Chapter 19
Impacts of Wastewater Reuse on Peri-Urban Agriculture: Case Study in Udaipur City, India

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Abstract The present study was undertaken to determine the effect of reuse of wastewater in the peri-urban area of Udaipur city on the quality of soil, vegetable crops and groundwater in reference to heavy metal contamination. For this study four sites were selected for soil, water and vegetable sampling. Three samples each of soil, irrigation water and selected vegetable crops were collected. These samples were analysed for iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), cadmium (Cd) and nickel (Ni) with the help of an Atomic Absorption Spectrophotometer (AAS) model EC 4141-8. The heavy metal accumulation in groundwater irrigated vegetables was found to increase with the increasing contamination of these metals in the groundwater at different locations. However, the metallic accumulation in all the selected vegetable crops (cauliflower, cabbage, brinjal, spinach, tomato and radish) irrigated by groundwater at all the selected locations were found to be within the maximum permissible limits as prescribed by World Health Organization (WHO). In the case of wastewater irrigation, accumulation of Fe, Zn and Cd in spinach, tomato and radish crossed the maximum permissible limits at site 3 (Kanpur – Madri Villave). Urban wastewater irrigated spinach was found to have accumulated Fe, Zn and Cd to a great extent (more than the maximum permissible limits) at all three selected locations and is most unsafe for human consumption.

Keywords Wastewater • Irrigation water • Reuse • Vegetable crops • Metallic accumulation
19.1 Introduction

The reuse of urban wastewater is one method of disposal and recycling the plant nutrient elements contained in the wastewater. The demand on fresh water is overstressed and the use of wastewater in the agricultural sector has increased to a great extent in many parts of the world (Scott et al. 2004; Yadav 2008). There are increasing concerns about water and food security in urban areas. For cities to be liveable and sustainable into the future there is a need to maintain the natural resource base and the ecosystem services in the peri-urban areas surrounding cities. The peri-urban agriculture is endorsed as a means to reduce poverty, improve food security and enhance the urban environment through the creation of green spaces (Ensink et al. 2007). Recently vegetable cultivation in peri-urban areas has become a profitable occupation because of the proximity to urban markets which reduces transport, handling and production costs and makes food products readily available to the urban poor. In many developing countries, as a result of rapid urbanisation and the absence of wastewater treatment facilities, peri-urban farmers often use wastewater either directly from sewage drains or indirectly through wastewater-polluted irrigation water which can pose a significant occupational and public health risk (Blumenthal and Peasey 2002). One of the major constraints with wastewater irrigation is the possible contamination of the human food chain with toxic substances, such as heavy metals, when food crops are grown on soils irrigated with wastewater or contaminated groundwater (Arora et al. 2008). Keeping in view the above facts, the present investigation was undertaken to study the extent of pollutants accumulation (heavy metals viz. Fe, Mn, Cu, Zn, Cd and Ni) in six important vegetables viz. cauliflower, cabbage, brinjal, spinach, tomato and radish grown in peri-urban areas of Udaipur City, India, irrigated with urban wastewater and polluted groundwater.

19.2 Experiment

19.2.1 Study Area

Udaipur city is a historical city (more than 460 years old) having a saucer shape surrounded by hillocks. Presently it is the divisional head quarter of Rajasthan, a state of India which is located at 24.52° N latitude and 73.68° E longitude with an average elevation of 598 m above mean sea level. Udaipur city has a population of 608426 (census, 2011) which is spread over 64 km² area. Udaipur city has no wastewater treatment plant and sewerage lines. Most of the wastewater of the city is being discharged through different channels to the Ahar River which is a seasonal river that runs diagonally (northwest to southeast) through the eastern suburbs of Udaipur (Fig. 19.1).
19.2.2 Agricultural Practices

The farms of the peri-urban areas especially the middle and lower reaches of the Ahar River are growing vegetables, flowers and fodder crops with wastewater irrigation. Among the vegetables cauliflower, cabbage, brinjal, spinach, tomato and radish are grown commonly and prominently with wastewater.

19.2.3 Sampling Sites

A total of four sites were selected for soil, groundwater and vegetable samples (Figs. 19.2 and 19.3). Site 1 is the Horticulture Farm of the university which is situated 3 km away from the Ahar River where land is irrigated only with good quality groundwater. The data of site 1 were used to compare the results. Site 2 is the Manva Kheda village which is located in the middle reach of the Ahar River where the lands are irrigated with domestic wastewater and polluted groundwater and site 3 is Kanpur-Madri village which is also located in the middle reach of the Ahar River where the lands are irrigated with a muddle of domestic+industrial wastewater and polluted groundwater. Site 4 is Matoon village which is situated in the lower reach...
of the Ahar River near Lake Udaisagar and the lands are irrigated with well aerated-mixed wastewater and polluted groundwater.

### 19.2.4 Collection of Samples

Three samples each of soil, groundwater and selected vegetable crops were collected from the Horticulture Farm as a control to compare with the samples collected from sites irrigated with polluted groundwater and wastewater. Soil, groundwater, wastewater and vegetable samples were collected from selected sites in the middle and lower reaches of the Ahar River, viz. Manva Kheda, Kanpur-Madri and Matoon villages.

### 19.2.5 Analysis

These samples were analysed for iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), cadmium (Cd) and nickel (Ni) content with the help of an Atomic Absorption Spectrophotometer (AAS) model EC 4141-8 following standard procedures.
19.3 Results and Discussion

19.3.1 Heavy Metal Accumulation in Soil

The continuous application of wastewater generally leads to undesirable changes in the soil and consequently an accumulation of contaminants. The results of 3 years of investigation regarding heavy metal accumulation in soil (Table 19.1) revealed that the mean values of the available heavy metals (Fe, Mn, Cu, Zn, Cd and Ni) at sites 2, 3 and 4 which are irrigated with wastewater increased to a large extent when compared to the control site (site 1: Horticulture Farm) which is never irrigated with wastewater. The highest metal accumulation was observed at site 3 (Kanpur-Madri Village) which is irrigated with the muddles of domestic+industrial wastewater. The
available metal (Fe, Mn, Cu, Zn, Cd and Ni) concentration at site 3 was observed at 4.3, 5.5, 2.4, 5.1, 6.1 and 89.0 times higher, respectively, when compared to the control site. Although the concentrations of the available heavy metals were far below the toxic levels because these soils were brought under wastewater irrigation only 10 years ago, the rate of increase is very high which may be a threat in the near future.

### 19.3.2 Heavy Metal Contamination of Groundwater

The data in Table 19.2 show that the groundwater was polluted with heavy metals to an enormous degree at site 2, 3 and 4 as compared to site 1. The highest contamination of these metals was found at sites 3 and 4, which are situated in the middle and lower reaches of the Ahar River. The mean values of Fe and Mn in groundwater at site 3 was found to be 5.9 and 1.7 times higher, respectively, when compared to the control site. The Cu, Zn, Cd and Ni in groundwater was also found in an appreciable amount at sites 2, 3 and 4. Cadmium (Cd) crossed the maximum permissible limit (0.01 mg/kg) at all three selected sites irrigated with wastewater.

### 19.3.3 Heavy Metal Concentration in Wastewater

The wastewater at site 3 is highly polluted with the metallic cations compared to the two other sites. This may be due to the addition of wastewaters from different industries having higher metals from the Madri Industrial Area (MAI). Further, the

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**Table 19.1** Heavy metal content in soil (available form) at different locations (mean of 3 years)

| Site  | Heavy metal content in soil (mg/kg) |
|-------|-----------------------------------|
|       | Fe      | Mn      | Cu      | Zn      | Cd      | Ni      |
| Site 1 | 1.081   | 1.236   | 0.970   | 0.953   | 0.017   | 0.003   |
| Site 2 | 2.808   | 4.537   | 2.054   | 3.855   | 0.067   | 0.203   |
| Site 3 | 4.650   | 6.842   | 2.372   | 4.817   | 0.104   | 0.267   |
| Site 4 | 3.842   | 5.972   | 2.270   | 4.026   | 0.089   | 0.217   |

**Table 19.2** Heavy metal contamination in groundwater at different locations (mean of 3 years)

| Site  | Heavy metal content in groundwater (mg/kg) |
|-------|-------------------------------------------|
|       | Fe      | Mn      | Cu      | Zn      | Cd      | Ni      |
| Site 1 | 0.031   | 0.019   | 0.000   | 0.000   | 0.000   | 0.000   |
| Site 2 | 0.180   | 0.025   | 0.035   | 0.015   | 0.012   | 0.083   |
| Site 3 | 0.183   | 0.032   | 0.037   | 0.021   | 0.014   | 0.084   |
| Site 4 | 0.165   | 0.035   | 0.030   | 0.022   | 0.012   | 0.049   |
metallic contamination in wastewater was found to be reduced at site 4 (Table 19.3). This may be due to natural chemical fixation of such metals during flow for a long distance or some absorption by trees and grasses grown in between these two sites.

### 19.3.4 Heavy Metal Accumulation in Vegetables Through Polluted Groundwater Irrigation

The perusal of data in Table 19.4 revealed that the vegetables under irrigation with groundwater at different sites have a large variation in metal concentration. At the control site the groundwater irrigated vegetables have normal contents of the metals but at the other sites where groundwater is polluted (highly contaminated with heavy metals), the contents of these metals was found to be very high. The highest metal accumulation in cauliflowers was observed at site 3. The Fe, Mn, Cu and Zn content in groundwater irrigated cauliflowers at site 3 was found to be 1.2, 1.4, 2.1 and 2.0 times higher when compared to site 1 (unpolluted groundwater). The Cd and Ni contents in cauliflowers at site 1 were Not Detectable (ND), whereas these two metals were found in a noticeable amount in cauliflowers at sites 2, 3 and 4 which were irrigated by polluted groundwater. Similarly in cabbages the highest metal accumulation was observed at site 3. The Fe, Mn, Cu and Zn content in groundwater irrigated cabbages at site 3 was found to be 1.5, 1.6, 2.3 and 2.4 times higher when compared to site 1 (unpolluted groundwater). Cd and Ni were not detected at all in cabbages at site 1 but at site 3 the mean values of Cd and Ni reached up to 0.06 and 0.69 ppm, respectively. It may be due to higher contamination of groundwater by these metals at this site. In the case of brinjal, the highest accumulation of Fe, Zn and Cd was observed at site 2 and Mn and Ni at site 3. The Cd contents in brinjal at all the sites were found very low but the Ni contents were markedly higher at the polluted groundwater irrigated sites (sites 2, 3 and 4).

Similar to the other vegetables, polluted groundwater irrigated spinach was also found to accumulate much higher heavy metals as compared to the control site. The extent of accumulation of Fe, Mn, Cu and Zn in spinach at site 3 was observed at 2.4, 2.0, 2.5 and 2.6 times more than at site 1. The Cd and Ni also accumulated to a great extent in spinach irrigated with polluted groundwater at sites 2, 3 and 4. The highest contents of Cd and Ni were found in spinach at site 3. The mean values of Cd and Ni content increased from 0.01–0.07 ppm and 0.01–0.72 ppm, respectively.

#### Table 19.3 Heavy metal concentration in wastewater (mean of 3 years)

| Site  | Fe (mg/kg) | Mn (mg/kg) | Cu (mg/kg) | Zn (mg/kg) | Cd (mg/kg) | Ni (mg/kg) |
|-------|------------|------------|------------|------------|------------|------------|
| Site 2 | 0.188      | 0.195      | 0.110      | 0.191      | 0.156      | 0.189      |
| Site 3 | 0.197      | 0.207      | 0.112      | 0.208      | 0.168      | 0.199      |
| Site 4 | 0.188      | 0.193      | 0.106      | 0.183      | 0.139      | 0.193      |
Furthermore, the data in Table 19.4 show that at the control site Cd and Ni contents in tomato were Not Detectable (ND) but at sites 2, 3 and 4 considerable amounts of Cd and Ni were accumulated and the highest mean values of Cd and Ni were observed at site 3 i.e. 0.07 and 0.63 ppm, respectively. Accumulation of Fe, Mn, Cu and Zn at site 3 were 2.0, 2.0, 1.3 and 3.2 times more than the control site. In the case of radish the highest accumulations of Fe, Mn, Cu, Zn and Cd were observed at site 3, whereas the highest mean accumulation of Ni (0.91 ppm) was observed at site 2. The Fe, Mn, Cu and Zn concentrations in radishes at site 3 were 1.9, 1.9, 1.4 and 2.8 times higher than the control site.

### Table 19.4 Heavy metal content in vegetables (mg/kg) through different quality groundwater (mean of 3 years)

| Site   | Fe    | Mn    | Cu    | Zn    | Cd    | Ni    |
|--------|-------|-------|-------|-------|-------|-------|
| Cauliflower |       |       |       |       |       |       |
| Site 1 | 30.75 | 52.02 | 3.85  | 21.64 | 0.00  | 0.00  |
| Site 2 | 34.55 | 67.65 | 6.78  | 38.71 | 0.02  | 0.39  |
| Site 3 | 37.33 | 72.69 | 8.10  | 43.04 | 0.04  | 0.45  |
| Site 4 | 33.43 | 59.90 | 6.05  | 34.53 | 0.03  | 0.38  |
| Cabbage |       |       |       |       |       |       |
| Site 1 | 39.62 | 60.27 | 4.32  | 21.06 | 0.00  | 0.00  |
| Site 2 | 48.17 | 83.60 | 8.71  | 42.95 | 0.04  | 0.57  |
| Site 3 | 58.65 | 98.89 | 10.09 | 49.90 | 0.06  | 0.69  |
| Site 4 | 49.63 | 79.33 | 8.72  | 41.58 | 0.05  | 0.60  |
| Brinjal |       |       |       |       |       |       |
| Site 1 | 47.97 | 50.22 | 2.18  | 12.54 | 0.00  | 0.00  |
| Site 2 | 64.93 | 80.44 | 4.22  | 18.11 | 0.02  | 0.27  |
| Site 3 | 62.23 | 92.20 | 4.60  | 13.17 | 0.01  | 0.33  |
| Site 4 | 62.38 | 84.91 | 4.86  | 13.15 | 0.00  | 0.27  |
| Spinach |       |       |       |       |       |       |
| Site 1 | 161.07| 47.41 | 4.10  | 30.02 | 0.01  | 0.01  |
| Site 2 | 312.50| 80.41 | 8.48  | 75.00 | 0.04  | 0.63  |
| Site 3 | 387.81| 96.37 | 10.23 | 79.32 | 0.07  | 0.72  |
| Site 4 | 300.23| 83.90 | 7.73  | 59.45 | 0.04  | 0.61  |
| Tomato |       |       |       |       |       |       |
| Site 1 | 119.31| 82.08 | 6.45  | 22.04 | 0.00  | 0.00  |
| Site 2 | 208.24| 156.45| 7.81  | 54.83 | 0.04  | 0.54  |
| Site 3 | 239.91| 160.40| 8.49  | 69.87 | 0.07  | 0.63  |
| Site 4 | 206.57| 149.35| 7.84  | 52.97 | 0.05  | 0.61  |
| Radish |       |       |       |       |       |       |
| Site 1 | 139.10| 71.52 | 7.09  | 29.32 | 0.01  | 0.02  |
| Site 2 | 252.17| 122.81| 9.50  | 55.47 | 0.06  | 0.91  |
| Site 3 | 266.27| 136.31| 10.27 | 81.37 | 0.07  | 0.90  |
| Site 4 | 248.93| 127.13| 8.75  | 75.05 | 0.07  | 0.85  |
### 19.3.5 Heavy Metal Accumulation in Wastewater Irrigated Vegetables

The data in Table 19.5 clearly revealed that highest metallic accumulation in wastewater irrigated vegetables selected for this study was observed at site 3 (Kanpur – Madir village) which also had the highest metallic concentration in the wastewater. At site 3 cauliflowers accumulated Fe, Mn, Cu and Zn at rates of 2.34, 2.63, 4.20 and 3.97 higher, respectively, than the normal concentration of these metals (site 1, Table 19.4). Cadmium and nickel were Not Detectable (ND) in cauliflowers at site 1 (Table 19.4) but considerable amounts (0.06 and 1.05 ppm) of these metals were found in wastewater irrigated cauliflowers. In the case of cabbages Fe, Mn, Cu and Zn accumulation were found to be 2.31, 2.85, 4.22 and 3.57 times higher in that order. These results are in close conformity with the findings of Yadav et al. (2012).

Under the most polluted site (site 3) the wastewater irrigated brinjal accumulated Fe, Mn, Cu and Zn at rates of 2.96, 2.89, 7.44 and 2.86 higher, respectively, than normal ranges at the control site given in Table 19.4. Spinach was found to contain Fe, Mn, Cu and Zn 3.24, 3.45, 4.39 and 4.25, respectively, higher than their normal ranges. At site 3, wastewater irrigated tomato was found to have the highest accumulation of Fe, Mn and Zn amongst the all selected vegetable crops. The Fe, Mn, Cu and Zn were found 4.03, 4.10, 2.50 and 5.75 times higher in that order in wastewater irrigated tomato as compared to the normal ranges. The wastewater irrigated radish was found to contain Fe, Mn, Cu and Zn at 3.78, 3.73, 2.41 and 4.36 times, respectively, higher than the control. The data in Table 19.5 revealed that the iron and zinc concentrations in spinach grown with wastewater irrigation at all three sites crossed the maximum permitted levels (425 ppm for Fe and 100 ppm for Zn) as prescribed by WHO. At site 2 the Cd concentration in spinach is on the MPL (Maximum Permitted Level) whereas at site 3 and 4, the Cd concentration crossed the MPL.

The critical observation of the data in Table 19.5 elucidated that tomato irrigated with wastewater at site 3 accumulated Fe at more than the maximum permitted level, whereas Zn accumulation crossed the maximum permissible limit (100 ppm) at site 2 and site 3. The cadmium accumulation also increased to an alarming level at site 2, whereas it crossed the maximum permissible limits at sites 3 and 4.

In the case of radish grown under irrigation with wastewater, Fe and Cd crossed the maximum permissible level at all three sites, whereas the Zn accumulation was found near the maximum permissible limits in the radish grown at site 2 and it crossed the limits at sites 3 and 4.
### Table 19.5 Heavy metal accumulation in vegetables (mg/kg) through wastewater irrigation (mean of 3 years)

| Site  | Fe    | Mn    | Cu    | Zn    | Cd    | Ni    |
|-------|-------|-------|-------|-------|-------|-------|
| **Cauliflower** |       |       |       |       |       |       |
| Site 2 | 62.53 | 122.63| 14.32 | 80.20 | 0.05  | 1.03  |
| Site 3 | 71.99 | 136.60| 16.17 | 85.82 | 0.06  | 1.05  |
| Site 4 | 59.59 | 107.64| 15.30 | 67.77 | 0.03  | 0.89  |
| **Cabbage** |       |       |       |       |       |       |
| Site 2 | 80.78 | 154.35| 14.68 | 74.60 | 0.07  | 1.10  |
| Site 3 | 91.58 | 171.78| 18.21 | 75.27 | 0.06  | 1.04  |
| Site 4 | 81.35 | 154.38| 16.16 | 68.74 | 0.06  | 0.92  |
| **Brinjal** |       |       |       |       |       |       |
| Site 2 | 125.45| 132.96| 10.94 | 31.50 | 0.05  | 0.88  |
| Site 3 | 142.04| 145.20| 16.21 | 35.88 | 0.06  | 0.96  |
| Site 4 | 133.83| 141.95| 16.31 | 31.87 | 0.05  | 0.84  |
| **Spinach** |       |       |       |       |       |       |
| Site 2 | 487.98| 136.13| 17.49 | 111.69| 0.10  | 1.22  |
| Site 3 | 522.54| 163.77| 17.99 | 127.45| 0.14  | 1.45  |
| Site 4 | 451.06| 157.30| 14.13 | 107.41| 0.13  | 1.03  |
| **Tomato** |       |       |       |       |       |       |
| Site 2 | 409.84| 274.01| 14.12 | 103.73| 0.09  | 0.98  |
| Site 3 | 480.93| 336.68| 16.11 | 126.73| 0.12  | 1.36  |
| Site 4 | 411.08| 325.38| 15.84 | 97.79 | 0.11  | 0.97  |
| **Radish** |       |       |       |       |       |       |
| Site 2 | 474.88| 244.77| 15.88 | 91.25 | 0.12  | 1.40  |
| Site 3 | 526.25| 267.08| 17.09 | 127.89| 0.13  | 1.57  |
| Site 4 | 500.11| 270.82| 15.56 | 107.37| 0.13  | 1.17  |

### 19.4 Conclusion

The heavy metal accumulation in groundwater irrigated vegetables was found to increase with increasing contamination of these metals in groundwater at different locations but the metallic accumulation in all the selected vegetable crops (cauli-flower, cabbage, brinjal, spinach, tomato and radish) irrigated by groundwater at all the selected locations were found to be within the maximum permissible limits as prescribed by WHO. In the case of wastewater irrigated spinach, tomato and radish the maximum permissible limits of Fe, Zn and Cd accumulation in edible parts were crossed at site 3 (Kanpur – Madri Village) which is irrigated with a muddle of domestic+industrial wastewater. Spinach is the most common and popularly grown leafy vegetable that with wastewater irrigation was found to accumulate Fe, Zn and Cd to a great extent (more than the maximum permissible limit) at all three selected locations. Hence, it can be inferred that vegetable crops mainly tomato, radish and spinach grown with untreated wastewater irrigation are unsafe for human consumption.
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