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Impact of Urban Wastewater Irrigation on Soil and Crop




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Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar, 751023, Odisha

2014

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Cell: 9132573795
Email : info.technotrade@gmail.com

FOREWORD

Water shortage needs no introduction as it is a widespread problem. Fresh water shortage is increasing all over the world and may become absolute in many countries within a decade or two. In India also, the problem is compounded everyday with rising inhabitants with higher per capita income, urbanization, industrial growth, demand for agricultural and allied sectors. India has 16% of world's population but only 4% of the total available fresh water. Many challenges are encountered in addressing the demand for water as most parts of the country face water shortage in some or other parts of a year. In many states ground water extraction surpasses the annual recharge resulting in retreating ground water table.

The anxiety is heightened when one becomes aware of the severity of surface water pollution. The water quality monitoring results during 1995 to 2006 in India show that the organic and bacterial contamination are continued to be critical in water bodies, mainly due to, discharge of domestic wastewater, mostly in untreated form, from the urban centres of the country because the municipal corporations at large are not able to treat the increasing load of municipal sewage flowing into water bodies and secondly the receiving water bodies also do not have adequate water for dilution. This results in higher BOD and microbial pollution responsible for water borne diseases.

Increased urbanization lead to more wastewater generation having significant potential towards peri-urban agriculture, while their improper management may pose serious threat to human health and environment. The cities like Bhubaneswar and Cuttack, generate huge sewage effluents everyday. These effluents are discharged into the river Mahanadi and Kathajodi in Cuttack, and Kuakhai and Daya in Bhubaneswar. The effluents may contain heavy metals like lead, chromium, cadmium, zinc and mercury. Appropriate measures to mitigate the risks of utilizing such waste water are necessary. To address the knowledge needs to support the measures, the research project entitled 'Characterization and utilization of Sewage Water of Urban/Peri-Urban areas for Agricultural purposes' was conducted with the objectives "Effect of sewage water on soil properties and plant's yield attributes, and quality". The present Bulletin embodied the research findings of the said project.

We sincerely hope the effort in bringing out this research bulletin will be helpful for all the stakeholders of agricultural water management, particularly, those involved in wastewater management, and users. Hope, this will also serve as a source of information to farmers, policy makers, entrepreneurs, researchers and extension workers as training guide.

Authors

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1.0 INTRODUCTION

Globally, more than 40% of food production comes from irrigated agriculture but using only 17% of land devoted to food production (Fereres and Connor 2004). As the pressure increases on limited water resource, it is increasingly important to look for nonconventional water resources. Wastewater may be an important source of water to overcome the increased water lack and produce the agricultural commodities close to the cities (Merker 2004). Use of urban wastewater is not new to India. The farmers in urban and periurban areas using the wastewater for growing various types of crops like vegetables, fruits, cereals, flowers and fodder is prevalent in India.

As a result of rapid population growth, massive industrialization, and the growing number of cities large amounts of municipal sewage are discharged into the water bodies. Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Though the actual composition of wastewater may differ from community to community, all municipal wastewater contains the following broad groupings of constituents:

i) Organic matter, ii) Nutrients (Nitrogen, Phosphorus, Potassium)
iii) Inorganic matter (dissolved minerals), iv) Toxic chemicals, v) Pathogens
Table 1 shows the levels of the major constituents of strong, medium and weak domestic wastewaters.

Table 1: Major constituents of typical domestic wastewater

Constituent	Concentration, mg/l		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)[1]	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride[1]	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5[2]	300	200	100

[1] The amounts of TDS and chloride should be increased by the concentrations of these constituents in the carriage water.
[2] BOD_5 is the biochemical oxygen demand at 20°C over 5 days and is a measure of the biodegradable organic matter in the wastewater.
Source: UN Department of Technical Cooperation for Development (1985)

The final composition of raw wastewater depends on the source and its characteristics. In the case of mixed municipal wastewater this depends on the types and numbers of industrial units and the characteristics of the residential communities. However, in arid and semi-arid countries, water use is often fairly low and sewage tends to be very strong, as indicated in Table 2 for Amman, Jordan, where water consumption is 90 l/d per person (Al-Salem 1987).

Table 2: Average composition of wastewater in Amman, Jordan

Constituent	Concentration mg/l
Dissolved solids (TDS)	1170
Suspended solids	900
Nitrogen (as N)	150
Phosphorus (as P)	25
Alkalinity (as $CaCO_3$)	850
Sulphate (as SO_4)	90
BOD_5	770
COD[1]	1830
TOC[2]	220

[1] COD is chemical oxygen demand, [2] TOC is total organic carbon

Municipal wastewater also contains a number of potentially toxic elements such as arsenic, cadmium, chromium, copper, lead, mercury, zinc, etc. Even if toxic materials are not present in concentrations likely to affect humans, they might well be at phytotoxic levels, which would limit their agricultural use (Abdel-Ghaffar *et al.* 1988). However, from the health point of view, a very important consideration in agricultural use of wastewater, the contaminants of greatest concern are the pathogenic micro- and macro-organisms. Pathogenic viruses, bacteria, protozoa and helminths may be present in raw municipal wastewater at the levels indicated in Table 3 and may survive in the environment for long periods. Pathogenic bacteria may be present in wastewater at much lower levels than the coliform group of bacteria, which are much easier to identify and enumerate (as total coliforms/100ml). *Escherichia coli* are the most widely adopted indicator of faecal pollution and they can also be isolated and identified fairly simply, with their numbers usually being given in the form of faecal coliforms (FC)/100 ml of wastewater Table 3 shows a typical pathogens level in wastewater

Table 3: Possible levels of pathogens in wastewater

Type of pathogen		Possible concentration per litre in municipal wastewater[1]
Viruses:	*Enteroviruses*[2]	5000
Bacteria:	Pathogenic *E. coli*[3]	?
	Salmonella spp.	7000
	Shigella spp.	7000
	Vibrio cholerae	1000
Protozoa:	*Entamoeba histolytica*	4500
Helminths:	*Ascaris Lumbricoides*	600
	Hookworms[4]	32
	Schistosoma mansoni	1
	Taenia saginata	10
	Trichuris trichiura	120

[?]Uncertain, [1]Based on 100 lpcd of municipal sewage and 90% inactivation of excreted pathogens, [2]Includes polio-, echo- and coxsackieviruses, [3]Includes enterotoxigenic, enteroinvasive and enteropathogenic *E. coli,* [4]*Anglostoma duedenale* and *Necator americanus*
Source: Feachem *et al.* (1983)

Impact from wastewater on agricultural soil, is mainly due to the presence of high nutrient contents (Nitrogen and Phosphorus), high total dissolved solids and other constituents such as heavy metals, which are added to the soil over time. Wastewater can also contain salts that may accumulate in the root zone with possible harmful impacts on soil health and crop yields. The leaching of these salts below the root zone may cause soil and groundwater pollution. Prolonged use of saline and sodium rich wastewater is a potential hazard for soil as it may erode the soil structure and affect productivity. Long term wastewater irrigation increased salts, organic matter and plant nutrients in the soil reported by Mohammad Rusan *et al* 2006. This may result in the land use becoming nonsustainable in the long run. The problem of soil salinity and sodicity can be resolved by the application of natural or artificial soil amendments. Saline agricultural drainage water may be used as a resource to grow high value horticultural crops and reduce the volume of drainage for eventual disposal (Scott *et al*, 2000) However, soil reclamation measures are sometimes costly, adding to economic constraints resulting in losses to crop productivity. The net effect on growth may be a reduction in crop yields and potential loss of income to farmers.

Wastewater irrigation may lead to transport of heavy metals to soils and may cause crop contamination affecting soil flora and fauna. Some of these heavy metals may bio-accumulate in the soil while others, e.g., Cd and Cu, may be redistributed by soil fauna such as earthworms (Kruse and Barrett 1985. The continuous use of raw sewage water generally leads to built of metals and organic residues in the soils depending upon composition, rate and frequency of sewage-irrigation as well as characteristics of the soil (Saraswat *et al*. 2005). Sometimes, build up of metals in agricultural soils may create phytotoxicity to crops (Paul *et al*. 2006), which warrants judicious use of sewage and other wastewater. Asadu *et al*, 2008 reported the long-term disposal of sewage sludge and effluents on the soils significantly ($P < 0.001$) increased the exchangeable bases, exchangeable acidity, available P, soil organic matter, total N and CEC, but significantly lowered the pH of the soil, thus fertility status of the sewage-treated soil was enhanced.

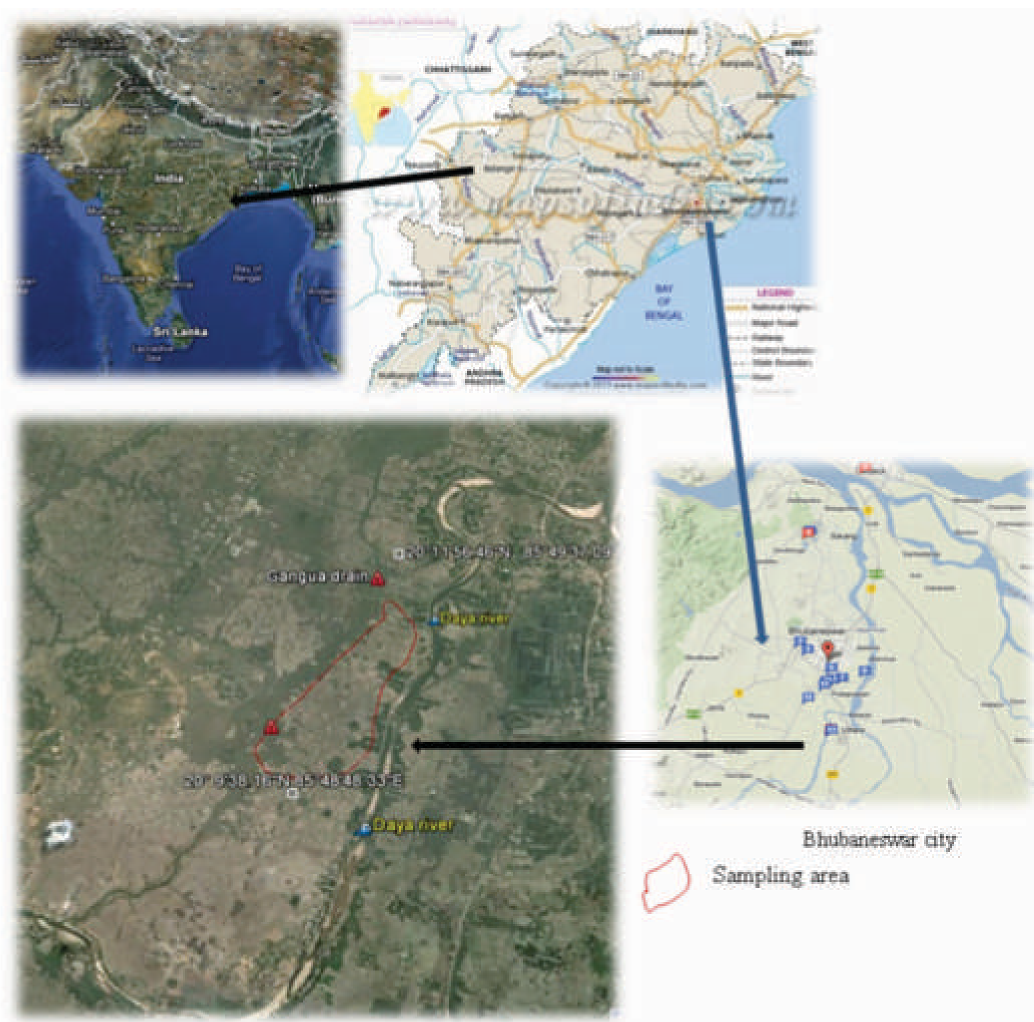
The cities like Bhubaneswar generate approximately 190 MLD sewage effluents. These effluents are discharged into the river Kuakhai and Daya in Bhubaneswar. The effluents may contain heavy metals like lead, chromium, cadmium, zinc and mercury. Besides, the sewage effluents are presumably contaminated with harmful bacteria and viruses which contaminate the river water. Appropriate measures to mitigate the risks of utilizing such waste water are necessary. To address the knowledge needs to support the measures the research project entitled 'Characterisation and utilization of Sewage Water of Urban/Peri-Urban areas for Agricultural purposes' was conducted with one of the objectives, impact of wastewater irrigation on soil properties and effect on crop growth and quality.

2.0 METHODOLOGY

2.1 Wastewater in Bhubaneswar City

The city has an undulating ridge and valley topology and is covered by number of natural drainage channels. The drainage is controlled by the Kuakhai and Daya rivers, girdling the city on the north and the south. Apart from this a number of open drains running west to east criss-cross the city, some of which finally joins to form Gangua Nallah. Gangua nallah meets River Daya, a distributary of River Kuakhai. The city is in the western side of River Kuakhai and to the northern part of River Daya. The land on which the city stands slopes from the north - west of the city area to the Kuakhai river in the east and Daya River in the south. The water requirement for Bhubaneswar city is mainly met from River Kuakhai, River Daya and Spring Tanks and from ground water sources. River Kuakhai and River Daya are the major surface water source. Both the rivers receive industrial and domestic discharges. The major sources of water pollution in Bhubaneswar city are the industrial and domestic discharges. The discharges are through wastewater drains, overflow of the septic tanks and oxidation ponds. There are 88 industries and 2 industrial clusters, of which 34 are water pollution potential industries, which discharge their effluent into the drains. Most of the sewage from the city reaches River Khuakai and River Daya through open drains. There are about 10 open drains in the city of Bhubaneswar discharging wastewater. The entire city has not been covered with surface water drain. The drains cover an area of about 103.43 sq km with the drainage length of 37.18 km. Drain No 1 (Patia) outfalls into Kukhai River directly and drain no 2 to 10 outfalls in Gangua nallah, which is the main drain between Daya West Branch Canal and Daya River. All the drains have to cut across the South Eastern Railway line, NH-203, Daya West Branch Canal and NH-5. The major drains.

As out of the 10 drains flowing in the city, 9 of them join the Gangua nallah at different locations. Drain No 1 (Patia) outfalls into Kuakhai River directly and drain number 2 to 10 outfalls in Gangua, the total BOD load discharged to River Kuakhai is 27.20 t/d and to the Gangua nallah (100.64 – 27.20 = 73.44) t/d.



2.2 Impact of wastewater on soil

A large area between Daya river and Gangua nala and particularly the areas adjacent to western sides of Gangua nala are irrigated with Gangua nala water for not less than 30 years. To understand the long term impact of wastewater irrigation on soil properties and crop quality some studies were carried out. The qualities of both sources of irrigation are given in Table 4.

Table 4. Water qualities of wastewater (Gangua drain) and Daya river water

Parameter	Gangua nala (drain)	Daya river	FAO (1985) guidelines
pH[1]	6.70 (± 0.21)	8.44 (± 0.42)	6.5–8.5 (NR)
EC (dS/m)[2]	0.48 (± 0.14)	0.24 (± 0.11)	SM
SAR[3]	4.3 (± 1.6)	2.9 (± 0.34)	SM
Total coliforms (TC)	>53000/100 ml	22500/100 ml	
Fecal coliforms (FC)	>18500/100 ml	9500/100 ml	< 1000/100 ml
Elemental composition (mg/kg)		Maximum permissible limit	
TN	26 (± 4.6)	14 (± 3.2)	35
P	2.8 (± 0.72)	0.52 (± 0.29)	-
K	10.3 (± 4.1	2.7 (± 1.3)	-
Fe	1.24 (± 0.421)	0.546 (± 0.123)	5.0
Mn	0.32 (± 0.061)	0.044 (± 0.022)	0.2
Zn	0.11 (± 0.032)	0.062 (± 0.041)	2.0
Cr	0.086 (± 0.042)	0.063 (± .034)	0.1
Cd	0.014 (± 0.008)	0.010 (± 0.006)	0.01
_Pb	1.13 (+ 0.16)	1.02 (+ 0.19)	5.0

NR : Normal Range. STDEV values in parenthesis. Slight to moderate restriction (SM).
Sources : Ayers and Westcott (1985).

The column experiment was conducted to understand the change in soil characteristic in terms of movement of nutrient elements through soil columns at different depths. Three different sizes of soil columns of length 15 cm, 30 cm and 45 cm were made by filling soil in cylindrical PVC pipes having a net at bottom. Filter papers were cut into appropriate sizes to fit into the bottom of cylinders on net. Wastewater from the Ganguanala was filled above the soil surface and 0.5 cm of hydraulic head was maintained with measured volume of water for 72 hours. Thereafter, leachates were collected at bottom of each column and analyzed for chemical parameters. Soils from 0-14 cm, 15-29 cm and 30-44 cm were air dried, powdered, sieved and analyzed for all the parameters done for leachates.

To study the impact of wastewater irrigation on soil properties soil samples were collected from Jaypurpatna, Lingipur and Dihipur area in clean transparent plastic bags from the post harvest paddy and vegetable fields irrigated with wastewater of Gangua nala and from the adjoining or nearby farmers's fields irrigated with other irrigation sources. The soils were then air dried, powdered and sieved through 50 mesh and then stored for analysis.

To study the impact of wastewater irrigation on crop quality both the soil and plant samples (vegetables) were collected from the fields irrigated with river water (Daya) or other source (OS) and adjacent or nearest fields irrigated with Gangua water (GI). Vegetable samples were collected from Gangua irrigated and other source irrigated fields, processed and analysed for heavy metals and major nutrients along with soil samples. The list of vegetables (edible part) analysed for heavy metals include *viz*. malabar climbing (poi), amaranthus red (lal saga), amaranthus green (sabuja saga) and three types of vegetables which are eaten cooked *viz* ladies finger, ridge gourd and bitter gourd and two types of vegetables/fruits often eaten raw *viz* tomato and watermelon was the alternative hypothesis. All the Gangua irrigated vegetables had higher concentrations of heavy/trace metals in their edible parts in comparison to the samples grown with other source of irrigation.

3.0 FINDINGS AND DISCUSSION

3.1 Impact on soil properties

3.1.1 Soil Column Study

To understand the movement of nutrients, a leaching experiment was conducted by irrigating a soil with nutrient rich water. The experiment was conducted by filling polyvinyl cylinders with dimensions of 7.1 cm diameter and varying length of 15, 30 and 45 cm length with a sandy clay loam soil uniformly having same mass/volume ratio 1.16 g/cc in all the columns. A constant head of 0.5 cm was maintained above the surface of soil column with water collected from Ganguah nalah for 96 hours. Thereafter, leachates were collected from all the columns i.e. 15, 30 and 45 cm columns and measured.

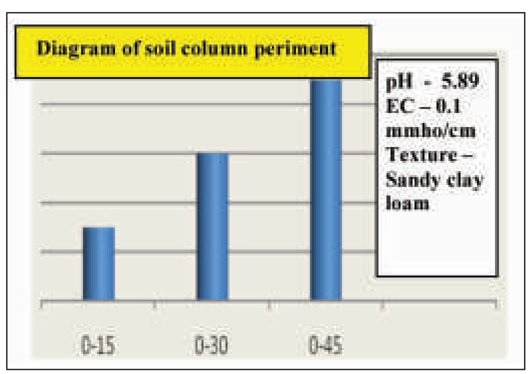


Diagram of soil column experiments

The pH was higher in surface leachate (0 – 15 cm) thereafter decreased with depth. The conductivity of leachates progressively increased with depths. The increase in exchangeable potassium and decrease in sodium in leachates indicate retention of potassium in soil column whereas sodium was washed out with percolating water (Fig 1). Calcium and magnesium concentrations in leachates also increased. Increase in conductivity in leachates with higher depths is evinced due to dissolution of salts. The concentration of nitrates in leachates decreased while the ammonium concentrations were found increased. The nitrates in wastewaters were retained by the soil, while increase in ammonium concentrations in leachates from the original inundating wastewaters reflects the dissolution of ammonium ions from soil to percolating waters (wastewaters) thereby increase in ammonium concentration. The general trend was observed that while the cations are leached more than the anions *viz.* nitrate and phosphates are retained in soil columns except chloride because chloride is not adsorbed or held back by soil (Ayers and Westcot 1976).

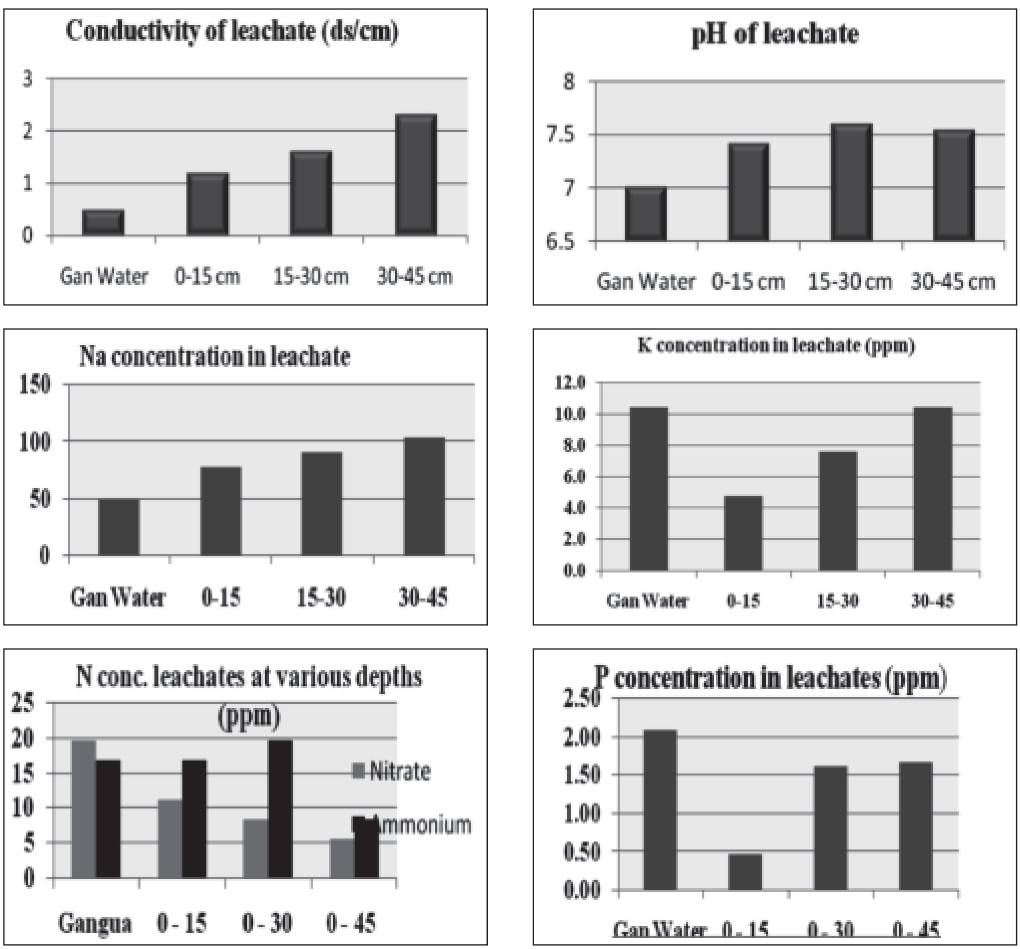


Fig 1 Leaching of different constituents at different depths

Soils at different depths leached with wastewater were air dried in the same way the original soil samples were prepared and analysed for pH, EC, organic carbon, nitrate-nitrogen, ammonium-nitrogen, available phosphorus, exchangeable sodium, potassium, calcium and magnesium (Fig 2).

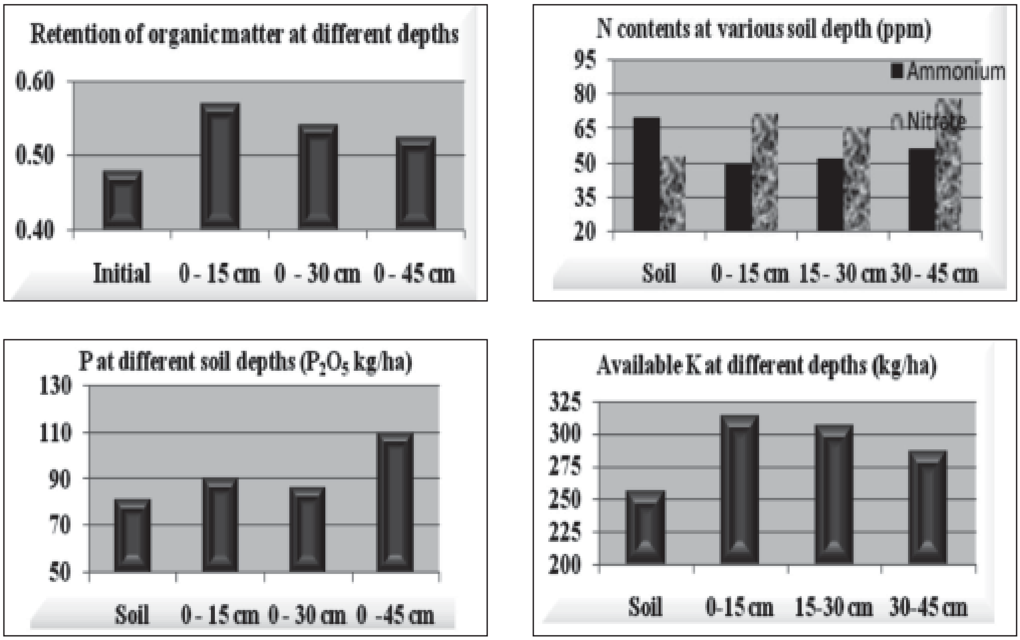


Fig 2 Retention of constituents from wastewater at various depths in soil

Microbes play very important role in maintaining soils nutrient supplying capacity and overall fertility. Addition of wastewater may have different types of repercussions. Presence of organic matters or organic pollutants increase the organic matter level in soils by providing congenial atmosphere for better microbial activities. Addition of microbes in wastewaters may also increase total microbial load in soils which again are conducive for biodegradability of soils. On the other hand, organic pollutants may have negative impact on soil microflora, presence of heavy metals may disrupt the microbial activity. To ascertain the impact of wastewater addition on microbial properties, some important microbial parameters were studied.

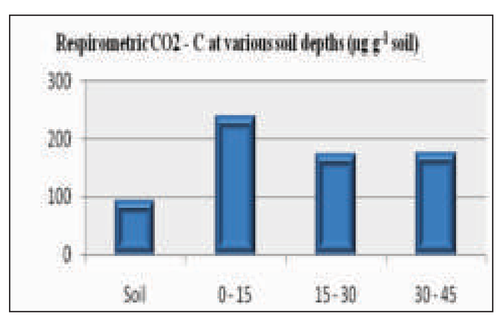


Fig 3 Effect of wastewater on microbial activity at various depths

Addition of wastewater increased the organic carbon levels at all the depths (Fig 2). The soils also showed higher respirometric C in soils at all depths. Higher respirations are indicative of higher microbial activity (Fig 3 & 4).

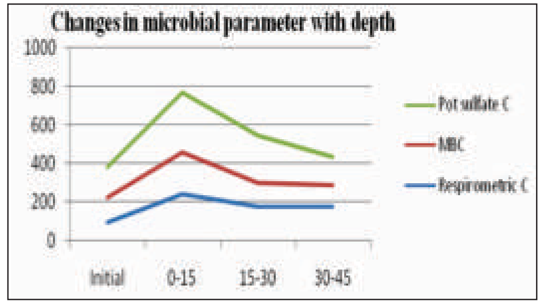


Fig 4 Effect of wastewater on microbial parameters at various depths

The organic matter (OC x 1.723) accumulation was highest in 0 – 15cm layer, although it increased at all depths. Soil respiration was also highest at 0 – 15 layer. Probably, availability of oxygen at top layer might have favoured higher respiration. The soil microbial biomass carbon (soil MBC), a good indicator of microbial population was also found maximum at surface layer probably addition of more microbe from wastewater or availability of nutrients rendered multiplication of microbes, thus, higher population and higher MBC. Therefore, higher respirometric activity could be due to higher microbial biomass at surface layers rather than only organic matters. The drop in MBC values at lower depths could be the result of retention of microbes in the upper layers when soil column acted as filter.

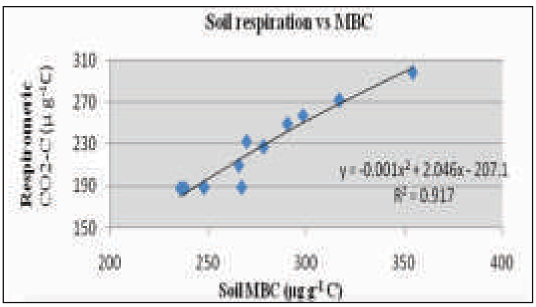


Fig 5 Correlation between soil MBC and respiration

The scattered plot of SMBC and OC was best fitted into polynomial equations having lower R^2 (0.277) value indicative of poor trend. While SMBC and respirometric C had much better relation (R^2 0.917) best fitted into polynomial equation. The relation between OC and soil respiration also had better relation (R^2 0.891) fitting into power equation than that between OC and SMBC. Therefore, it may be concluded that higher respiration was more due to addition of microbes through wastewater than increased organic matter (Fig 5).

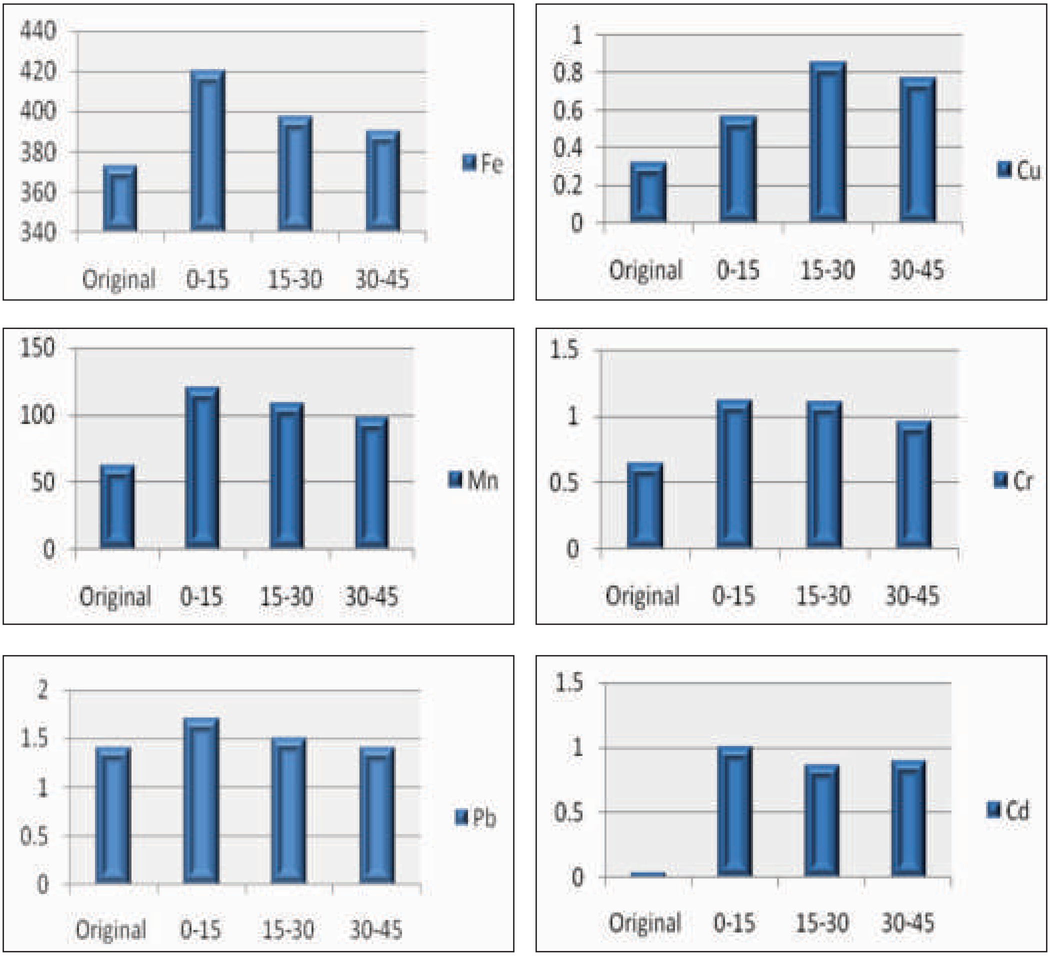


Fig 6 Changes in metal concentrations (DTPA) with soil depth

The presence of heavy metals in wastewater due to discharge of various industrial activities particularly small scales, in urban areas into the storm water drains of Bhubaneswar city may have impact on soil health. The concentrations of metals (DTPA extractible) in soils at various depths were determined. The Fe concentration increased at all depths having maximum value at surface soil and then progressively decreased while Cu was found maximum at 15 – 30 cm layer, but higher than initial value at all depths. Mn, Cr, Pb also similar trend as found in Fe. But Cd concentration was much higher than the original Cd level in soil and maximum at surface. Fe, Mn, Cr and Pb concentration increased by 13, 94, 72 and 21 percent respectively in surface soils. However, Cd increased manifold of the initial Cd content in soil before wastewater addition at surface soil while at lower depths it ranged between 82 and 99 percent. However, Cu was found maximum percent (93) increase at 15 – 30 cm layer (Fig 6).

Thus, accumulation of heavy metals due to wastewater addition was conspicuous from the results. To ascertain the probable impact of increased heavy metals on microbial parameters correlation coefficients were determined among parameters of microbial significance and heavy/trace metals. Significant correlation between OC and Cd could be an indication of Cd containing organic pollutants in wastewater, however, OC bears no other significant correlation with other metals (Table 5).

Table 5 Pearson correlation coefficients of microbial parameters and heavy metals

	OC	OC Res	RespC	MBC	Fe	Cu	Zn	Mn	Cr	Pb
Fe	.351	.931(**)	.771(*)	.862(*)						
Cu	.580	-.089	.433	-.293	.169					
Zn	.690	.564	.813(*)	.409	.698	.631				
Mn	.439	.767(*)	.901(**)	.638	.887(**)	.522	.876(**)			
Cr	.303	.726	.887(**)	.599	.847(*)	.547	.770(*)	.973(**)		
Pb	.016	.904(**)	.824(*)	.856(*)	.787(*)	.035	.679	.786(*)	.730	
Cd	.794(*)	.090	.173	-.053	.280	.521	.560	.270	.165	.007

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

The respirometric carbon had significant correlations with most of the metals except Cu and Cd. Significant relations with Fe, Zn, Mn and Cr with respirometric C may have reason as these metals are required in living cells. Thus, quantity of added metals might have contribution in higher respiration. But significant relation or respirometric C with Pb was inexplicable. Probably, enrichment of Pb was associated with other factor which was congenial for better respiration. Similarly, MBC also showed significant correlations with Fe and Pb. Probably, due to low bioavailability of Pb, practically had no bearing on these to parameters i.e MBC and respirometric C. In fact, Pb showed significant correlations with Fe and Mn. MBC showed insignificant negative relations with Cu and Cd.

3.1.2 Field studies on effect of sewage water on soil properties

3.1.2.1Physical properties of soil

The mechanical analyses of soil by Hydrometer method to determine texture showed that sand contents were lower with a mean value of 46 percent while silt and clay contents were higher i.e mean values of 10 and 44 percent respectively in Gangua irrigated soils than those irrigated with other sources having mean values of 62, 7 and 31 percent for sand silt and clay respectively. Texturally the Gangua irrigated soils (clayee to sandy clay) were heavier than those with other irrigation sources (sandy clay loam). On the other hand, the values of apparent density and absolute density often referred to as bulk density and particle density, respectively, indicate that Gangua irrigated soils having mean values of apparent and absolute density 1.2 and 2.1 g/cc, were lighter or so to say, not at least heavier than the soils irrigated with other irrigation sources. The mean values of moisture holding capacity and volume expansibility were 10 and 33 percent higher in Gangua irrigated soils. In spite of higher silt and clay in Gangua irrigated fields, the lower density could be attributed to the higher pore space. Possibly, higher clay provides greater surface area for reactivity and opportunities for formation of clay organic complexes, retaining more organic particles. That provides better opportunities for microbial interaction, thus, higher soil respiration. Higher respiration leads to more carbon dioxide generation or gaseous exchanges, making the soils porous. The mean values of parameters analysed for all the samples with both the type of irrigated fields are shown in Table 6. Significant change in soil physical properties was not observed with long term wastewater irrigation using Gangua water.

Table 6 Physical properties of soils irrigated with wastewater and other sources

Physical parameters	Other sources	Gangua irrigated
% sand	62 ± 13	46 ± 10
% silt	7 ± 4.82	10 ± 3.6
% clay	31 ± 9.01	44 ± 7.6
apparent density (g/cm^3)	1.23 ± 0.09	1.18 ± 0.76
ab sp gravity (g/cm^3)	2.15 ± 0.1	2.10 ± 0.09
% MHC	39 ± 5.2	43 ± 4.8
% pore space	47 ± 2.8	49 ± 3.0
volume expansion (%)	12.3 ± 8.6	16.2 ± 2.7
Hydraulic Conduct. (cm/hr)	1.39 ± 1.4	0.15 ± 0.16

3.1.2.2 Chemical properties of soil

The pH varied between 5.43 and 6.2 in fields irrigated with other sources of irrigation having mean value of 5.75 while Gangua irrigated soils had pH between 5.06 and 5.94 with mean value of 5.55. The wastewater treated fields had lower pH but higher electrical conductivity, probably, due to the higher salt concentration in wastewaters (Table 7).

The organic carbon was higher in wastewater irrigated fields than those when irrigated with other sources. The organic carbon content varied between 0.2 and 0.5 percent in other source irrigated soils while it ranged from 0.3 to 0.7 percent in wastewater irrigated soils. The mean values of organic carbon were 0.39 and 0.51

percents in other source irrigated and Gangua irrigated soils, respectively. The higher organic carbon in gangua irrigated fields further strengthens the logic ascribed to it's lower density in spite of higher clay content.

The total nitrogen content in Gangua irrigated soils was higher. Analyses of drain water samples, indicated that all the drain waters had appreciable quantity of nitrogen, thus contributing to the nitrogen reserve of soil. The total N varied between 0.084 and 0.112 percent in Gangua irrigated soils with a mean value of 0.099, while in other source irrigated fields it was between 0.042 and 0.098 percent.

The available nitrogen content was also higher in Gangua irrigated soils as expected. The available nitrogen content varied between 140 and 280 ppm in Gangua irrigated soil with mean value of 179 ppm while it varied between 98 and 140 ppm with a mean value of 126 ppm with other irrigation source. Previous discussion pointed that higher clay, organic matter resulting in higher pore space indicative of higher microbial interaction. Thus, microbial transformations or higher nitrogen mineralization could be appropriate reason for higher available nitrogen in Gangua irrigated soils. The other point of view could be that the available nitrogen determination by alkaline permanganate oxidation which takes into account of the easily degradable organic matter present in soil. As the Gangua irrigated soils had higher organic carbon, the higher available N content by alkaline permanganate was expected.

The available phosphorus in Gangua irrigated soils was lower than other source irrigated soils. It varied between 36 and 50 kg P_2O_5 per hectare having mean value of 45 kg/ha in Gangue irrigated soils. But the soil with other irrigation source varied between 25 and 31 kg per ha with a mean value of 28 kg/ha. Then, the important question may arise that if the wastewaters contain appreciable quantity of phosphates (as it was evident in past section of wastewater quality), then why wastewater treated soils had lower available phosphorus. The possible explanation could be that, phosphate ions are known for frequent transformations. Slight changes in pH render phosphates to transform from one form to other or soluble form to insoluble form. The Gagua irrigated soil pH was lower than that with other source irrigated soils, rendering the phosphates transformed to insoluble forms, thus, making them unavailable in such conditions, which Bray's extractant could not extract. Although, total soil phosphates could not be analyzed, but can be presumed to be higher in Gangua irrigated soils than others. Because, the wastewaters contain significant quantity of phosphorus.

The other most important plant nutrient i.e potassium was also much higher in Gangua irrigated soils. The exchangeable potassium varied between 410 nad 461 kg/ha in Gangua irrigated soils and 245 and 432 kg/ha with other irrigation sources. The mean values of exchangeable K in Gangua soils was about 1.6 times higher than that with other irrigation sources. The higher potassium content in Gangua irrigated soils were retained from the nutrient rich wastewater could be inferred as similar results were observed in column study conducted in laboratory condition.

Table 7 Chemical properties of soils irrigated with wastewater (Gangua) and other sources

Chemical parameters	Other sources	Wastewater irrigated
pH	5.75 ± 0.26	5.55 ± 0.32
EC mmho/cm	0.038	0.10
OC	0.390 ± 0.11	0.510 ± 0.14
Tot N%	0.073 ± 0.02	0.099 ± 0.01
Av N ppm	126 ± 18.3	179 ± 47
P_2O_5 kg/ha	28 ± 5.90	45 ± 8.30
K_2O kg/ha	297± 85	427 ± 93.5
Ca%	0.425 ± 0.26	0.592 ± 0.16
Mg%	0.125 ± .05	0.274± 0.17
(Ca + Mg)%	0.550 ± 0.29	0.866 ± 0.16
Na ppm	30 ± 8	40 ± 6.2

The exchangeable calcium and magnesium were higher in Gangua irrigated soils and so also sodium. However, the sodium concentration was not so alarming, because, higher calcium and magnesium concentrations counteract the sodium toxicity. However, higher magnesium concentration in comparison to that of calcium may aggravate sodium toxicity. While higher Ca/Mg ratio (>1) suppress the sodium toxicity. Even though the exchangeable sodium concentration in soils was higher in Gangua irrigated soils due to sodium rich wastewaters than other soils, their level was not high enough to invite any special attention. Probably, the sodium ions were not retained by soils or easily washed down the surface soils through rain water. Column study as discussed in previous section that, even though the higher concentration of Na in wastewaters, while inundated, it was not retained by soil.

3.1.2.3 Microbial properties

The microbial parameters of both the soils that irrigated with Gangua water and OS of water were analyzed. Microorganisms are considered as the driving force or catalyst behind the decomposition, transformation processes. In that sense the magnitude of microbial biomass (MBC) may indicate the potential C flux (Rice at al 1996). Carbon dioxide released due to microbial respiration is another important parameter to measure soil's biological health. Different carbon fractions viz. water soluble C, MBC, potassium sulfate extractible C were determined and respirometric studies (BAS) were conducted with ten number of OS irrigated and eight number of GI soils. The descriptive statistics of the results obtained for both the OS and GI soils are presented in Tables. The GI soils had higher mean MBC (235 µg g^{-1} dried soil), respirometric CO_2 – C (196 µg g^{-1} soil) while OS irrigated soils had mean values of 162 and 191 respectively. The mean MBC varied between 149 and 297 in GI and 91 and 233 µg g^{-1} dried soil in OS irrigated soils respectively (Table 8).

The GI soil had values of respirometric CO_2 – C ranging from100 to 345 but in the OS irrigated soil, it varied between 100 and 328. The water soluble organic carbon (WSC) andpotassium sulphate extractable carbon (PSC) were also higher in the GI soil. From the study on microbial parameter, the soil that irrigated with water of gangua nalah had significantly higher value due to the presence of high organic matter that influence the microbial growth in the soil.

Table 8 Descriptive statistics for microbial parameters in GI soils

	Minimum	Maximum	Mean	Std. Deviation
Organic Carbon	3.00	6.90	5.11	1.41
Water Soluble C	135.00	225.0	179.3	26.29
Microbial Biomass Carbon	149.00	297.0	234.9	48.81
Potassium Sulfate soluble C	184.00	316.0	238.0	49.06
Respirometric C	100.00	345.0	195.9	84.27
OS irrigated soils				
Organic Carbon	2.78	8.55	4.96	1.54
Water Soluble C	84.00	193.00	142.20	37.11
Microbial Biomass Carbon	91.00	233.0	161.80	48.05
Potassium Sulfate soluble C	106.00	297.0	204.60	60.58
Respirometric C	100.00	328.0	191.10	75.63

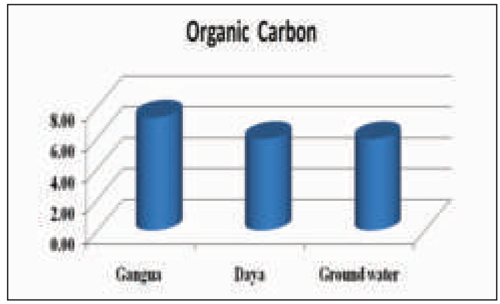
The OC had significant correlations with other microbial parameters except WSC in GI soils as organic matter is the food source of microorganisms, higher organic matter is congenial for microbial growth and their activities. However, higher significant coefficients for GI soils between OC and other parameters could be an indication of organic pollutants in Gangua water from domestic or industrial discharges did not have negative impact on soils microbial activity rather it encouraged the microbial activities. The respirometric C had a significant correlation with OC in GI soil where no such correlation was obtained in OS irrigated soil (Table 9).

Table 9 Pearson correlation coefficients for microbial parameters for Gangua soils

	GI				OS irrigated			
Parameters	**OC**	**WSC**	**MBC**	**PSC**	**OC**	**WSC**	**MBC**	**PSC**
WSC	.561				.667(*)			
MBC	.982(**)	.618			.739(*)	.890(**)		
PSC	.817(*)	.576	.798(*)		.771(**)	.898(**)	.992(**)	
RespC	.869(**)	.382	.852(**)	.626	.190	.064	.292	.297

Effect of different irrigation sources on soil properties

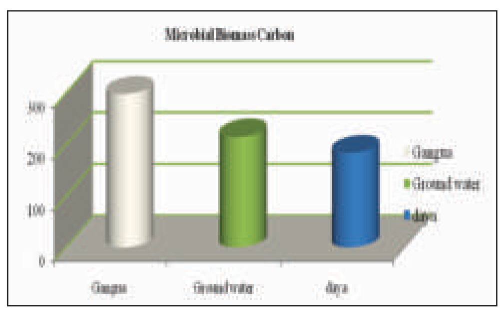
The effect of different irrigation sources on soil organic carbon is shown in Fig below. The soil OC insignificantly increased with Gangua water irrigation over DI and GRWI (Fig 7).



Dependent Variable	(I) water source	(J) water source	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
OC	Gangua	Daya	1.51	.83	.090	-269	3.2945
	Gangua	Groundwater	1.31	.72	.089	-.225	2.8466
	Daya	Groundwater	-1.51	.83	.090	-3.294	.2649

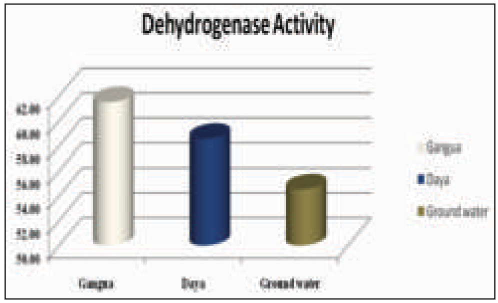
Fig 7 Effect of different irrigation sources on soil organic carbon (OC in g per kg)

The soil microbial biomass carbon increased significantly in GI soils over DI soils and insignificantly over GRWI soils. GRWI soils also had higher SMBC (soil microbial biomass carbon) over DI soils (Fig 8).



Dependent Variable	(I) water source	(J) water source	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
MBC	Gangua	Daya	59.85(*)	17.6	.004	22.03	97.67
	Gangua	Groundwater	24.00	15.2	.137	-8.60	56.60
	Daya	Groundwater	-35.85	17.12	.055	-72.57	.8741

Fig 8 Effect of different irrigation sources on soil microbial biomass carbon (g per kg)

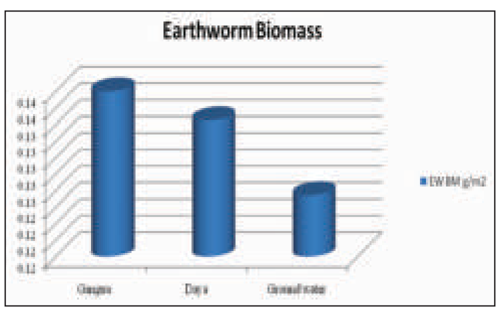


Dependent Variable	(I) water source	(J) water source	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
DHA	Gangua	Daya	2.47	11.2	.829	-21.58	26.52
	Gangua	Groundwater	6.64	9.6	.503	-14.09	27.37
	Daya	Groundwater	-2.47	11.2	.829	-26.52	21.58

Fig 18 Effect of different irrigation sources on dehydrogenase activity (μg g^{-1} hr^{-1} soil)

The dehydrogenase activity was found highest in GI soils among the three irrigation sources but statistically insignificant. No significant change was observed in dehydrogenase activity with different sources of irrigation (Fig 8).

The earthworm biomass did not vary significantly with irrigation water sources. Even though higher earthworm biomass was found in GI soils which was insignificantly higher than that in GRWI and DI soils.



Dependent Variable	(I) water source	(J) water source	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
EWBM	Gangua	Daya	.01450	.0459	.757	-.08	.11
	Gangua	Groundwater	.04486	.0396	.276	-.04	.13
	Daya	Groundwater	-.01450	.0459	.757	-.11	.08

Fig 9 Effect of different irrigation sources on earthworm biomass (g m^{-2})

3.2 Studies on effect of sewage water on plant yield and quality

To understand the effect of wastewater irrigation on crop quality, paddy samples were collected from the same fields irrigated with wastewater and other sources where from the soil samples were collected as mentioned previously. The paddy samples were considered in two parts for analyses i.e. straw and grain.

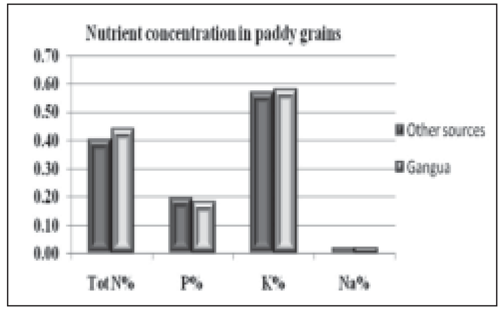


Fig 10 Major nutrient contents in different water sources

The digested straw and grain samples both were analysed for major nutrients viz. N, P and K and some trace elements viz. Fe, Mn, Zn and Cd. The nitrogen content was higher in grain than straw part in all the paddy samples. In straw, it varied between 0.13 and 0.49% with a mean value of 0.23 with Gangua water irrigation whereas it was from 0.12 to 0.27 with a mean value of 0.17% with other irrigation sources.

In grain from Gangua irrigated soils nitrogen content varied between 0.33 and 0.69% with mean value of 0.44 percent while with other irrigation sources it was between 0.35 and 0.52 having mean of 0.4 percent. Higher nitrogen content is indicative of higher protein could be considered as better quality. The higher nitrogen in straw part also shows a positive indication when used as fodder (Fig 10).

However, the phosphorus content was found lower in Gangua irrigated paddy grain and straw both in comparison to those irrigated with other sources. The lower available phosphorus of gangua irrigated soils would have resulted in lesser uptake phosphorus by paddy crops.

The potassium content was found in highest concentrations among all the nutrients analysed in both the straw and grain part of paddy samples. In straw, potassium is retained about four times higher than that in grain part. The potassium concentration in grain varied between 0.49 and 0.68 percent in Gangua irrigated crops while it was between 0.53 and 0.65 percent with other irrigation sources. The sodium concentrations in both the straw and grain part of the paddy samples did not vary much with both the irrigation type.

The heavy metal concentrations were higher in wastewater irrigated paddy grains irrigated with wastewater. The Cd concentration in grains from wastewater irrigation (60% of samples) were higher than the maximum acceptable concentration of 1.5 ppm, (*agmarket. nic.in/paddy _manual.html*), while none of the samples had Zn concentration beyond the acceptable limit (50 ppm).

Table 10 Mean concentrations trace/heavy metals in paddy grains (mg/kg)

Irrigation source	Mn	Fe	Zn	Cd	Cr	Pb
Other sources	143 ± 4.7	158± 5.32	30.69 ± 1.42	1.98 ± 0.07	1.29 ± 0.08	0.990 ± 0.03
Gangua	110 ± 1.23	172 ± 3.13	35.72 ± 3.80	1.73 ± 0.10	1.37 ± 0.09	0.980 ± 0.03

While Zn was absorbed much higher in straw part of the Gangua irrigated soils than those with other sources, the Zn concentration was of the same level in grain with both the type of irrigation. Cadmium contents in both the straw and grain and manganese in grain part of Gangua irrigated paddy were less whereas zinc was higher. While iron was higher in grain parts of Gangua soils, the straw part absorbed less and manganese was found in reverse trend.

3.3 Relation between metal TFs and soil parameters

Generally, the uptake of metals by living organisms depends on the concentration and chemical forms of metals (Bordin et al 1992). The external visible symptoms of paddy grown with wastewater did not have much difference with other source irrigated paddy except higher vegetative growth as per the farmers' observation. However, the Transfer factor (TF) may have relations with soil parameters. Thus, the correlation coefficients (Pearson's) were determined between important soil parameters and metal TFs (DTPA) and shown in Tables 11 and 12.

Table 11 Pearson correlations among TF of heavy metals of OS irrigated soils

	pH	OC	Tot N	Av N	clay	MHC
TFMn	.596	.195	-.701	-.098	-.608	-.631
TFFe	-.493	-.395	.081	-.793(*)	.341	.030
TFZn	-.497	.425	.774(*)	-.193	.679	.171
TFCd	.314	.502	.231	.155	-.419	-.442

Table 12 Pearson correlations among TFs of heavy metals of GI soils

	pH	OC	Tot N	Av N	clay	MHC
TF Mn	-.213	.686	.253	.235	-.428	-.181
TF Fe	.508	-.745(*)	-.428	-.438	-.093	.222
TF Zn	.103	.047	-.643	.496	.002	.008
TF Cd	.470	-.155	.144	.173	-.477	-.181

The concentration of TF for DTPA extractable Fe showed a high significant and negative correlation with soil OC in GI soils and same but insignificant in OS soils which indicate higher Fe mobility with low organic matter. But in OS irrigated soil, transfer factor of extractable Fe had a high significant and negative correlation with available nitrogen. The higher transformation of extractable Fe from paddy soil to rice grain was supported by lower concentration of available nitrogen.

A highly significant positive correlation was observed between the total nitrogen and DTPA extractable Zn TF that reveal that the lower rate of Zn transformation, higher the concentration of total nitrogen in the paddy soil.

The C/N ratio is an important parameter for microbial activities. The potassium permanganate oxidisable N (available) was higher in GI soil than that in OS soils. The mean PMN (Potential mineralizable nitrogen) was also higher in GI soils than that in OS soils.

No significant correlation found with pH in GI soils and OC in OS soils and other parameters. However, significant correlation between PMN and OC in GI soils indicates the better microbial activity due to OC in GI soils due to addition of organic matter through Gangua water.

3.4 Relations among heavy metals and soil parameters

Correlation between soil microbial properties and the DTPA extractable heavy metals/micronutrient (Zn, Fe, Mn, Cd, Pb, Cu, Cr) was performed by person correlation analysis. Mn had no significant correlation with any parameters in OS water while significant negative correlation were found with PMN and MBC and positive with OC. The possible explanation could be the presence of Mn associated organic pollutants from Gangua water was added to the soil, while the Mn had negative impact on microbial population and respiration because of high concentration of DTPA extractible Mn in GI soils DTPA extractible Fe born significant correlation only with respirometric C in OS soils while in GI soils it had significant negative correlation with pH and positive with OC, MBC, and Mn. The decreased solubility of Fe with increased pH might have resulted in negative correlation. Fe being essential element for living cells, significant relation with MBC was observed, however, a higher correlation with respirometric C (0.61) was found even though insignificant. The availability of extractable Fe in soil of GI could be influenced positively by the OC and MBC ($r^2 = 0.774$ and ($r^2 = 0.760$ respectively). That indicate soil rich in organic carbon and MBC plays a dominant role in mobility and transport of Fe in the waste effluent treated soil that had higher concentration DTPA-Extractable form. Among other metals, Cu had significant negative correlations with respirometric C in OS soils while significant negative correlations with all the microbial parameters in GI soils indicate Cu had strong influence on microbial activities. Cr had no significant relations with any of the parameters in GI soils while in OS soils it showed positive relation with it was pH and it was negative with MBC.

The availability of the nutrients is also influenced by the presence or absence of other micronutrients. OS irrigated soils showed that extractable Cu had high and significant negative correlation with the concentration of Mn and Zn while extractable Fe was positively influenced by concentration of Zn.

The availability of Fe in soil that irrigated with Gangua water had a highly significant positive correlation with Cd concentration while it was negative in OS (other source irrigated).

3.5 Heavy metal enrichment

Enrichment factor (Barman et al 2000) has been calculated to determine the degree of soil pollution rather heavy metal accumulation in soil contaminated (wastewater irrigated viz. Gangua) with respect to soil to soil at the uncontaminated sites i.e OS irrigated.

EF = Concentration of metals in GI soils/ Concentration of metals in OS irrigated soils

Table 13 Enrichment factor for heavy metals/trace elements

	Minimum	Maximum	Mean	Std. Deviation
Mn	0.70	5.9	2.4	1.75
Fe	0.50	11.7	4.1	3.82
Zn	0.80	9.9	2.9	3.22
Cd	0.00	3.7	2.4	1.44
Pb	0.30	2.6	.99	0.758
Cu	0.60	3.0	1.3	0.845
Cr	0.70	3.2	1.4	0.836

All the metal concentrations in Gangua irrigated soils were higher in compared to OS irrigated soils. The enrichment factors were in the order, Fe > Zn > Mn = Cd > Cr > Cu. The higher enrichment value indicates higher retention of metals in soils from irrigating water thereby higher rate of accumulation.

3.6 Effect of different water sources on Mn uptake in vegetables and transfer factor

City sewage water contains different types of organic, metals, heavy metal pollutants from domestic, industrial and other discharges. To understand the effect of city sewage in the form of Gangua water on soil and accumulation in plant Mn (assumed as an indicator metal) was estimated in soils irrigated with Gangua water in comparison to other water sources. The plant samples viz. Ladies finger, Ridge gourd and Bitter gourd were collected from the fields irrigated with different water sources and transfer of metals from soil to plants was calculated by dividing the Mn concentrations in plant samples by Mn concentration in the same soil (TF) and shown in Fig 11 to 13.

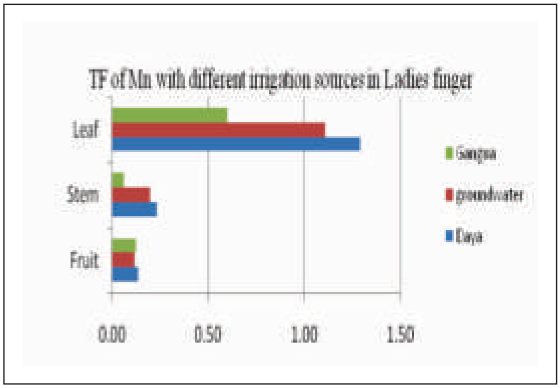


Fig 11 Transfer of metals from soil to different plant parts with differen irrigation sources in ladies finger

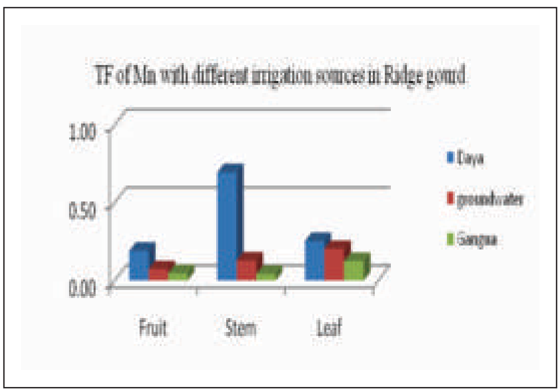


Fig 12 Transfer of metals from soil to different plant parts with differen irrigation sources in ridge gourd

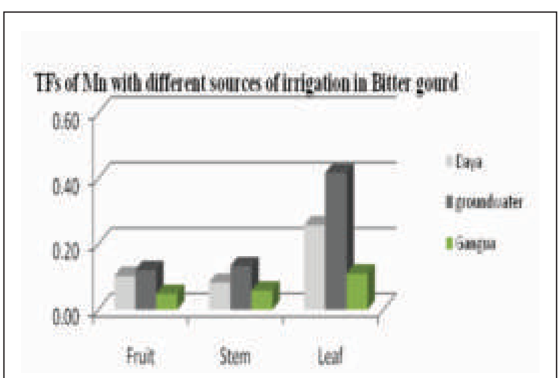


Fig 13 Transfer of metals from soil to different plant parts with differen irrigation sources in bitter gourd

In ladies finger and bitter gourd, the transfer factors were highest in leaf parts than that in stem or fruit parts. In ladies finger, the transfer factor was lower in all the leaf, stem and fruit parts in GI soils than those in other sources. In ridge gourd and bitter gourd also same trend was observed.

Vegetables grown with Gangua water and other water sources were also analyzed for trace/heavy elements. The vegetables (edible part) analysed for heavy metals include *viz*. malabar climbing (poi), amaranthus red (lal saga), amaranthus green (sabuja saga) and three types of vegetables which are eaten cooked *viz* ladies finger, ridge gourd and bitter gourd and two types of vegetables/fruits often eaten raw *viz* tomato and watermelon. All the Gangua irrigated (GI) vegetables had higher concentrations of heavy/trace metals in their edible parts in comparison to the samples grown with other irrigation sources (OS). The mean transfer factors of all vegetables on other source irrigated soils was higher than that in Gangua (wastewater) irrigated soils. The transfer factors (TF) varied among the crops analyzed and among the different parts of the same crop suggesting. The transfer of heavy metals from soil to plant for different vegetables were in the order

Amaranths Red= Tomato> Amaranths green> Water melon> Malabar Climbing> Bitter gourd> Ladies finger> Ridge gourd. This shows that consumption of leafy vegetables grown with wastewater irrigation is risky due to higher accumulation of metals in leaves.

In general Fe concentrations were highest in tomato among all the metals in the vegetable samples tested with both the type of irrigations followed by the Fe contents in watermelon and amaranthus green. The relative concentrations of metals analysed in vegetables were found in the following order,

Plant	Irrgation	Concentrations of metals
Malabar climbing	(OS irrigated)	Fe > Zn > Mn > Cu > Cd > Cr
	(Gangua irrigated)	Fe > Zn > Mn > Cd > Cu > Cr
Amaranthus red	(OS irrigated)	Fe > Mn > Zn > Cu > Cd >Cr
	(Gangua irrigated)	Fe > Mn > Zn > Cd > Cr > Cu
Amaranthus green	(OS irrigated)	Fe > Mn > Zn > Cd > Cr > Cu
	(Gangua irrigated)	Fe > Mn > Zn > Cd > Cr > Cu
Tomato	(OS irrigated)	Fe > Zn > Mn > Cd > Cr > Cu
	(Gangua irrigated)	Fe > Zn > Mn > Cd > Cr > Cu
Ladies finger	(OS irrigated)	Fe > Zn > Mn > Cd > Cu > Cr
	(Gangua irrigated)	Fe > Zn > Mn > Cd > Cr > Cu
Ridge gourd	OS irrigated)	Fe > Mn > Zn > Cu > Cr > Cd
	(Gangua irrigated)	Fe > Zn > Mn > Cr > Cu > Cd
Water melon	OS irrigated)	Fe > Zn > Mn > Cu > Cd > Cr
	(Gangua irrigated)	Fe > Zn > Mn > Cu > Cd > Cr
Bitter gourd	(OS irrigated)	Fe > Mn > Zn > Cd > Cu > Cr
	(Gangua irrigated)	Fe > Mn > Zn > Cd > Cu > Cr

The Cd concentrations far exceeded the permissible standards (0.2 mg/kg) of FAO for most of the vegetables in both the type of irrigation. It also even exceeded the Indian standards for permissible Cd of 1.5 mg/kg. Cr and Cu concentrations were higher in wastewater irrigated vegetables although within permissible limits in all vegetable samples while Zn exceeded in most of the samples.

3.7 Conjunctive use of wastewater and fresh water

Field experiment was conducted with four vegetables viz., okra, bitter gourd, ridge gourd and cucumber. The vegetable crops were grown with three irrigation water treatments viz., Daya water irrigated, Gangua water irrigated, and Daya and Gangua water alternately irrigated during the dry season of 2010-11 in 7 farmers' field.

The soils had mean initial pH 5.75, EC 80 µS/cm, total N 0.021% permanganate oxidisable N 281 kg/ha, 48 kg/ha P_2O_5 and 182 kg exchangeable K_2O and 30 ppm sodium. The Gangua water had pH 6.7, EC 0.48 dS/m, 25 ppm NO_3^-, 2.8 ppm P, 10 ppm K, 35 ppm Na, 0.615 ppm Fe, 0.075 ppm Mn. The soil chemical properties under the influence of different water sources are shown in Table14.

Table 14 Soil chemical properties under different treatments.

Soil Parameters	Initial	Daya (T1)	Gangua (T2)	Daya+Gangua (T3)
pH (1:2.5)	5.75 ± 0.16	5.95 + 0.13	5.82 + 0.19	5.83 + 0.21
EC (S cm^{-1})	80 ± 13	85 ± 15	96 ± 19	88 ± 21
OC (g kg^{-1})	5.61 ± 0.35	5.60 ± 0.43	5.64 ± 0.41	5.62 ± 0.34
TN (%)	0.21 ± 0.02	0.21 + 0.03	0.22 + 0.02	0.21 + 0.02
Av N (kg ha^{-1})	281 ± 28	302 ± 34	316 ± 35	310 ± 42
P_2O_5 (kg ha^{-1})	48 ± 13	49 ± 16	42 ± 18	43 ± 21
K_2O (kg ha^{-1})	182 ± 18	188 ± 21	193 ± 25	191 ± 19
Na (mg kg^{-1})	30 ± 9	33 ± 11	38 ± 16	35 ± 14

The mean soil pH under all the three types of irrigation increased from the initial pH level (5.61) as the water sources had pH much higher than soil pH. The higher electrical conductivity in only wastewater irrigated fields was conspicuous due to addition of salts present in urban wastewater. The soil organic C in T2 (wastewater) and T3 soils was higher probably due to addition of organic pollutants carried usually by urban wastewater. Total N, phosphorus and potassium levels in soils under all the treatments were at par while mean available N in T2 was 12% higher than initial mean soil available N.

Insignificant differences in total heavy metal contents in soils under the different treatments were observed. However, the mean heavy metal concentrations in soils under different treatments were in the order T2>T3>T1 and were within the permissible range of metals (WHO/FAO 2007).

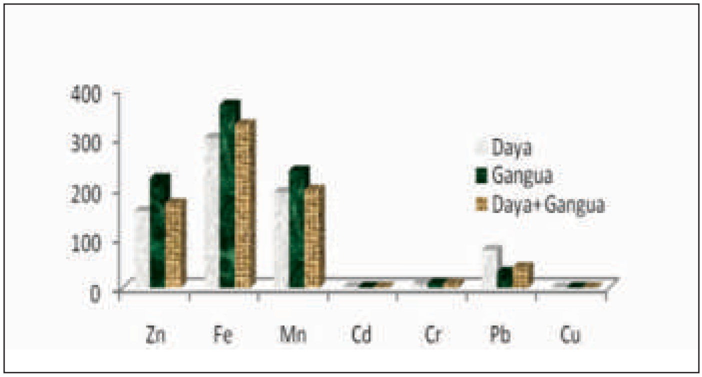


Figure 14 Heavy metal concentrations in soils under different irrigation

The mean concentrations of Pb, Cr and Cd in fruit parts of okra and ridge gourd are shown in figure 2 and 3. Under the treatments the concentrations of Pb, Cr and Cd were lower in the fruits with wastewater + river water than wastewater alone. The concentrations of both the Cr and Pb were below the maximum permissible level (WHO/FAO 2007) while the Cd level was above the permissible level of 0.2 ppm under all the treatments.

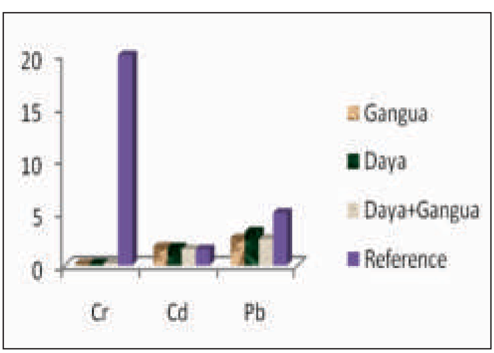


Fig 15 Heavy metal concentration in okra fruits

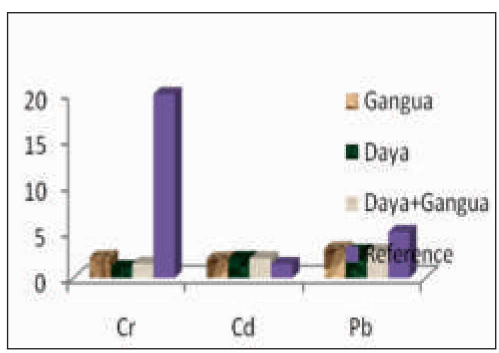


Fig 16 Heavy metal concentration in ridge gourd fruits

Table 15 Yield and yield attributes of vegetables with different water sources

	Vine length (cm)	Yield (t/ha)	Number of fruits/plant	Fruit weight (g)
Ridge gourd				
Daya water irrigated	348 ± 22	15.3 ± 0.54	34.7 ± 2.28	55.1 ± 2.34
Gangua water irrigated	355 + 8	16.6 ± 0.66	36.6 ± 2.27	58.3 ± 1.99
Daya and Gangua	350 ± 14	16.2 ± 0.45	36.2 ± 2.05	57.7 ± 0.83
Bitter gourd				
Daya water irrigated	292 ± 7	11.7 ± 0.82	32.8 ± 1.44	28.4 ± 1.56
Gangua water irrigated	303 ± 10	12.6 ± 0.46	35.6 ± 1.97	31.2 ± 3.022
Daya and Gangua	295 ± 13	12.2 ± 0.61	33.8 ± 1.97	29.9 ± 3.13
Cucumber				
Daya water irrigated	165 ± 13.3	8.51 ± 0.29	9.3 ± 0.95	70.3 ± 5.8
Gangua water irrigated	169 ± 1.4	9.2 + 0.19	10.1 ± 0.57	73.2 ± 1.82
Daya and Gangua	166 ± 11.42	8.97 ± 0.18	9.8 ± 0.54	72 ± 2.98
Okra				
Daya water irrigated	69.7 ± 2.24	8.37 ± 0.65	10.2 ± 0.69	14.3 ± 0.27
Gangua water irrigated	71 ± 1.85	8.79 ± 0.34	11.6 ± 0.98	15.1 ± 0.322
Daya and Gangua	70.7 ± 3.59	8.45 ± 0.43	10.8 ± 1.35	14.7 ± 0.235

There was an increasing trend for the yield and yield attributes viz. vine length, fruits per plants, fruit weights of test crops irrigated with Gangua water as compared with those irrigated with Daya water (Table 15). The yield advantage ranged from 9% (13.1 t/ha) for bitter gourd to 15% (9.2 t/ha) with cucumber. When the crops were irrigated with Daya and Gangua water (1:1), yield advantage was also noted which ranged from 3% with okra to 11% with ridge gourd.

It may be concluded that conjunctive use of wastewater with other fresh water may save up to 50% of fresh water. The heavy metal concentrations were within permissible limit in edible parts of vegetables grown with conjunctive irrigation and was lower than only wastewater irrigation. However, higher level of Cd is a concern which may be addressed through addition of ameliorative agents like lime for reduced uptake of Cd along with diluting wastewater with fresh water for irrigation.

4.0 CONCLUSION

Overall increase in fertility was observed in terms of major nutrients (N, P and K) along with increase in organic matter with wastewater irrigation. The studies on the impact of increased organic matter on microbial activities, showed positive impact. Because microbes play very important role in maintaining soils nutrient supplying capacity and overall fertility. Increased microbial activities could be due to the addition of microbes through the wastewater irrigation containing high microbial loads comprising total coliforms indicating fecal contamination. The coliforms might have contributed in the higher microbial respiration in soil indicating better soil quality. At the same time, it was an indication of higher chances of pathogenic contaminants in wastewater irrigated vegetables.

Presence of higher level of microbial population in surface soils was evinced from higher soil microbial biomass carbon in surface soils. Higher level of coliforms in surface soils as an indicator suggests more chance of infection through skin and consumption of raw vegetables. The population of helminth ova was not enumerated but their higher presence in wastewater irrigated soils could be presumed due to the presence of more coliform bacteria as an indicator of fecal contaminant. The drop in MBC values at lower depths could be the result of retention of microbes in the upper layers when soil column acted as filter. Therefore, the chances of pathogenic contamination of ground water through wastewater irrigation was less.

Increase in Fe, Mn, Cr and Pb concentration by 13, 94, 72 and 21 percent respectively was observed in surface soils. Thus, accumulation of heavy metals due to wastewater addition was conspicuous and the enrichment of heavy metals in the wastewater irrigated soils were in the order Fe > Zn > Mn = Cd > Cr > Cu.

All the Gangua irrigated vegetables had higher concentrations of heavy/trace metals in their edible parts in comparison to the samples grown with other source of irrigation. Among all the heavy metals studied, Cd had the highest transfer factor among all the metals and far crossed the permissible limit of Cd in all vegetables studied probably due to its higher mobility.

The transfer of heavy metals from soil to plant for different vegetables were in the order, Amaranths Red= Tomato> Amaranths green> Water melon> Malabar Climbing> Bitter gourd> Ladies finger> Ridge gourd. This shows that consumption of leafy vegetables grown with wastewater irrigation is risky due to higher accumulation of metals in leaves. However, lower mean transfer factors in Gangua irrigated soils do not imply or guarantee the safety of vegetables grown in Gangua irrigated soils. It rather gives an indication regarding selection of crop to grow in such soils with lesser risk of heavy metal accumulation.

Conjunctive use of wastewater with other fresh water for vegetables may save up to 50% of fresh water which could be used for other potable/non-potable uses. Concentrations of heavy metals in vegetables are lowered with conjunctive irrigation, yet Cd is a concern which can be addressed through addition of ameliorative agents like lime for reduced uptake of Cd along with diluting the wastewater with fresh water for irrigation.

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