# Sewage Water Irrigation and Heavy Metal Accumulation in Vegetables in Patna By - Pass Area – A case study

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## – A case study


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# FOREWORD

The use of industrial or municipal waste water in agriculture is a common practice in almost all the parts of the world. Changing scenario with economic development of the society towards large scale urbanization, increasing population and industrialization is leading to production of huge quantities of effluents in India. Industrial and domestic effluents are either used or disposed off on land for irrigation purposes that create both opportunities and problems. The sewage effluents from municipal origin provide a reliable source of water supply to the farmers and adding appreciable amounts of major and micronutrients and organic matter to the soils.

Treatment of waste water usually produces effluents of suitable quality that can be used for irrigation purposes with minimum impacts on human health or environment, but this also contains variable amounts of heavy metals, which may limit the long term use of effluents for agricultural purposes. Transfer of these metal cations to the soil and subsequently to the plants that enter the feed and food chain, pose significant health concerns which is a matter that needs proper attention. Waste water irrigation may have significant contribution towards solving the problem of water shortage to some extent and safe disposal of sewage water to a larger extent. Hence most of the farmers, especially in urban areas, use sewage water because it is available free of cost and act as an effective fertilizer. However, its harmful effects on quality of produce which need to be studied for taking safety measures.

The information generated by the team of scientists of AICRP on Ground Water Utilization, on soil pollution due to heavy metal accumulation, is quite useful for taking precautionary measures in advance especially in those area where sewage sludge is being disposed off and used by the farmers as organic manures.

This bulletin embodies the useful information generated by the scientists on trace & heavy metal accumulation in soils and varieties of vegetable and field crops. Though the study confirms that the sewage water can effectively increase water resources for irrigation but there is need for continuous monitoring of the concentration of these metal cations in soils and plants.

I congratulate and appreciate the scientists for their efforts in the preparation of this bulletin entitled `Sewage Water Irrigation and Heavy Metal Accumulation in Patna by-pass Area' and hope that this will be useful to the researchers, scientists, students, planners, environmentalists and farmers in sustainable use of waste waters for augmenting the agricultural production of the state.

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***Pusa, dated January 26, 2016*** ***(Authors)***

# CONTENTS

## INTRODUCTION

Bihar is undergoing fast economic development with its impact on life style, natural resource and the environment. Agriculture plays a vital role in poverty alleviation, because of more than 85 % population are of rural background. The assured availability of ground water is the key factor in shaping the future economic scenario of the state. The crop yield in assured ground water irrigated areas being higher, the future for increasing irrigated area will depend mostly on groundwater. Bestowed with substantial ground water resources, 2526 bcm static and 27.42 bcm dynamic resources can substantially increase the cropping and irrigation intensity. Groundwater can safely be developed at least to the stage of 60-70% for raising cash crops, increasing the irrigation intensity from 52% at present to 80%, in the north Bihar plain with prolific aquifers and shallow water level. While the south Bihar plain, particularly in the marginal alluvial areas, along with the development of ground water it is essential to implement artificial recharge schemes including rejuvenation of traditional ahar and pyne system. By 2050, the population of the state is to cross about 20 crores. Hence probably there would be an increase of 249% in demand from the year 2001. Keeping drinking water as first priority and setting aside 5.342 bcm required for drinking in 2051, 12.21 bcm can be diverted for enhancing the irrigation potential.

## WASTE WATER GENERATION

The huge volume of wastewater generated in Ganga basin and its disposal is presented in table 1. As per CPCB (2009) report there are 23 Class I cities and 14 Class II cities in Bihar generating 1009.7 and 107.42 MLD sewage respectively. The treatment capacity exists only for 135.5 and 2 MLD in Bihar for Class I and Class II cities respectively which is only 10.6 and 1.47 percent of the sewage generated. Out of the seven Sewage treatment Plants (STPs) in Bihar, four STPs are at Patna which are also not in working condition either due to lack of power or under construction or renovation. The treated sewage is disposed in land and rivers like, Budhi Gandak, Phalgu, Gandak, Ghugri, Ghaghara, Chandrabhaga, Daha, Son and Simrahi streams and the untreated sewage water is disposed for irrigation and also to rivers and land. In Patna, the capital city of Bihar, 249.2 MLD of sewage is generated and treatment capacity exists for 109 MLD (43.7%). It has been also found that with total water supply of 348.93 MLD in Patna, about 279.14 MLD sewage is generated.

| *Category* | *Wastewater Volume (MLD)* | *Disposal* |
|---|---|---|
| Class - I (36) | 2637.7 | Ganga river |
| Class - II (14) | 122.0 | Ganga river |
| **Total** | **2759.7** | |
| Class - I (113) | 7841.5 | Other rivers (tributaries) |
| Class - II (18) | 134.6 | Other rivers (tributaries) |
| **Total** | **7976.1** | |
| Class - I (30) | 907.4 | Land |
| Class - II (115) | 767.3 | Land |
| **Total** | **1674.7** | |
| **Grand Total** | **12410.5** | |

## IMPORTANCE OF SEWAGE WATER

The use of industrial or municipal sewage water in agriculture is a common practice in many parts of the world. About at least 20 million hectares in 50 countries are irrigated with raw or partially treated sewage water as reported by (Hussain et al. 2001). The major objectives of sewage water irrigation are that it provides a reliable source of water supply to the farmers and has the beneficial aspects of adding valuable plant nutrients and organic matter to the soil. As we know that a safe disposal of sewage sludge and domestic wastes is problem for municipalities throughout. The sewage water of domestic origin is the most dynamic substances and if applied in the soils exert profound influence on the solubility and mobility of trace-metal cations. These organic wastes contain substantial amount of the plant nutrient, which on recycling provide available nutrient to plant. Consequently, disposal or recycling of domestic/municipal sewage on agricultural lands must be carried out in a way which provides a beneficial impact to the crop without developing pollution problem. In addition, evaluation effect of sewage water irrigation, type of crop to be grown, irrigation methods, and agronomic practices, will determine quality and suitability of irrigation water to the greater extent.

There are several trace metal cations viz. Zn, Cu, Fe, Mn, B, Mo and Ni which have been considered essential for plant growth. A continuous disposal of sewage sludge contains sufficient amount of heavy metals whose application to the agricultural land increases the content of these metals in soils and crops growing therein. Continuous use of these wastes by farmers in their fields results the buildup of heavy metals to such a level that may become phytotoxic and hazardous to animals and human health.

## TRACE AND HEAVY METAL IN PLANTS

Heavy metals are naturally occurring metals present in soils and have common across the globe due to increase in geologic anthropogenic activities. Plants growing on such soils show a reduction in growth, performance and yield. Although plants require certain heavy metals for their growth and upkeep, excessive amounts of these metals can become toxic to plants. These metals cannot breakdown, when concentration within the plants exceeds optimal levels; they adversely affect the plant directly and indirectly. Some of the trace metals cations namely Fe, Mn, Zn, Cu, Mo and Ni are essential for plant growth. Some of them have unknown biological function like Cd, Cr, Pb, Co, Ag and Hg. These metal cations have harmful effect on biological system and do not undergo bio-degradation. They accumulate in living organisms causing various diseases/ disorders even in relatively lower concentrations. Various researchers have carried out studies on waste water application in agricultural crops as discussed below.

Shahalam et al. (1998) carried out a study to monitor the impact of wastewater irrigation on the soil, percolating water and crop growth. The yield resulted from the use of waste water with fertilizers were comparable with those of use of fresh water. Ranwa (1999) studied the waste water and its effect on soil and crops. He reported that treated wastewater when used in low concentrations or in combination with canal and tube well water may have a good effect on crop growth and yield. The direct use of waste water in high concentrations should be avoided for its reuse in agriculture.

Brar et al. (2000) conducted study on tuber vegetable potato (Solanum tuberosum L.) crop and reported that sewage water increased concentrations of all elements in soil except As, and the increase was significant to 60 cm depth for Fe, Mn, Zn, Al and Ni and to 30 cm depth for Cu and Cr. Irrigation with sewage water also increased the concentrations of these elements in potato leaves and tubers and the ratio was generally higher in leaves than in tubers. The proportional increase of Cu, Fe, Zn and Al was less in plants than in soils, that of Mn and Cr was almost similar in plants and in soil, and that of Ni was more in plants than in soil.

Lone et al. (2003) found that, heavy metal and micronutrient contents in two vegetables were present in significantly higher amount in order of sewage and tube well water except Cu and Fe which showed variation for both the crops. Spinach leaves showed higher accumulation of heavy metals and micronutrients as compared to okra fruit.

Saraswat et al. (2005) reported that treated sewage water-irrigated vegetables contained relatively higher amounts of micronutrients than the tube well water irrigated vegetables, wherein okra (Abelmoschus Esculentus), cauliflower (Brassica oleracea var. botrytis), radish (Raphanus sativus) and broad beans (Viciafaba) had higher amount of Zn, Fe, Cu and Mn, respectively, in their edible parts.

Abedi-Koupai et al. (2006) conducted a study on three crops viz. sugar beet, corn and sunflower and determined the concentration of Pb, Mn, Fe, Cd, Ni, Co, Cu and Zn and reported that accumulation of Pb, Mn, Ni and Co in the soil increased significantly. Sharma et al. (2006) investigated the level of heavy metals in irrigation water, soil and vegetables grown in the irrigated areas of Varanasi, Uttar Pradesh. In okra the concentrations of Cu, Zn, Cd, Pb, Ni and Cr ranged from 1.75 to 8.70, 18.85 to 132.70, 1.10 to 9.20, 6.50 to 29.00, 3.45 to 12.00 and 2.95 to 12.85 µg/g dry weights, respectively.

Singh and Kumar (2006) reported that in spinach and okra Zn, Pb and Cd levels were higher after sewage water irrigation as compared to the limits specified by WHO in spinach and okra crops. The levels of Cu were at their safe limits. Metal contamination was higher in spinach than in okra. Bigdeli and Seilsepor (2008) reported that the Pb concentration in all vegetable samples was more than maximum permitted concentrations, while Cd pollution was observed in radish, Cress, Dill, spinach and eggplant and Zn concentration in Celery, Mint, Dill, Spinach and Green pepper was more than permitted levels.

Qishlaqi et al. (2008) reported excessive accumulation of Ni and Pb in wheat due to continuous addition of heavy metals through long term wastewater application. Singh and Biswas (2008) reported that after sewage irrigation yield of okra, spinach and cauliflower was increased approximately 12%, 12% and 15%, respectively. Radar et al. (2008) reported the response of okra was significant due to both irrigation as well as micronutrient application. The N, P, K, Zn, and Fe uptake by the crop was significant.

Jena et al. (2009) reported that the concentration of cations was in the order of Ca>Mg >Na >K. Sewage water soils had toxic amounts of Fe, B and Mo. The concentrations of Cd, Pb and Cr in rice, mustard, sunflower, maize, tomato, grain, amaranthus, cabbage, cauliflower, brinjal and lady's finger were below upper level of phytotoxicity and contents of heavy metals in leaf of crops grown in normal soils were lower than sewage water irrigated soils.

Adewoye et al. (2010) studied the crop growth, crop yields and nutrient uptake of Okra and reported that the 75% treated sewage effluent gave the highest fruit yield of 10.5 t/ha while the 100% stream water gave the lowest fruit yield of 5.40 t/ha. The highest dry matter yield of 9.8 t/ha was obtained with 100% partially treated sewage. The sewage resulted in higher P, K, and Cu content of the soil.

Lan Houng et al. (2010) carried out a study to identify the impact of wastewater irrigation on the level of heavy metals in the soils and vegetables and to predict their potential mobility and bioavailability. The concentrations of all heavy metals in the study site were much greater than the background level in that area and exceeded the permissible levels of the Vietnamese standards for Cd, Cu, and Pb. The concentrations of Zn, Ni, and Pb in the surface soil decreased with distance from the canal. Leaching tests for water and acid indicated that the ratio of leached metal concentration to total metal concentration in the soil decreased in the order of Cd > Ni > Cr > Pb > Cu > Zn and in the order of Cd > Ni > Cr > Zn > Cu > Pb for the ethylene diamine tetra aceitc acid (EDTA) treatment.

Murtaza et al. (2010) reported that higher accumulation of metals in fruits and vegetable roots was recorded compared to that in plant leaves. Edible parts of vegetables (fruits and/or leaves) accumulated metals were more than the permissible limits despite the soils contained ammonium bicarbonate di-ethylene triaminepenta acetic acid extractable metals within a safe range. Cadmium appeared to be the most threatening metal especially in leafy vegetables.

Mushtaq and Khan (2010) found that the EC, SAR, RSC and TDS of most effluent/ waste water samples were above the critical limits. Cd and Cr were above the critical limits in almost all the effluent samples, whereas Ni was high in 14, Pb was high in 10, Cu was high in 5 and the Fe was high in 3 effluent samples as compared to critical limits. Regarding heavy metals contents of soils irrigated by these effluents/ waste water, total Fe, total Cd and total Ni were higher in almost all the sampled sites, whereas total Cr was high at 7 sampled sites. AB-DTPA extractable Fe and Zn were higher at all the sampled sites, while the extractable Cd was higher at 2 sampled sites.

Sidhu et al. (2010) reported that the vegetable crops grown with sewage water showed higher content of micronutrients than those grown with tube well water. Comparatively higher build up of zinc, copper and manganese was observed in spinach irrigated with any type of water. The iron content was observed maximum in coriander with sewage water. In sewage irrigated fields, the lowest build up of Zn in carrot (48 mg $Kg^{-1}$) and of Mn (68 mg $Kg^{-1}$) and Fe (218 mg $Kg^{-1}$) in cauliflower were observed. Tiwari et al. (2011) carried out an investigation to evaluate metals concentration in ten vegetable crops growing in mixed industrial effluent irrigated agricultural field near Vadodara, Gujarat, India. They reported that the metals accumulation in root and top of vegetables varied significantly both in relations to metal concentration in the soil and the plant genotype. Among ten vegetable species studied five vegetable species, i.e. Spinach, Radish, Tomato, Chili and Cabbage growing in mixed industrial effluent irrigated agricultural field showed high accumulation and translocation of toxic metals (As, Cd, Cr, Pb and Ni) in their edible parts.

## STUDY AREA

In Patna, the locations of STPs are Saidpur, Beur, Pahari (Southern zone) and Karmali Chak (Eastern zone). The STPs of Saidpur and Beur were old plants and constructed during 1936 and 1969 respectively with a capacity of 28 and 20 MLD. Under Ganga Action Plan, treatment capacity augmented (17 MLD in Saidpur and 15 MLD in Beur) in two STPs and other two STPs with a capacity of 25 MLD (Pahari) and 4 MLD (Karmali Chak) were planned. The STP at Pahari has been commissioned, whereas the construction of STP at Karmali Chak has so far not been completed except that of earthwork. The present population of Patna city is 13.2 lakhs and the total water supply in the town is about 175 MLD. The wastewater generation is about 143 MLD. The total sewage treatment capacity created in the town is of the order of 101.45 MLD putting together the capacity of Saidpur, Beur and Pahari STPs. But, due to various, problems in the functioning of STPs, only 49 MLD capacities could be made operational. Thus, there is a gap of about 94 MLD, which is not at all getting treatment and is discharged into river Ganga and river Punpun (which ultimately joins river Ganga).

The Patna by-pass area is situated in both sides of National highway No. 30. The study area is located near chhoti Pahari STP. The designed capacity of Pahari STP in Patna is 25 MLD and the plant is designed to treat the sewage by aeration in the lagoon. The plant is not in operation due to one or the other technical as well as electrical faults. The fish pond of this plant was observed to be full of algae, which indicates that the aerated lagoon is not in operation for a considerable period of time. There was no fish in the pond. It is observed that the power supply is also one of the main hindrances.

The whole area is receiving a continuous use of sewage sludge for a period of over 50 years. The farmers grow a variety of vegetables and field crops by lifting sewage water through pumps and open wells. Altogether, 30 sampling sites were selected for collecting surface samples of soils and various crop species during the years 2010 – 2013 (Table 2). All these soils, plants and sewage water samples were studied for micronutrients and heavy metal cations. (Table 3). A Google image of sampling sites at Patna By pass is presented here.

*Fig. 1. Google image of the study area (Patna bye-pass).*

## EXPERIMENTAL DETAILS

### *Soil*

Thirty bulk surface soil samples (0-15 cm) of old alluvium (Vertisol) soils of by-pass, Patna receiving sewage sludge effluents were collected for the studies. Two samples from each location at an interval of 100 m from both sides of the NH-30 were collected nearby the discharge point of the treatment plant. The elemental analysis of the samples was carried out through Atomic absorption spectrophotometer. The micronutrients and heavy metals were estimated by standard procedure proposed by Lindsay and Norvell (1978). The extracting reagent is prepared by taking DTPA and $CaCl_2$ $2H_2O$ and added TEA by 100 ml double distilled water. The pH of the solution is adjusted to 7.3 with dilute acid. Then 10 gm soil with 20 ml DTPA reagent is shaken for two hours. The extract is filtered and concentrations of these trace metal cations are estimated with the help of atomic absorption spectrophotometer.

### *Plants*

All the plant samples were collected from the sites from which soils were collected. The plants with roots intact as far as possible were uprooted from the soils after a span of (45-50) days growth of the crops. The whole plants were washed and thoroughly acidulated in water and then in distilled water. The washed samples were first dried in air then in an oven at 650C. The dried samples were powdered in grinder. 0.5 g powdered plant samples were digested in tri-acid mixture of $HNO_3$ : $HClO_4$ : $H_2SO_4$ in the ratio of 10 : 3 : 1 on hot plate. It was fully digested till few drops of white residue were left. The residue was dissolved in double-glass-distilled water and final volume was made to 50 ml. The samples were filtered and used for chemical analysis like Zn, Cu, Mn, Fe, Ni, Cr, Cd and Pb through atomic absorption spectrophotometer.

### *Sewage Water Quality*

Physico-chemical characteristics of sewage water being used by the farmers at Patna by-pass area are presented in Table 3. The experimental data revealed that sewage water contained higher amount of micronutrients and heavy metals except Pb which on continued application to agricultural lands may contaminate surface soils to the greater extent (Table 3). The plants growing on such soils accumulate excess amount of trace metal cations like Fe, Cd, Cr, Ni and Co in their tissues may be hazardous for animals and human beings and move down to the lower profile of soils and contaminate the ground water.

## IMPACT OF SEWAGE WATER IRRIGATION ON SOIL

### *Physico-chemical Characteristics*

In general, pH of the soil ranged between 6.55 to 7.64 which fall under neutral to medium saline category. The electrical conductivity in those soils varied from 0.12 to 1.82 $dSm^{-1}$. It is evident from the data that there was gradual increase in EC along the distance might be due to disposal of soluble salt through the open channel. Although, there was accumulation of soluble salts due to disposal of sewage sludge, but the extent was below the tolerance limit for most of the crops. The organic carbon content in soils of various locations varied from 0.65 to 1.87 per cent. The highest amount of organic carbon content was found in the surface soil of site ($S_1$) nearest to the discharge point of sewage sludge. In general the organic carbon declined with increasing distance from the discharge point. The available phosphate and potash in surface soils of various sites ($S_1$ to $S_{16}$) ranged from 191.9 to 406 (kg/ha) and 559 to 2495 kg/ha, respectively. It was noticed that nearest site ($S_1$) contained highest (406 kg/ha) $P_2O_5$ as compared to distant site of the discharge point. The results indicated higher accumulation of $P_2O_5$ in surface soil due to sewage sludge application. Similarly, accumulation of available $K_2O$ in soils was observed, but the extent was much less as compared to $P_2O_5$. The high content of $P_2O_5$ in sewage-sludge treated soil might be due to higher content in waste as well as due to solublization of insoluble phosphorus by various constituents of sewage-sludge. The content of 'B' in soils of different sites varied from 1.09 to 2.3 ppm, however indicating that the extent was found lower than the tolerance limit of the crops. The sulphur content varied from 11.76 to 368.75 ppm in soils of different locations. The results also indicated that sulphur content decreases with increasing distance from the discharge point.

Table 2. Details of Soil and Plant sampling sites of bye-pass area of Patna.

| Sl. No. | Sampling Sites | Distance From source (km) | (Soils) Site No. | Crops |
|---|---|---|---|---|
| 1. | Chhoti Pahari | 0.0 | S1 | Amaranthus,Okra |
| | | | S2 | Cow pea, Okra Poi |
| | | 0.50 | S3 | Poi |
| | | | S4 | Chilli |
| 2. | Bari Pahari | 1.50 | S5 | Amaranthus, Chilli |
| | | | S6 | Brinjal, Pumpkin |
| | | 2.50 | S7 | Cow pea, Chilli |
| | | | S8 | Bitter gourd Pumpkin, Okra |
| 3. | Ranipur Pajhaba | 4.00 | S9 | Cabbage, Sponge gourd |
| | | | S10 | Maize, Okra |
| | | 4.50 | S11 | Cow pea, Okra |
| | | | S12 | Cow pea, Sponge gourd |
| 4. | Mahadeo Sthan | 6.00 | S13 | Cow pea |
| | | | S14 | Cabbage |
| | | 6.50 | S15 | Okra, Spinach |
| | | | S16 | Pumpkin, Amaranthus |
| 5. | Begampur | 8.50 | S17 | Cow pea, Sponge gord |
| | | | S18 | Okra |
| | | 9.00 | S19 | Chilli |
| | | | S20 | Okra, Pumpkin |
| 6. | Karmali Chowk | 10.0 | S21 | Cow pea, Amaranthus |
| | | | S22 | Sponge gourd, Okra |
| | | 10.5 | S23 | Okra |
| | | | S24 | Cow pea |
| 7. | Sati Chowk | 11.5 | S25 | Okra |
| | | | S26 | Pumpkin |
| | | 12.0 | S27 | Okra |
| 8. | Deedarganj | | S28 | Pumpkin |
| | | 13.5 | S29 | Okra |
| | | 14.0 | S30 | Cowpea |



*Table 3. Physico-chemical characteristics of sewage water*

| Sl. No. | Parameters | Contents | S. No. | Parameters | Content |
|---|---|---|---|---|---|
| 1. | pH | 8.21 | 10 | Zn (ppm) | 0.36 |
| 2. | EC ($dSm^{-1}$) | 1.42 | 11 | Cu (ppm) | 0.19 |
| 3. | Na (me/L) | 5.28 | 12 | Fe (ppm) | 7.56 |
| 4. | Ca + Mg (me/L) | 7.66 | 13 | Mn (ppm) | 0.47 |
| 5. | $CO_3^{--}+HCO_3^{-}$ (me/L) | 6.32 | 14 | Ni (ppm) | 0.18 |
| 6. | TDS (ppm) | 908 | 15 | Cr (ppm) | 0.06 |
| 7. | $Cl^{-}$ (me/L) | 7.2 | 16 | Cd (ppm) | 0.09 |
| 8. | $NO_3^{-}N$ (ppm) | 8.9 | 17 | Co (ppm) | 0.03 |
| 9. | SAR | 2.76 | 18 | Pb (ppm) | 0.00 |

## MICRONUTRIENTS

The DTPA extractable micronutrients and heavy metal contents in sewage- sludge treated soils are depicted in Table 4. The results obtained for individual elements are given below:

### *Zinc (Zn)*

The concentration of Zn in sludge treated soils of various locations ranged from 1.08 to 5.60 ppm (Table 4). The soils S1+S2 nearest to the discharge point of sewage discharge point contained appreciably more extractable Zn (4.08-5.12 ppm) than other sampling sites away from the discharge point (Table 4). It is revealed that surface soils at all the sites were sufficiently rich in Zn content and were beyond the critical limit. This might be due continuous disposal of sewage-sludge, resulting in enrichment of surface soil with extractable Zn. It was also observed that the distant sites (S29 & S30) receiving no sewage sludge had least Zn content.

### *Copper (Cu)*

The concentration of DTPA extractable Cu in soils as influenced by disposal of sewage-sludge varied from 5.31 to 37.57 ppm (Table 4). All the soils contained appreciably very high Cu content than the critical limit (<1.2 ppm) in the soils. Gradual decrease in its content was observed with increasing distance from the discharge point.

### *Iron (Fe)*

The iron exists in water in soluble ferrous form and ferric form as insoluble. The concentration of extractable Fe at various sites ranged from 10.25 to 24.67 ppm (Table 4). It is evident from the data that all the thirty sites were sufficiently rich in Fe with maximum accumulation at the point of discharge i.e. nearest sites ($S_1$+$S_2$) 24.43 ppm. This might be due to the fact that the sites away from the discharge point, received comparatively lower quantity of sewage, resulting in lower amount of extractable Fe. Manganese (Mn)

The concentration of extractable Mn was found in the range of 7.05 – 15.87 ppm are presented in Table 4. At all sites, extractable Mn accumulated in the surface soil and the extent of accumulation was recorded much higher than critical limits (>5.0 ppm). An application of sewage water seems to be responsible for the accumulation of available Mn in surface soil. It was also observed that there was irregular distribution of extractable Mn along the distance might be due to tendency of its movement towards sub-surface soils.

## HEAVY METALS

### *Nickel (Ni)*

Extractable Ni accumulated in the surface soil up to the extent of 0.13 to 4.78 ppm depending on the distance from the discharge point (Table 4). In general, the site (S1+S2) nearest to the discharge point contained appreciably higher amount of extractable Ni (2.63-4.51 ppm) and gradually declined up to 0.13 ppm with increasing distance from the discharge point (Table 8). The sites gradually away from discharge point, received comparatively lower quantity of sewage–sludge resulting in lower amount of extractable Ni.

### *Chromium (Cr)*

The DTPA extractable chromium differed markedly in the surface soil ranging from 0.02 to 0.38 ppm (Table 4). The Surface soil from the sites nearest to the sewage discharge point (S1+S2) contained appreciably high amount of extractable Cr (0.37 ppm) as compared to the farthest site (S29+S30) i.e. 0.02 ppm. The data also revealed that there was a gradual decrease in its content almost up to 6.5 km farthest from the discharge point after that irregular trend was obtained with increasing distance.

### *Cadmium (Cd)*

The concentration of extractable Cd was found in the range of 0.04 to 3.13 ppm (Table 4). Gradual decrease was observed in its content with increasing distance from sewage sludge disposal point and with the amount of sewage water application in soils. This might be the fact that soils nearest to the discharge point received high quantity of these organic wastes which form soluble metal chelates.

### *Lead (Pb)*

The soil nearest to the sewage discharge point ($S_1$+$S_2$) contained appreciably high amount of DTPA extractable Pb (26.92 ppm) which gradually decreased as the distance from the discharge point increased 26.92 to 1.02 ppm (Table 4). The site nearby the discharge point contained high Pb content due to receiving higher amount of sewage sludge and city wastes for longer periods on agricultural lands. This showed that Pb is preferentially held on the colloidal matrix of the soils forming clay-humus-complexes resulting in less movement.

The over all results showed that there was an accumulation of micronutrients and heavy metals in soils. The concentration of these trace meal cations (Cu, Zn, Fe, Mn, Ni, Cd, Cr and Pb) were beyond the critical limit prescribed for phytotoxicity of these metals. Spatial variation of micronutrients and heavy metal in sewage sludge affected area of Patna by-pass along with the distance are presented through Fig. 2 and Fig. 3. It is evident that the concentration of these metal cations decreases with increasing distance from the outlet of the sewage.

## TRACE METAL ACCUMULATION IN PLANTS

Various crop species were collected from different sites of sewage-sludge disposal area of Patna. Plant growing on such soils accumulates excess amount of trace-metal cations in their tissues which upon entering in the systems, may be hazardous for animals and human beings. The distributions of micronutrients and heavy metal cations in different crop species are presented in Table 5 and Table 6 respectively.

### *Zinc (Zn)*

The Zn concentration in different crop species varied from 123.0 to 241.9 (Amaranthus), 123 to 231 (Cow pea), 111.0-215.9 (Okra), 113 to 240 (Chilli), 93.0-155.0 (cabbage), 102.0 to 144.0 (sponge gourd), 144 (Bitter gourd), 247.0 (Poi), 122 to 165 (Pumpkin) and 165.0 ppm (Brinjal). It was also observed that the plant grown on site S1 contained much higher Zn than the sites away from the discharge point. The relative accumulation in different crop species based on mean values may be arranged as: Poi (247)> Red spinach (180)>Brinjal (164.7)>Chilli (156.6)> Okra (145.2) >Bitter gourd (144)>Pumpkin (142) >Cowpea (127.5) > Sponge gourd (126.3) > Cabbage (124) ppm.

### *Copper (Cu)*

The concentration of Cu varied to a great extent from crop to crop and increase in distance of sewage-sludge disposal area. It varied from 23.0 to 51.4 ppm (Amaranthus), 16.2 to 74.6 ppm (Cow pea), 30.0-63.0 ppm (Okra), 27.0 to 55.0 ppm (Chilli), 21.6-43.3 ppm (cabbage), 28.6 to 40.3 ppm (Sponge gourd), 33.0 ppm (Bitter gourd), 58.8 ppm (Poi), 30.4 to 40.4 ppm (Pumpkin) and 37.2 ppm (Brinjal). Based on the average accumulation of Cu (ppm), the different plant species may be kept in the order of Poi (58.8)> Amaranthus (38.8)> Brinjal (37.2)> Cowpea (34.0)> Pumpkin (33.7)> Sponge gourd (33.5) > Bitter gourd (33.0)> Cabbage (32.5)> Okra (32.2)> Chilli (23.0).

### *Iron (Fe)*

The total concentration of Fe in various plant species grown on soils receiving differential quantities of sewage-sludge varied widely. The Fe content in different plant species varied from 1074 to 1173 ppm (Amaranthus), 911 to 1283 ppm (Cow pea), 1030 to 1122 ppm (Okra), 924 to 1137 ppm (Chilli), 1033 to 1178 ppm (Sponge gourd), 1025 to 1093 ppm (Cabbage), 948 ppm (Bitter gourd), 859 to 1156 ppm (Pumpkin), 1119 ppm (Brinjal) and 1191 ppm (Poi). It was also observed that, plant species grown on nearer to the disposal point, contained maximum Fe content. The data also revealed that highest Fe was accumulated in Poi and lowest in Bitter gourd. Based on the average accumulation (ppm), the crop species fall in the order of: Poi (1151)> Amaranthus (1123)> Brinjal (1119)> Okra (1096)> Sponge gourd (1093)> Chilli (1063)> Cabbage (1053)> Cowpea (1037)> Pumpkin (1023)> Bitter gourd (948).

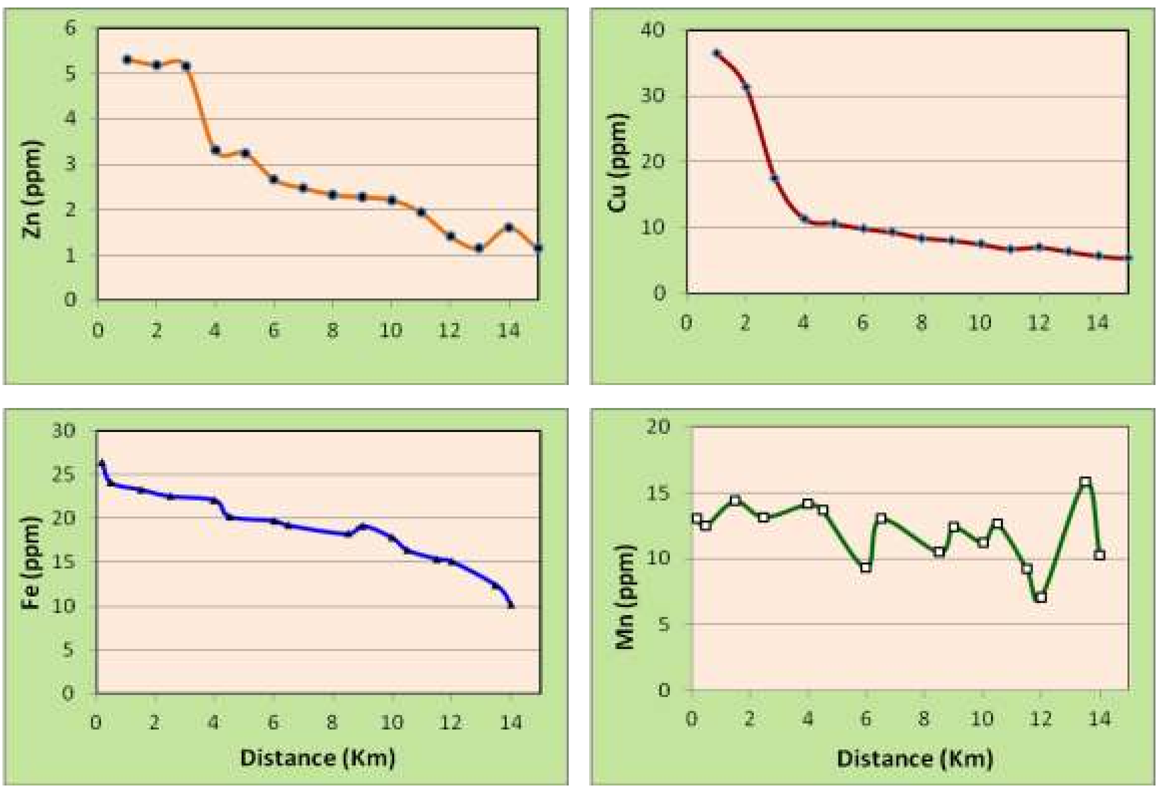


*Fig. 2. Spatial variation of micronutrients in sewage sludge treated soils of Patna bye-pass area.*

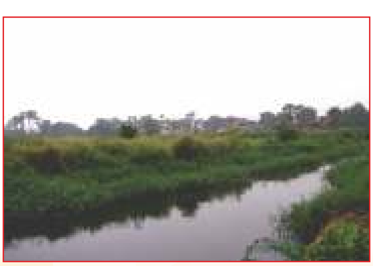

*Table 2. Details of Soil and Plant sampling sites of bye-pass area of Patna.*

| Site No. | DTPA extractable concentration (ppm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Zn | Cu | Fe | Mn | Cd | Cr | Ni | Pb |
| S1 | 5.60 | 37.57 | 24.67 | 12.87 | 3.16 | 0.43 | 4.78 | 29.10 |
| S2 | 4.64 | 36.42 | 24.19 | 13.16 | 3.07 | 0.40 | 4.23 | 27.73 |
| S3 | 4.09 | 30.24 | 24.23 | 12.94 | 3.09 | 0.36 | 2.61 | 24.75 |
| S4 | 4.07 | 32.61 | 24.03 | 12.02 | 2.39 | 0.38 | 2.64 | 28.18 |
| S5 | 4.09 | 18.64 | 24.88 | 14.46 | 2.26 | 0.32 | 2.42 | 16.84 |
| S6 | 3.91 | 16.38 | 22.81 | 14.27 | 2.23 | 0.32 | 2.22 | 12.21 |
| S7 | 3.47 | 12.01 | 22.72 | 14.25 | 2.24 | 0.30 | 2.67 | 14.54 |
| S8 | 3.62 | 10.74 | 22.67 | 12.60 | 1.31 | 0.28 | 2.09 | 13.12 |
| S9 | 3.32 | 10.47 | 22.47 | 13.60 | 0.77 | 0.26 | 2.o7 | 7.67 |
| S10 | 3.09 | 10.86 | 22.37 | 14.67 | 0.75 | 0.27 | 2.02 | 6.66 |
| S11 | 3.02 | 10.80 | 22.89 | 12.88 | 0.59 | 0.24 | 2.02 | 4.79 |
| S12 | 3.06 | 9.87 | 21.60 | 14.40 | 0.55 | 0.22 | 1.56 | 3.35 |
| S13 | 2.45 | 9.82 | 21.65 | 11.95 | 0.47 | 0.19 | 1.36 | 3.58 |
| S14 | 2.59 | 8.81 | 21.89 | 6.54 | 0.43 | 0.17 | 1.23 | 2.88 |
| S15 | 2.21 | 8.54 | 21.78 | 13.02 | 0.40 | 0.15 | 1.20 | 2.81 |
| S16 | 2.14 | 8.39 | 20.78 | 13.02 | 0.28 | 0.16 | 0.85 | 2.48 |
| S17 | 2.14 | 8.31 | 20.67 | 8.34 | 0.25 | 0.10 | 0.89 | 2.41 |
| S18 | 2.18 | 7.89 | 20.55 | 12.64 | 0.24 | 0.10 | 0.93 | 2.26 |
| S19 | 2.10 | 7.67 | 20.42 | 11.07 | 0.17 | 0.12 | 0.89 | 2.15 |
| S20 | 2.10 | 7.31 | 20.07 | 13.65 | 0.16 | 0.15 | 0.84 | 1.75 |
| S21 | 1.95 | 6.68 | 19.89 | 12.00 | 0.12 | 0.09 | 0.58 | 1.70 |
| S22 | 1.92 | 6.89 | 19.79 | 10.43 | 0.08 | 0.06 | 0.49 | 1.39 |
| S23 | 1.82 | 7.87 | 19.08 | 11.66 | 0.08 | 0.12 | 0.31 | 1.36 |
| S24 | 1.80 | 7.99 | 19.09 | 13.55 | 0.06 | 0.09 | 0.48 | 1.29 |
| S25 | 1.80 | 6.40 | 18.75 | 10.73 | 0.06 | 0.03 | 0.27 | 1.18 |
| S26 | 1.67 | 6.35 | 18.47 | 7.66 | 0.06 | 0.03 | 0.17 | 1.26 |
| S27 | 1.42 | 6.19 | 19.10 | 5.45 | 0.05 | 0.06 | 0.16 | 1.26 |
| S28 | 1.42 | 5.49 | 18.11 | 8.59 | 0.04 | 0.04 | 0.16 | 1.16 |
| S29 | 1.10 | 5.37 | 18.37 | 15.87 | 0.05 | 0.02 | 0.20 | 1.02 |
| S30 | 1.08 | 5.31 | 18.25 | 7.05 | 0.04 | 0.02 | 0.13 | 1.02 |

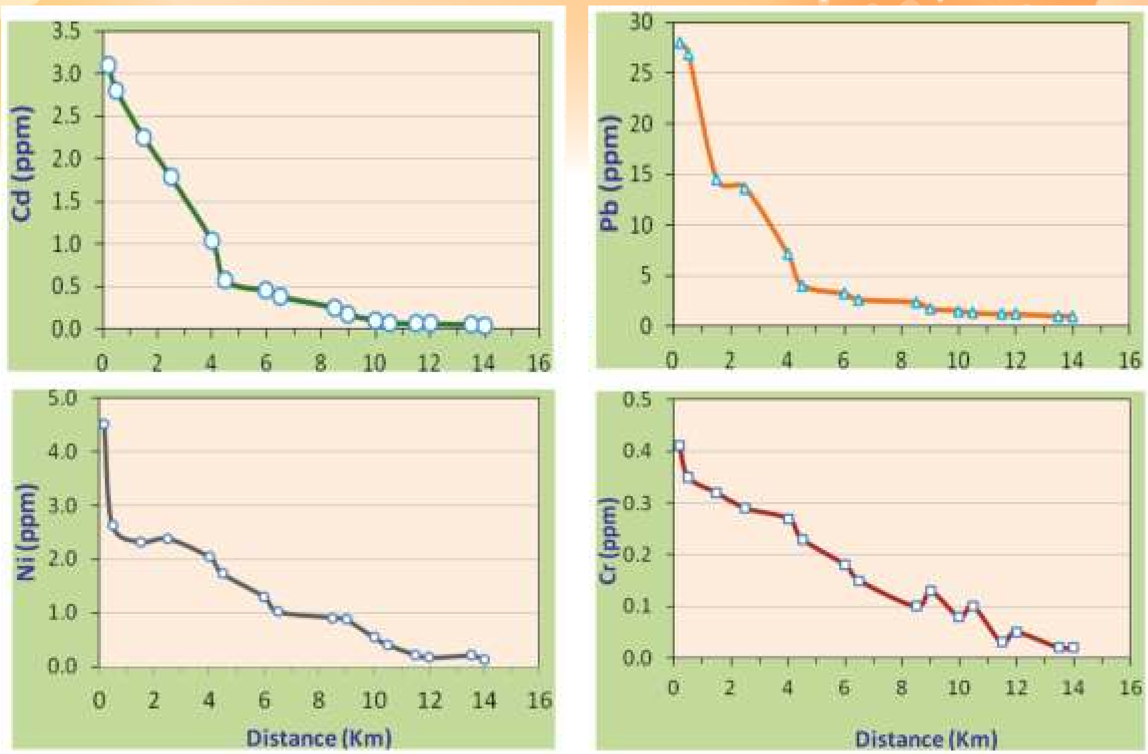


*Fig 3. Spatial variation of heavy metals in sewage sludge treated soils of Patna bye-pass area.*

### *Manganese (Mn)*

The Zn concentration in The concentration of Mn in different plant species varied from crop to crop. The concentration in different plant varied from 63.8 to 130 ppm (Amaranthus), 58.0 to 181.3 ppm (cow pea), 56 to 175 ppm (Okra), 52.4 to 136 ppm (Pumpkin), 71.4 to 162 ppm (Chilli), 90.2 to 108 ppm (Cabbage), 57.0 ppm (Bitter gourd), 81.8 ppm (Poi), 109.3 ppm (Brinjal) and 100.7 to 159.4 ppm (Sponge gourd). The average accumulation of Mn (ppm) in plant species may be kept in the order of Sponge gourd (124)> Okra (113)> Brinjal (109)> Cow pea (107)> Chilli (102)> Cabbage (99)> Red spinach (91)> Pumpkin (82)> Bitter gourd (57).

However, the contents of micronutrients in sewage water irrigated crops were higher and found beyond the critical limits which might be phytotoxic to the plants. A comparative picture of accumulation of trace metal cations in different crop species grown in sewage sludge affected area of Patna by-pass region is shown in Fig 4.

## HEAVY METAL ACCUMULATION IN PLANTS

### *Nickel (Ni)*

The concentration of Ni in different plant species grown on sewage-sludge treated soils disclosed a wide variation in its concentration in Amaranthus, Bitter gourd, Okra, Cabbage, Sponge gourd, Pumpkin, Chilli, Cow pea, Poi and Brinjal as 45.4 to 63.6 ppm, 51.0 ppm, 17.0 to 66 ppm, 45.6 to 51.7ppm, 36.3 to 45.7ppm, 18.2 to 41.7 ppm, 37.4 to 55.8 ppm, 16 to 62 ppm, 69 ppm, and 52.8 ppm, respectively. Hence, different plant species varied greatly in their Ni content (ppm) as Poi (59)> Amaranthus (55.2)> Brinjal (52.8)> Bitter gourd (51.0)> Chilli (49.2)> Cabbage (48.7)> Cow pea (44.8)> Sponge gourd (42)> Okra (41.5)> Pumpkin (32.1). The accumulation of Ni in plant depended on DTPA extractable Ni in soil as well as other soil properties.

### *Chromium (Cr)*

The Cr concentration in Amaranthus varied from 51.0 to 74.6 ppm, Cow pea 36.2 to 63.3 ppm, Poi 130 ppm, Bitter gourd 59.0 ppm, Chilli 53 to 61.5

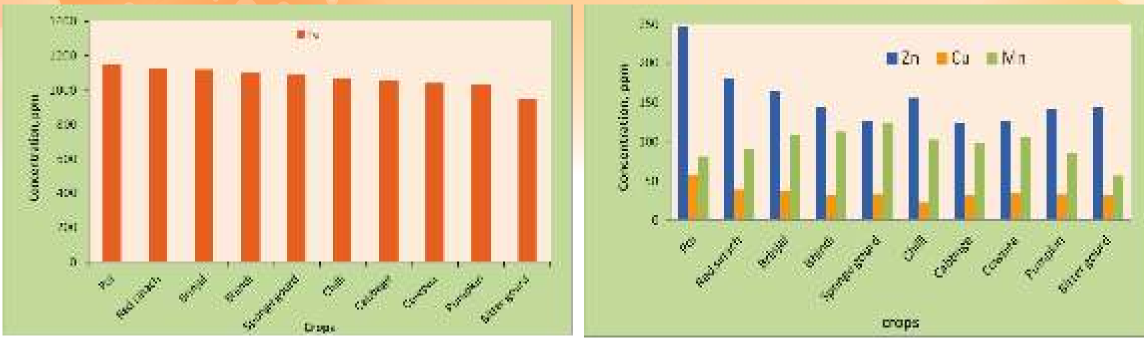


*Fig 4. Average accumulation of micronutrients in various crops grown in sewage treated soils of Patna bye-pass area.*

ppm, Cabbage 44.0 to 62.0 ppm, Brinjal 60.6 ppm, Sponge gourd 50.0 to 60.0 ppm, and Pumpkin 48.0 to 59.6 ppm. The average relative accumulation of Cr (in ppm) in different crop species can be placed in the order of: Poi (130)> Amaranthus (62.3)> Brinjal (60.6)> Okra (60.2)> Bitter gourd (59.0)>Chilli (58.8)> Sponge gourd (56.5)> Cow pea (54.1)> Cabbage (53)> Pumpkin (52.5) ppm.

### *Cadmium (Cd)*

The perusal of the data presented in table 6 showed that different species of the crops behaved differently for accumulation of Cd. It varied from 7.1 to 12.9 ppm for Amaranthus, 5.2 to 10.3 ppm for Cow pea, 7.4 ppm for Brinjal, 5.0 to 12.0 ppm for Pumpkin, 6.7 to 12.5 ppm for Chilli, 8.3 to 10.5 for Cabbage, 11.7 ppm for Poi, 7.3 ppm for Bitter gourd and 6.9 to 9.5 ppm for Sponge gourd. Considering the average values (ppm), Cd accumulation in different crop species was found in the order: Poi (11.7)> Amaranthus (9.82)> Cabbage (9.5)> Okra (8.5)> Chilli (8.3)> Sponge gourd (8.17)> Cow pea (7.8)> Brinjal (7.4)> Bitter gourd (7.3) > Pumpkin (7.24).

### *Lead (Pb)*

The data (Table 6) revealed that the Pb concentration in different crop species varied greatly and were found in the range of 87.3 to 124 ppm for Amaranthus, 20.3 to 101.3 ppm for Cow pea, 57.0 ppm for Poi, 26.7 to 40.4 ppm for Pumpkin, 15.1 to 85.5 ppm for Cabbage, 14.6 to 37.1 ppm for Sponge gourd, 53.0 to 103.8 ppm for Chilli, 99.7 ppm for Brinjal and 46.2 ppm for Bitter gourd. It was also noticed that Pb concentration also varied greatly in same crop at different sites receiving differential amount of sewage-sludge. Considering the mean Pb content (in ppm) in different plant species the crops may be arranged as: Amaranthus (105.5)> Brinjal (99.7)> Bhindi (73.0) = Chilli (73.0)> Cow pea (57.0)> Cabbage (50.3)> Bitter gourd (46.2) > Pumpkin (33.5) and > Sponge gourd (25.0). Higher accumulation of heavy metals in plants was also observed in sewage water irrigated crops which might be phytotoxic to the plants. A picture of the extent of accumulation of heavy metals in various crop species grown in sewage sludge treated soils of

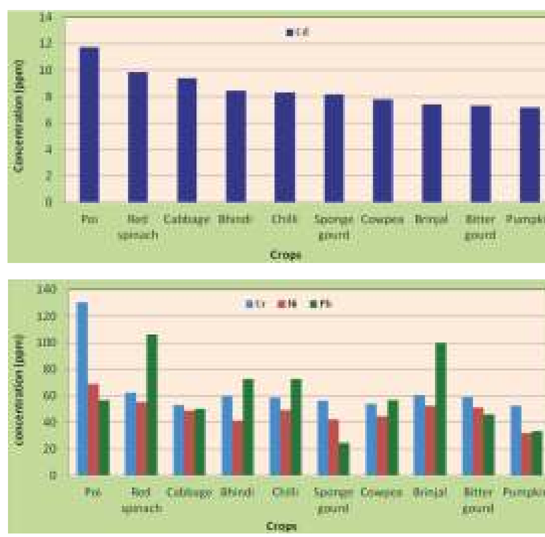


*Fig 5. Average accumulation of heavy metals in crops grown in sewage affected area of Patna bye-pass.*

*Table 5. Concentration of micronutrients in different crop species in sewage sludge treated soils of bye-pass area in Patna.*

| Sampling sites | Crops | Zn (ppm) | Cu (ppm) | Fe (ppm) | Mn (ppm) |
|---|---|---|---|---|---|
| Chhoti Pahari (S1) | Amaranthus | 241.9 | 38.8 | 1173 | 130.2 |
| | Bhindi | 143.5 | 46.0 | 1200 | 139.4 |
| (S2) | Cow pea | 231.6 | 74.6 | 1157 | 111.7 |
| | Bhindi | 215.9 | 63.3 | 1132 | 98.8 |
| (S3) | Poi | 247.3 | 58.8 | 1151 | 81.8 |
| (S4) | Chilli | 240.5 | 54.9 | 1129 | 71.4 |
| Bari Pahari (S5) & (S6) | Amaranthus | 233.2 | 51.4 | 1074 | 63.8 |
| | Chilli | 152.7 | 36.2 | 1000 | 79.4 |
| | Brinjal | 164.7 | 37.2 | 1119 | 109.3 |
| | Pumpkin | 141.21 | 34.5 | 1070 | 77.9 |
| (S7) & (S8) | Cow pea | 26.4 | 25.4 | 917 | 74.6 |
| | Chilli | 116.8 | 26.8 | 924 | 75.1 |
| | Bitter gourd | 144.1 | 33.0 | 948 | 57.0 |
| Ranipur Pajhaba (S9) & (S10) | Pumpkin | 138.6 | 40.4 | 895 | 52.4 |
| | Bhindi | 142.3 | 37.4 | 1105 | 56.0 |
| | Cabbage | 155.4 | 43.3 | 1093 | 108.2 |
| | Sponge gourd | 144.2 | 40.3 | 1051 | 100.7 |
| (S11) & (S12) | Maize | 157.4 | 53.7 | 1111 | 111.3 |
| | Bhindii | 131.2 | 30.8 | 1122 | 86.2 |
| | Cow pea | 128.1 | 32.4 | 1074 | 120.0 |
| | Bhindi | 130.0 | 30.4 | 1088 | 124.4 |
| Mahadeo Sthan (S13) & (S14) | Cow pea | 103.3 | 32.0 | 1116 | 134.5 |
| | Sponge gourd | 102.1 | 31.3 | 1033 | 132.8 |
| | Cow pea | 131.9 | 47.9 | 1283 | 181.3 |
| (S15) (S16) | Cabbage | 93.1 | 21.6 | 1025 | 90.2 |
| | Bhindi | 123.8 | 30.9 | 1091 | 82.8 |
| | Amaranthus | 138.8 | 28.8 | 1065 | 75.7 |
| Begampur (S17) & (S18) | Pumpkin | 122.4 | 30.4 | 979 | 91.3 |
| | Amaranthus | 122.6 | 23.0 | 1087 | 77.1 |
| | Cow pea | 123.5 | 23.1 | 976 | 77.7 |
| | Sponge gourd | 133.5 | 34.1 | 1105 | 105.0 |
| (S19) & (S20) | Bhindi | 136.5 | 32.7 | 1156 | 102.7 |
| | Maize | 113.3 | 30.9 | 1137 | 161.8 |
| Karmali chowk (S21) & (S22) | Bhindi | 111.4 | 29.5 | 1030 | 167.2 |
| | Pumpkin | 164.7 | 31.9 | 1062 | 68.2 |
| | Cow pea | 160.0 | 44.2 | 1186 | 125.6 |
| | Amaranthus | 161.4 | 31.6 | 1118 | 106.4 |
| (S23) & (S24) | Sponge gourd | 126.4 | 28.6 | 1178 | 159.4 |
| | Bhindi | 134.5 | 34.2 | 1081 | 175.0 |
| | Chilli | 129.0 | 27.3 | 1125 | 112.9 |
| Sati chowk (S25) & (S26) | Bhindi | 123.4 | 26.6 | 1119 | 119.9 |
| | Pumpkin | 122.8 | 24.5 | 1196 | 101.4 |
| (S27) & (S28) | Bhindi | 161.5 | 33.1 | 1056 | 88.8 |
| | Pumpkin | 142.7 | 32.0 | 1156 | 136.0 |
| Deedarganj (S29)(S30) | Bhindi | 108.1 | 20.1 | 857 | 60.5 |
| | Cow pea | 96.2 | 16.2 | 911 | 58.0 |

*Table 6. Concentration of heavy metals in different crop species in sewage sludge treated soils of bye-pass area in Patna.*

| Sampling sites | Crops | Cd (ppm) | Cr (ppm) | Ni (ppm) | Pb (ppm) |
|---|---|---|---|---|---|
| Chhoti Pahari (S1) | Amaranthus | 12.9 | 74.6 | 63.6 | 123.7 |
| | Bhindi | 8.2 | 74.7 | 66.0 | 102.6 |
| (S2) | Cow pea | 9.4 | 63.3 | 62.2 | 101.3 |
| | Bhindi | 8.6 | 58.6 | 61.4 | 88.9 |
| (S3) | Poi | 11.7 | 69.0 | 57.0 | 126.9 |
| (S4) | Chilli | 12.5 | 61.5 | 55.8 | 103.8 |
| Bari Pahari (S5) & (S6) | Amaranthus | 12.7 | 65.0 | 58.7 | 87.3 |
| | Chilli | 7.3 | 61.9 | 48.8 | 71.2 |
| | Brinjal | 7.4 | 60.6 | 52.8 | 99.7 |
| | Pumpkin | 12.5 | 60.7 | 54.4 | 96.2 |
| (S7) & (S8) | Cow pea | 7.7 | 60.1 | 57.3 | 62.9 |
| | Chilli | 7.5 | 53.0 | 54.4 | 52.9 |
| | Bitter gourd | 7.3 | 59.0 | 51.1 | 46.2 |
| Ranipur Pajhaba (S9) & (S10) | Pumpkin | 7.1 | 53.6 | 41.7 | 26.7 |
| | Bhindi | 12.5 | 55.1 | 53.4 | 78.2 |
| | Cabbage | 10.5 | 62.1 | 51.7 | 85.5 |
| | Sponge gourd | 9.5 | 60.0 | 45.2 | 37.1 |
| (S11) & (S12) | Maize | 7.8 | 62.4 | 48.0 | 55.6 |
| | Bhindi | 10.7 | 45.3 | 34.1 | 55.9 |
| | Cow pea | 7.9 | 53.0 | 40.1 | 47.8 |
| | Bhindi | 8.7 | 52.7 | 40.7 | 45.0 |
| Mahadeo Sthan (S13) & (S14) | Cow pea | 6.8 | 49.9 | 43.9 | 34.2 |
| | Sponge gourd | 7.5 | 49.9 | 45.7 | 14.6 |
| | Cow pea | 8.3 | 58.1 | 47.3 | 20.3 |
| (S15) (S16) | Cabbage | 8.3 | 44.2 | 45.6 | 15.1 |
| | Bhindi | 7.1 | 56.6 | 32.2 | trace |
| | Amaranthus | 5.1 | 57.5 | 18.1 | trace |
| Begampur (S17) & (S18) | Pumpkin | 7.0 | 49.3 | 40.4 | trace |
| | Amaranthus | 8.7 | 51.3 | 32.2 | trace |
| | Cow pea | 10.3 | 50.8 | 41.1 | trace |
| | Sponge gourd | 8.8 | 53.8 | 36.3 | trace |
| (S19) & (S20) | Bhindi | 5.8 | 60.0 | 17.7 | trace |
| | Maize | 6.7 | 55.8 | 37.7 | trace |
| Karmali chowk (S21) & (S22) | Bhindi | 7.0 | 45.9 | 41.3 | trace |
| | Pumpkin | 5.2 | 59.6 | 18.2 | trace |
| | Cow pea | 7.0 | 40.6 | 31.6 | trace |
| | Amaranthus | 7.7 | 60.1 | 45.4 | trace |
| (S23) & (S24) | Sponge gourd | 7.5 | 58.0 | 41.5 | trace |
| | Bhindi | 6.7 | 56.0 | 36.9 | trace |
| | Chilli | 6.4 | 52.5 | 31.4 | trace |
| Sati chowk (S25) & (S26) | Bhindi | 8.6 | 59.8 | 29.9 | trace |
| | Pumpkin | 8.6 | 55.2 | 22.5 | trace |
| (S27) & (S28) | Bhindi | 10.2 | 42.0 | 28.0 | trace |
| | Pumpkin | 12.0 | 48.1 | 28.2 | trace |
| Deedarganj (S29)(S30) | Bhindi | 5.1 | 38.2 | 12.2 | trace |
| | Cow pea | 5.2 | 36.2 | 16.1 | trace |

## CONCLUSIONS

The study of present investigations revealed that there is an accumulation of micronutrients and heavy metals in soils with maximum accumulation at the point of discharge. Continuous disposal of sewage-sludge, containing domestic and industrial effluents on agricultural land is a major source of plant nutrients, but it also contains a sufficient amount of non-essential and heavy metals causing soil pollution. Transfer of metals from added sewage sludge to the soils and subsequent uptake by the plants that enter the feed and food-chain pose threats for human health and animals. Moreover, it is pointed out that continued monitoring or treatment of sewage water before disposal into the land or integrated water management are some of the suitable measures for effective utilization of poor quality water in sustainable agricultural production. The results of the investigation carried out on various aspects of trace metal cations are outlined below.

- The study revealed that the sites nearest to discharge point contained appreciably higher concentration of metal cations in comparison to the sites away from the discharge point of the waste water. By and large most of the trace metal cations accumulated in surface soils are found to be beyond the critical limit prescribed for the soils.

- Plants growing on such soils accumulate excessive amount of micronutrients and heavy metals in their tissues which may enter in the system of animal and human being. Accumulation of trace metal cations in different plant species differed widely which varied from crop to crop and place to place.

- In general it was noticed that leafy vegetables viz. poi and Red spinach (Amaranthus) accumulated most of trace metal cations to the greater extent in comparison to other crops. Toxic concentration of these trace metal cations in plants and soils should be the matter of concern and indicate the need for continuous monitoring and treatment of waste water before it is delivered to the field.

- Though the study confirms that use of sewage water (of domestic and urban origin) for irrigation provides opportunity to increase water resource but it requires regular monitoring of the concentration of trace metal cations and potentially toxic elements in soils as well as in plants to check the ill effects of its use.

## RECOMMENDATIONS

Based on the experiment during the investigations it was observed that an appropriate waste water treatment must be applied to raw municipal sewage water before it can be use for agriculture. Hence to minimize the potential risk to the health of humans, animals and plant it is necessary to coordinate sludge application in time with, grazing or harvesting operations.

- In order to assess the long terms effects of irrigation with sewage water, intensive survey needs to be done for entire areas where sewage sludge and municipal wastes are being used or disposed off.

- Profile study of sub-surface soil should be done to evaluate the depth wise distribution of heavy metals.

- Critical values of toxicity of heavy metals in soils as well as in crop species including fodder crops for cattle's and human being need to be established.

- Genotypes of various crops should be screened out for their relative to susceptibility/tolerance to heavy metals concentration.

- Vegetables which are eaten raw, viz., tomato, water melons, radish, and turnip should be irrigated with treated sewage water through drip irrigation.

- The cultivation of leafy vegetables viz. red spinach, spinach, poi, cabbage etc. should be discouraged in the areas receiving continuous disposal of sewage sludge and farmers are advised to grow cereal crops and forest trees.
- Regular monitoring of the concentrations of trace metal cations and potentially toxic elements in soils as well as in plants should be carried out in the areas where such waste water is extensively used for irrigating vegetable crops.

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