Influence of wastewater application and fertilizer use on the quality of irrigation water, soil and food crops: case studies from Northwestern India

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Abstract
This paper summarizes the available information on the pollution of groundwater and water bodies from anthropogenic sources in northwestern states of India leading to contamination of the soil-plant-animal-human foodchain, and possible mitigation options. Excessive applications of fertilizers to field and vegetable crops lead to nitrate and phosphate leaching and contamination of groundwater and water bodies. In certain situations, nitrates exceed the dangerous level of 10 mg N/L. Industrial effluents, released without any treatment to sewage drains, contain potentially toxic elements in concentrations that are several fold higher than those in domestic sewage water and exceed the maximum permissible limits for their disposal onto agricultural lands. The mean concentrations of Pb, Cr, Cd and Ni in sewage water were, respectively, 21, 133, 700, and 2200 times higher than those in tubewell water. The water of several shallow hand-pumps installed in vicinity of a sewage-water drain had several fold higher concentration of Pb, Cr, Cd and Ni than in deep tubewell water.

Key Words
Anthropogenic contamination, nitrate, phosphate, cadmium, lead, chromium, nickel.

Introduction
Worldwide efforts have increasingly been focused on environmental pollution and its ill effects on humans and animals. Water is one of the important and precious natural resources. The agricultural sector is the major consumer of water. In India, agriculture accounts for ~89% of total water use, as against 8% by domestic sector and 3% by industrial sector. Rapid industrialization and urbanization during the past few decades have increased the demand for available water and put stress on the already dwindling water resources. In northwestern states of India, which constitute the subtropical region, the expansion of irrigation facilities has supported 2-3 crops annually, and the region is regarded as the 'food basket of the country'. However, the groundwater is depleting at a fast rate because of its excessive use and mismanagement (Kang *et al.* 2008). Nitrate leaching into groundwater, P movement into surface water and groundwater in soil can be associated with inefficient or excessive application of fertilizers and manures. The most important anthropogenic factor responsible for groundwater pollution is urban and industrial wastewater. Direct release of untreated effluents to land and water bodies can potentially contaminate surface and groundwater as well as soils and eventually the crops grown on these soils which affect the quality of the food produced. This paper synthesizes the results of several studies conducted to investigate the impact of agricultural, urban and industrial activities on water pollution, which lead to contamination of the soil-plant-animal-human foodchain, and explore possible options for mitigating water pollution.

Agricultural activities
Increased use of fertilizers in farming because of large-scale adoption of high-yielding, fertilizer-responsive crops and varieties has led to a gradual build up of nutrients in soil and groundwater. Movement of N and P below the root zone and leaching into the groundwater can cause human and animal health problems. If the drinking water has more than the safe limit of 10 mg NO_3^--N/L, ingested nitrate is converted to nitrite that is absorbed in blood, causing methemoglobinemia, commonly known as 'Blue Baby Syndrome', and gastric cancer. There are reports of eutrophication of water bodies due to both high nitrate and phosphate concentration. The concentrations of P that cause eutrophication range from 0.01 to 0.03 mg/L (Sharpley *et al.* 1996).

Nitrogen
High rates of leaching and nitrification in permeable or porous soils and relatively high fertilizer N rates combine to make nitrate-leaching a serious problem in many irrigated soils (Aulakh and Malhi 2005). In intensively cultivated semiarid subtropical region of India, where average fertilizer N consumption increased

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from 56 to 188 kg N/ha/y during 1975 to 1988, NO_3^--N concentration in the shallow-well waters increased by almost 2 mg/L (Aulakh and Bijay-Singh 1997). In some central districts of Punjab, fertilizer N levels exceed 300 kg N/ha/y and on several farms, fertilizers are poorly managed. The soils in this region are predominantly coarse textured and about 75% of the total rainfall of more than 600 mm is received during the monsoon period (July-September). A survey of groundwater samples from 21-38 meter-deep tubewells located in cultivated fields in various blocks revealed that 78% water samples had less than 5 mg NO_3^--N/L and 22% samples had 5-10 mg NO_3^--N/L. Sixty percent of water samples from shallow-depth (9-18 m) hand-pumps had 5-10 mg NO_3^--N/L and 2% samples had more than 10 mg NO_3^--N/L. Animal wastes appear to be the major contributors to high NO_3^--N in groundwater under village inhabitations and feedlots. In Punjab, animal wastes are generally dumped near feedlots in the outskirts of villages. The level of NO_3^--N in the water samples of 367 hand-pumps used in several villages of four districts and in 45 water samples collected beneath feedlots, was several folds higher than in 236 water samples of tubewells of adjoining areas, clearly illustrating that animal wastes and feedlots act as a point source of nitrates. Vegetation retards NO_3^--N leaching from the root zone by absorbing nitrate and water. Rooting habits/patterns of different plants influence NO_3^- mobility in the rooting zone. Maximum leaching of NO_3^--N below the root zone occurs from heavily fertilized shallow-rooted crops, such as potato, maize and rice as well as heavily manured vegetable crops. In the predominant rice-wheat cropping system of Punjab, NO_3^- leaching to 60 cm during the rice crop was used by the subsequent wheat crop, which has a deeper and more extensive root system (Figure 1). Application of 120 kg fertilizer N/ha to each of these two crops for 4 years resulted in 35 kg of residual NO_3^--N/ha in the 150-cm soil profile, whereas only 17 kg NO_3^--N/ha remained where 120 kg N/ha was applied through the consecutive use of 20 t/ha of fresh sesbania green manure and fertilizer N, decreasing potential for groundwater nitrate contamination.

Phosphorus

Excessive accumulation of residual P in soil may enhance downward movement of P, which may eventually reach groundwater. Sandy soils have a large number of macropores and thus the resultant by-pass flow can lead to greater and deeper leaching of P in such soils. Besides the potential for groundwater contamination, P lost from agricultural soils through leaching may be intercepted by artificial drainage or subsurface flow, accelerating the risk of P transport to water bodies with serious implications for water quality. Long-term studies, where fertilizer P has been applied at different rates, frequencies and periods, have revealed the possibility of P leaching especially in coarse-textured soils (Aulakh *et al.* 2007). After 29 years of using groundnut – based cropping systems, 45 to 256 kg of residual fertilizer P accumulated as Olsen-P/ha in 150-cm soil profile (43-58% below 60 cm depth), illustrating enormous movement of fertilizer P to deeper layers in a coarse-textured soil having low absorption and retention capacity for nutrients (Figure 2). Recent studies with different cropping systems have further revealed that interplay between the fertilizer P management, amount of labile P accumulated in soil profile, and soil characteristics (silt, clay and organic C) largely control P leaching in subtropical soils (Garg and Aulakh 2010).

Urban and industrial activities

Application of sewage sludge to agricultural soils, and irrigation of field crops with sewage water and untreated industrial effluents alone, or in combination with ground/canal water, are common practices, especially in the vicinity of large cities, as these are considered reusable sources of essential plant nutrients and organic C. It is estimated that more than 15000 million liters of sewage water is produced every day in India, which approximately contributes 3.2 million t of N, 1.4 million t of P and 1.9 million t of potassium (K) per annum, with an economic value of about Indian Rs. 2600 million (US$ 52 million). However, some of the elements present in sewage water and untreated industrial effluents could be toxic to plants and pose health hazards to animals and humans.

Chemical composition of sewage waters

The concentration of potentially toxic elements was higher in sewage water of industrial towns as compared with less or non-industrial towns. Further, the composition of sewage water varies within a city. The domestic zone sewage contained relatively low amounts of toxic elements whereas the effluents from the electroplating area contained toxic elements, such as chromium (Cr), nickel (Ni) and cyanide (CN), in amounts higher than maximal tolerable limits for disposal on agricultural lands. The chemical analysis of sewage-water samples collected from different locations of an open drain, commonly known as "Budda Nullah," downstream from entry into Ludhiana city, revealed that the concentration of metals in the drain increases many folds as it passes through Ludhiana city (Table 1). The mean concentrations of Fe, Zn, As, Pb, Ni, and Cr, in the sewage-water samples collected at the entry point, were 0.03, 0.04, 0.005 0.004, 0.002 and 0.001 mg/L, respectively, which increased to 10.8, 0.78, 2.10, 0.075, 0.28 and 0.26 mg/L, respectively, in the samples collected from about 15 km downstream of the entry point. This is because the number of industries pouring their untreated effluents increased as the distance downstream increased turning it into a highly polluted sewage channel. A study of leather complex in Jalandhar city, comprising leather-manufacturing factories, revealed that the concentration of both Cr and Al drastically increased in the sewage water after the disposal of effluents from the leather complex (Brar and Khurana 2006). The concentration of both the elements at 200 m downstream of the leather complex increased many fold as compared with that from 500 m upstream, indicating the high pollution potential of these elements. However, the concentration of Cr decreased 2 km downstream of the leather complex because of settling of some of the elements at the base of the drain.

Effects of polluted water on soil
It has well been documented that irrigation with sewage water increases soil electrical conductivity and organic C, decreases soil pH, and could result in the accumulation of heavy metals in the plow layer of agricultural soils. Khurana *et al.* (2003) found that mean concentrations of DTPA-extractable Pb, Ni, Cd, Zn, Mn and Fe in surface soils (0-15 cm) surrounding the densely industrialized city of Ludhiana, irrigated largely with sewage effluents, were 4.2, 3.6, 0.30, 11.9, 25.4 and 49.2 mg/kg as compared, with 2.8, 0.40, 0.12, 2.1, 8.3, 10.9 mg/kg, respectively, in the soils around a less industrialized city of Sangrur, indicating greater loading of soils of Ludhiana with potentially toxic metals through sewage irrigation. In industrialized cities of Amritsar and Jalandhar, mean concentrations of these metals, except Pb and Zn in Amritsar, were in-between the values for Ludhiana and Sangrur.

Effects of polluted water on plants
Plant species absorbed higher concentration of potentially toxic metals like Pb, Cu, Co, Cd, Ni, Zn, Mn, and Fe in different plant parts when grown in sewage-irrigated soils, as compared with tubewell-irrigated soils. For example, the concentration of Cd in aboveground parts of maize (*Zea mays* L.), rapeseed (*Brassica juncea* L.) and lady's finger (*Abelmoschus esculentus* L.) grown on polluted soils was 2.0–3.5 times the amount of Cd when grown on non-polluted soils. The increase in Ni concentration in various crops with waste-water-irrigated crops was 16 to 136% higher than that in tubewell-irrigated crops (Khurana *et al.* 2003). The roots of all the crops, with a few exceptions, accumulated higher amounts of potentially toxic elements than aboveground parts. Vegetables like spinach (*Spinacea oleracea* L.), cauliflower (*Brassica oleracea* L. *var botrytis*) and cabbage (*Brassica oleracea* L. *var capitata*) tended to accumulate relatively higher concentrations of potentially toxic elements as compared with cereal crop like maize. Among the four vegetables, spinach accumulated the highest amount of all the metals.

Possible mitigation options for water pollution, and recommendations
Contamination of groundwater and water bodies due to agricultural, urban and industrial activities poses a threat to ecosystem of northwestern India. It is evident from several studies that the dangers of groundwater pollution are genuine, and in some cases, the situation is alarming particularly beneath dumps of animal wastes and feedlots. Some crops receive large applications of fertilizers, which lead to nitrate and phosphate leaching. Formulation and adoption of careful strategies for applying appropriate amounts of fertilizers and manures at proper times, using correct methods, should help synchronize nutrient supply with crop need and avoid excessive use in crops, and, in turn, reduce nitrate and phosphate pollution of groundwater and water bodies. Water-pollution potential in industrialized cities like Ludhiana and Amritsar is many-folds higher as compared with non- or less-industrialized cities .Therefore, sewage-water of such cities can only be used safely for irrigation after proper treatment. Local bodies need to install effluent treatment plant and only treated waste water should be allowed to be disposed of in water bodies. Efforts should be made to encourage the industries to install their own plants within some agreed time frame to become zero discharge industries. Since very high cost is involved in the installation of treatment plants, many industries cannot install their own treatment plants. Therefore new industries should be allotted plots in such a way that a cluster of identical industries are grouped together so that common treatment plants could be set up for effective treatment economically. There is an urgent need to effectively enforce regulations for the release of industrial effluents pertaining to primary, secondary and tertiary treatments. Educating farmers and public at large about the consequences of dumping animal wastes near feedlots, pumping out shallow polluted water for drinking and domestic purposes, depleting groundwater resources, etc., is desirable. Farm yard manure, calcium carbonate, phosphate, zinc and zeloites as suitable ameliorants for mitigating pollutant toxicity in

soils and crops needs to be utilised. Crops belonging to brassica species and aromatic grasses accumulate higher amounts in their shoots and roots. The hyper-accumulation capability of these crops could be exploited for phytoremediation of toxic elements from polluted soils. Growth of timber and floriculture crops and use of aquatic macrophytes and constructed wetlands need to tested for the removal of toxic pollutants.

Figure 1. Nitrate-N in 60 cm soil profile after 2-years of rice and wheat crops (A), and Olsen-P accumulation and leaching in soil profiles of no-P control and four fertilizer P treatments after 29 years of groundnut – based cropping systems (B). (Adapted from Aulakh *et al.* 2007).

Table 1. Concentration of toxic elements (mg/L) and pH of the effluents of open Budda Nullah drain at different locations in Ludhiana city. (Adapted from Khurana *et al.* 2003).

Sampling sites	pH	As	Pb	Ni	Cr	Fe	Zn
Entry point	8.2	0.05	0.004	0.002	0.001	0.30	0.04
2 km downstream	7.8	1.60	0.060	0.12	0.170	5.8	0.18
15 km downstream	7.2	2.10	0.075	0.28	0.260	10.8	0.78

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