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Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area

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Abstract

Studies were undertaken to assess the impact of wastewater/sludge disposal (metals and pesticides) from sewage treatment plants (STPs) in Jajmau, Kanpur (5 MLD) and Dinapur, Varanasi (80 MLD), on health, agriculture and environmental quality in the receiving/application areas around Kanpur and Varanasi in Uttar Pradesh, India. The raw, treated and mixed treated urban wastewater samples were collected from the inlet and outlet points of the plants during peak (morning and evening) and non-peak (noon) hours. The impact of the treated wastewater toxicants (metals and pesticides) on the environmental quality of the disposal area was assessed in terms of their levels in different media samples viz., water, soil, crops, vegetation, and food grains. The data generated show elevated levels of metals and pesticides in all the environmental media, suggesting a definite adverse impact on the environmental quality of the disposal area. The critical levels of the heavy metals in the soil for agricultural crops are found to be much higher than those observed in the study areas receiving no effluents. The sludge from the STPs has both positive and negative impacts on agriculture as it is loaded with high levels of toxic heavy metals and pesticides, but also enriched with several useful ingredients such as N, P, and K providing fertilizer values. The sludge studied had cadmium, chromium and nickel levels above tolerable levels as prescribed for agricultural and lands application. Bio-monitoring of the metals and pesticides levels in the human blood and urine of the different population groups under study areas was undertaken. All the different approaches indicated a considerable risk and impact of heavy metals and pesticides on human health in the exposed areas receiving the wastewater from the STPs.

Keywords: STPs; Wastewater; Metals and pesticides; Impact assessment; Agriculture, environment and health

1. Introduction

Soil and water quality are issues, which affect the quality of our food, health and environment in general. Growing levels of pollution and over-consumption of resources demand some sort of solution. Anthropogenic impact on natural environments and especially on

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aquatic ecosystems is currently a topic of increasing concern. Deterioration of surface water and especially river water quality has recently observed in many aquatories (Boehm et al., 2002; Campolo et al., 2002; Jain, 2002; Nobukawa and Sanukida, 2002; Tara et al., 2003). The potential causes of such a situation are various point and non-point sources (Duda, 1993). Most of these sources lead to the pollution of rivers. The quality of river water may vary depending on the geological morphology, vegetation and activities in the catchments, as well as on the location of the sampling site, either upstream in the mountains or the lower reaches of the river course (Markantonatos et al., 1995; Brezonic et al., 1999).

The Ganga is the most important river system in India. It rises in the Gangotri glacier in the Himalaya mountains at an elevation of 7138 m above mean sea level in the Uttar Kashi district in the state of Uttaranchal, India. Already half a billion people almost one-tenth of the world's population live within the river basin at an average density of over 500 per square kilometer. This population is projected to increase to over one billion people by the year 2030. Today the 2510 km long river supports 29 class I cities, 23 class II cities and 48 towns, and thousands of villages. Nearly all the sewage from these populations goes directly into the river, totaling over 1.3 billion liters per day. Further 260 million liters of industrial waste, run off from the 6 million tons of fertilizers and 9000 tons of pesticides used in agriculture within the basin enters into the river. A large quantity of solid waste including thousands of animal carcasses and several hundred human corps also released into the river every day for spiritual rebirth.

In view of this, Ganga Action Plan (GAP) was formulated in the 25 class I towns along the bank of the river based on comprehensive survey of the Ganga basin. In the planning stages of GAP-I in the mid 80s, conventional technologies for sewage treatment were adopted with designs on normative basis by the state implementing agencies due to lack of experience in this area. For the first time in the country under integrated sanitation project of Indo-Dutch cooperation of the Ganga Action Plan, Phase-I, and innovative sewage treatment technology called up-flow anaerobic sludge blanket process (UASB) was experimented with sewage of 5 MLD capacity and had been in successful operation since then. Sewage treatment plants (STPs) provide agriculture benefits by supplying irrigation and non-conventional fertilizer. Farmers for irrigation in the adjoining villages use partly treated water from STPs with significant amount of nutrients. Therefore STPs under GAP, apart from reducing the pollution load of households and industrial effluents to meet pollution standard, provide irrigation and fertilizer benefits to farmers. There are about 35 STPs under GAP with 13 located in Uttar Pradesh, 7 in Bihar, and 15 in West Bengal. Besides providing irrigation, some of the STPs are supporting pisciculture, especially in West Bengal. All these STPs have capacity to treat a wastewater volume of 919.82 million liters per day. A variety of pollutants can be removed from the sewage by biological and chemical degradation, sorption to sludge or volatilization (Rogers, 1996). In different countries, studies have been carried out for the occurrence and removal of pollutants and comparative evaluation in sewage and landfill leachates (Hannah et al., 1986; Marttinen et al., 2003). Very few studies are available on the impact assessment of wastewater/sludge disposal on the environment quality. Thus the aim of this study was to investigate the impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agriculture and environmental quality in the wastewater disposal areas.

2. Study area

To assess the impact of the wastewater/sludge disposal (metals and pesticides) on the environmental quality of the receiving/application areas around sewage treatment plants (STPs), two plants viz., UASB, Jajmau, Kanpur (5 MLD) and STP, Dinapur, Varanasi (80 MLD) were identified and selected for study. Environmental samples (surface water, ground water, soil, vegetables, crops, food grains, milk etc.) were collected from different villages, both in the receiving (exposed) viz., Shekhpur, Motipur, Kishanpur, Madarpur, Hannia, Trilokpur, Gadarianpurva, Karvigaon, Dinapur, Kotawa, Kamauli, Danipura, Nawapura and non-receiving (unexposed) viz., Paligaon, Kurgaon, Chakeri, T. Pagambarpur, Gauria, C. Chhatimara, B. Chhatimara, Tetepur, Kapildhara, Khalispur areas identified and finally selected. The water, soil, crop/vegetation and food grains samples were collected from the treated/untreated wastewater receiving and non-receiving areas around UASB Kanpur and STP Varanasi and were transported immediately to Industrial Toxicology Research Centre, Lucknow under low temperature conditions. The samples were processed and analyzed for some selected heavy metals viz., cadmium, chromium, copper, iron, manganese, lead, nickel, and zinc and major pesticides viz., BHC isomers, DDT isomers and metabolites, endosulfan, malathion, methyl parathion, ethion and dimethoate. The total numbers of water, soil, vegetables/crops, and food grains samples collected were 32, 15, 20, and 17 respectively from the exposed area and 36, 13, 14 and 12 respectively from unexposed area. In preliminary field survey it was noted that the treated wastewater from Jajmau UASB plant at Kanpur (5 MLD) is mixed up with the untreated wastewater and used for irrigation in the nearby adjoining outskirts area of the city. Total area receiving this wastewater for irrigation purpose is about

25 km^2. Along with this site near Kanpur city receiving the mixed treated/untreated wastewater, a nearby area adjoining to it but not receiving the wastewater at all was also selected to serve as control for impact evaluation. A total eight villages in the receiving (exposed) viz., Shekhpur, Motipur, Kishanpur, Madarpur, Hannia, Trilokpur, Gadarianpurva, Karvigaon, and seven villages in non-receiving area (unexposed) viz., Paligaon, Kurgaon, Chakeri, T. Pagambarpur, Gauria, C. Chhatimara, B. Chhatimara were selected for further studies. For impact analysis of exclusively treated wastewater as proposed, an area near Varanasi receiving treated wastewater from 80 MLD sewage treatment plant (STP) set up by NRCD in Dinapur was also selected along with an adjoining non-receiving area to serve as control for impact evaluation. A total area receiving the treated wastewater from this STP is about 10 km^2. A total of five villages in the receiving (exposed) viz., Dinapur, Kotawa, Kamauli, Danipura, Nawapura and three villages in the non-receiving (unexposed) viz., Tetepur, Kapildhara, Khalispur areas were selected for further studies. The sewage treatment plants (STPs) after treatment of the raw wastewater discharge the treated wastewater usually being utilized for agricultural irrigation purpose in the nearby outskirts area of the town and the generated sludge disposed through selling to the horticultural or agricultural farmers. These components may be contaminated with high levels of the toxicants (such as heavy metals and pesticides). In long run these may contaminate the surface and ground water, soils, crops and vegetation (food/fruits/vegetables) causing considerable adverse impact on health of the consumers/local population as a result of environmental exposure. Therefore, to analyze and evaluate the impacts of the treated wastewater (toxicants), it is very much required to assess and estimate the quantum of these toxicants loading to the study area, which obviously needs characterization of both the treated wastewater and sludge generated by the STPs of these heavy metals and pesticides. The effect of wastewater toxicants on human health in the areas receiving the effluents from STPs was assessed through three different methods:

(a) bio-monitoring of the metals and pesticides levels in the human blood and urine under study areas;
(b) standard questionnaire based survey of the exposed and unexposed population;
(c) environmental exposure risk analysis.

3. Material and methods

3.1. Chemicals and instrumentations

All the solvents and chemicals were of analytical grade. Distilled water was occasionally analyzed similar to wastewater samples to control the laboratory contamination if any. The pH measurements were made using a pH meter model Elico, L-27. An ANTEK-3000 Gas Chromatograph equipped with ECD/FPD and capillary column was employed for the analysis of BHC isomers, DDT isomers and metabolites, endosulfan, malathion, methyl parathion, ethion and dimethoate residue levels. The capillary column (RTX-1) supplied by Restek Corporation, USA having dimensions (L 30 m × ID 0.32 mm) and film thickness 1 μm was used. The metal concentrations in the samples were determined using Inductive Coupled Plasma (ICP) spectrophotometer model LABTAM 8440, Australia. Porosity and density of the soil samples were determined using mercury porosimeter and specific gravity bottles respectively. Sodium, and potassium were analyzed using flame photometer from Elico. The samples of water/wastewater/sludge were collected following the standard method of chemical analysis (APHA, 1998). Stock solutions of the test regents were prepared in double distilled water.

3.2. Quality assurance

Precision and accuracy of the data were assured through repeated analysis of National Bureau of Standards No. 70 G for Cd and 42 G for the rest of the metals and the results were found to be within ±2% of certified values. Average values of five replicates were taken for each determination. Operational conditions were adjusted to yield optimal determination. Quantification of metals was based on calibration curves of standard solutions of metals. The detection limit for different metals were 4, 7, 6, 7, 2, 15, 40, and 2 $\mu g\,l^{-1}$ for Cd, Cr, Cu, Fe, Mn, Ni and Pb respectively. The precision of the analytical procedures expressed as the relative standard deviation (rsd) ranged from 5% to 10%. The precision for the analysis of standard solution was better than 5%. Recoveries of metals from the samples were also studied for evaluation the matrix effect by the standard addition technique and found to be between 94% and 106%. In different experiments blanks were run and corrections applied if necessary. All the observations were recorded in triplicate and average values and their standard deviations are reported.

Pesticides residues were more than 99.8% pure. Recoveries of residue undergoing the analytical regime were greater than 92% and reliable sensitivity of detection was 1 ppb for *pp*-DDE and α-BHC and 2 ppb for β-BHC, Lindane, Aldrin, Endosulfan, *op*-DDT and *pp*-DDT. Data obtained for various pesticides in this investigation were corrected accordingly. All samples were run in duplicate. Levels of all compounds were well above the detection limits.

4. Results and discussion

4.1. Characterization of untreated/treated wastewater/sludge (STPs)

4.1.1. Wastewater (untreated/treated)

The raw (untreated) and treated wastewater samples were collected from the inlet and outlet of both the sewage treatment plants (STPs) in Jajmau, Kanpur (5 MLD) and Dinapur, Varanasi (80 MLD) during the peak (morning and evening) and non-peak (noon) hours and analyzed for metals and pesticides. The metals and pesticides residue levels (mean) at the inlet and out let of the two-sewage treatment plants (Kanpur and Varanasi) are given in Table 1. The result of the physicochemical analysis and bacteriological enumerations of the peak and non-peak hours from the two STPs inlet and outlet are presented in Figs. 1–11 while the range and mean values of these parameters as observed during these months are given in Table 2 along with standard deviation. From the mean levels of metals and pesticides in the treated (outlet) wastewaters of the two STPs, their total input/discharge and loading of these pollutants can be estimated as received in the respective disposal/application areas and are given in Tables 3 and 4.

As far as the suitability of the treated wastewaters with particular reference to the heavy metals for irrigation of the agriculture land is concerned, from Table 1, it may be noted that leaving apart the cadmium levels in treated water from the two STPs and that of chromium in Jajmau (Kanpur) STP, the levels of all the other metals are within the permissible limits as prescribed for the agricultural land irrigation purpose. Further, the higher levels of nitrogen (N), phosphorous (P) and potassium (K) in the treated wastewater result in positive impact on the crop productivity in the areas receiving it.

4.1.2. STPs sludge

STPs sludge samples were also collected regularly from both the treatment plants and analyzed for heavy metals, pesticides residue, N, P, K, and organic C contents. The results (mean values) are presented in Tables 5–7.

From Table 5, it is clear that sludge generated by both the STPs have cadmium and nickel levels above their tolerable amounts as prescribed for agriculture land application. However in terms of fertilizer values (N, P, K and organic content) as given in Table 7, it can be estimated that about 14 kg nitrogen (N), 6.75 kg phosphorus (P) and 4.25 kg potassium (K) would be available per ton of the generated sludge and in terms of its economic value at existing market rates as given in Table 7. From this table, it may be noted that the cost of fertilizer ingredients (NPK) per ton of the STPs sludge generated is about Indian Rs. 486 (~US$10).

Table 1
Mean metal and pesticides residue levels in wastewater (mg/l)

STP	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	α-BHC	β-BHC	γ-BHC	T-BHC	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Jajmau, Kanpur (UASB, 5 MLD)																
Inlet	0.05	6.45	0.88	8.80	0.55	0.22	0.19	1.82	0.11	0.095	0.027	0.232	ND	0.02	2.25	2.51
Outlet	0.01	0.37	0.03	0.42	0.17	0.05	0.05	0.14	0.027	0.016	0.009	0.051	ND	0.002	0.55	0.56
Dinapur, Varanasi (STP, 80 MLD)																
Inlet	0.16	8.12	0.16	3.32	0.47	0.14	0.15	1.58	0.098	0.038	0.030	0.166	ND	ND	0.121	0.132
Outlet	0.02	0.02	0.03	0.30	0.14	0.05	0.05	0.12	0.018	0.009	0.008	0.035	ND	ND	0.021	0.024
WQ crit irrigation	0.01	0.1	0.2	5.0	0.2	0.2	0.5	2.0	–	–	–	–	–	–	–	–

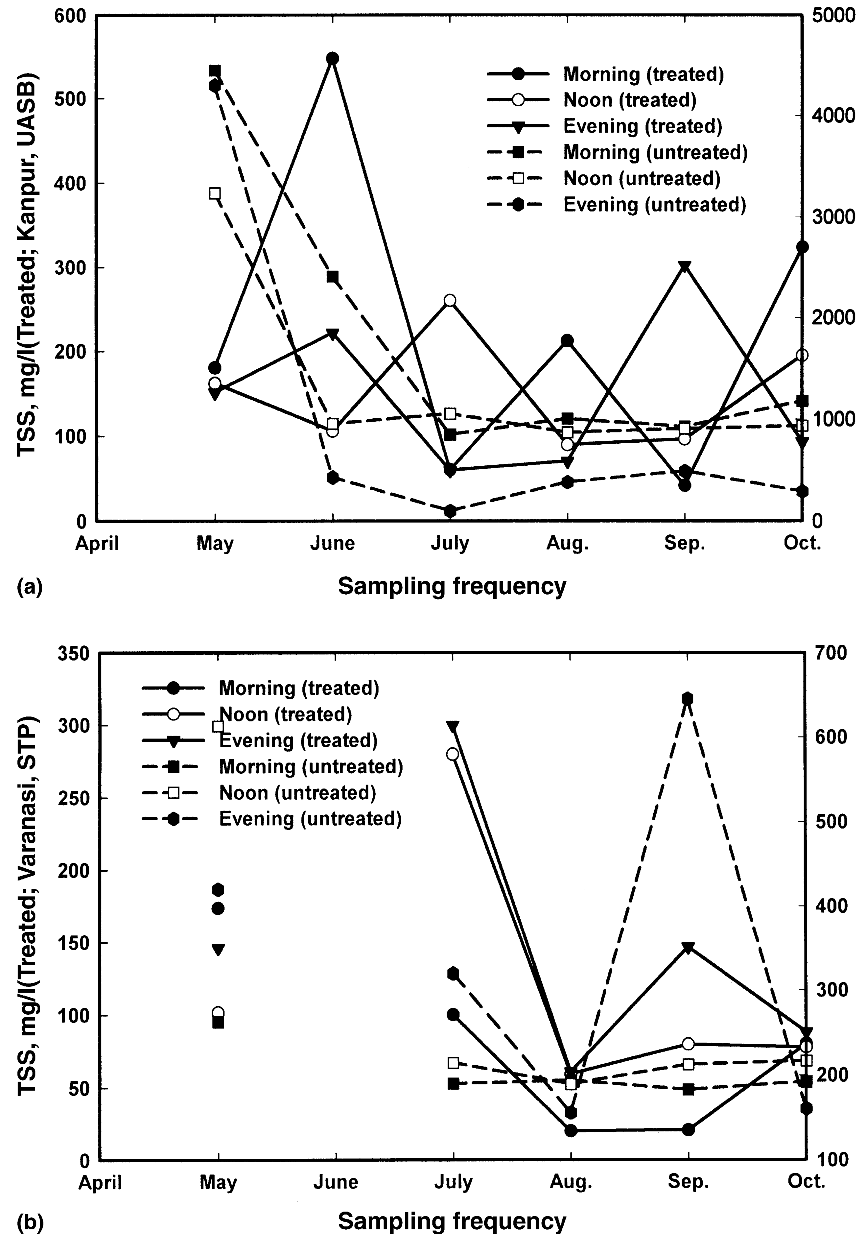

Fig. 1. Seasonal variation in TSS of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

4.2. Impact of wastewater toxicants (metals and pesticides) on environmental quality of the disposal area

To assess the impact of wastewater/sludge disposal (metals/pesticides) on the environmental quality around the respective STPs, environmental samples (surface water, ground water, soil, vegetables, crops, and food grains) were collected from different villages both in the receiving and non-receiving areas selected near UASB, Jajmau, Kanpur and STP, Dianapur, Varanasi. Range and mean levels of metals and pesticides in different environmental media (surface water, ground water, soil, veg./crops, and food grains) are provided in Tables 8–11 for Kanpur and Varanasi in receiving and non-receiving areas. From these data, it may be noted that the levels of heavy metals as well as pesticides (BHC and DDT) in each of the environmental media are very much higher in the area receiving the wastewater for irrigation purpose as compared to the adjoining area where there is no irrigation with this water. Further, it may be noted that

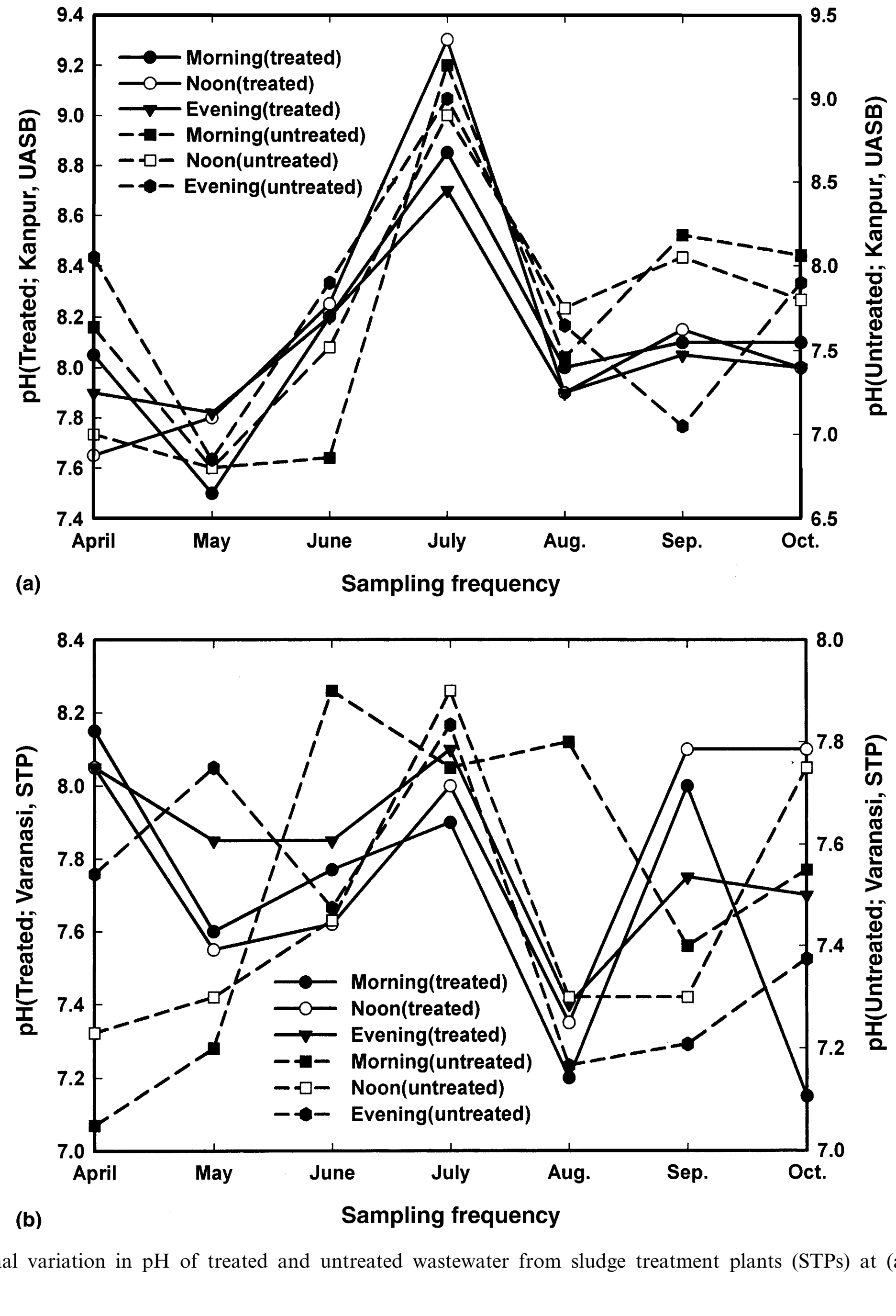

Fig. 2. Seasonal variation in pH of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

the concentrations in ground water are not much different, it may be due to common ground water aquifers in both the areas. Surface water collected from only a few available ponds shows higher levels of metals as well as pesticides. This water is usually used as drinking water for the cattle. Metal and pesticides levels in soils from wastewater disposal area are also much higher than those from the respective unexposed areas. This might have resulted due to continued application of the wastewater. Metals and pesticides residue levels in the vegetation/crops, vegetables and food grains as consumed by the cattle and human beings are also much higher in the wastewater disposal areas over those not receiving the wastewater. The soil samples were also analyzed for their characteristic physiochemical parameters (pH, densities, pore space, electrical conductance,

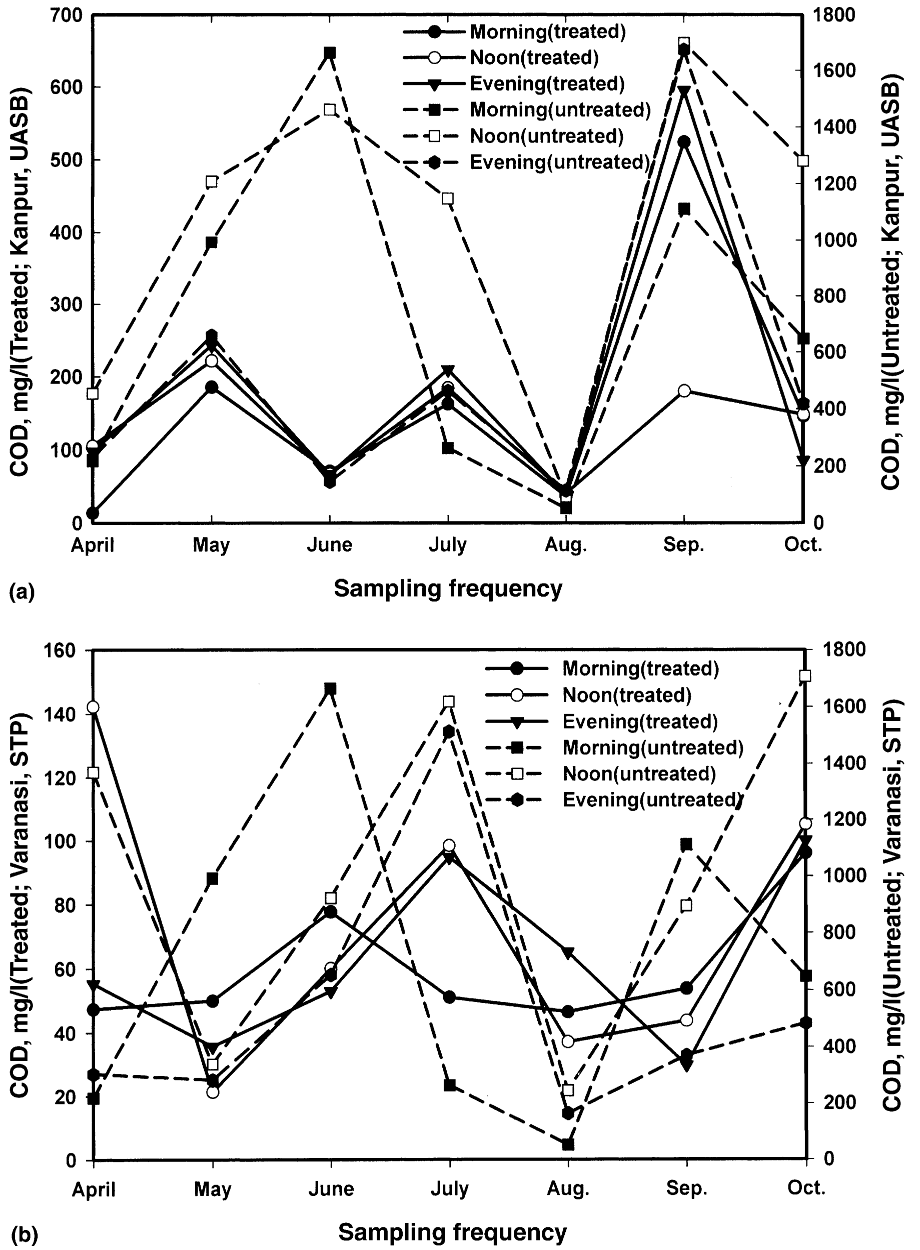

Fig. 3. Seasonal variation in COD of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

nitrogen (N), phosphorous (P), potassium (K), organic carbon (C), calcium (Ca), magnesium (Mg) and sodium (Na) contents) and the values are provided in Table 12. The heavy metals and pesticides residue levels in the soils both near Kanpur and Varanasi irrigated with the wastewater from STPs were found to be much higher as compared to those in adjoining soils not receiving the wastewater. Further, the soil characteristics results indicate a considerable alteration in the soil quality of the areas irrigated with the wastewater over the one not receiving the same.

4.3. Impact of wastewater toxicants (metals and pesticides) on agricultural

Irrigation use of treated effluent and sludge must be given the fullest consideration in planning any waste disposal scheme. There is sound logic in returning the

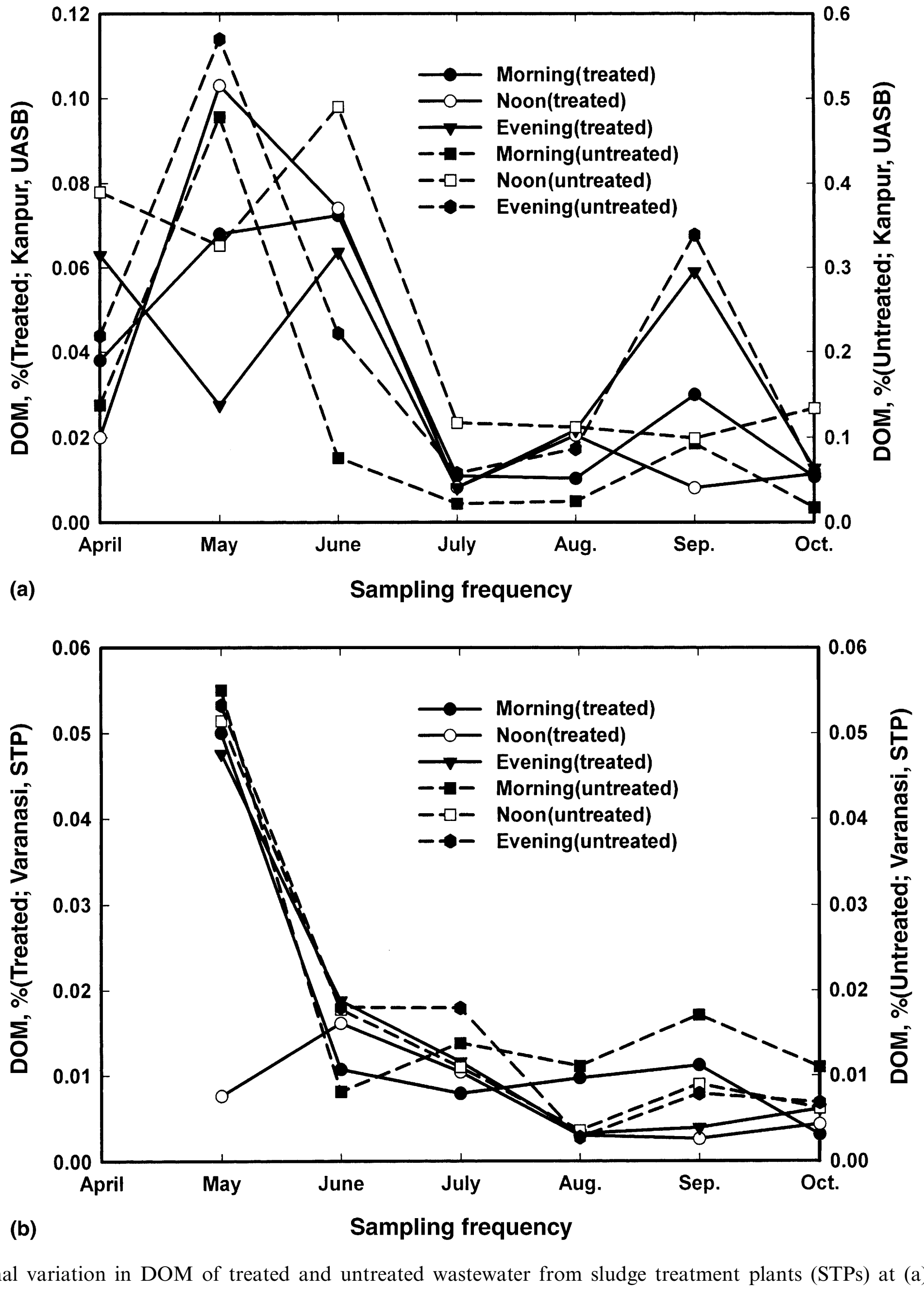

Fig. 4. Seasonal variation in DOM of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

solids back to land and reusing the wastewater whenever feasible.

The elevated levels of persistent type toxicants such as metals and to some extent pesticides in long run disposal of treated wastewater and sludge for irrigation or amendment of the agricultural land may lead to build higher concentrations in soils as a result of accumulation. The higher metal levels in soil may cause negative impact on crops, inhibiting the growth in one or other way. However, one of the most important factors is the pH of the soils. Alkaline pH of the soil would usually restrict the mobilization of the metal in soil matrix and consequently, the metal uptake by crop plant would be controlled, obviously reducing the risk of metal toxicity. From Tables 8 and 10 it may be noted that the mean level of Cd and Cr are above their critical levels in

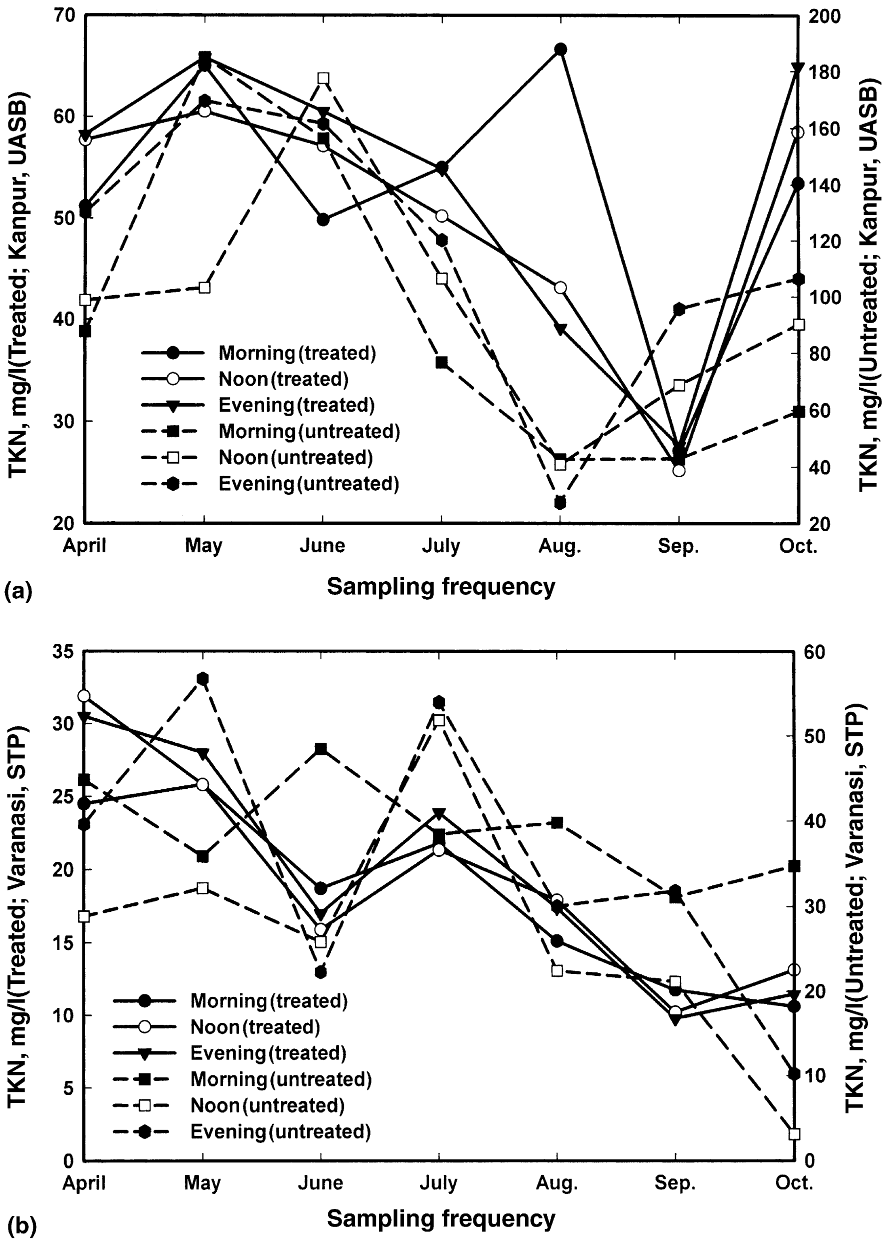

Fig. 5. Seasonal variation in TKN of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

agricultural soils of the area near Kanpur STP irrigated with wastewater. The mean levels of Cd, Ni and Pb in soils of treated wastewater irrigated area near Varanasi STP are above their respective tolerable limits for agricultural crops. However, the disposed wastewater in both the areas has mean pH value of about 8 and the mean pH value for the agricultural soils irrigated with wastewater was found to be more than 8. Therefore, even though, the level of a few metals in soils was above their critical limits, their mobilization and plant uptake might be restricted by alkaline pH. Further, it may be mentioned that the critical levels of the heavy metals in soils displaying negative impacts on agricultural crops are considerably high as encountered in our study areas irrigated with treated wastewater. Therefore, as yet, there seems to be no adverse impact of metals and pesticides on agricultural crops in these areas. However, a questionnaire based individual farmer's survey was conducted in all the four exposed and unexposed areas near Kanpur and Varanasi STPs collecting information

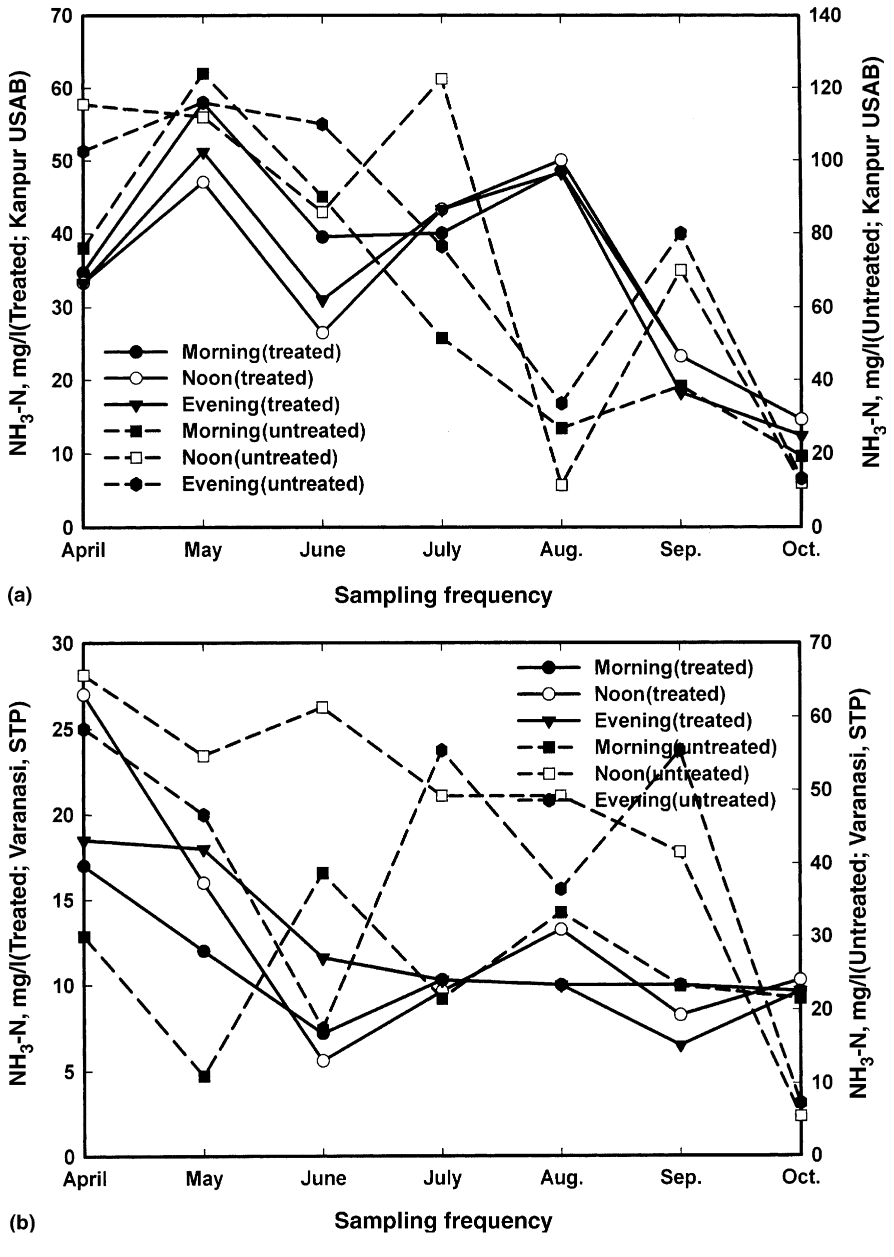

Fig. 6. Seasonal variation in NH_3–N of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

on agricultural crops production trends during last few years. In the exposed areas near Kanpur, the majority (90%) reported that the crops yield has declined over past few years due to some root disease infestation causing the plant death or weakness leading to small grain size. But in area near Varanasi irrigated with treated wastewater, the response of the farmers was totally reverse. The majority of farmers (65%) reported an enhancement in crops yield over last few years. The reason of declined productivity near Kanpur may not be the toxic metals but it is principally due to irrigation with mixed wastewater with high solids/bacterial biomass resulting into deposition on soils as observed during survey and making the soil–root interface more susceptible to plant root diseases. However, the enhanced yield in area near Varanasi irrigated with treated wastewater may be accounted for more irrigation water availability with high nutrient/fertilizer value water to the crops as discharged by the Dinapur STP. Soil samples in the area receiving (exposed) and non-receiving

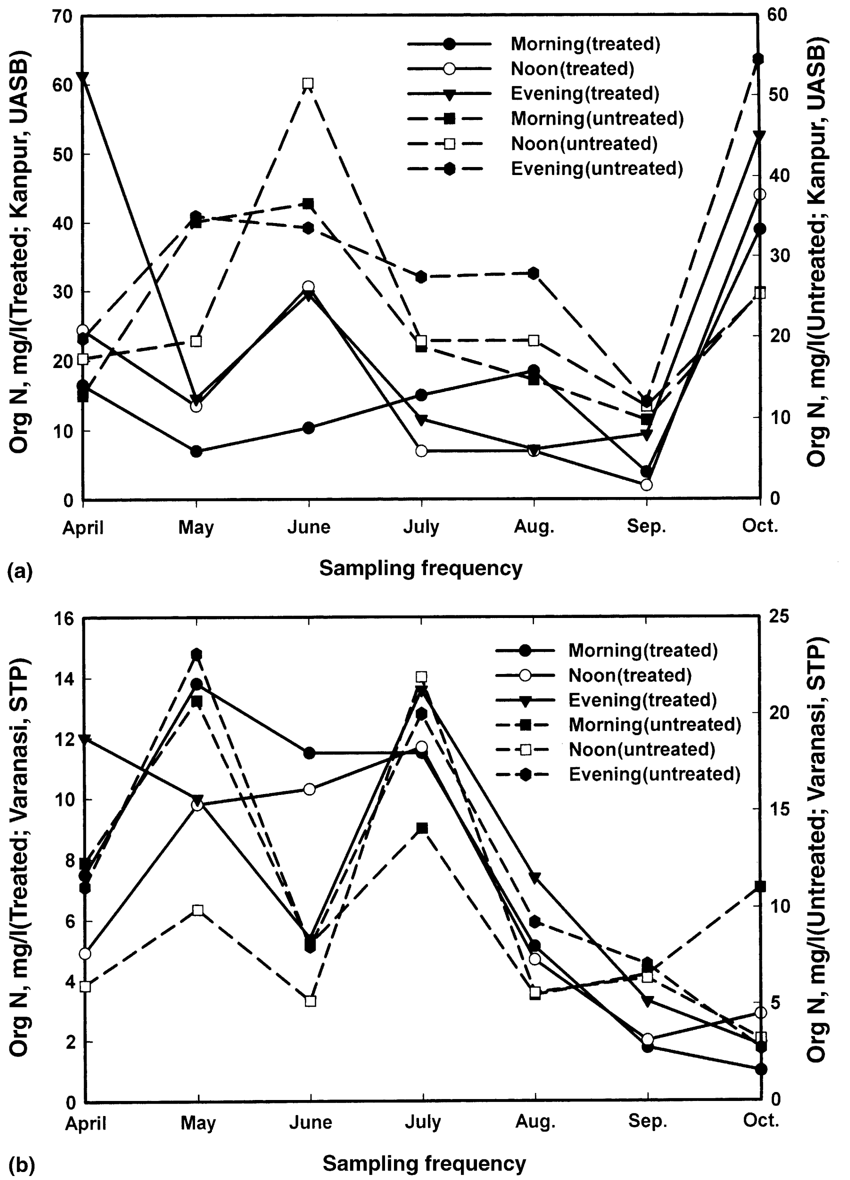

Fig. 7. Seasonal variation in Org-N of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

(unexposed) wastewater were also characterized for their physical properties such as pH, electric conductivity, bulk density, particle density, porosity etc. and are give in Table 12.

4.4. Impact of wastewater toxicants on health

Exposure to heavy metals and pesticides may be exhibited by several signs and symptoms (Ramond et al., 1991; Otto et al., 1994; Lili and Elsner, 1995; William, 1996) but they are only recognized when achieve chronic and clinical levels. Since the pesticides and heavy metals are both proven neurotoxic, there are several methods developed and reported (Hanninen and Lindstrom, 1979; Anger, 1989) to assess the exposure at very low concentration of these substances (sub-clinical level). Since the heavy metals and pesticides exposure of the population may cause the neurobehavioral disorders such as fatigue, insomnia, decreased concentration, depression, irritability, gastric symptoms, sensory symptoms and motor symptoms. A standard questionnaire based on chemical (metal and pesticides) symptoms and comprised a total 35 items covering eight different functions (Hanninen and Lindstrom, 1979) was modified and used for recording

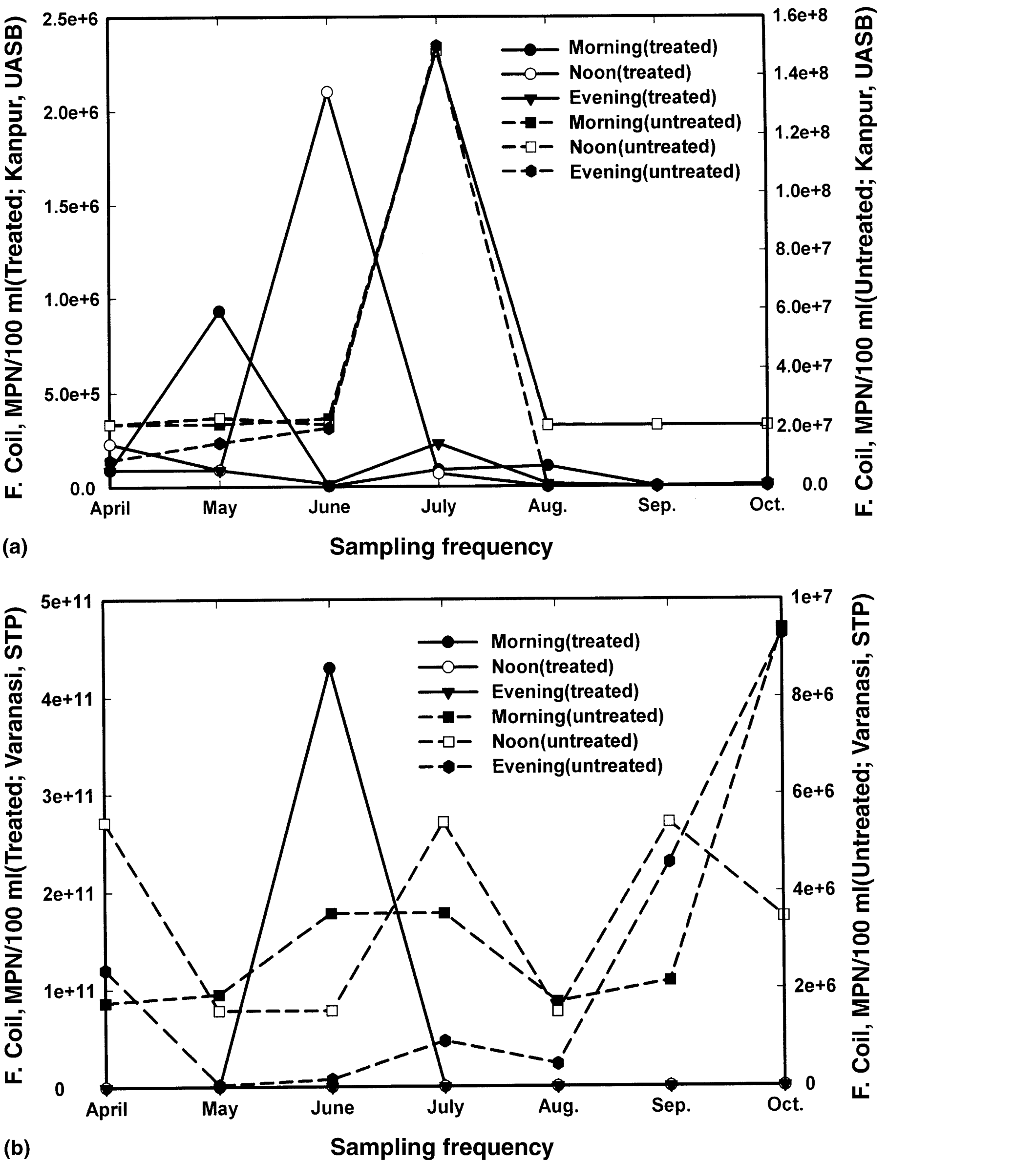

Fig. 8. Seasonal variation in *F. coli* of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

information from the selected populations with regard to any impact of these toxicants (Table 13) through personal interviews. Neurobehavioral analysis was done on the basis of the mean scores for each function of every individual. Representative population groups in all the four areas (near Kanpur and Varanasi) were surveyed for general health status and neurobehavioral functions of the population through questionnaire based personal interviews. The collected information/response of the selected individuals from the exposed and unexposed areas are summarized in Tables 14 and 15.

The neurobehavioral information was analyzed statistically applying the '*t*' test to see the significant difference in the mean of different parameters between exposed and unexposed population groups near sewage treatment plants (STPs) separately and the results indicating level of significance (p) are given in Table 16. It may be noted that overall and for the individual neurobehavioral function, the difference in the population selected from the area receiving wastewater from the UASB, Jajmau, Kanpur (exposed) were significant over the respective unexposed population group selected

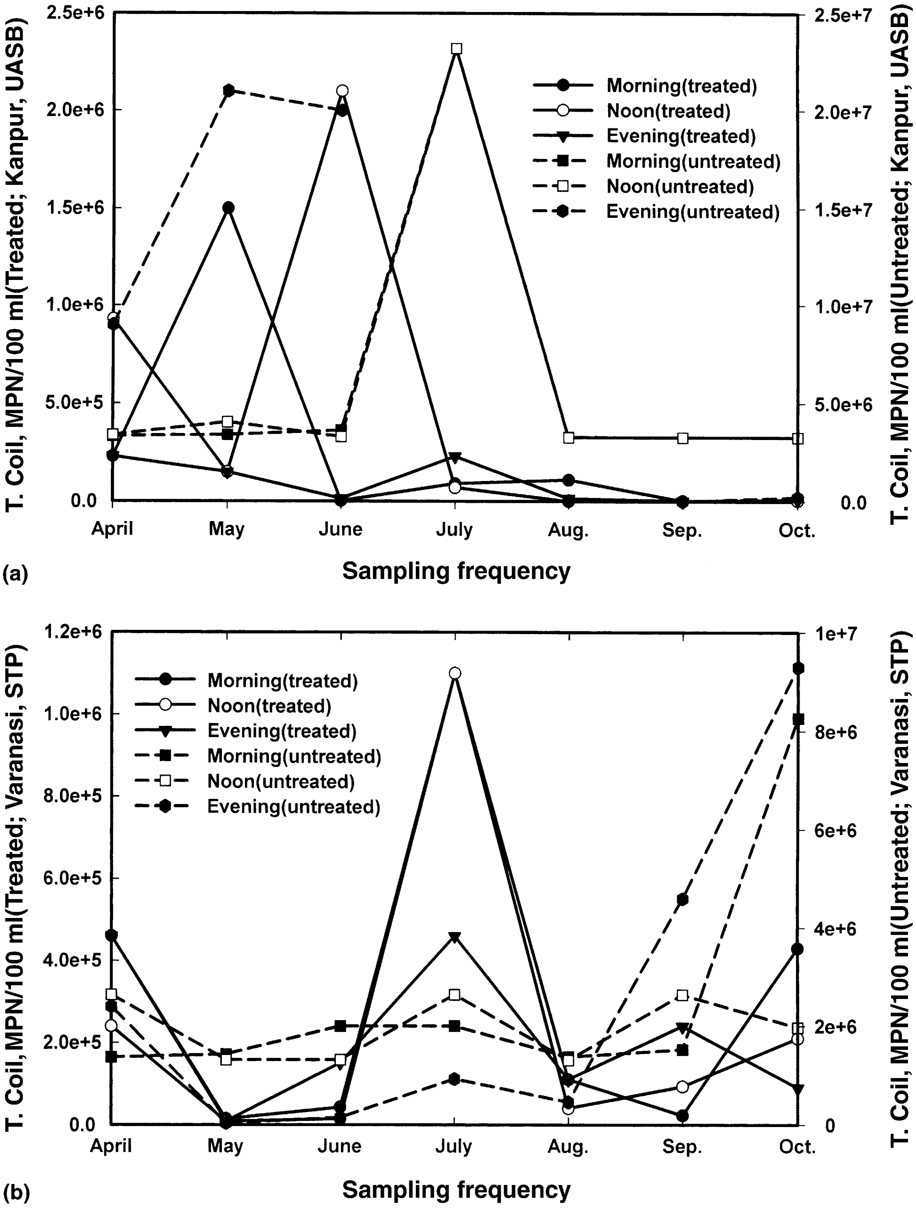

Fig. 9. Seasonal variation in *T. coli* of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

from the adjoining area receiving no wastewater. Further, the difference among Varanasi population groups was non-significant for all the functions. However, this does not mean that there is no significant exposure near the Varanasi area receiving treated wastewater from the Dinapur STP (80 MLD). One of the possible reasons seems to be the duration of disposal as the area near Kanpur is receiving wastewater for several decades, while the one near Varanasi has started receiving it only for the last few years. This is further supported by observed higher levels of metals and pesticides in different environmental compartments in the disposal area near Kanpur as compared with those near Varanasi.

4.5. Bio-monitoring of metals and pesticides levels (human blood and urine) in exposed/unexposed population

In order to further assess the extent of the metals and pesticides exposure to the population in the area receiving the wastewater, the levels of various metals

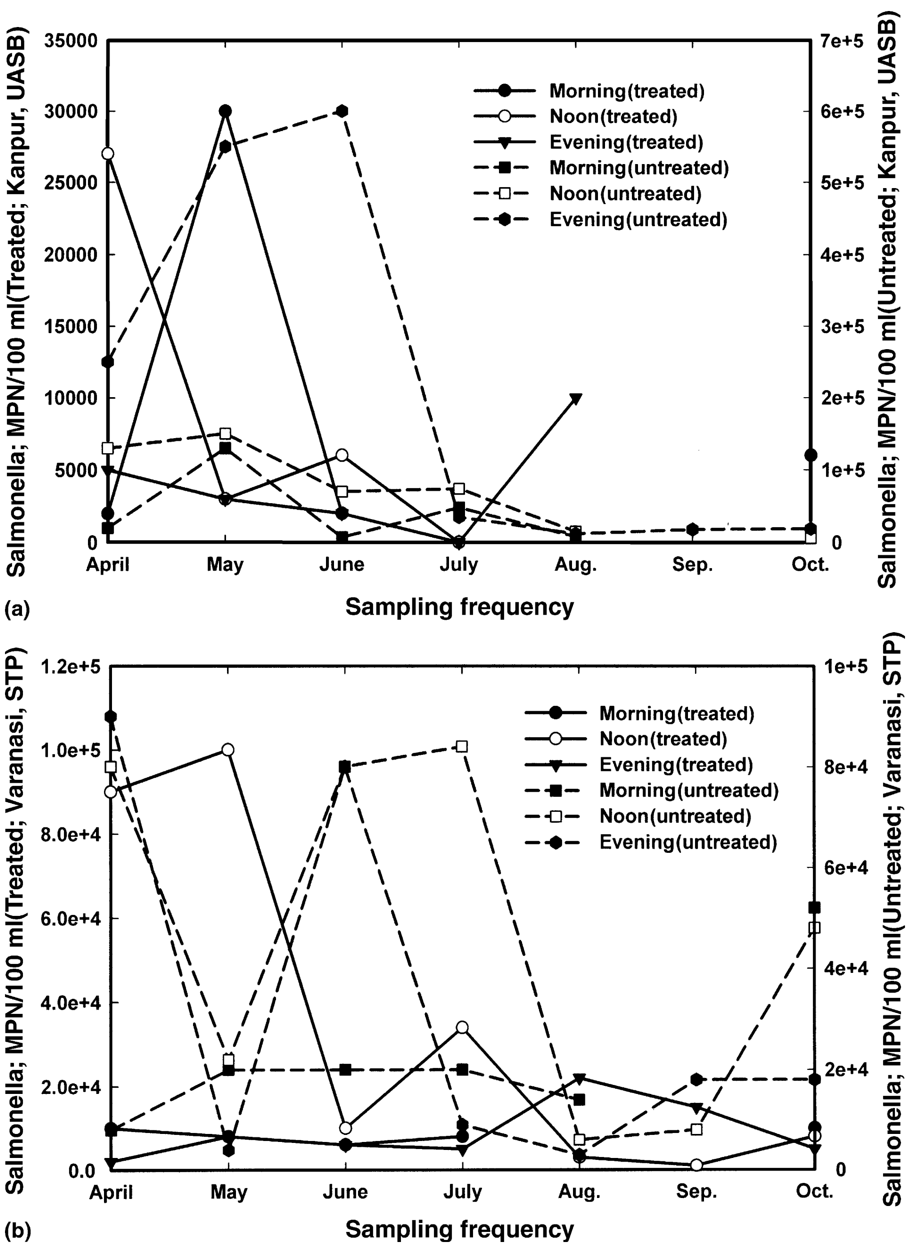

Fig. 10. Seasonal variation in Salmonella of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

and pesticides were measured in human blood and urine samples. Total number of blood samples collected from Kanpur were 12 each from exposed and unexposed area while form Varanasi the same were 12 and 14 respectively. Similarly total number of urine samples collected from Kanpur were 38, and 30 from exposed and unexposed area while form Varanasi the same were 32 and 22 respectively. The intravenous blood samples of about 10 ml and urine (24 h) samples were collected from all the four areas from representative population groups. These samples were immediately transported to the laboratory (Industrial Toxicology Research Centre, Lucknow) under low temperature conditions (in ice boxes) and were processed for the analysis of heavy metals and pesticides separately as per standard methods. The analytical results (Tables 17–24) indicate that the metals as well as pesticides levels (mean) in blood and urine samples collected from the populations representing

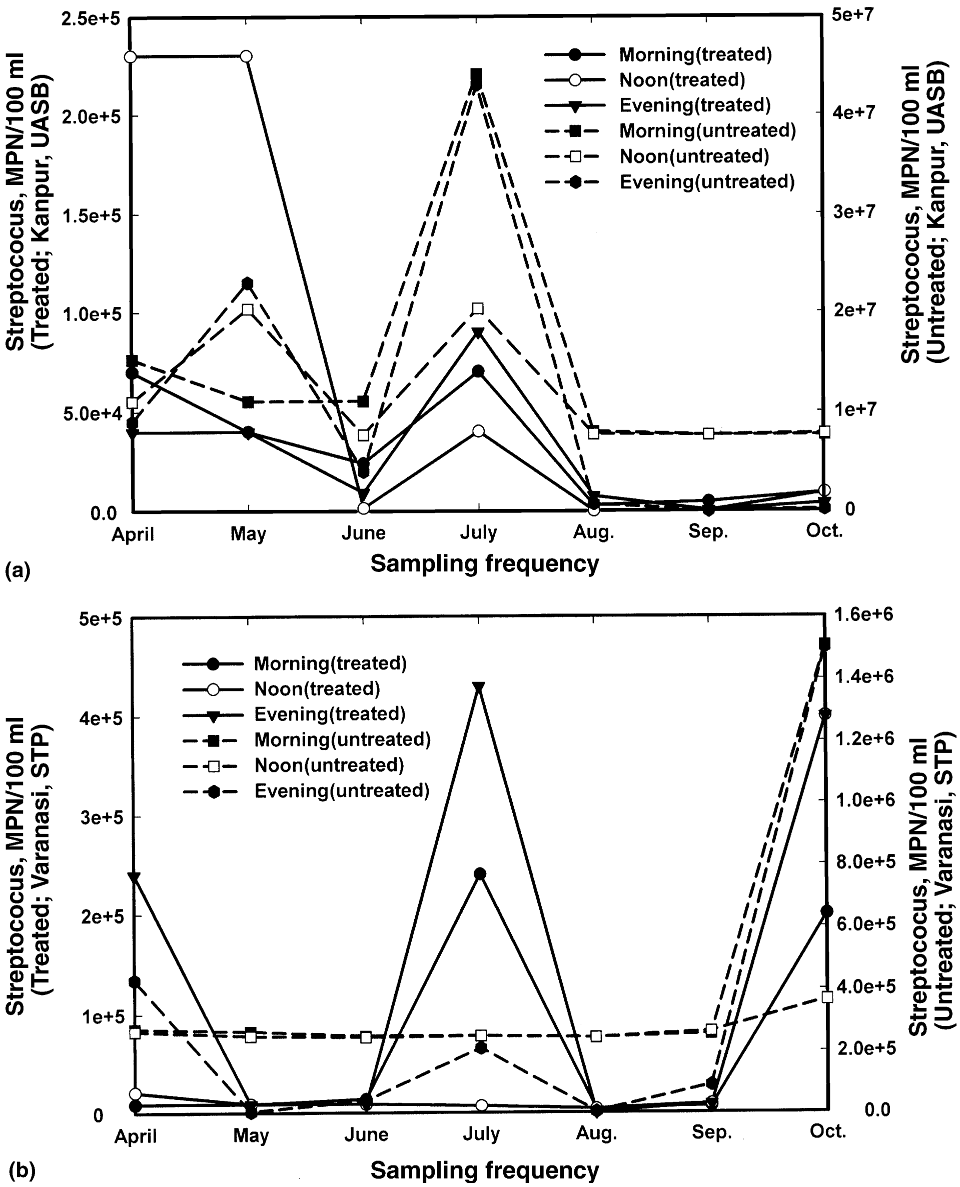

Fig. 11. Seasonal variation in Streptococcus of treated and untreated wastewater from sludge treatment plants (STPs) at (a) Kanpur and (b) Varanasi.

wastewater irrigated areas were higher than those collected from the areas not receiving the wastewater in case of both the Kanpur and Varanasi. Further, it may be noted that the residue levels of metals and pesticides in human blood as well as in urine samples of the exposed and unexposed population groups in Kanpur were higher as compared to those of Varanasi exposed and unexposed population groups, respectively. This may again be due to the prolonged disposal of the wastewater in the area near Kanpur over decades and resulting in long time exposure of the population.

4.6. Environmental exposure risk assessment of metal and pesticides

The environmental exposure risk to the populations from these elevated levels of metals and pesticides in different environmental media (water, food, vegetables, crops/vegetation) in areas receiving wastewater over those unexposed ones has been evaluated by first computing the mean estimated total daily intake (TDI) of each of these toxicants (individual metal and pesticides) using Eq. (1)

Table 2
Range and mean values of selected quality parameters of untreated and treated wastewater

Parameters		UASB, Kanpur			STP, Varanasi		
		Range	Mean	SD	Range	Mean	SD
TSS	(mg/l)	42.0–547.8	176.4	122.3	20.0–300	102.3	67
		(99.60–4344.8)	(962.0)	(1379.1)	(55.2–976.0)	(340.1)	(236.6)
pH		7.5–9.3	8.1	0.4	7.2–8.2	7.8	0.3
		(6.8–9.3)	(7.9)	(0.64)	(7.1–8.0)	(7.5)	(0.3)
COD	(mg/l)	36.70–595.0	168.8	141.0	21.4–142.3	67.9	29.2
		(51.70–1664.6)	(578.6)	(453.6)	(39.1–310.1)	(152.7)	(67.6)
DOM	(%)	0.01–0.10	0.035	0.03	0.003–0.050	0.013	0.014
		(0.02–0.48)	(0.08)	(0.11)	(0.004–0.071)	(0.021)	(0.02)
TKN	(mg/l)	25.2–66.6	52.0	12.4	9.8–31.9	19.2	6.7
		(18.5–185.0)	(78.5)	(40.0)	(16.0–49.6)	(34.0)	(8.8)
NH_3–N	(mg/l)	12.4–58.0	34.9	13.2	5.6–27.0	11.9	4.8
		(16.6–124.0)	(48.5)	(25.8)	(11.0–38.7)	(22.4)	(6.4)
Org-N	(mg/l)	2.0–52.6	18.1	13.9	1.0–13.8	7.2	4.2
		(4.6–100.5)	(31.6)	(23.1)	(2.7–26.3)	(11.7)	(6.7)
T. coli	(MPN/100 ml)	40–2 100 000	280 000	540 000	9000–1 100 000	260 000	310 000
		(2400–100 000 000)	(120 000 000)	(320 000 000)	(7000–24 000 000)	(3 100 000)	(5 200 000)
F. coli	(MPN/100 ml)	40–2 100 000	20 000	470 000	4000–430 000 000 000)	20 000 000 000	9 200 000 000
		(2400–1 100 000 000)	(1 200 000)	(320 000 000)	(2400–1 100 000 000)	(2 400 000)	(28 000 000)
Salmonella	(MPN/100 ml)	Nil–30 000	4600	8200	Nil–100 000	17 000	27 000
		Nil–600 000	100 000	170 000	Nil–90 000	22 000	24 000
Streptococus	(MPN/100 ml)	40–230 000	44 000	66 000	700–430 000	97 000	150 000
		(2100–43 000 000)	(8 300 000)	(13 000 000)	(4000–9 300 000)	(660 000)	(200 000)

Table 3
Mean metal discharge through treated wastewater

STP	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Jajmau, Kanpur (UASB, 5 MLD)								
kg/day	0.06	1.84	0.16	2.08	0.83	0.25	0.27	0.67
kg/year	0.02	0.67	0.06	0.76	0.30	0.09	0.097	0.25
Dinapur, Varanasi (STP, 80 MLD)								
kg/day	1.90	1.62	2.57	28.5	13.5	4.47	4.56	11.60
kg/year	0.694	0.59	0.94	10.4	4.92	1.63	1.66	4.23

Table 4
Pesticide discharge through treated wastewater

STP		γ-BHC (Lindane)	Total DDT
Kanpur (5 MLD)	(g/day)	0.045	2.85
	(kg/year)	0.016	1.04
Varanasi (80 MLD)	(g/day)	0.760	2.28
	(kg/year)	0.277	0.83

Table 7
Mean NPK contents of STPs sludge and it cost economics

Parameters	Kanpur	Varanasi	Rate per ton of sludge (per kg)	
			Ingredient	Cost
OC	661.12	552.28	–	–
K	4.54	4.00	4.25 kg	Rs. 136
P	7.25	6.32	6.75 kg	Rs. 243
TKN	13.10	14.89	14.0 kg	Rs. 107

$$\text{TDI (mg/day)} = \sum C_i D_i \quad (1)$$

where C_i is the mean concentration of individual toxicant in the ith media and D_i is the mean daily intake of the same media by a person. The major intake routes considered are: drinking water (2.5 l/d), food grains (600 g/d); vegetables (300 g/d) and milk (200 g/d).

The computed TDI (mg/d) values for each toxicant are then compared with their respective acceptable daily intake (ADI) values (mg/d), worked out from their individual ADIs (mg/d/kg bw) as available in the literature for a person of 60 kg body weight.

The risk quotient (RQ) for each toxicant was computed using Eq. (2)

$$\text{RQ} = \text{TDI}/\text{ADI} \quad (2)$$

The computed results for the metals (only for which ADI values are available) and pesticides for both the populations (exposed and unexposed) in both the selected areas (Kanpur and Varanasi) are presented in Tables 25–28.

As a general principle, the population exposed to some particular toxicant (chemical) will be at risk with respect to the toxicant, if the value of the respective risk quotient (RQ) is above 1.0. However, if we compare the two population groups for their relative risk with respect to some common toxicant to which these are exposed, their respective RQs may give an assessment of their relative risk level for that particular toxicant.

The exposure risk levels of the exposed and unexposed population groups to heavy metals and pesticides are given in Tables 25–28. It may be noted that for any of these toxicants (metals and pesticides), none of the populations is at significant exposure risk level, as in none of the cases, the computed RQ value (TDI/ADI) exceeded 1.0. However, it is very much clear

Table 5
Mean metal levels in STPs sludge (g/kg)

STP	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Kanpur	0.041	8.11	0.393	6.40	0.22	0.214	0.091	1.18
Varanasi	0.054	1.30	0.543	7.21	0.31	0.293	0.129	1.51

Table 6
Mean pesticide levels in STPs sludge (mg/kg)

STP	α-BHC	β-BHC	γ-BHC	T-BHC	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Kanpur	0.07	0.44	0.36	0.69	0.09	0.05	0.12	0.24
Varanasi	0.07	0.08	0.05	0.19	0.09	0.03	0.02	0.11

Table 8
Range and mean of the metal levels in different environment media near Kanpur

Media	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Kanpur exposed (receiving) area								
Surface water (mg/l)	0.001–0.003 (0.006)	0.036–0.079 (0.058)	0.008–0.027 (0.018)	2.342–10.306 (6.324)	0.189–0.497 (0.343)	0.027–0.054 (0.041)	0.024–0.057 (0.041)	0.054–0.105 (0.080)
Ground water (mg/l)	ND–0.008 (0.001)	ND–0.011 (0.003)	0.002–0.035 (0.006)	0.047–3.235 (0.767)	0.014–0.494 (0.119)	0.013–0.029 (0.021)	0.014–0.061 (0.0216)	0.037–0.614 (0.182)
Soil (μg/g)	2.663–5.18 (3.03)	106.759–477.4 (249.16)	31.60–135.0 (60.59)	1048.4–11 712.29 (6700.25)	266.6–516.2 (297.71)	41.57–56.13 (38.01)	91.75–142.28 (89.59)	110.05–378.28 (169.92)
Veg./crops (μg/g)	ND–0.011 (0.002)	ND–0.970 (0.278)	ND–ND (ND)	ND–1.296 (0.449)	ND–2.61 (0.508)	ND–1.108 (0.479)	ND–0.988 (0.142)	ND–4.21 (1.402)
Food grains (μg/g)	0.04–0.45 (0.17)	ND–0.061 (0.012)	ND–5.502 (2.472)	14.20–109.84 (50.636)	10.98–55.58 (41.032)	0.841–1.432 (1.123)	ND–0.845 (0.207)	30.10–65.09 (47.16)
Kanpur control (non-receiving) area								
Ground water (mg/l)	ND–0.001 (0.001)	ND–0.011 (0.003)	0.002–0.008 (0.004)	0.166–4.137 (0.89)	0.006–0.215 (0.083)	0.01–0.034 (0.018)	0.011–0.034 (0.022)	0.021–0.144 (0.080)
Soil (μg/g)	1.406–3.881 (2.455)	18.874–39.72 (29.361)	13.0–28.7 (18.814)	6557.05–11356.1 (8789.7)	171.54–385.13 (248.24)	20.383–47.71 (31.41)	38.246–101.58 (61.41)	46.03–79.68 (60.08)
Veg./crops (μg/g)	ND–0.005 (0.001)	ND–0.245 (0.076)	ND–ND (ND)	ND–0.762 (0.212)	ND–0.94 (0.222)	ND–0.055 (0.015)	ND–0.354 (0.058)	ND–2.85 (1.120)
Food grains (μg/g)	ND–0.40 0.10	ND–ND (ND)	ND–4.51 (2.17)	0.541–46.65 (25.89)	7.327–44.98 (27.227)	0.469–1.608 (1.002)	ND–0.464 (0.093)	19.858–49.37 (32.892)

Table 9
Range and mean of the pesticide residue levels in different environment media near Kanpur

Media	α-BHC	β-BHC	γ-BHC	T-BHC	*op*-DDT	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Kanpur exposed (receiving) area									
Surface water (mg/l)	ND–0.004 (0.002)	ND–ND (ND)	ND–ND (ND)	ND–0.004 (0.002)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.022 (0.011)	ND–0.025 (0.013)
Ground water (mg/l)	ND–0.148 (0.016)	ND–ND (ND)	ND–0.07 (0.0124)	ND–0.21 (0.028)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.395 (0.077)	ND–0.44 (0.086)
Soil (μg/g)	ND–0.065 (0.026)	0.009–0.364 (0.11)	ND–0.035 (0.01)	0.016–0.464 (0.142)	ND–0.026 (0.008)	ND–0.084 (0.019)	ND–0.007 (0.002)	ND–0.031 (0.008)	0.002–0.114 (0.032)
Veg./crops (μg/g)	ND–0.040 (0.01)	0.001–0.083 (0.033)	ND–0.08 (0.020)	0.01–0.20 (0.063)	ND–0.09 (0.011)	ND–ND (ND)	ND–0.001 (0.0001)	ND–0.04 (0.012)	ND–0.013 (0.023)
Food grains (μg/g)	ND–0.012 (0.005)	ND–1.49 (0.312)	ND–0.140 (0.312)	ND–1.64 (0.35)	ND–0.031 (0.003)	ND–ND (ND)	ND–ND (ND)	ND–0.09 (0.021)	ND–0.099 (0.024)
Kanpur control (non-receiving) area									
Ground water (mg/l)	ND–0.008 (0.003)	ND–ND (ND)	ND–0.004 (0.001)	ND–0.008 (0.003)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.016 (0.005)	ND–0.018 (0.006)
Soil (μg/g)	0.0004–0.015 (0.003)	0.003–0.037 (0.019)	ND–ND (ND)	0.003–0.052 (0.021)	ND–0.003 (0.0004)	ND–0.005 (0.001)	ND–ND (ND)	ND–ND (ND)	ND–0.005 (0.001)
Veg./crops (μg/g)	ND–0.003 (0.001)	0.002–0.104 (0.028)	ND–0.003 (0.001)	0.002–0.11 (0.029)	ND–0.006 (0.001)	ND–ND (ND)	ND–0.0003 (0.0001)	ND–0.008 (0.003)	ND–0.013 (0.004)
Food grains (μg/g)	ND–0.004 (0.002)	0.018–0.187 (0.106)	ND–0.009 (0.005)	0.021–0.199 (0.109)	ND–ND (ND)	ND–0.002 (0.0004)	ND–0.001 (0.0002)	ND–ND (ND)	ND–0.003 (0.001)

Table 10
Range and mean of the metal levels in different environment media near Varanasi

Media	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Varanasi exposed (receiving) area								
Ground water (mg/l)	ND–0.006 (0.001)	ND–0.049 (0.009)	ND–0.203 (0.016)	0.02–17.90 (1.951)	0.008–0.559 (0.08)	0.01–0.22 (0.04)	0.012–0.088 (0.0290)	0.023–1.17 (0.24)
Soil (μg/g)	3.05–5.82 (4.61)	40.95–72.2 (54.87)	52.7–107.0 (74.48)	9984.67–13 004.7 (11 754.67)	402.61–602.61 (502.36)	41.57–77.22 (58.85)	88.07–178.95 (133.86)	112.86–151.97 (132.91)
Veg./crops (μg/g)	ND–ND (ND)	ND–0.345 (0.17)	ND–ND (ND)	ND–1.35 (45)	ND–0.002 (0.006)	ND–1.391 (0.70)	ND–0.607 (0.30)	ND–3.936 (1.312)
Food grains (μg/g)	0.03–0.26 (0.14)	ND–0.06 0.01	1.06–3.12 (2.29)	34.74–59.64 (42.77)	11.6–54.0 (35.22)	0.89–1.82 (1.19)	ND–1.04 (0.57)	18.11–59.43 (37.61)
Varanasi control (non-receiving) area								
Ground water (mg/l)	ND–ND (ND)	ND–0.036 (ND)	ND–0.054 (0.005)	0.018–0.738 (0.24)	0.002–0.048 (0.011)	0.008–0.024 (0.015)	0.013–0.026 (0.019)	0.017–0.137 (0.061)
Soil (μg/g)	3.64–4.64 (4.16)	37.66–63.64 (46.26)	43.6–64.2 (53.09)	1157.95–11 027.52 (9132.14)	325.97–483.19 (402.89)	35.67–49.49 (43.34)	82.63–124.56 (106.42)	80.05–103.49 (93.98)
Veg./crops (μg/g)	ND–ND (ND)	ND–0.190 (0.065)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.095 (0.046)	ND–0.38 (0.095)	ND–3.12 (1.10)
Food grains (μg/g)	0.01–0.10 (0.06)	ND–0.02 (0.005)	0.02–1.40 (0.85)	8.02–40.40 (14.62)	5.40–43.20 (22.80)	0.54–1.04 (0.82)	ND–0.76 (0.32)	12.20–45.60 (23.82)

Table 11
Range and mean of the pesticide residue levels in different environment media near Varanasi

Media	α-BHC	β-BHC	γ-BHC	T-BHC	*op*-DDT	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Varanasi exposed (receiving) area									
Ground water (mg/l)	ND–0.077 (0.029)	ND–0.215 (0.1170)	ND–0.014 (0.005)	ND–0.301 (0.151)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	0.033–0.158 (0.0973)	0.036–0.176 (0.109)
Soil (μg/g)	ND–0.02 (0.006)	ND–0.024 (0.007)	ND–0.010 (0.003)	ND–0.054 (0.016)	ND–0.002 (0.001)	ND–0.008 (0.002)	ND–ND (ND)	ND–0.006 (0.001)	ND–0.016 (0.004)
Veg./crops (μg/g)	ND–0.004 (0.001)	0.001–0.083 (0.033)	ND–0.04 (0.009)	0.002–0.095 (0.036)	ND–ND (ND)	ND–ND (ND)	ND–0.001 (0.0001)	ND–0.08 (0.03)	ND–0.081 (0.03)
Food grains (μg/g)	ND–ND (ND)	ND–0.103 (0.035)	ND–0.055 (0.017)	ND–0.158 (0.046)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.085 (0.021)	ND–0.095 (0.0234)
Varanasi control (non-receiving) area									
Ground water (mg/l)	0.002–0.064 (0.013)	ND–ND (ND)	ND–0.009 (0.003)	0.002–0.064 (0.013)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.011 (0.0008)	ND–0.012 (0.0009)
Soil (μg/g)	ND–ND (ND)	ND–0.013 (0.003)	ND–ND (ND)	ND–0.013 (0.003)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.002 (0.0005)	ND–0.003 (0.0008)
Veg./crops (μg/g)	ND–ND (ND)	0.004–0.059 (0.02)	ND–0.006 (0.002)	0.004–0.065 (0.022)	ND–0.001 (0.001)	ND–ND (ND)	ND–0.005 (0.001)	ND–0.002 (0.001)	0.0001–0.009 (0.003)
Food grains (μg/g)	ND–ND (ND)	ND–0.020 (0.011)	ND–0.008 (0.004)	ND–0.024 (0.015)	ND–ND (ND)	ND–ND (ND)	ND–ND (ND)	ND–0.004 (0.002)	ND–0.004 (0.002)

Table 12
Characteristics of soil in the area receiving (exposed) and non-receiving (unexposed) wastewater

Identification	pH (1:5)	EC (1:10) (μmho/cm)	Bulk density (g/cc)	Particle density (g/cc)	Porosity (%)	Organic carbon (%)	Total nitrogen (μg/g)	P (μg/g)	Na (μg/g)	K (μg/g)	Ca (μg/g)	Mg (μg/g)
Kanpur exposed area												
Range	7.5–8.9	1050–1250	0.96–1.63	1.54–2.50	19.44–50.74	1.12–2.36	392–1120.0	4.95–7.95	58.80–305.6	38.4–130.0	0.89–4.60	0.34–1.77
Mean	8.1	1160	1.22	1.88	35.56	1.50	738.5	5.96	148.3	93.7	3.36	0.81
Kanpur unexposed area												
Range	7.9–9.0	1050–1250	0.93–1.35	1.82–2.22	31.32	0.62–1.49	56.0–1120.0	1.74–8.47	26.6–137.2	28.8–49.6	1.39–3.39	0.31–1.36
Mean	8.71	1130	1.19	1.97	39.63	1.05	556.0	4.16	50.6	34.86	2.47	0.80
Varanasi exposed area												
Range	7.0–8.5	900–1150	0.88–1.48	0.92–2.0	3.94–41.85	0.14–0.51	765.0–1228.0	3.45–10.94	58.8–104.0	52.8–114.0	–	–
Mean	8.09	1030	1.21	1.72	26.65	0.35	1108.0	6.36	78.8	83.74	–	–
Varanasi unexposed area												
Range	8.2–8.55	825–1050	1.01–1.25	1.79–2.0	29.86–49.7	0.29–0.47	840.0–1400.0	8.21–13.56	70.4–99.4	76.0–114.0	–	–
Mean	8.43	995	1.16	1.9	38.51	0.37	1071.0	10.76	87.65	97.6	–	–

Table 13
Neurobehavioral functions covered in questionnaire

Function	No. of items	Possible score range
Fatigue	4	0–4
Insomnia	3	0–3
Decreased concentration	4	0–4
Depression	5	0–5
Irritability	6	0–6
Gastric symptoms	4	0–4
Sensory symptoms	4	0–4
Motor symptoms	5	0–5

that the exposure risk level of the exposed population groups (Kanpur and Varanasi) with respect to each of these metals and pesticides is much higher (2–4 times) as compared to the respective unexposed population groups.

5. Conclusions

5.1. Impact of wastewater toxicants (metals and pesticides)

The conventional type STPs are basically to reduce the organic load, these are not very effective in reducing the levels of metals and pesticides except that a large fraction of these toxicants present in the wastewater is retained with the sludge generated by STPs while the remaining part getting out with the treated wastewater/effluents.

5.1.1. On environmental quality

The impact of these treated wastewater toxicants (metals and pesticides) on the environmental quality of the disposal areas as assessed in terms of their elevated levels in different media samples viz., water, soil, crops, vegetation, food grains, and biological samples collected from exposed areas over the respective unexposed areas near Kanpur and Varanasi STPs, indicate that as a result of long run disposal of these toxicants, their high levels built up and obviously will be hazardous to the population exposed to these. Since both metals and organo-chlorine pesticides are of persistent type staying for long in the environment, their higher levels built up in long run are well understood. The analytical data generated on metals and pesticides levels in various environmental media in both the exposed as well as unexposed areas shows their elevated levels in all the environmental compartments. Therefore, these toxicants have definite adverse impact on the environmental quality of the disposal areas.

5.1.2. On health

Impact of the wastewater toxicants (metals and pesticides) on human health in the areas receiving waste-

Table 14
Survey of health status in rural population (exposed and control) near Kanpur

Name		Exposed						Control					
		Total		Male		Female		Total		Male		Female	
		Nos	%	Nos	%	Nos	%	Nos	%	Nos	%	Nos	%
Total		53		37		16		52		45		7	
Literate		36	67.92	28	75.67	8	50	36	69.23	33	73.33	3	42.85
Illiterate		17	32.07	9	24.32	8	50	6	11.53	4	8.88	4	57.14
Vegetarian		36	67.92	22	59.45	14	87.50	31	59.61	24	53.33	7	100.0
Non-vegetarian		11	20.75	10	27.02	1	6.25	19	36.54	19	42.22	0	0.00
Smoker		8	15.09	7	18.91	1	6.25	23	44.23	23	51.11	0	0.00
No-smoker		45	84.90	30	81.08	15	93.75	29	55.76	22	48.88	7	100.0
Addiction		13	24.52	13	35.13	0	0.00	11	21.15	11	24.44	0	0.00
Non-addict		40	75.47	24	64.86	16	100	41	78.84	34	75.55	7	100.0
Eyes	(+)	19	35.84	11	29.72	8	50.00	12	23.07	9	20.00	3	42.85
	(−)	33	62.26	25	67.56	8	50.00	40	76.92	36	80.00	4	57.14
Ears	(+)	4	7.54	4	10.81	0	0.00	4	7.69	4	8.88	1	14.29
	(−)	49	92.45	33	89.18	16	100.0	47	90.38	42	93.33	6	85.71
Cardiovasc.	(+)	6	11.32	2	5.40	4	25.00	3	5.76	3	6.66	1	14.29
	(−)	47	88.67	35	94.59	12	75.00	48	92.30	42	93.33	6	85.71
Respiratory	(+)	8	15.09	4	10.81	4	25.00	6	11.53	5	11.11	0	0.00
	(−)	43	81.13	31	83.78	12	75.00	43	82.69	40	88.88	7	100.0
Teeth	(+)	20	37.73	11	29.72	9	56.25	4	7.69	4	8.88	1	14.29
	(−)	33	62.26	26	70.27	7	43.75	47	90.38	41	91.11	6	85.71
Gums	(+)	15	28.30	9	24.32	6	37.50	8	15.38	7	15.55	2	28.57
	(−)	38	71.69	28	75.67	10	62.50	43	82.69	38	84.44	5	71.43
Gastriinst.	(+)	13	24.52	8	21.62	5	31.25	9	17.30	8	17.77	2	28.57
	(−)	40	75.47	29	78.37	11	68.75	42	80.77	37	82.22	5	71.43
Muscular	(+)	10	18.86	5	13.51	5	31.25	5	9.61	3	6.66	3	42.85
	(−)	33	62.26	32	86.48	11	68.75	46	88.46	42	93.33	4	57.14
Nervous	(+)	11	20.75	4	10.81	7	43.75	2	3.84	1	2.22	5	71.43
	(−)	42	79.24	33	89.18	9	56.25	49	94.23	44	97.77	2	28.57
Genito	(−)	53	100	37	100	16	100	51	98.07	45	100	7	100

(+) with problem and (−) without problem.

water was assessed through a standard questionnaire based survey of the exposed and unexposed population groups near Kanpur and Varanasi STPs. The questionnaire contained total 35 items, which cover eight neurobehavioral functions established to be affected by the chemicals (heavy metals and pesticides) exposures. Neurobehavioral analysis was done on the basis of mean scores for each function of every individual. This statistical analysis for overall and function-wise difference between the unexposed and exposed population groups indicated a significant difference between the two groups near Kanpur. Therefore, there has been a considerable impact of these toxicants (metals and pesticides) on human health in the exposed area.

Further the environmental exposure risk analysis for these four population groups (two exposed and two unexposed) was carried out for each of these toxicants and individually. The approach based on evaluation of the risk quotient (RQ) for each individual toxicant by first computing the total daily intake (TDI) of each one through the major routes (drinking water, food grains, vegetables, milk etc.) and then comparing with respective acceptable daily intake (ADI). The final values of RQs indicated that although, in none of these cases, the RQ values exceeded 1.0 (positive risk), however the RQ values for all the metals and pesticides for the two exposed areas were 2–4 times higher over their respective unexposed population groups. This also supports that there is considerable risk of the metals and pesticides exposure on the human health.

The impact was further confirmed through biomonitoring of the metals and pesticides levels in the

Table 15
Survey of health status in rural population (exposed and control) near Varanasi

Name		Exposed						Control					
		Total		Male		Female		Total		Male		Female	
		Nos	%	Nos	%	Nos	%	Nos	%	Nos	%	Nos	%
Total		51		50				50		45		5	
Literate		27	52.94	27	54.00	Not Available		27	54.00	26	57.77	1	20.00
Illiterate		23	45.09	22	44.00			19	38.00	16	35.55	3	60.00
Vegetarian		14	27.45	13	26.00			17	34.00	14	31.11	5	100.0
Non-vegetarian		34	66.66	34	68.00			30	60.00	27	60.00	0	0.00
Smoker		20	39.21	20	40.00			10	20.00	9	20.00	2	40.00
No-smoker		31	60.78	30	60.00			40	80.00	35	77.77	3	60.00
Addiction		27	52.94	26	52.00			15	30.00	15	33.33	0	0.00
Non-addict		24	47.05	24	48.00	Not Available		35	70.00	30	66.66	5	100.0
Eyes	(+)	14	27.45	13	26.00			16	32.00	13	28.88	3	60.00
	(−)	36	70.58	36	72.00			34	68.00	32	71.11	2	40.00
Ears	(+)	6	11.76	5	10.00			2	4.00	2	4.44	0	0.00
	(−)	46	90.19	45	90.00			48	96.00	43	95.55	5	100.0
Cardiovasc.	(+)	4	7.84	3	6.00			6	12.00	4	8.88	2	40.00
	(−)	47	92.15	47	94.00			44	88.00	41	91.11	3	60.00
Respiratory	(+)	5	9.80	5	10.00			6	12.00	4	8.88	2	40.00
	(−)	46	90.19	45	90.00			44	88.00	41	91.11	3	60.00
Teeth	(+)	15	29.41	14	28.00			17	34.00	11	24.44	3	60.00
	(−)	37	72.54	36	72.00			33	66.00	31	68.88	2	40.00
Gums	(+)	5	9.80	5	10.00			12	24.00	9	20.00	3	60.00
	(−)	46	90.19	45	90.00			38	76.00	35	77.77	2	40.00
Gastriinst.	(+)	13	25.49	13	26.00			18	36.00	15	33.33	0	0.00
	(−)	38	74.50	37	74.00			32	64.00	30	66.66	5	100.0
Muscular	(+)	7	13.72	6	12.00			3	6.00	1	2.22	2	40.00
	(−)	44	86.27	44	88.00			47	94.00	44	97.77	3	60.00
Nervous	(+)	9	17.64	8	16.00			6	12.00	4	8.88	2	40.00
	(−)	43	84.31	42	84.00			44	88.00	41	91.11	3	60.00
Genito	(+)							3	6.00	3	6.66		
	(−)	51	100	100	100			47	94.00	42	93.33	5	100

(+) with problem and (−) without problem.

Table 16
Analysis of the neurobehavioral functions in population groups (exposed and unexposed) near Kanpur and Varanasi STPs

Functions	Kanpur	Varanasi
Fatigue	+	−
Insomnia	+	−
Decreased concentration	+++	−
Depression	++	−
Irritability	++	−
Gastric symptoms	+++	−
Sensory symptoms	++	−
Motor symptoms	+	−

(+) Significant at $p < 0.05$.
(++) at $p < 0.01$.
(+++) at $p < 0.001$.
(−) non-significant.

human blood and urine of the different population groups under study. The levels of both the metals as well as pesticides in the human blood and urine samples of the two exposed population groups (Kanpur and Varanasi) were considerably higher than those of the respective unexposed population groups.

Thus all the three different kind of approaches indicated a considerable risk and impact of the heavy metals and pesticides on the human health in the exposed areas receiving the wastewater from STPs.

5.1.3. On agricultural

The mean level of Cd and Cr in soils near Kanpur and Cd, Ni, and Pb near Varanasi are above their respective tolerable limits for agricultural crops.

Table 17
Range and mean of the metal levels in human blood samples (Varanasi)

Human blood (μg/ml)	Age	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Exposed area	20–60	0.103–0.283	0.657–2.905	0.440–1.101	341.05–852.75	0.717–2.135	0.677–2.595	1.077–6.00	4.13–45.73
Exposed area mean ± SD	39 ± 14	0.184 ± 0.06	1.082 ± 0.59	0.846 ± 0.15	491.11 ± 123.5	1.134 ± 0.34	1.592 ± 0.62	3.512 ± 1.73	26.42 ± 8.87
Unexposed area	17–40	0.051–0.220	0.229–0.678	0.662–1.003	333.99–484.29	0.552–1.061	0.307–1.882	0.629–4.187	8.19–25.87
Unexposed area mean ± SD	27 ± 9	0.101 ± 0.06	0.508 ± 0.16	0.781 ± 0.12	414.57 ± 56.64	0.830 ± 0.19	0.791 ± 0.53	1.0708 ± 1.24	15.27 ± 5.62

Table 18
Range and mean of the metal levels in human blood samples (Kanpur)

Human blood (μg/ml)	Age	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Exposed area	20–60	0.061–1.23	1.415–2.503	0.570–1.210	279.58–630.60	0.541–1.570	0.570–1.148	ND–1.416	8.83–18.92
Exposed area mean ± SD	35 ± 9	0.094 ± 0.02	2.091 ± 0.35	0.845 ± 0.15	472.15 ± 109.79	0.841 ± 0.34	0.851 ± 0.15	0.176 ± 0.39	14.51 ± 3.312
Unexposed area	16–40	0.040–0.127	0.300–2.177	0.525–1.084	243.10–510.77	0.347–1.020	0.305–1.038	ND–0.862	7.08–24.30
Unexposed area mean ± SD	30 ± 8	0.078 ± 0.03	1.277 ± 0.57	0.810 ± 0.17	430.33 ± 88.29	0.829 ± 0.17	0.637 ± 0.24	0.087 ± 0.24	13.03 ± 5.41

Table 19
Range and mean of the metal levels in human urine samples (Varanasi)

Human blood (μg/ml)	Age	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Exposed area	22–74	0.003–0.009	0.049–0.599	0.005–0.283	0.064–2.453	0.002–0.111	0.041–0.115	0.032–0.095	0.153–0.663
Exposed area mean ± SD	45 ± 17	0.005 ± 0.002	0.107 ± 0.129	0.030 ± 0.066	0.697 ± 0.717	0.032 ± 0.032	0.073 ± 0.022	0.06 ± 0.020	0.357 ± 0.152
Unexposed area	18–52	ND–0.008	0.142–0.138	0.009–0.033	0.066–0.65	0.002–0.026	0.025–0.094	0.011–0.08	0.062–1.515
Unexposed area mean ± SD	26 ± 13	0.002 ± 0.002	0.075 ± 0.032	0.016 ± 0.006	0.214 ± 0.144	0.015 ± 0.006	0.048 ± 0.020	0.038 ± 0.017	0.326 ± 0.341

Table 20
Range and mean of the metal levels in human urine samples (Kanpur)

Human blood (μg/ml)	Age	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Exposed area	13–75	0.001–0.19	0.008–0.235	0.003–0.073	ND–6.741	0.012–0.083	0.039–0.136	0.061–0.166	0.173–1.202
Exposed area mean ± SD	46 ± 20	0.008 ± 0.004	0.102 ± 0.07	0.020 ± 0.014	0.671 ± 1.421	0.029 ± 0.016	0.087 ± 0.027	0.116 ± 0.026	0.538 ± 0.277
Unexposed area	16–50	ND–0.013	0.004–0.060	0.004–0.026	0.103–1.581	0.007–0.135	0.039–0.107	0.069–0.164	0.152–1.262
Unexposed area mean ± SD	31 ± 10	0.007 ± 0.003	0.032 ± 0.015	0.016 ± 0.007	0.575 ± 0.391	0.029 ± 0.03	0.071 ± 0.020	0.113 ± 0.026	0.542 ± 0.254

Table 21
Range and mean of the pesticide residue levels in human blood samples (Varanasi)

Human blood (ng/ml)	Age	α-BHC	β-BHC	γ-BHC	T-BHC	*op*-DDT	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Exposed area	20–60	ND–8.61	ND–9.312	ND–3.954	1.643–13.266	ND–0.455	ND–ND	ND–3.254	ND–6.311	ND–6.50
Exposed area mean ± SD	39 ± 14	2.89 ± 1.95	3.92 ± 2.17	1.05 ± 0.97	7.86 ± 2.75	0.073 ± 0.11	ND	0.43 ± 0.80	1.64 ± 1.53	2.14 ± 1.80
Unexposed area	17–40	0.122–6.882	0.522–6.424	ND–1.467	2.568–9.104	ND–2.206	ND–ND	ND–1.885	ND–4.346	ND–4.362
Unexposed area mean ± SD	27 ± 9	2.05 ± 2.29	3.80 ± 1.90	0.72 ± 0.53	6.58 ± 2.36	0.05 ± 0.07	ND	0.32 ± 0.70	1.08 ± 1.51	1.45 ± 1.68

Table 22
Range and mean of the pesticide residue levels in human blood samples (Kanpur)

Human blood (ng/ml)	Age	α-BHC	β-BHC	γ-BHC	T-BHC	*op*-DDT	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Exposed area	20–50	ND–8.912	ND–9.234	ND–4.315	ND–12.952	ND–0.567	ND–ND	ND–3.876	ND–7.42	ND–7.497
Exposed area mean ± SD	35 ± 9	3.11 ± 2.01	3.99 ± 2.34	1.21 ± 1.07	8.31 ± 3.39	0.08 ± 0.16	ND	0.47 ± 1.04	1.91 ± 1.79	2.46 ± 2.16
Unexposed area	16–40	ND–7.344	ND–7.838	ND–1.888	ND–11.812	ND–0.32	ND–ND	ND–1.956	ND–5.531	0.035–4.861
Unexposed area mean ± SD	30 ± 8	2.42 ± 1.98	3.22 ± 1.78	0.81 ± 0.58	6.45 ± 3.00	0.04 ± 0.09	ND	0.35 ± 0.62	1.19 ± 1.10	1.51 ± 1.28

Table 23
Range and mean of the pesticide residue levels in human urine samples (Varanasi)

Human blood (ng/ml)	Age	α-BHC	β-BHC	γ-BHC	T-BHC	*op*-DDT	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Exposed area	22–74	ND–1.113	ND–6.921	ND–2.211	ND–8.697	ND–0.348	ND–ND	ND–0.204	ND–3.34	ND–3.418
Exposed area mean ± SD	45 ± 17	0.37 ± 0.37	1.48 ± 1.36	0.49 ± 0.56	2.33 ± 2.02	0.02 ± 0.06	ND	0.04 ± 0.05	0.89 ± 0.98	0.95 ± 1.01
Unexposed area	18–52	ND–0.406	ND–4.52	ND–0.779	ND–5.655	ND–0.048	ND–ND	ND–0.056	ND–2.064	ND–2.12
Unexposed area mean ± SD	26 ± 13	0.11 ± 0.14	1.24 ± 1.49	0.23 ± 0.29	1.58 ± 1.87	0.01 ± 0.02	ND	0.02 ± 0.02	0.41 ± 0.56	0.44 ± 0.57

Table 24
Range and mean of the pesticide residue levels in human urine samples (Kanpur)

Human blood (ng/ml)	Age	α-BHC	β-BHC	γ-BHC	T-BHC	*op*-DDT	*pp*-DDT	*pp*-DDD	*pp*-DDE	T-DDT
Exposed area	13–75	ND–2.122	ND–7.328	ND–3.112	ND–9.858	ND–0.199	ND–ND	ND–0.214	ND–3.745	ND–3.89
Exposed area mean ± SD	46 ± 20	0.63 ± 0.77	2.23 ± 1.97	0.66 ± 0.69	3.34 ± 2.89	0.02 ± 0.05	ND	0.04 ± 0.07	0.92 ± 0.84	0.98 ± 0.87
Unexposed area	16–50	ND–1.445	ND–5.593	ND–1.225	ND–7.734	ND–0.06	ND–ND	ND–0.054	ND–2.384	0.009–2.384
Unexposed area mean ± SD	31 ± 10	0.26 ± 0.36	1.80 ± 1.63	0.41 ± 0.42	2.46 ± 2.27	0.02 ± 0.02	ND	0.02 ± 0.02	0.59 ± 0.66	0.63 ± 0.66

Table 25
Exposure risk of metals and pesticides in area near Varanasi receiving water

Varanasi exposed (metal/pesticides)	Metal concentration				Intake per day				TDI (mg/day)	ADI (mg/kg bw)	TDI (mg/day) (bw = 60 kg)	Risk quotient (TDI/ADI)
	Water (µg/l)	Food (µg/g)	Vegetable (µg/g)	Bov milk (µg/g)	Water (µg/d) (2.5 l/d)	Food (µg/d) (600 g)	Vegetable (µg/d) (300 g)	Milk (µg/d) (200 g)				
Cadmium	1.0	0.14	0	–	2.5	84.0	0.00	–	0.087	0.007	0.42	0.206
Chromium	9.0	0.01	0.17	–	22.5	6.0	51.00	–	0.80			
Copper	16.0	2.29	0	–	40.0	1374.0	0.00	–	1.414	0.5	30	0.047
Iron	1951.0	42.77	0.45	–	4877.5	25 662.0	135.00	–	30.675	0.8	48	0.639
Manganese	80.0	35.22	0.0006	–	200.0	21 132.0	0.18	–	21.332			
Lead	29.0	0.57	0.3	–	72.5	342.0	90.00	–	0.505	0.05	3	0.168
Nickel	40.0	1.19	0.7	–	100.0	714.0	210.00	–	1.024			
Zinc	240.0	37.61	1.312	–	600.0	22 566.0	393.60	–	23.560			
Lindane	0.005	0.017	0.009	0.144	0.013	10.2	2.70	28.80	0.042	0.010	0.6	0.070
DDT	0.109	0.0234	0.030	0.128	0.273	14.0	9.00	25.60	0.049	0.005	0.3	0.163

Table 26
Exposure risk of metals and pesticides in area near Varanasi not receiving water

Varanasi unexposed (metal/pesticides)	Metal concentration				Intake per day				TDI (mg/day)	ADI (mg/kg bw)	TDI (mg/day) (bw = 60 kg)	Risk quotient (TDI/ADI)
	Water (µg/l)	Food (µg/g)	Vegetable (µg/g)	Bov milk (µg/g)	Water (µg/d) (2.5 l/d)	Food (µg/d) (600 g)	Vegetable (µg/d) (300 g)	Milk (µg/d) (200 g)				
Cadmium	0.0	0.06	0.00	–	0.0	36.0	0.00	–	0.036	0.007	0.42	0.086
Chromium	6.0	0.005	0.065	–	15.0	3.0	19.50	–	0.038			
Copper	5.0	0.85	0.00	–	12.5	510.0	0.00	–	0.523	0.5	30	0.017
Iron	240.0	14.62	0.00	–	600.0	8772.0	0.00	–	9.372	0.8	48	0.195
Manganese	11.0	22.8	0.00	–	27.5	13 680.0	0.00	–	13.708			
Lead	19.0	0.32	0.095	–	47.5	192.0	28.50	–	0.268	0.05	3	0.089
Nickel	15.0	0.82	0.046	–	37.5	492.0	13.80		0.543			
Zinc	61.0	23.82	1.10	–	152.5	14 292.0	330.00	–	14.775			
Lindane	0.003	0.004	0.002	0.094	0.008	2.400	0.600	18.80	0.022	0.010	0.6	0.036
DDT	0.0009	0.002	0.003	0.056	0.002	1.200	0.900	11.20	0.013	0.005	0.3	0.044

Table 27
Exposure risk of metals and pesticides in area near Kanpur receiving water

Kanpur exposed (metal/pesticides)	Metal concentration				Intake per day				TDI (mg/day)	ADI (mg/kg bw)	TDI (mg/day) (bw = 60 kg)	Risk quotient (TDI/ADI)
	Water (μg/l)	Food (μg/g)	Vegetable (μg/g)	Bov milk (μg/g)	Water (μg/d) (2.5 l/d)	Food (μg/d) (600 g)	Vegetable (μg/d) (300 g)	Milk (μg/d) (200 g)				
Cadmium	1.0	0.17	0.002	–	2.5	102.0	0.06	–	0.1051	0.007	0.42	0.250
Chromium	3.0	0.012	0.28	–	7.5	7.2	84.00	–	0.0987			
Copper	6.0	2.47	0	–	15.0	1482.0	0.00	–	1.497	0.5	30	0.050
Iron	767.0	50.64	0.45	–	1917.5	30 384.0	135.00	–	32.4365	0.8	48	0.676
Manganese	119.0	41.03	0.51	–	297.5	24 618.0	153.00	–	25.0685			
Lead	26.0	1.123	0.48		65.0	673.8	144.00		0.8828	0.05	3	0.294
Nickel	21.0	0.21	0.14	–	52.5	126.0	42.00	–	0.2205			
Zinc	182.0	47.16	1.400	–	455.0	28 296.0	420.00	–	29.171			
Lindane	0.010	0.029	0.020	0.16	0.025	174	6.00	32.0	0.055	0.010	0.6	0.092
DDT	0.086	0.024	0.023	0.112	0.215	14.4	6.90	22.40	0.044	0.005	0.3	0.146

Table 28
Exposure risk of metals and pesticides in area near Kanpur not receiving water

Kanpur unexposed (metal/pesticides)	Metal concentration				Intake per day				TDI (mg/day)	ADI (mg/kg bw)	TDI (mg/day) (bw = 60 kg)	Risk quotient (TDI/ADI)
	Water (μg/l)	Food (μg/g)	Vegetable (μg/g)	Bov milk (μg/g)	Water (μg/d) (2.5 l/d)	Food (μg/d) (600 g)	Vegetable (μg/d) (300 g)	Milk (μg/d) (200 g)				
Cadmium	1.0	0.1	0.001	–	2.5	60.0	0.30	–	0.0628	0.007	0.42	0.150
Chromium	3.0	0	0.076	–	7.5	0.0	22.80	–	0.0303	–	–	
Copper	4.0	2.17	0	–	10.0	1302.0	0.00	–	1.312	0.5	30	0.044
Iron	890.0	25.89	0.21	–	2225.0	15 534.0	63.00	–	17.822	0.8	48	0.371
Manganese	83.0	27.23	0.22	–	207.5	16 338.0	66.00	–	16.6115	–	–	
Lead	22.0	0.09	0.058	–	55.0	54.0	17.40	–	0.1264	0.05	3	0.042
Nickel	18.0	1.00	0.015		45.0	600.0	4.50	–	0.6495	–	–	
Zinc	80.0	32.89	1.120	–	200.0	19 734.0	336.00	–	20.27	–	–	
Lindane	0.001	0.005	0.001	0.052	0.003	3.0	0.30	10.40	0.014	0.010	0.6	0.023
DDT	0.006	0.001	0.004	0.06	0.015	0.6	1.20	0.014	0.014	0.005	0.3	0.046

However, since, the pH of the wastewater as well as receiving soils are more than 8, the metal mobilization and plant uptake would be restricted by the alkaline pH. Further, the critical levels of the heavy metals in soils for agricultural crops are much higher than those observed in our study areas irrigated with wastewater; there seems no adverse impact of metals and pesticides on agricultural crops in these areas. However, questionnaire based information on agricultural crops yield during last few years collected from these areas revealed that the crops yield has declined (90% cases) over past few years. While, an enhancement yield was reported (65%) in area near Varanasi irrigated with treated wastewater. The decreased productivity in previous case was due to high soils/bacterial bio-mass making the soil–root interface more susceptible to plant root diseases. However, the enhanced yield in later case may be due to more irrigation water availability with high nutrient/fertilizer (N, P, K, and organic carbon) value water.

5.2. Impact of STPs sludge

The STPs sludge has both positive as well negative impacts as it is enriched with high levels of toxic heavy metals and pesticides and also with several useful ingredients such as N, P, and K providing fertilizer value. The STPs sludge studied here has cadmium, chromium and nickel levels above their tolerable levels as prescribed for agricultural land application. However, the soil pH (mean) in alkaline range (>8.0) encounters with metal mobilization and restrict their uptake by the crops to much extent and thus reducing the expected toxicity.

However, in terms of the fertilizer value (N, P, K etc.) it has been estimated that about 14 kg nitrogen (N), 6.67 kg phosphorous (P) and 4.25 kg potassium (K) would be available per ton of the generated sludge and its value at existing rates will be about Rs. 486.

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