CHAPTER - II
CHAPTER - II
REVIEW OF LITERATURE

This Chapter presents a critical review of the information documented by various workers pertaining to the nature of sewage effluents and their effect on soil-plant system under the following heads:

2.1 Nature of sewage effluent

2.2 Effect of long-term application of sewage effluent on physico-chemical properties of soil

2.3 Effect of long-term application of sewage application on accumulation of essential plant nutrients in soil

2.4 Effect of long-term application of sewage effluent on accumulation of heavy metals in soil

2.5 Effect of long-term application of sewage effluents on accumulation of nutrients and heavy metals in crops

2.1 Nature of sewage effluent

Qualitative as well as quantitative nature of the domestic sewage depend upon certain parameters such as pattern of water supply, food habits of people, community types population size, sewage collection, treatment provided (if any) and drainage system etc. (Ganguli and Maiti, 2004). The nature of sewage effluent is quite variable depending largely on contributing source. Sewage irrigation has been in practice for centuries throughout the world (Shuval et al, 1986). It provides farmers with a nutrient enriched water supply and society with a reliable and inexpensive system for wastewater disposal (Feigin et al, 1991). Some of these waters are rich source of plant
nutrients and the soil provides logical sink for their disposal. In India also, farmers are applying this water to their fields because of being cheap source of irrigation. When industrial effluents are mixed up with domestic sewage, some toxic substances depending upon the type of industry may add into the sewage. Sewage effluents and wastes are rich sources of both beneficial and harmful elements (Narwal, 2005).

Many untreated and contaminated sewage effluents may have high concentration of several heavy metals such as Cd, Ni, Pb and Cr (Arora et al, 1985). Their continuous disposal on agricultural soils may result in metal accumulation in soil (Gupta et al. 1986, Narwal et al. 1993). Higher concentration of these metals in soil may be toxic to plants and may create animal and human health hazards. The heavy metals namely Cd, Pb, Cr, Cu, Zn, Mn and Fe may be readily available to crops grown on these soils (Singh and Singh, 1994).

The raw sewage effluent available from Indian cities is a mixture of domestic, commercial and industrial activities. Although a large portion of the sewage effluent is organic in nature and contains essential plant nutrients, yet at some cities, heavy metals are also present in appreciable amounts. Long-term application of these materials may result in the accumulation of heavy metals in soil, affecting adversely the plant growth and animal health (Adhikari et al, 1993).

Characterization of Hyderabad city sewage water revealed its own distinct characteristics, reflecting the kind of pollutants that are entering into stream from domestic as well as industrial units (Ramesh et al, 2006). The
sewage water generated at Hyderabad were within safe limit for irrigation in case of pH, EC and B but total dissolved salts (TDS), total suspended solids (TSS), Na, Ca and Mg were beyond the permissible limits prescribed by Bureau of Indian Standards (BIS). Among Trace elements and heavy metals except Mn, Cd, Cr and all other constituents were within permissible limits.

While comparing different effluents of industrial cities of Gujarat namely Ahmedabad, Vadodara, Bharuch and Ankleshwar, it was reported that the pH values ranging from 7.2 to 8.5 were within the permissible limits of pH for irrigation which vary between 6 to 9. The salt content i.e, EC values in most cases were medium with exception to 10.20 which was higher and exceeded the toxic limit as per the US Salinity diagram (U.S Salinity Laboratory Staff 1954). TDS values were within the maximum recommended limit (1500 mg L⁻¹) for land application except at Ahmedabad.

At Ahmedabad Na was predominantly present in effluent followed by Mg and Ca while K was low. According to the suitability for irrigation purpose, effluents were poor in quality indicating possibility of either salinity, sodicity or both (Patel et al, 2004). High SAR (Sodium Adsorption Ratio) values and EC of effluents may cause salinization or sodification if continued as a source of irrigation for longer period. On analysing sewage waste water, form different points of the drain of Amritsar, Hundal and Sandhu, (1990) observed that the pH of the waste water varies from 7.4-7.5 which was almost neutral while EC decreased with distance. The concentration of metals in wastewater was also found to be decreasing with distance along the sewage drain. Although the
concentration of all the metals was within the limits but continuous use of sewage wastewater for irrigation may enrich the soil with these metals.

The EC of the sewage wastewater of Aligarh was reported to be between medium and high salinity range of waters (Aziz and Inam, 1995), which may cause adverse effect on soil properties. This effect on soil was because of the presence of Na, K, CO\(_3\) and HCO\(_3\) whose values were higher than the normal. Adequate quantities of Ca and Mg were also present. The effluents were rich in N and K while poor in P. Among micronutrients Fe and Zn were present in high amount, however, Ni, Cr and Pb were present as a result of mixing of industrial effluent in sewage water.

Calcutta sewage effluents were reported rich in NO\(_3\)-N, NH\(_4\)-N and available P. The effluents showed higher pH, medium EC values and high salt contents. The contents of Na, K, Ca and Mg were also higher which give higher values of SAR. Among the cations Na was the dominant followed by Mg, Ca and K. The SAR values were within the critical limits for irrigation. The chloride and bicarbonate contents were higher and remained in toxic level (Maiti et al., 1992).

Adhikari & Gupta (2002) reported sewage effluents of Calcutta as alkaline in reaction, EC values 2.75 dS m\(^{-1}\) within critical limits, TDS being higher but within permissible limits for land irrigation. Among cations Na being higher followed by Ca, Mg and K. The SAR value being 3.43 well within the limits. The effluent was suitable for irrigation. The concentration of Mn, Cu, Zn and Fe was 65, 87, 357 and 840 mg L\(^{-1}\) respectively. Heavy metal followed the order Ni > Cr > Pb > Cd. Analysis of wastewater revealed the
presence of appreciable amount of plant nutrients N, K, Ca, Mg, Na, Fe, Cu and heavy metals like Pb and Ni (Gladis et al, 1996).

Wide variations in physicochemical properties of sewage water were observed under all locations of Ranchi in several aspects (Singh et al, 2002). On the basis of SAR, sewage was falling into low category.

Average concentration of TSS was reported above the permissible limit by Mitra and Gupta (1999). Higher TSS concentration was reported in monsoon as compared to that of winter season and could be due to addition of loose soil particles from the adjacent land along with run off water. Both macro NH$_4$-N, NO$_3$-N, P and K and micronutrients Fe, Cu, Mn and Zn concentration in sewage water was sufficient to meet the irrigation quality standards but Calcutta sewage effluents particularly from China town, Chingrighata and Pagladanga were reported to be hazardous for vegetable production since they contain high levels of NH$_4$-N and K and low level of P (Adhikari et al, 1993).

The raw sewages of Allahabad were rich in plant nutrients. The concentration of N varied from 28.73 to 53.00 mg L$^{-1}$, P from 4.21 to 8.36 mg L$^{-1}$, K from 42.61 to 103.60 and S from 19.00 to 34.20 mg L$^{-1}$. Sewage water also provides organic carbon (93-243 mg L$^{-1}$) that will improve the soil physical properties (Shrivastava, 1998).

The Tung Dhab drain of Amritsar shown mean values of Na content as 8 m.e. L$^{-1}$, Ca and Mg less than 4 and SAR varied from 5.03 to 5.33 which is low (Below 10) indicated a reasonably good quality irrigation water for crops. Organic carbon content was found to be 86.9 μg ml$^{-1}$, NH$_4$-N contents varied from 3.2 to 6.5 μg ml$^{-1}$, P content were estimated in the range of 2.10 – 2.80 μg
ml⁻¹ and K as 31.2 μg ml⁻¹. Analysis of heavy metal concentration showed that Pb concentration varied from 0.30 to 0.70 μg ml⁻¹, the Zn content was 0.36 μg ml⁻¹ and Cu, Mn and Cd were found as 0.20, 0.37 and 0.015 μg ml⁻¹ respectively. The concentration of Ni varied from 0.06 to 0.95 μg ml⁻¹ while that of Cr varied from 0.042 to 0.06 μg ml⁻¹. The observed concentrations of these metals were high in sewage waters near the industrial site as compared to domestic site (Dhillon et al, 1997).

The dissolved solids of the waste water was reported to be high (188 to 432 mg L⁻¹) because domestic and city effluents which collects through surface drains find their way into city disposal system of Allahabad (Mishra et al, 1992). Besides, sewage water was found to carry heavy metals like Cd, Cr, Pb, Fe and Mn. Arora et al (1992) reported wide variation in metal contents of sewage water around Ludhiana. The irrigation with untreated sewage particularly in arid and semi-arid regions is often a potential source of pollution of Pb, Cu, Zn and Fe to soils, plants and animals (Gafoor et al, 2004). The concentration of NH₄-N was higher whereas contents of NO₃-N was undetected. Among micronutrients Fe and Zn were prominent whereas Cu and Mn were present in small amounts. The heavy metal status of sewage effluent followed the order Ni > Cr > Pb > Cd (Adhikari and Gupta, 2002). The raw sewage water contains beneficial as well as toxic metals such as Cd, Pb, Ni, and Cr etc. These waters are used for irrigating forage and vegetable crops in immediate surroundings of their disposal (Kuhad et al, 1989).

Sewage effluents differ widely among themselves in respect of physico-chemical nature, nutrient and metal status. These properties have been
summarized under Table R1, R2 and R3. The table indicates that the pH varies from 6.8 to 8.5 which were neutral to alkaline and were well within the limits 5.5-9.0 prescribed for inland surface waters. The EC values ranged from 0.58 to 2.45 with exception at few places where these values were high 8.2 and 10.20 but other were within the safe limits of less than 2.5 dS m⁻¹. The TDS values ranged from 364 to 1608 and those of TSS from 221 to 400 mg L⁻¹. The values of TSS were higher but the values of TDS were within permissible safe limits for agricultural use of waters. The sulphate contents varied from 0.34 to 27 me L⁻¹ and the chloride contents varied from 0.51 to 15.71 me L⁻¹. The values of sulphate at Calcutta were slightly higher than the permissible limit. The values of Na vary from 4.1 to 18.7, Ca varies from 2 to 70 and Mg varies from 1.07 to 30 me L⁻¹. The most of the SAR values were below 10, which were low as compared to 12.3 at Ahmedabad falling under medium class as per water quality criteria for irrigation. The Ammonium nitrogen values ranged from 1.4 to 42 mg L⁻¹. The values were within the prescribed limits. The values of Phosphorus varied from 0.7 to 7.5 with highest 20.7 mg L⁻¹ at Nagpur. These values were well within the permissible limits. The values of Zn varied from 0.1 to 6.0 mg L⁻¹, Cu varied from 0.01 to 0.38 mg L⁻¹, Mn varied from 0.04 to 1.10 mg L⁻¹ and Fe varied from 0.1 to 3.9. These values were well within the criteria for surface waters.

Amongst heavy metals the contents of Ni varied from 0.05 to 2.80, Cd varied from 0.01 to 5.8, Cr varied from 0.01 to 0.13 and Pb varied from 0.03 to 3.78 mg L⁻¹. The values of Ni and Cr were within the criteria whereas the values of Cd and Pb were slightly higher in sewage effluent waters of Hissar.
Table R.1: Physico-chemical status of sewage effluent water of few Indian cities.

<table>
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<tr>
<th>City</th>
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<th>Mg</th>
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<th>K</th>
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<td>(mg L⁻¹)</td>
<td>(m.e L⁻¹)</td>
<td>(m.e L⁻¹)</td>
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<td>(mg L⁻¹)</td>
<td>(m.e L⁻¹)</td>
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<th>$\text{NO}_3^-\text{-N}$</th>
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<th>$K$</th>
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<th>$Cu$</th>
<th>$Mn$</th>
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2.2 Effect of long-term application of sewage effluent on physico-chemical properties of soil

The sewage irrigated soils from different sites showed neutral to alkaline reaction. The pH varied from 7.1 to 8.1 at sewage irrigated sites. The TSS (Total soluble salts) content of the sewage-irrigated soil was 3 times more than tube well irrigated soil. Accumulation of salt could be due to the presence of Na, Ca and Mg salts in the effluent. The CEC of soil was higher in both the areas along with high contents of organic carbon (Mitra and Gupta, 1999).

Maiti et al (1992) while comparing sewage fed upland and lowland soils of Calcutta reported that sewage fed soils were slightly alkaline in reaction. pH of the sub-surface soil was slightly higher than surface soils. The salt content in the lowland was more than upland soils. Further sub-surface soils of upland had higher salt content than surface soils. This might be due to the high capillary action. Upland soils show slightly higher CEC than lowland. The dominant cation was Ca$^{2+}$ followed by Mg$^{2+}$, Na$^+$ and K$^+$. The surface soil contained higher amount of organic carbon than sub-surface soil. Available N, P and K were at moderate level. According to the fertility status, these soils were suited for vegetable cultivation. When sewage water and sludges applied in the field as manure, will certainly improve the physical condition and nutrient status of soil but some toxicity may result due to presence of micronutrients and heavy metals, which they generally possess.

Baddasha et al, (2002) in a soil leaching study using sewage water of Karnal reported an increase in pH of the soil from 8.08 to 8.30. The increase in pH of the surface layers was possibly caused by the preferential increase in Na
over Ca content of the soil caused by application of Na rich sewage water. The relative increase in EC with application of sewage water was from $0.29 - 0.62$ dS m$^{-1}$ that was well below the tolerable limit for most crops.

Baddasha *et al* (1997) reported no change in the pH of soil and sub-soil layer of Karnal after application of sewage water for 18 months. Lowering of EC of the soil and a significant increase in organic carbon contents of the surface soils. An increase in Na, Ca and Mg contents were noticed in 0-15 and 15-30 cm soil layer.

Soils irrigated with industrial and municipal wastewaters indicate that soils irrigated with industrial effluents shown greater CEC throughout the profile and decreased with the depth of soil profile. The pH of the soils receiving mix irrigation was comparatively higher. The clay contents were almost similar in all the profiles. The CaCO$_3$ contents in the soil increased with the depth in all the profiles. Highest CaCO$_3$ was observed in soils irrigated with municipal wastewater while lowest in industrial effluent irrigated soils (*Sharma et al*, 2004).

An increase in the pH of sewage irrigated soils of Dharwad was noticed. Sewage irrigation increased EC of soils and may pose problem on prolong use on ill drained soils. This may be attributed to addition of soluble ions through sewage irrigation. Higher organic carbon and CEC in sewage irrigated soils was due to the addition of organic matter through sewage. Sewage irrigated soils had lower bulk density and higher porosity and more water holding capacity as compared to unirrigated soils. This may be due to addition of organic matter through sewage irrigation (*Renukaprasanna et al*, 2002).
The mean soil pH of the soils of Hyderabad varied from 6.1 of control site to 8.5 of treated site. The soil pH increased due to application of alkaline pH > 8.5 garbage over years. Similarly, increase in EC was also observed to a depth of 30 cm as compared to control. The CEC of all the sites shown increase over control (Rao and Santaram, 1994).

The maximum value of pH of the waste disposal site was found to be 7.5, which was slightly higher than control site indicating alkaline nature of the soil. The EC values of the surface soil decreased sharply at a depth of 75 cm and remained constant indicating that the ionic constituents did not migrate further within the profile, which suggests that migration of ions in ground water is not likely. Concentration of Na, Ca and Mg contents decreased with the profile depth. Thus, the application of wastewater resulted in an small increase in these parameters in upper surface only (Jain and Ram, 1997).

Kansal et al, (1993) while working on Budha Nalla of Ludhiana which carries industrial as well as domestic wastewater reported pH of the soil below 7 in all cases. The chloride and sulphate contents were high. Maiti et al (1992) observed rise in pH and EC value of soil with sewage irrigation.

At Coimbatore, wastewater irrigation produced variable effect on soil pH and EC. The increase in EC was attributable to the higher amount of salts carried by the wastewaters. The CEC was found to increase in sewage irrigated plots. This corroborates with the increased organic carbon matter carried by these waters. Better soil properties resulted due to sewage irrigation and resulted better growing conditions particularly the increased root proliferation and also led to increased uptake of minerals (Gladis et al, 1996).
carbon was found to have maximum influence on accumulation of available heavy metal contents in soils receiving wastewater irrigation followed by pH and EC (Singh and Kansal, 1998) while calcium carbonate had only a marginal effect.

2.3 Effect of long-term application of sewage application on accumulation of essential plant nutrients in soil

Klimo and Fekete (1990) reported that sewage irrigation raised N, P and K content in the soil. Singh and Mishra (1987) reported increase in fodder yield due to the essential nutrients contained in the wastewater and sewage.

An increase in available N, P and K contents were observed due to irrigation with sewage water. Continuous application of sewage water significantly increased the level of DTPA extractable micronutrients in surface soil layer (Baddasha et al, 1997).

Singh and Chandel, (2006) while working on soils receiving effluent irrigation since long time reported increase in organic carbon content of the soil as compared to control, which may be beneficial to improve soil health. The N, P and K content of the soil increased with the sewage irrigation at all sites. Copper, Fe and Mn concentrations ranged from 0.2 to 0.69, 2.54 to 4.53 and 2.7 to 4.64 mg kg\(^{-1}\) respectively. These were above the prescribed limits except Fe and shown good quality of soils for crop production.

Renukaprassanna et al (2002) reported that sewage irrigation has considerably increased nutrient status of the soils as compared to unirrigated soils particularly N, P, K and micronutrients such as Fe, Mn, Cu and Zn.
Azad et al (1987) have observed an increase in the total and available contents of N, P and K in the soils by the use of sewage water for irrigation.

Bio-solids increased organic matter, total N and available P in the soil. Most pronounced OM accumulation was in topsoil. Significant accumulation of total Zn and Cu were detected in amended topsoils but no other heavy metals (Montovi et al, 2005). While working on irrigation effect of sewage on crop plants and soils, Aziz and Inam (1995) reported higher values of NP and K and those of Zn, Cu and Fe in surface soils irrigated with sewage water. Sewage sludge applications increased organic matter P, N, Ca, Zn, Pb, Ni and Cu contents in soil (Heras de las et al, 2005).

Use of sewage for irrigation in various proportions improved the organic matter to 1.2-1.78 % and fertility status of soils especially down to the distance of 1 km along the disposal channel. Build up of N, P and K was observed in surface soils. Vertical distribution of these parameters also varied with most accumulations occurring in surface, 30 cm soil (Yadav et al, 2002).

Soil N, P and K increased with increasing bio-waste application. Levels of Zn and Cu were higher in treated plots and increased in both years after application (Martinez et al, 2003).

Application of municipal effluents resulted in a 2-3 fold increase in concentrations of soil K, Cu, Fe, Mn and Zn whereas NH₄-N and P availability increased by 8.1 and 4.5 fold respectively. Accumulation of NO₃-N, Na, Cu, Fe, Mn and Zn were more in lower soil layers but others showed their greatest value in upper soil layer. Results suggest that municipal effluents could be
utilized, as an important source of water and nutrients in growing season to increase biomass production (Singh and Bhati, 2005).

Better soil properties led to increased uptake of minerals. The concentrations of Ca, P, Fe, Mn, Zn, Cu and heavy metals like Pb and Ni were significantly increased due to wastewater irrigation (Gladiš et al, 1996).

In Allahabad, untreated sewage waters are utilized directly for irrigating 100 hectares of vegetable crops. Shrivastava et al (1998) while assessing nutrient status of raw sewage waters reported that sewage irrigation of 8.2 cm per hectare would provide every hectare, 181 kg N, 28 kg P, 250 kg K, 110 kg S, 1.1 kg Zn, 0.4 kg Cu, 25.8 kg Fe and 1.2 kg Mn.

Maximum concentration of macronutrients was present in the soil of Ranchi, irrigated with sewage since last 20 years (Singh et al, 2002). Due to continuous use of sewage on soil the quantity of organic carbon, N and K was high in all the cases but P was low in most of the cases.

Use of sewage for irrigation in various proportions improved the organic matter from 1.24-1.78 % and fertility status of the soils especially down to a distance of 1 km along the disposal channel. Built up in total N was upto 2908 kg ha⁻¹, available P 58 kg ha⁻¹, available K 305 kg ha⁻¹, in surface 0-15 cm soil (Yadav et al, 2002). Vertical distribution of these parameters also varied, with most accumulation in surface 0-30 cm depth.

Comparatively higher concentration of micronutrients in comparison to normal soils (Adhikari et al, 1998) has resulted from addition of these elements through the continuous application of sewage water and the maximum concentration was of Zn followed by that of Fe, Cu and Mn.
Maximum accumulation of micronutrient elements was observed in the surface horizon of all the soils. The contents decreased with increase in depth. High concentration of extractable micronutrients in surface soils will not only reduce the plant growth but will also affect the availability of other essential elements to plants (Kuhad et al. 1989).

The content of DTPA extractable Zn, Cu, Fe and Mn in soils were mainly restricted to 0-15 cm depth. With the increased duration of irrigation, the values of micronutrients increased in surface soils (0-15 cm) and maximum increase was in Zn followed by that of Cu, Mn and Fe. The contents of these nutrients decreased after 15 cm depth. The increase in organic matter content may have restricted movement of these metals largely in the top soil (Bansal et al., 1992).

Datta et al. (2000) reported accumulation of available P in sewage effluent irrigated soils and a decrease to the extent of 20 per cent in available K status. The DTPA extractable Zn, Cu and Zn were 15 to 70 times higher in the sewage irrigated soils as compared to non-sewage irrigated soils.

Application of sewage effluent indicated a beneficial increase in plant available nutrients, micronutrients Fe and Zn. Soil samples show building of Fe forms in the plough layer below which most Fe may have been fixed by clays or precipitated to more active crystalline forms. Effluent is a potential source of irrigation and plant nutrient (McCaslin and Lee, 1979).

Dubey et al. (2006) reported on agricultural uses of sewage waters that a total volume of sewage water disposed (485 million litres/per day) had a potential for supplemental irrigation to a land area of more than 16000 hectares.
per annum in peri-urban areas and created a nutrient potential of 8100, 1200 and 11000 tons in terms of N, P and K.

2.4 Effect of long-term application of sewage effluent on accumulation of heavy metals in soil

The organic carbon was found to be significantly and positively correlated with Zn, Cu, Cd, Cr and Pb while pH was negatively correlated with Ni and EC negatively correlated with Fe (Patel et al, 2004).

Singh and Sing (1994) while working in fields contaminated by untreated municipal sewage observed negative correlations between heavy metals (except Fe), soil pH, CEC and clay contents.

Potential phytotoxicity, bioaccumulation and plant uptake of toxic heavy metal depends not only on total metal content of the soil but on soil pH, CEC of the soil and chemical forms in which metal exists in the systems. It is reported that when solid waste containing heavy metals is composted or is amended with soil, the chemical form of the metal changes. Hence, the chemical form or species of metals present in the amended soil in which the vegetable crops are grown is an important parameter. These metal species may become available to plants under different environmental conditions. Another, important parameter is the DTPA extractable heavy metals in waste amended soils for assessing metal content of different species grown in that soil, which indicates the metal accumulation potential of vegetable species. The DTPA extractable metals are considered as plant available metals (Olaniya et al, 1998).

The concentration of Pb, Ni, Co, Cr and Cd increased in sewage irrigated soils as compared to the control soils. Concentrations of these heavy metals
were limited mostly to the upper layer (0-20 cm) and there was marginal downward movement (Bansal 1998).

Application of municipal wastewater increased the accumulation of available Fe, Mn, Zn, Cu, Pb and Cd in soils (Singh and Kansal 1983). The DTPA extractable and total Pb, Cd Cr, Co and Ni in sewage irrigated soils were found lower and also except Cr and Ni all other heavy metals were mostly accumulated in the surface horizons (Adhikari and Gupta, 2002).

Lead, Cr, Cd concentration were much in sewage irrigated soils and in most of the cases were above the maximum tolerable limit. DTPA extractable Pb and Cd accumulated mainly in the surface soils and that might be due to the deposition of metals as particulate matter emitted from automobile fuel burning (Mitra and Gupta, 1999).

Jeyabaskaran and Sri Ramulu (1996) while working with the sewage farms of Madurai and Coimbatore observed that the DTPA extractable micronutrients and metals accumulated more in surface soil and decreased with the increasing soil depth and distance from the sewage entry point. The vertical movement of these metals was more in light textured soils. But reverse was in lateral or horizontal movement of extractable metals. Soil texture and location played major role in distribution pattern of metals in the soils of different sewage farms. The DTPA extractable Fe, Cu, Mn, Zn, Cd, Cr, Pb and Ni accumulated more in the surface soil and decreased significantly up to 0.45 m depth in the soils. The soils of upper layer registered highest metal contents. Although the farms were irrigated with sewage for 50 years but metal contents of these soils varied more or less within the same range and their vertical
distribution pattern was also similar. Significant positive correlation between the OC content and DTPA extractable metal contents were found.

Adhikari, *et al.*, (1993) observed high concentration of Cu and low in case of Mn. The accumulation of heavy metals was more in surface soils than subsurface soils. Hundal and Sandhu, (1990) reported 3 to 8 times increase in Zn and Cu contents in the sewage effluent treated soils, reaching at a level toxic to plants.

Soils irrigated with sewage effluents showed elevated total content of metals Pb>Cd>Ni >Co. The organically bound fraction of metal was dominant accounting for 31, 39, 43, 51 % of the Ni, Cd, Co and Pb respectively (Elgandi, *et al.*, 1999).

Prolonging the period of sewage irrigation was associated with significant increases in DTPA extractable Cd, Cu, Fe, Mn, Ni and Zn in the top plough layer of the soil in fields. Despite more than adequate levels of Mn in soil, severe Mn deficiency symptoms were observed in fields where large amounts of Zn and Fe have accumulated as a result of continuous sewage irrigation (Singh and Verloo, 1996).

Marked accumulation of heavy metals (Cu, Fe, Zn, Mn, Pb, Cd, Co and Ni) was observed in most of the soils, which had been given raw sewage effluent for several years (Adhikari *et al.*, 1993).

Wastewater irrigation markedly increased the amount of trace metals extracted from the soils. The amount of metal was proportional to the amount of wastewater applied. Copper, Cr and Pb concentrations were related to the soil organic matter contents (Cajuste *et al.*, 1990).
Azad et al (1986) reported increase in total Cd, Ni and Co contents due to sewage water addition by 36, 86 and 46.4 percent as compared with the irrigation with tube well water. Irrespective of the sewage application, the total Cd content decreased with depth. Similarly, total Ni content decreased with depth in the soil profile. Nickel was mainly concentrated up to 30 cm depth. The Co content also decreased gradually with depth. Accumulation of Cd, Ni and Co was generally positively associated with EC, organic matter, silt and clay contents but negatively with pH.

The application of sewage sludge resulted in significant increase in DTPA extractable metals, which appeared to be related to the decomposition of sludge with time (Schauer et al, 1980).

The predominate trend in both available and total metal contents showed highest concentrations of Cd, Pb and Zn in surface soils and highest concentrations of Cr, Cu and Ni in subsoils (Pierce et al, 1992).

In sludge treated soils, heavy metals Cd, Cr, Cu, Ni, Pb and Zn accumulated almost entirely (more than 90%) in the 0-15 cm soil depth. Little movement of heavy metal occurred below the 30 cm depth (Chang et al, 1984).

The DTPA extractable Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn contents in the soil increased by irrigation with sewage water (Singh et al, 1991).

The sludge application significantly increased the total concentration of Cu, Zn and Pb in the surface layer but the contents of DTPA extractable Mn were decreased. DTPA extractable Co, Zn, Cd and Fe were correlated with the organic matter and negatively with pH (Samras and Tsadilas, 1998). Available forms of all heavy metals except Cd, were positively correlated with organic
matter content and negatively with pH (Tsadilas et al, 1999). Concentration of Cd and Ni in soils was not severe as that of Zn and Cu. The apparent mobility and bioavailability of these four metals in the soil were Zn > Cu > Cd > Ni (Ma and Rao, 1979).

The concentrations of Pb, Cd, Zn, Cu, Mn and Fe were mostly confined to the plow layer, which markedly decreased up to 45 cm depth. There was hardly any variation in the decreasing trends below 45 cm depth of soil profile. Continuous application of sewage water to arable lands will increase the concentration of heavy metals in the feeding zone of plant roots, which may become toxic to plants and create clinical problems to animals and human beings. Extractable Cu was negatively correlated with pH and positively correlated with EC, OC and clay content of the soil (Sakal et al, 1992).

Concentration of total Mg, Hg, Mo, Ca, Cu and Cr, available concentrations of Pb, Cd and Cu increased with length of irrigation but were not hazardous concentration (Remirez et al, 2002).

The amount of available Zn, Cu, Fe and Mn showed that the soils of sewage affected areas were rich in available Cu and Zn than those from sewage free areas (Arora and Chibba, 1992).

Total soil concentrations of Cd, Cr, Cu, Ni, Pb and Zn significantly enhanced by sludge application to a soil depth of 30 cms. The DTPA extractable levels of Cu, Ni and Pb were higher in subsoil than surface soils in the profile (Baveya, et al, 1999). Concentration of Cu, Zn and Ni in amended topsoils was more than 10 times higher than control soils. Plant available Zn and Cd remained in the topsoil as indicated by excess uptake and phytotoxicity.
symptoms in vegetable crops (Murrey, et al, 1997). Soil analysis indicated that concentrations of Zn, Cu, Cd, Ni and Pb remained in the zone of sludge incorporation with minimal or no movement beyond 15 cm soil depth (Sommers et al, 1997). Total soil concentrations of Cd, Cr, Cu, Ni, Pb and Zn had been significantly enhanced by sludge application to a soil depth of 30 cms but total Cu, Pb and Ni were not increased with depth. In surface samples, the percentage of total metal contents extracted with DTPA ranged from a low 0.03 for Cr to a high of 59 for Cd. The DTPA extractable levels of Cu, Ni and Pb were higher in sub soils of sewage treated soils, indicating that these metals have been redistributed from surface layer to deeper zones in the profile despite absence of elevated total concentrations of these three metals in the deeper sub soil (Baveye et al, 1999). The total and variable Pb, Zn, Hg, Cd and Cr in the sewage irrigated soils were found lower than normal range as proposed by WHO (1989). It was interesting to note that heavy metal constituted only a small fraction of the effluents but their contents in the soil were much higher because of the long-term application of the effluent. It was also evident that except for Pb and Cd, all other heavy metals were mostly accumulated in the surface horizons (Som et al, 1994). Singh and Singh (1994) while working in the sewage cultivated fields around Varanasi polluted by metals due to application of untreated municipal solid and liquid waste reported that almost all the soil surface layers contained higher amount of metals and the contents decreased with the depth. The organic compound present in the surface soils might have checked the mobility of metals to the lower horizons, by way of forming insoluble complexes with organic matter.
Mishra and Tiwari (1993) reported an increase in DTPA-extractable and total amount of heavy metal on use of sludge. However, the crops removed only a small amount of heavy metals, hence most of the metal in the sludge get accumulated in the soil. This gives rise to metallic pollution of the soil.

Bio available concentrations of Pb, Cu, Zn and Fe metals were within safe limits. Low rate of metal input, relatively high organic matter due to its addition through sewage and conversion of metals into non-available forms due to metal-metal and metal-clay-organic matter interactions and insolubilization of metal under alkaline soil reaction seems to be reason for low DTPA extractable metals in soils. Higher contents of all these four metals in the 0-20 cm soil indicated the accumulation of metals in surface soils only (Gafoor et al, 2004).

The mean concentration of Zn, Cu, Cd and Pb in the top and subsoil horizons of sewage soils was 79.3, 32, 0.29 and 1.15 mg kg\(^{-1}\) respectively. These levels were high enough to constitute health and phytotoxic risks. All the metal levels were much higher in the sewage in the sewage than in the non-sewage soil profile. There was a significant correlation between organic matter, Zn and Cd. Application of sewage sludge/effluents significantly increased total Zn and Cu in the topsoil (0-20 cm depth) as compared to the control (Tandi et al, 2004). The contents of Cu in soil increased from 70 mg Cu kg\(^{-1}\) to 101 mg Cu kg\(^{-1}\) in wastewater irrigated soils and Cu mostly accumulated in the surface layer (0-10 cm) of paddy soils (Cao and Hu, 2000).
2.5 Effect of long-term application of sewage effluents on accumulation of nutrients and heavy metals in crops

An increase in order of uptake of different heavy metals was reported to be Cr < Pb < Cd < Fe (Mishra and Tiwari, 1993).

Lark et al (2002) reported high Cu, Fe, Cd, Pb and Cr in vegetables namely Spinach, Methi, Saag-Sarson, pudina, Cauliflower, Radish, Carrot, Brinjal and Onion which received irrigation through Gundanallah of Amritsar city where untreated city sewage is drained. The water is extensively used throughout the year and as much as three different crops are produced and marketed in a year. The content of Cu varies from 55 to 300 µg g⁻¹. The content of Fe was quite large. In case of Cd the maximum concentration was found in radish and onion seems to absorb this metal more. Lead was found in appreciable amount in radish, onion and brinjal. Chromium, Pb and Cd were in higher amount in spinach and saag-sarson. Among vegetables namely, basil, spinach, gourd, mustard and radish, the concentration of Pb was higher in leaves than normal range, Cr was detected in the leaves of all the vegetables except spinach, Co was detected only in basil, gourd and mustard, Ni was detected in basil and gourd and was higher than normal range of 1.0 ppm and Cd remained undetected in the leaves of all the vegetables.

The concentration of Cu, Ni, Zn and Cr increased in ear leaf, grain and straw of maize. In Barley grain and straw the concentration of Cu, Ni, Zn, Cr, Cd and Mn increased by application of sewage but were within normal limits (Bansal, 1998).
Leafy vegetables such as lettuce, chard, spinach and turnip may contain Cd exceeding 100 ppm without showing any toxicity symptoms. Radish leaves were reported to contain the maximum Cd (0.8 ppm), while Chinese onion stems contained maximum Cd (2.15 ppm) followed by radish roots (0.8 ppm). Maximum Cr concentration was in spinach roots (12.75 ppm) followed by spinach leaf (10.8 ppm). The maximum Cu concentration was observed in Chinese onion stem (56.85 ppm) followed by red vegetable root (52.02 ppm). Maximum Pb was observed in Chinese onion stem (28.95 ppm) followed by spinach leaves (23.15 ppm). Maximum Mn was observed red vegetable root (82.12 ppm) followed by cauliflower root (80.31 ppm). Some vegetable parts contained more than 30 ppm Cu. Zinc concentration was maximum in Chinese onion stem (541.5 ppm). Though these plants did not show any toxicity symptoms, such high levels of Cu and Zn may be harmful to human beings. It was found that metals accumulate more in root region followed by leaves. Accumulation of Cr, Ni and Pb is less while that of Cd, Cu, Mn and Zn is more in plants and may pose a hazard to plants and human beings (Olaniya et al, 1998).

The Fe content was found to be invariably very high in different crops irrespective of effluent water used for irrigation. The contents of both Zn and Cu were very high in Sorghum irrigated with tube well water. The cauliflower grown by using sewage and industrial effluent shown lowest level of Cu, while tobacco plant irrigated with refinery effluent contained the lower Fe content. The content of Cr was found to be above the toxic limit irrespective of crop and
site. The contents of Pb in pigeon pea, maize and tobacco plants were below toxic limits (Patel et al, 2004).

In bitter gourd plants the contents of Pb, Cu, Zn and Fe were high in leaves than in its fruits. In okra, Fe and Cu contents were higher in fruits. Since fruits are edible part in okra, growing this crop on soils contaminated with Pb and Zn will be dangerous for consumers. In spinach leaves, the contents of Pb, Cu, Zn and Fe were 13.5, 11.6, 37.0 and 432 mg kg\(^{-1}\) dry matter respectively. Contents of all the four metals were above the safe limits of Pb 2.0 mg kg\(^{-1}\), Zn 5.0 mg kg\(^{-1}\), Cu 10.0 mg kg\(^{-1}\) and Fe 20.0 mg kg\(^{-1}\) as prescribed by WHO (1996). Concentrations of metal in plant tissues and quantity of plant consumed as food determine the level in the human body and health risk. Intake rates of Pb, Cu, Zn and Fe into human body have been calculated assuming bitter gourd, okra and spinach consumptions @ 0.2 kg and mint concentration @ 0.01 kg dry weight daily. Lead (2.8 mg) and Zn (11.6 mg) daily intake was highest through mint, followed by spinach and were lowest through bitter gourd. However, Pb intake was lowest (1.00 mg) through mint. Continuous ingestion of untreated sewage irrigated vegetables (bitter gourd, okra, mint) may develop Pb, Cu, Zn and Fe level in human body to toxic level (Gafoor et al, 2004).

Datta et al (2000) while working on sewage effluent irrigated vegetables observed that crop species behave differently in accumulating metals in their tissues. By and large, the concentrations of metals in all crops were below the critical level of phytotoxicity except Fe. Plant analysis further revealed that
metal toxicities have not inflicted these soils in spite of having being irrigated with sewage effluents for more than three decades.

The vegetables, which are grown, were cauliflower, mustard, spinach, gourd, radish etc. Among the heavy metals, the concentration of Zn in the leaves of all vegetables was exceptionally high (Som et al, 1994).

Vegetables commonly grown in the sewage and non-sewage irrigated area around Calcutta are radish, gourd, spinach, cauliflower etc. Among the heavy metals, present in the consumable parts of the vegetables, the concentration of Fe and Mn were comparatively high. The concentration of Cu, in the root, fruit, leaf portion of vegetables were also very high in raw sewage irrigated site. Findings indicated that contents of heavy metals in sewage-irrigated vegetables were 2-40 times higher than non-sewage irrigated vegetables (Mitra and Gupta, 1999).

High concentration of Zn, Fe and Cu in different parts of vegetables were observed (Adhikari et al, 1998) which were above the toxic limits for these metals. The Mn in different parts of the vegetables was less than the critical level. This may be attributed to the antagonistic interaction of the metals present in the sewage.

Vegetable cultivated fields are likely to be polluted by heavy metals due to indiscriminate application of untreated municipal solid and liquid waste. The heavy metals namely, Cd, Pb, Cr, Cu, Zn, Mn and Fe may be readily available to crops grown on these soils. These soil contaminants can modify nutritional value of food crops and consequently their safety for human consumption (Singh and Singh, 1994). The contents of Zn, Cu and Fe in 60-day old leaf
samples of wheat increased while Mn contents were low and below than 20 mg/kg (Mn deficiency level). The low content of Mn in plants appears to have resulted from the decrease in its absorption as a result of the antagonistic effect of high contents of Cu, Zn and Fe. This resulted in negative correlation between DTPA-Mn in soil and its content in plant. It is reported that the Mn present in the soil gets inactivated as an organic complex by organic matter (Bansal et al, 1992).

In the maize foliage Ni showed highest concentration followed by Pb, Co and Cd. In the grain, Ni, Co, Cd and Pb were 26, 23, 10 and 1.5 times greater than for uncontaminated soil (El-gandi et al, 1999).

Cjusta et al, (1990) observed wide ranges in tissue concentration of metals. Zinc was the metal most absorbed by Lucerne and oats. Levels of Ni and Pb in plants and to some extent, those of Co and Cu were increased by wastewater irrigation. Accumulation of Cr and Pb were above the tolerance level and Co content was high in this legume and may be health risk for animals and human beings.

Irrigation using sewage waste water caused enrichment of heavy metals in soils and led to increased uptake of Zn, Cd and Pb by leaf vegetables (Cabbage, lettuce, beets, spinach), root vegetables (carrots, potatoes, radish, beetroots, onion), cucumbers and tomatoes. Low levels of heavy metals were found in the fruit vegetables but in leaf and root vegetables Zn and Cd levels were generally high and exceeded statutory limits (Truby and Raba, 1990). It was also noted that uptake of heavy metals was highly variable. It was concluded that the
uptake of heavy metals by vegetables could not be predicted by measuring the contents of heavy metals in the soil alone.

Marshall et al, (2003) reported that 72% of samples of palak of Delhi vegetable market contained Pb concentration exceeding permissible limit and 21 % of sample contained Zn above the limit while Cd and Cu contents were within the safe limits.

Leafy vegetables of sewage-irrigated area of Coimbatore were found with high levels of heavy metals contamination including Cd, Zn, Cu, Mn and Pb (Somsundaram, 2003). The concentration of heavy metal ranged from 16.4-21.4 mg Cd kg⁻¹, 17.4-23.8 mg Ni kg⁻¹ and 21.2-26.0 mg Pb kg⁻¹ respectively. Among heavy metals Cd and Ni contents were above the toxic limits in the Amaranthus. Fodder grass grown in this area was also supplied to the animals, which was loaded with high content of heavy metals. The content of heavy metal ranged from 17.2-22 mg Cd kg⁻¹, 17.0-33 mg Ni kg⁻¹ and 20.2-23.4 mg Pb kg⁻¹.

Concentrations of Zn, Cu, Ni and Cd were increased in corns, legume and small grain tissue by sludge treatments. Corn seedling Zn and Cu concentrations exceeded that of ear leaves. Zine was in highest concentration. This preference for Zn was noted for all vegetable analyzed (Schauer, et al, 1980), whether the tissue was shoot (lettuce), roots (radish and carrots) or fruits (Tomatoes). Cadmium concentrations were greatest in lettuce, followed by carrots, tomatoes and radish. The acid conditions perhaps explain the increased availability and uptake of Cd by tissue. The concentration of Cu was greatest in lettuce shoots and tomatoes with smaller quantitites in radish and carrots.
Tomatoes exhibited significant increase in Cu concentrations. Concentrations of Ni in edible plant tissue generally followed in the order of carrots > radish > lettuce > tomatoes.

Crop absorption of heavy metals removes an insignificant amount (< 1%) of the heavy metals introduced into the soil through land application (Chang et al., 1984).

Copper was absorbed in greatest amount by both edible and non-consumable part of green beans and tomatoes and least amount by Sweet corn grain. Significantly more Cu was found in radish roots and tops, carrot roots, cabbage heads, bean leaves and tomatoes. Highest Zn concentrations were found in carrot roots and radish tops and lowest concentration in tomato leaves. Significantly more Zn was observed in the radish roots and tops, carrot tops, cabbage heads, green beans, tomato leaves and fruits at all growth stages. Cadmium concentrations of the edible portion of all vegetable were below 0.8 mg kg⁻¹. Chromium accumulated to the largest extent in radish tops. This element was not significantly absorbed by most crops. Nickel was absorbed in largest amounts by cabbage heads, radish roots and tops and green bean leaves and pods. Sweet corn absorbed the least Ni (Keefer et al., 1986).

Important factors affecting metal uptake was influenced by soil pH. Soybean shoots were shown to be higher in Zn, Mn, Cd and Ni at low pH (Heckman, et al., 1987).

The fertilizer produced higher yields of grass forage than sludge and compost but equivalent to sludge and Comport in corn yields. Forage and corn N, P, K contents varied with crop and treatment. Both sludges and compost
could be used as effective source of N, P and K for crop production (Warman and Termeer, 2005).

Tissue N, P, K, Zn and Cu levels increased with the bio waste application, but concentrations of tissue Pb, Cd, Ni and Cr did not increase significantly (Martinez et al, 2003). The average Cu contents in Brown rice, rice hull and rice straw from non waste water irrigated soils were 1.4, 7.3 and 14.5 mg Cu kg\(^{-1}\), while those from wastewater irrigated soils were 15.5, 133 and 101.4 mg Cu kg\(^{-1}\) respectively (Cao and Hu, 2000). Bio solid application increased the contents of N, P, Zn and Cu in wheat grain, N and Cu in sugar beet roots and Cu in maize grain (Montovi et al, 2005).

The contents of heavy metals and dry matter yield increased by irrigation with sewage water. Among these, the concentration of Cu, Fe and Mn was higher in Berseem plants. The concentration of Cd, Pb and Ni was more with sewage water (Singh et al, 1991).

Observations of Arora and Chhibba (1992) showed that the sewage is contributing to Zn nutrition of rice plants besides Cu and Fe. But shown low content of leaf Mn, this can be attributed to the antagonistic interaction of the heavy metal load in the sewage.

Organic matter may improve the structure and water holding capacity of poor soils and N and P in sludge have fertilizer value. However, the important consideration in applying sludge to land is the limitation of addition of toxic elements. Crops can accumulate toxic elements from sludge-amended soils and plants may accumulate concentrations, which are phytotoxic. The extent of accumulation varies considerably with plant species and cultivar. Cereals and
Legumes lower concentrations than leafy plants such as lettuce and spinach (Sterritt and Laster, 1980).

Considering heavy metals concentrations in plant parts it was noted (Aziz and Inam, 1995) that except Mn all metals were accumulated at toxic levels. Leaf and stem accumulated more Cu in all parts except wheat. Elevated concentration of Pb, Ni and Cr were noted in leaves of all plants except wheat. Plant uptake studies showed high amounts of heavy metals in fodder grasses as compared to vegetables and crop plants (Ramesh et al, 2006), which were cultivated for period of time (> 30 years). Among crops tested, para grass was found to be better in case of uptake of trace metals and heavy metals with high dry matter yields as compared to maize. Analysis of trace elements and heavy metals in crops grown with sewage water showed more trace elements and heavy metals. The trace elements and heavy metals were more in roots than in foliage and stem except radish.

Sewage sludge and effluent application significantly increased Zn uptake by both the test crops, while Cu uptake was significant in the first crop of lettuce and the second crop of mustard rape in an experiment conducted at Harare, Zimbabwe (Tandi et al, 2004). The toxicological implications for Zn will however be more severe exceeding the maximum daily intake (MDI) by 77% through exposure by lettuce consumption and by 251% consumption of mustard rape. The consumption of leafy vegetables produced on these soils pose a health risk to poor communities that reside around the study site through possible Zn toxicity.
Distribution of Pb, Cd, Ni, Cr and Zn was examined (Shrikant et al, 1992) in forage grass (Guinea grass), which is cultivated along with the bank of river Musi, which receives the sewage water of Hyderabad. The accumulation of Pb, Cr and Ni in the grass was low while the contents of Zn and Cd were reported high. Accumulation of Cd, Ni and Zn in carrots and spinach showed the greatest increase whereas Cu and Pb showed only a small increase in the contents as compared to their background levels (Hooda et al, 1997).

Mishra and Mani (1995) reported no harmful effect of sludge on vegetative growth of lettuce crop. There was increase in uptake of heavy metals by lettuce when the dose of sludge was increased. However, when sludge is added in combination with Mussorie rock phosphate (MRP), the concentration of Cd, Cr and Pb was reduced with increasing doses of MRP as compared to the treatments without MRP. Only the contents of Zn in vegetative material showed higher levels even in MRP treated plots. Decrease in uptake of pollutants Cd, Cr and Pb on addition of MRP can be due to antagonistic effect of P on availability of these metals. Increased uptake of Zn may be due to the higher content of Zn in domestic sewage sludge. Accumulation pattern of Pb in different parts of three different crops, sorghum, maize and wheat cultivated adjacent to the state highway was studied (Saxena, et al, 1991). Lead accumulated more in the leaves than in roots of all the three crops. Leaf surface of sorghum had deposited more lead but accumulated lead was significantly high in Maize. Inspite of high concentration of Pb in the leaves and root of maize, the seeds had low accumulated Pb, compared to that of other two crops.
Long term indiscriminate application of raw sewage effluent or letting of sewage water directly to agricultural field without prior treatment which contains heavy metals in association with suspended solids (Sludge) particles may cause accumulation of toxic metals in surface and sub surface soils with subsequent transfer to food chain.
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