metal concentration higher than permissible levels, the metal concentration in vegetables was found higher, while in soil the concentrations of all the metals was below the permissible levels.

Table 3. Contents of heavy metals in different crops irrigated with wastewater

Crop	Contents of heavy metals (µg g^{-1}) dry weight of crop					
	Cd^{2+}	Cr^{6+}	Ni^{2+}	Pb^{2+}	Zn^{2+}	Cu^{2+}
Mitra and Gupta (1999)						
Lettuce	13.4	61	52	35	171	25
Mint	10.4	68	54	22	139	26
Cauliflower	13.8	87	59	31	97	16
Celery	12.0	35	43	24	93	21
Spinach	14.6	96	69	50	154	34
Coriander	14.0	48	51	31	136	25
Chinese onion	11.5	46	47	34	125	18
Radish	17.8	78	63	58	139	28
Heavy metal contents in wastewater used for irrigation (µg L^{-1})	4.9	20	113	7	356	85
Yadav et al. (2015)						
Beet (root)	3.14	1.89	1.72	6.42	--	--
Faba bean (pod)	1.84	NT	0.96	1.34	--	--
Cauliflower (curd)	0.92	NT	NT	1.48	--	--

Crop	Contents of heavy metals (µg g^{-1}) dry weight of crop					
	Cd^{2+}	Cr^{6+}	Ni^{2+}	Pb^{2+}	Zn^{2+}	Cu^{2+}
Mitra and Gupta (1999)						
Brinjal (fruit)	1.18	NT	NT	1.87	--	--
Okra (fruit)	1.43	1.06	1.37	3.19	--	--
Bottle gourd (fruit)	1.65	0.52	0.64	2.86	--	--
Heavy metal contents in wastewater used for irrigation* (mg L^{-1})	24	94	88	101	NA	NA
LSD($p \leq 0.05$)	0.60	NS	0.47	1.24	--	--
Safe limits (Awashthi, 2000)	1.5	20	2.5	50	30	1.5

NT stands for non-traceable; NA-not available * not used in statistics among crops

Source: Yadav and Dagar (2016)

4.3 Management Interventions for Risk Reduction Using Wastewater

In big cities, oxidation pond or activated sludge process is still the most commonly used technology (Gloyana, 1971), followed by up-flow anaerobic sludge blanket technology (Hosetti et al., 1995; Scholz, 2016). A series of waste stabilization ponds, are also used as the most suitable wastewater treatment system in developing countries. Regarding industrial wastewater, small-scale industries may not be able to afford the cost of wastewater treatment plant and common effluent treatment plants (CETPs) can be set-up for clusters of small-scale industries. The treatment methods generally adapted in these plants include dissolved air floatation, dual media filter, activated carbon filter, sand filtration and tank stabilization, flash mixer, clariflocculator, secondary clarifiers, and sludge drying beds. Coarse material and settable solids are removed during primary treatments by screening, grit removal and sedimentation. As treated industrial wastewater from CETPs is disposed in rivers. it must be treated completely before its disposal, and sewage must at least be treated primarily, so that it is not loaded with heavy metals.

As stated above, sewage is usually rich in nutrients, and if used after primary treatment, may find popularity in urban agriculture. In a long-term irrigation with sewage water from municipal origin, Yadav et al. (2003) observed build-up of total N (up to 2,908 kg ha^{-1}), available P (58 kg ha^{-1}), total P (2,115 kg ha^{1}), available K (305 kg ha^{-1}) and total K (4,712 kg ha^{-1}) in surface soil with variable vertical distribution. Traces of NO_3-N (up to 2.8 mg l^{-1}), Pb (up to 0.35 mg l^{-1}) and Mn (up to 0.23 mg l^{-1}) could also be observed in open wells near the disposal point, thus contaminating the groundwater. The risks of using untreated or partially treated wastewater in agriculture can be reduced through wastewater treatment and non-treatment options or a combination of both (WHO, 2006). These include: water-quality improvements, human exposure control, technical interventions (phytoremediation), farm-level wastewater management, crop restrictions, localized (drip) irrigation, cessation of irrigation before harvest, and harvest and post-harvest interventions.

4.3.1 Water-quality improvements

The first and foremost step towards improving wastewater quality is its primary treatment. This is simply a sedimentation process in which the organic and inorganic solids are allowed to settle and then removed. The process reduces biological oxygen demand (BOD) by 25-50%, total suspended solids by 50-70%, and oil and grease contents by 55-65% (FAO, 2006; Yadav et al., 2016). Some organic nitrogen, phosphorus and heavy metals are also removed. Primary treated effluents may be of acceptable quality for irrigation of trees, orchards, vineyards, fodder crops and some food crops (Ayers and Westcot, 1985).

Secondary treatment can be implemented using methods such as waste-stabilization ponds, constructed wetlands, infiltration-percolation, and up-flow anaerobic sludge blanket reactors (Mara, 2003). Judicious storing of reclaimed water in reservoirs improves its micro-biological quality and provides peak-equalization capacity, which increases reliability of supply and improves the rate of re-use (Qadir et al., 2010). Constructed wetlands also serve as habitat for wildlife, anthropogenic wastewater discharge and treatment, and stabilizing other related ecological disturbances. Aquatic plants such as emergent *Typha latifolia, T. angustifolia, Phragmites australis, P. karka, Juncus acutus, J. maritimus, J. rigidus, Colocassia esculenta, Rumex dentata, Acorus calamus, Sagittaria sagittifolia, Iris pseudacorus* and species of *Cyperus, Scirpus* and *Carex;* and floating *Eichhornia crassipes, Salvinia molesta, Pistia stratiotes, Lemna minor, Azolla pinnata* and *A. filiculoides* can be established in wetlands and some of these have use for paper pulp. The wetland acts as a bio-filter, removing sediments and pollutants from water. Groundwater recharge with deep percolation through soil aquifer treatment (SAT), as practiced in Tula Valley (Mexico), can remove micro-organisms (Asano and Cotruvo, 2004) and help in treatment of wastewater.

4.3.2 Human exposure control

In respect of pathogen concentrations, raw wastewater should never be considered safe (WHO, 2006). It requires awareness campaigns against diseases that can be transmitted through wastewater use. Protective measures such as wearing of gloves, boots, masks, washing hands properly and changing irrigation methods can reduce farmers' exposure. The sprinklers should not be used for wastewater irrigation. Sub-surface drip irrigation is more appropriate method of irrigation, particularly in food crops and furrow irrigation in tree crops. Precautions such as cessation of irrigation before harvest, harvest and post-harvest measures, harvesting cereal and fodder crops slightly above the ground, and proper washing of food crops with good-quality water after harvest will certainly help in reducing the health risk of field workers.

4.3.3 Technical interventions (Bioremediation)

Toxic inorganic and organic chemicals present in wastewaters are major contributors to environment contamination and pose a severe health risk to the human population. Removal of these chemicals and prevention of further contamination from them presents an immense technical challenge. Unlike organic compounds that can be mineralized, the remediation of inorganics requires removal or conversion into a biologically inert form. **Bioremediation** is a natural process, which relies on bacteria, fungi, and higher plants to remove, reduce, degrade, or immobilize environmental pollutants from soil and water, thus restoring contaminated sites to a relatively clean nontoxic environment (Wang et al., 2021). Metabolic processes of these organisms are capable of using chemical contaminants as an energy source, rendering the contaminants harmless or less toxic products, therefore, bioremediation is often considered a cost-effective and environment friendly method and is gradually making inroads for environmental clean-up applications (Ashraf et al., 2019). This activity can be carried out by green plants that are able to remove pollutants from the soil or water by absorption through the roots and accumulation into the leaves (**phytoremediation**); and can make use of microorganisms to detoxify or remove inorganic pollutants from the environment **(micro-organism remediation**). The technology is cost-effective, efficient, novel, eco-friendly, and solar-driven with good public acceptance as compared with engineering techniques like excavation, soil incineration, soil washing, flushing, and solidification. The efficiency of bioremediation on removing inorganic pollutants usually depends on numerous plants, microbes, and soil/water factors such as the physicochemical properties of the soil/water, microbial, and plant exudates as well as the capacity of living organisms to uptake, accumulate, sequester, translocate, and detoxify pollutants (Khalid et al., 2017). Hasanuzzaman and Prasad (2021) have compiled comprehensive account of physiological, molecular and biotechnological interventions of bioremediation.

Physicochemical approaches have been widely used for remedying polluted soil and water, especially at a small scale. However, more difficulties are experienced for a large scale of remediation because of high costs and side effects (Lone et al., 2008). The use of plant species for cleaning polluted soils and waters (phytoremediation) has gained increasing attention since last two decades, as an emerging cheaper technology. The ability to accumulate heavy metals varies significantly between species and among cultivars within species, as different mechanisms of ion uptake are operative in each species, based on their genetic, morphological, physiological and anatomical characteristics.

Hooda (2007) listed terrestrial plant species, having 100 to 1,000 times more accumulation potential for one or more heavy metals than those normally accumulated by plants grown under the same conditions. In comparison to food crops, wastewater irrigation in plantations is a relatively safe, cost-efficient and environmentally safe way to treat and dispose wastewater (Minhas et al., 2015). On wastewater irrigated soils, trees accumulate relatively higher heavy metals than several bushes and grass species. Beneficial effects of organic load in wastewater and sludge on tree growth processes outweighed any adverse impacts of the added metals. Prolonged sewage irrigation markedly increases Fe, Zn, Mn, Cu, Pb and Ni in leaves and fruits of *citrus* and olive trees without adversely affecting their growth and accumulation of metals beyond the safe limits in fruits (Aghabarati et al., 2008). Lone et al. (2008) mentioned that more than 400 plant species have been reported to act as metal hyperaccumulators. These include either high biomass plants such as willow (*Salix* spp) or those that have low biomass but high hyperaccumulating characteristics (*Thlapsi* and *Arabidopsis)*. The number of species identified to have ability to accumulate one or more metals >1000 mg kg^{-1}dry weight is listed in Table 4 (Reeves, 2003; Lone et al., 2008).The metal ions that are accumulated in the aerial parts can be harvested to dispose or burnt to recover metals. More in-depth studies are needed in this field.

Table 4. Number of plant species that are reported to have hyper accumulation traits

Metals	Number of species	Metals	Number of species
As	04	Pb	14
Cd	01	Se	20
Co	34	Zn	04
Cu	34	Hg	01
Ni	>320		

Some aquatic species have been identified and tested for the phytoremediation of heavy metals from polluted wastewater. These include sharp dock (*Polygonum amphibium*), duck weed (*Lemna minor*), water hyacinth (*Eichhornia crassipes*), water lettuce (*P. stratiotes*), water dropwort (*Oenathe javanica*), calamus *(Lepironia articulata*) and pennywort (*Hydrocotyle umbellata*) (Prasad and Freitas, 2003).To identify plants with the ability to accumulate these metals, 300 accessions of 30 plant species were tested by Ebbs et al. (1997) and found that many species of *Brassica* (*juncea, napus, rapa*) exhibited moderately enhanced Zn and Cd accumulation. While reviewing the uptake of heavy metals (As, Pb and Hg) by plants, Tangahu et al. (2011) reported that fern *Pteris vittata* is capable of accumulation of arsenic (As) to the extent of 0.7 mg g^{-1} dry weight of plant, and aquatic *Azolla caroliniana* and terrestrial *Populus nigra* can accumulate 0.2 mg of arsenic per gram dry weight of plant root. Although some species have shown hyperaccumulation of different metals; for example, *Brassica campestris, B. carinata, B. juncea* and *B. nigra* accumulated> 100 mg Pb g^{-1} dry weight; and *B. napus, B. oleracea* and *Helianthus annuus* > 50 mg Pb g^{-1} dry weight; and *B. juncea*> 1 mg Hg g^{-1} dry weight, these may contaminate the food chain. Species of two genera *Thlapsi* and *Arabidopsis* have been most extensively studied by scientific community as hyperaccumulators. *Thlaspi* spp. are known to hyperaccumulate more than one metal, i.e., *T. caerulescens* for Cd, Ni, Pb and Zn;*T. goesingense* for Ni and Zn; *T. ochroleucum* for Ni and Zn; and *T. rotundifolium* for Ni, Pb and Zn (Prasad and Freitas, 2003). Robinson et al.(1998) found *T. caerulescens* as hyperaccumulator for Cd and Zn that could remove as high as 60 kg Zn ha^{-1} and 8.4 kg Cd ha^{-1}.

Cultivation of fuel wood trees, aromatic plants and cut-flowers can serve the purpose of phytoremediation more effectively. Lal et al. (2013) recorded 16% higher biomass yield of lemon grass (*Cymbopogon flexuosus*); and increasing plant Cd, Cr, Ni and Pb concentrations from 1.54 to 1.85, 3.27 to 4.04, 4.35 to 5.58, and 3.53 to 4.46 mg kg^{-1} dry biomass,respectively, but without any contamination of essential oil. In similar studies conducted earlier, Lal et al. (2008) observed that cut-flowers such as marigold (*Tagetes erecta*), chrysanthemum (*Chrysanthemum indicum*) and gladiolus (*Gladiolus grandiflorus*) have potentialin Cd-contaminated environment. Other ornamental and cut-flower species such as *Jasminum sambac*, *Jasminum grandiflorum* and *Polianthes tuberosa* are also suitable for urban greening and avenue culture with wastewater irrigation. Hence, these income generating crops can be successfully grown by small farmers utilizing contaminated wastewaters. Further, we need to develop eco-friendly low-cost remediation technologies such as *Jalopchar*™ developed by IARI (Box 1). Instead of the aerators and

Box-1. Jalopchar technology and its demonstration

Jalopchar™ is an innovative, eco-friendly, scientifically validated and scalable Plant-Media-(Native) Microbe integrated decentralized wastewater treatment technology of ICAR-IARI that is associated with high multi-pollutant reduction at low CAPEX/ OPEX demand and can be retrofitted to both rural / peri-urban and urban environments (Kaur, 2020). It has now emerged as a milestone in the water management research programme of ICAR, and already recommended for national level adoption and implementation by the Parliamentary Committee on Agriculture, and for extension to Indian cities by the Ministry of Urban Development. The technology has been validated through its wide scale operationalization as 2.2 million litres per day capacity large community scale sewage treatment facility; 50,000 litres per day capacity combo rainwater harvesting and wastewater treatment facility and 1,500 litres per day capacity rural household facility at the IARI experimental farm along with a 75,000 litres per day capacity rural sewage treatment facility at Pandit Deen Dayal Upadhyay village in Farah, Mathura; 50,000 litres per day capacity sewage treatment facility at All India Women's Conference, New Delhi; 1,00,000 litres per day capacity sewage treatment facility at residential boarding schools under Jawahar Navodaya Vidyalaya at Kansiram Nagar, Uttar Pradesh and at Palwal, Haryana and 1,00,000 litres per day capacity sewage treatment facility at ICAR-CAZRI, Jodhpur, Rajasthan as shown in Box 2.

chemicals, conventionally used in sewage treatment plants, the technology harnesses the pollutant sequestering potential of the hyper-accumulative emergent wetland plants such as *Typha latifolia, Arundo donax, Phragmites karka, Acorous calamus* and *Vetiver zizanioides* and the native micro-organisms. The technology has demonstrated exceptional efficiencies with respect to BOD (78 to 88%), turbidity and pathogen load (90 to 99%) as well as nitrate and phosphate reduction (30 to 57%). Unlike conventional sewage treatment plants, it could also demonstrate exceptional metal reduction efficiencies (57 to 100%), thereby making the so-treated wastewaters completely safe for agriculture / aquaculture (Kaur, 2020).

The details of the effectiveness of Jalophar Technology as demonstrated by the unit set up in ICAR-CAZRI, Jodhpur is given in Box 2.

Box 2: Use of sewer water for income generation

- A sewer wastewater treatment plant with100-thousand-liter capacity is functional at CAZRI Jodhpur, which was used for growing green fodder. The treated wastewater contains Zn (0.47 ppm), Mn (0.22 ppm), Cu (0.14 ppm), Fe (3.78 ppm), Ni (0.08 ppm), and Pb, Cr and Cd (nil) within the safe limits. The area of fodder crops under the system was 0.60 ha where Napier Bajra Hybrid and tree *Moringa oleifera* were taken as base crops to supply round the year green fodder. These perennial crops were planted at 3.0 m × 0.8 m spacing and the open inter-spaced area was used to grow fodder sorghum and bajra during summer season and lucerne and oat during *rabi*.
- Napier hybrid was cut six times from August to June and *Moringa* lopped four times in a year. The *kharif* sown cereals produced about 118.5 Mg green fodder from a single cut while Napier Bajra Hybrid and *Moringa* produced 31.25 and 2.5 Mg green leaf fodder, respectively. The *rabi*-sown lucerne and oat were sown in the last week of October. Seven cuttings were taken from December to April from lucerne and two from oat. These crops produced 24.30 and 22.17 Mg green fodder, respectively.
- The total green fodder produced from the 0.60 ha system crossed 200 Mg with a net return of ₹ 363,743. The cost of irrigation system including main and sub-main pipes, sand and disc filter and inline laterals was ₹142,000. In the first year, the system realized a net income of ₹ 221,743. This system has the capacity to meet round the year green fodder requirement of 36 adult cattle unit (ACU). System has potential to give a net return of ₹ 606,238 ha^{-1}.
- To mitigate the deficit supply of green and dry fodder, such type of models needs to be included in livestock development policies. Incentives may also be given to the local administrative bodies for construction of wastewater treatment plants so that the programme may be adopted both for environmental safety and revenue generation.

Source: Anonymous (2020)

Although bioremediation is a promising approach for remediation of inorganic pollutants from contaminated media, it also has several challenges (Ashraf et al., 2019): it requires a long time for clean-up; phytoextraction efficacy of most hyperaccumulator plants is generally restricted by their low biomass and slow growth rate; environmental conditions are a great determinant of the efficiency of phytoremediation; contamination by multiple pollutants require the use of specific species as only very few species absorb multiple pollutants; safe disposal of the polluted biomass; introduction of invasive plant species as hyperaccumulators may affect the indigenous floral diversity; and the exogenous application of microorganisms could disturb the stability of biological treatment systems.

4.3.4 Farm-level wastewater management

In peri-urban areas, improved wastewater irrigation management at farm-level includes suitable practices such as crop selection, irrigation management and other soil-based interventions. Cultivating crops not intended for human consumption like cotton, cut flowers etc. may be preferred for wastewater irrigation. Such interventions can reduce potential health and environmental risks to some extent. However, it was found that diluted or untreated wastewater is frequently used in vegetables and cereals near all the cities, which is very dangerous for food chain contamination as many of the vegetables are consumed raw and also contain metals beyond the permissible levels. A safer alternative could be production of urban forestry and agroforestry, avenue and roadside plantations grown for fuel and timber as well as aromatic crops (e.g., *Matricaria*, lemon grass, ross grass, and vetiver grass) and cut-flower yielding species (C*hrysanthemum*, gladiolus, jasmine and *Polianthes*) in urban green areas, which do not come directly in the food chain.

When choosing irrigation methods, growers should consider quality of water supply and health and environmental implications due to pathogenic and metal contamination of crops. Furrow irrigation and sub-surface drippers provide better health protection to farmers and consumers as compared to flooding (Minhas and Samra, 2004). An additional possibility is the cessation of irrigation prior to harvest to allow pathogens' natural die-off. Soil based intervetnions may be recommended in situations where the waste waters are containing heavy metals in non-edible crops as heavy metals tend to accumulate on the soil surface. For moderate levels of metals and metalloids in wastewater, there is no particular management needed if the soils are calcareous. However, there can be a problem in acidic soil that require lime treatment and when irrigating with wastewater containing elevated levels of sodium, soil structure deterioration may occur and we require application of calcium source such as gypsum (Qadir et al., 2010). Care is also to be taken regarding detrimental effects of salts, nitrates, metals and pathogens reaching groundwater; the shallower the water table the more the danger (Deshmukh et al., 2011; Yadav et al., 2016)

4.3.5 Harvest and post-harvest interventions

These interventions involve process of harvest, post-harvest cleaning, handling during transport, marketing, storage, and preparation in kitchens. Harvesting cereal and fodder crops above a certain height from ground minimizes pathogens.

4.4 Judicious Use of Wastewaters

The hard fact is that the enormous amount of sewage generated is beyond the recycling capacity of local systems, and it is the need of the hour to explore safe, environmentally sound and cost-efficient ways for its treatment and disposal. Some of the practices are briefed here:

4.4.1Tree plantations/agroforestry interventions for wastewater use

The wastewater provides sufficient irrigation water and nutrients to improve plant growth (Deshmukh et al., 2011; El Moussaoui et al., 2019; Lal et al., 2020). However, excess supply of nutrients needs to be taken care of by selecting suitable crops, fast-growing tree species and better planning of plantation projects to produce more biomass and develop urban and peri-urban green spaces and green belts. The biggest advantage of growing trees with wastewater is the immobilization of heavy metals in the form of wood and no need of worrying about their disposal for a long period. They also sequester carbon and help improve local environment and mitigation of adverse impacts associated with climate change. Some success stories related to urban forests development using wastewater are shown in Box 3.

Box 3: Some successful models of Urban Forests in India

1. The Warje forest in Pune, Maharashtra is the first ever urban forestry project developed on a 16 ha barren strip of land by TERRE under a public-private partnership model as a corporate social responsibility initiative. It is rich in biodiversity of flora and fauna.
2. Aravalli Biodiversity Park of Gurugram (Haryana) was created on 153.7 ha degraded mined landscape by a unique partnership between the municipal corporation and residents. It has now hundreds of flowering trees and shrub species and attracting more than 200 bird species.
3. On the occasion of World Environmental Day in 2020 under the Nagar Van Scheme, it was decided to develop 200 Urban Forests across the country in the next five years with a renewed focus on people's participation and collaboration between the Forest Department, Municipal bodies, NGOs, corporates and local citizens. This is a good way to involve and educate people, especially youth about the importance of UPA and mitigating climate change.

Urban Forestry Operate at Scales Ranging from
Single Trees to Landscapes and Ecosystems

Photos by SR Gupta

A major concern with wastewater irrigation is the fate of the excess sequestration potential of nitrogen (N) and phosphorus (P) in environment, as they pollute surface and groundwater (Duncan et al., 1998; Yadav et al., 2015). Another serious concern associated with wastewater irrigation in agriculture is the management of metallic and pathogenic pollution. The tree species for urban greening should be selected on the basis of the nature of elements present in wastewater to be used. Species of *Acacia, Mimosa, Anadenanthera* and *Salix* are efficient in absorbing Cd; *Eucalyptus* and mangroves are efficient in Pb accumulation; *Genipa americana* is efficient in Cr absorption; and *Salix viminalis* can remove up to 20% Cd and 5% Zn (Duncan et al., 1998).

Therefore, tree plantations can accumulate and lock-up lot of loads of heavy metals in wood. Many hyperaccumulators such as species of *Arabidopsis, Brassica, Sedum* and *Thlapsi* can be cultivated and biomass removed for harvesting the accumulated metals.

Landscaping is a very important intervention in urban and peri-urban areas. The common local avenue trees, which can easily be grown in peri-urban areas along roadsides, parks and other public places and irrigated with partially treated sewage water, may be given preference.

The potential benefits of wastewater irrigation in tree plantations include– relatively safer and low-cost treatment and disposal; augmentation of nutrient and water supplies; environmental services such as climate improvement, soil enrichment, biodiversity improvement, and carbon sequestration. Urban plantations and green areas provide some direct and indirect benefits to the society. In addition to the direct benefits such as fuel wood, food, fodder, and fuels; these improve air, water and land resources and also provide safer outlet for the disposal of urban wastes. Plantations also help in controlling erosion, urban water supplies, and habitats for wildlife.

Selection of plantation species for urban agroforestry or greening with use of wastewater will depend on the prevailing environmental conditions for which they are planned. However, after due consideration of local climate and soils, wastewater quality and quantity, the important traits that should be considered in species selection include (i) fast-growth (e.g., *Populus* and *Eucalyptus*), (ii) tolerance to soil conditions, (iii) tolerance to climatic conditions, (iv) ease of propagation, and (v) evergreen characteristic. Wastewater used for irrigation of plantations in urban green areas is suggested as safer and relatively more productive alternative in arid zone areas. Re-used wastewater recharges aquifers and also reduces demand for scarce freshwater. The practice of at least partially treating wastewater in stabilization ponds integrated into park systems and other green areas must be considered as an economic and ecological alternative to conventional urban wastewater treatment. In plantations, the higher wastewater use is due to the combination of deeper rooting, extended growing seasons, and higher inputs of radiant energy because of lower albedos as compared to herbaceous covers or cropped lands.

4.4.2 Horticultural interventions

Environmental benefits and synergies can be achieved when horticulture is planned as a part of urban landscapes. Trees and other ornamental plants reduce carbon footprint. Generally, the ornamental value is the main consideration in selecting horticultural plantation species for greening public urban areas as these are less subject to damage and theft. India has responded well in giving importance to horticulture both for vegetable production in peri-urban areas and greening the landscapes in urban areas. Farmers in the peripheral of cities are cultivating ornamental cut-flowers such as marigold (*Tagetes erecta*), chrysanthemum (*Chrysanthemum indicum*), gladiolus (*Gladiolus grandiflorus*), *Jasmine sambac, J. grandiflorum*, and *Polianthes tuberosa* successfully which are sold in urban markets. Other high value cut flowers may also be tried using wastewaters. Lal et al. (2013) observed that lemon grass (*Cymbopogon flexuosus*) could be successfully grown using primary treated municipal wastewater for achieving higher productivity without contamination of the end product-the essential oil. This grass also accumulated heavy metals like Cd, Cr, Ni and Pb from the wastewater used for irrigation containing these metals. Some of the aromatic plants such as mentha (*Mentha arvensis*), lemon grass, Java citronella (*Cymbopogon winterianus*), palmarosa (*C. martini*), and vetiver (*Vetiveria zizanioides*) could be grown successfully as inter-crops with poplar (*Populus deltoides*) and *Eucalyptus tereticornis* (Singh et al., 1998). Teak (*Tectona grandis*) plantations with patchouli (*Pogostemon patchouli*), an essential oil crop, cut-flowers and foliage crops such as species of *Anthurium* and *Heliconia* have been successfully cultivated using wastewater (Wilkinson and Elevitch, 1998). Therefore, growing aromatic crops and cut-flowers using wastewater is a win-win situation for both earning profit and saving environment.

In the peri-urban areas of Hubli in Karnataka, the main wastewater irrigated land uses consisted of orchards and agro-silviculture which consists of spatially mixed tree–crop combinations. Two important fruit tree species are sapota (*Achras zapota*) and guava (*Psidium guajava*) and the other species that are mostly grown on bunds include coconut (*Cocos nucifera*), mango (*Mangifera indica*), tamarind (*Tamarindus indica*), and arecanut (*Areca catechu*). About 20-25% yield advantage has been observed from wastewater irrigation as compared to tube-well water irrigated fields (Bradford et al., 2003). Fruit trees such as goose berry (*Emblica officinalis*), mango (*Mangifera indica*), lemon (*Citrus limon*), guava (*Psidium guajava*), pomegranate (*Punica granatum*) and *Moringa oleifera* are common in homegardens. In peri-urban areas, farmers grow vegetables using untreated waters that may cause health and environmental hazards.

Though requiring higher investment, vertical farming is another horticultural intervention, where treated wastewater can be used for producing fresh vegetables and ornamentals in limited space (NAAS, 2019). Mushroom production can be called as a simple example of vertical farming. It is an ideal example of successful, economical and sustainable farming. Many cucurbits and ornamental climbers can easily be trained for vertical growth.

Although enough attention is paid to develop urban areas through horticultural with emphasis on green space, green building, development of parks and gardens, and promotion of peri-urban vegetables production yet their integration appears to be poor. The development plan must include a large component of horticulture aimed at improving access to food and enhancing livelihoods of people living in and around cities besides nurturing the environment. The government's initiative of peri-urban vegetable production and smart-city programmes are not enough to meet the huge challenge of livelihood security of urban citizens. This necessitates holistic approach having vertical and horizontal integration of the efforts of all the stakeholders.

4.4.3 Livestock interventions

Livestock is an important component of agriculture. Its importance has increased in recent times because of changing food habits i.e. increased dairy and non-vegetarian components in dietary pattern. Large number of dairy farms are being operated in the outskirts of the big cities to meet the needs of urban dwellers. Keeping livestock in urban areas is a major environmental and health problem, hence, this sector is to be developed in peri-urban areas. As such no suitable guidelines have been developed regarding use of wastewaters in animal husbandry but at least one-third of total required water can easily be used as treated wastewater in washing, cooling and other purposes excluding drinking requirement of animals. There lies a scope for utilisation of partial (removal of heavy metals) treated wastewaters in fodder production and in cooling devices for animals. The natural resources, including the good quality water, are thus, under increased pressure due to rapid growth of dairying. Commercial poultry production is mostly located on outskirts of urban areas, and the poultry feedstock can be prepared from wastewater irrigated crops.

The existing dairy farming practices in peri-urban and urban areas are largely characterized by modern dairy farming practices covering a range of intensive management practices and zero grazing. To meet the fodder needs of these dairies, farmers have taken up fodder production on a large scale depending upon the land available with them. Most of these farmers already irrigate the fodder crops with wastewater from the city without caring for the toxic elements present in the water. Domestic wastewater provides a good source of nutrients for luxuriant fodder crop growth, but the usage of untreated water especially industrial wastewater with lot of pollutants is a matter of great concern. There are no separate channels for the disposal of domestic and industrial wastewater in most of the big cities in the country. Commonly grown fodder crops in peri-urban areas include hybrid napier, para grass (*Brachiaria mutica*), maize, sorghum, Egyptian clover (*berseem*), brassica fodder (*Brassica compestris*) and lucerene (*Medicago sativa*). Some of the leguminous forages such as *Medicago rugosa, M. polymorpha, Trifolium spumosum, T. yanninicum, T. brachycalycinum* and *T. alexandrinum* could successfully be grown as inter-crops under wastewater irrigated plantations (Muscas et al., 2017; Lal et al., 2020). As mentioned earlier, species of *Brassica* are among the greatest accumulators of heavy metals while grass fodders accumulate lower quantity of metal ions but may be still at toxic levels. Under similar growth conditions, legumes generally accumulate almost 4-times and Brassicas almost 5- times more toxic elements as compared to maize and sorghum fodders (NAAS, 2016). Therefore, it is important to monitor the toxic element contents in peri-urban fodder crops to avoid toxicity to both animals and humans through food-chain.

4.4.4 Aquaculture

Domestic wastewater, mainly sewage, is being traditionally used for aquaculture since long. East Kolkata wetlands (now a Ramsar site) use raw sewage for growing fish and even vegetables. The health of the fish, the fishers and the farmers has been completely ignored which is a matter of great concern. The fish grown in the wastewaters (mainly tilapias) are those requiring low oxygen concentration, and acquiring larger biomass, but of a poorer quality. In China, an integrated system of agri-aquaculture (dyke pond system) is widely practiced to grow a variety of aquatic animals using treated wastewater.

Aquaculture also provides an important opportunity to recycle wastes generated by zero grazing and other agriculture practices increasingly common in the urban and peri-urban areas, contributing positively to tackle problem of urban waste disposal, and adding value to and supplementing scarce water resources. In metro cities, catfish are mainly cultured in tanks of varying sizes, which are linked to re-circulating systems of varying degrees of sophistication and in earthen ponds. Since catfish are air-breathing fish, they can be stocked at high densities. Cultivation of ornamental fish in treated wastewater may add to the opportunity for increased income in urban and peri-urban areas. The system of sewage aquaculture should, however, be restricted to the use of at least primary-treated sewage only. The sewage aquaculture will remain socially unacceptable in most of the communities unless the practice is greatly improved.

5. RECOMMENDATIONS

5.1 Research Issues

- The National Agricultural Research System should devise comprehensive water quality indices for various agriculture production systems including livestock and aquaculture.
- Low-cost and user- and environment-friendly techniques for treating wastewaters including bioremediation measures for removing heavy metals and pathogens need to be developed and adopted on large scale.
- Research and development of eco-friendly strategies for removal of toxic compounds including metals and refractory organics, nitrogen and phosphorus, biological nitrification and denitrification.

- Long term studies need to be initiated to quantify the use of treated/ semi-treated/ untreated wastewater in urban and peri-urban agriculture and consequent effects on the soil-plant-animal-human-environment in different agro-ecosystems.
- A network programme needs to be set up on estimating pollutant bioaccumulation including its modelling under representative soil-water-crop-weather combinations for reducing the cost, labour, and time involved in large-scale multi-location and multi-commodity field experiments and also to help develop local wastewater re-use guidelines for effective agriculture planning.

5.2 Developmental Issues

- Develop different business models for safe utilisation of wastewater by private-sector, washing stations and up-scale them.
- Evolve strategies for use and management of domestic, municipal and individual household wastewater based on public-private partnership model.
- Government Schemes such as Smart City Development Programme, Swachh Bharat Abhiyan and Atal Mission for Rejuvenation and Urban Transformation Project, etc. need to be linked with utilization of wastewater involving different stakeholders to adopt already evolved technologies like *Jalopchar* (developed by IARI) and CAZRI technique for effective utilization of sewage.
- Ensure proper coordination between different stakeholders/departments in handling wastewater and capacity building.
- Provide frameworks for comprehensive urban plans in implementing different land uses for different systems. Norms and protocols to cultivate fodder, agroforests, horticultural systems, greenbelts and landscapes, development of dairy, food parks, aquaculture ponds and other activities need be encouraged.
- Create awareness among all stakeholders for their involvement in addressing the safe disposal of wastewater for safeguarding environment in urban and peri-urban areas using suitable and economically viable species/crops.

5.3 Policy Issues

- The Ministry of Jal Shakti should consider wastewater as a resource and develop protocols for converting it into nutrient-rich safe irrigation water to supplement the scarce fresh water resources as increasing industrialization and urbanization will generate more wastewater with time.
- Already developed affordable phyto-remedial and economically viable technologies need to be popularized and upscaled through adequate financial and appropriate technical support.
- Since the industrial sector uses good-quality fresh water for its various uses and releases poor-quality wastewater, it should be made mandatory for the industry to adopt zero grey water foot print which must be regulated strictly.
- The Ministry of Housing and Urban Affairs may devise policies and action plan for adopting/ installing the Ecosan toilets in all the urban households.
- A national-level database on wastewater use in urban, semi-urban, peri-urban and rural areas be created to accommodate detailed information, which can be used by the stakeholders in planning, development and monitoring appropriate use etc.

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