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Trace Elements Pollution of Soils Due to Agricultural Land Irrigation with Sewage Waterin Semi-Arid Environment and its Impact on Groundwater Quality

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Abstract: The Kandi region of Jammu, India, is characterised by extremely low and irregular rainfall. Thetemperature of the areaduring summer is above 40°C, dust storms, poor soil fertility and undulating topography. The water supply in the region is constrained by natural water scarcity, conflicting demands, intensive development, sudden spurt in population growth, dilapidated infrastructure and allocation among users in time and space, aquifer recharge capacity, contamination & land subsidence. The sewage water, both grey and black water, were analysed for various elements. The black water was found to be highly nutritive as against grey water and when applied to soil for irrigation enhanced the crop productivity tremendously. Sodium contents werehigher in grey water. The sewage effluents were analysed and found to have 25, 3 and 12 mg L^{-1} in grey water and 54, 14, 28 mg L`$^{-1}$in black water of N, P and K, respectively. The average values of Cd^{2+}, Cu^{2+}, Pb^{2+} and Zn^{2+} were; 0.02, 0.03, 0.04 and 0.8 mg L^{-1}, respectively. Application of sewage water for irrigation for long period of time contaminated the soil with Cd^{2+}, Cu^{2+}, Pb^{2+} and other undesired elements. However, it increased the crop required nutrients like, N, P and K and other micronutrients, enhancing crop productivity on short term basis.

Key words: Trace Elements · Pollution of Soils · Arid Environment · Agricultural Land Use · Sewage Water · Groundwater Quality · Kandi Region

INTRODUCTION

The role of arid regions of the world in global food production is increasing as a result of large irrigation development projects. Management of arid zone resources to produce more food in a sustainable manner in order to feed the world growing population has become increasingly important. The most important issue is to understand the risks of toxic trace and heavy elements released into the soils by increased human activities in arid environments. Anthropogenic contamination of groundwater by sewage and industrial chemicals has become a major source of concern. Often a remediation programme is needed to rectify a contaminant problem before it affects potable water supplies [1]. Trace elements refer to a number of elements that occur in natural systems in small concentrations [2]. Trace elements include chemical elements used by organisms in small quantities that are essential to their physiology as well as those elements with no known physiological function, which are toxic to living organisms at high concentrations [3]. Trace elements are present in less than 0.1% average abundance in the earth's crust [3-6]. Important trace elements in arid and semi-arid soils include Cd, Cu, Co, Cr, Ni, Pb, Hg, Mn, As, Se, Mo and B. Soil solution composition reflects the intensity and distribution of trace elements in the soil aqueous phase and represents the integration of multiple physical, chemical and biological processes occurring concurrently within the soil [7, 8]. The input of toxic trace elements into soils is increasing as a result of the reuse of agricultural chemicals, sewage water for irrigation, the disposal of wastewater sludge and municipal refuse. Soil pollution with toxic trace elements including heavy metals may be virtually "permanent" [9]. It has become clear that riparian zones and wetland play an important role in the attenuation of nitrate (NO_3) in groundwater. However, the role of hydrological cycle in NO_3 attenuation is not clearly understood, mainly due to complicated hydrological conditions [10]. The use of fertilizers, pesticides and other

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agricultural chemicals in an effort to increase crop productivity has polluted the ground water in *Kandi* region. Precipitation causes large soil, nutrient and heavy metal ions losses through leaching resulting in contamination of ground water in the basin [11, 12]. No systematic study has been conducted on the effect of sewage on the soil and groundwater pollution in the semi-arid *Kandi* region and so, the investigation was undertaken on this aspect.

MATERIALS AND METHODS

The site of study is the *Kandi* region of Jammu Province of Jammu and Kashmir state of India and is characterized by low rainfall, undulating topography, deep water table, low soil organic matter, light soil texture and frequent droughts. The region is about 200 km in length with width varying from 15 to 50 km and lying between 74° 21' and 75° 45' E longitude and 32° 22' and 32° 55' N latitude (Fig. 1). The elevation of the northern portion is about 1050 m and the southern part mergewith plains with an elevation of about 300 m above mean sea level. The area is mostly denuded with sparse vegetation due to felling of forest vegetation. Because of hilly terrain and undulating topography, the region is prone to heavy soil erosion. Extreme water stress is experienced during summers and winters and even water for drinking becomes scarce. The groundwater is one of the earths' most widely distributed natural resources and is the only replenishable mineral. Due to high evapotranspiration and surface and sub-surface flows, the groundwater recharge in the region is poor. Biophysical features, such as fragility, marginality, low accessibility and resource heterogeneity, are constraints in groundwater management in the region [26]. The study was undertaken in Kandi (drought prone) environment of Jammu Province of India. Arid environments are extremely diverse in terms of their land forms, soils, fauna, flora, water balances and human activities. The input of toxic trace elements into

Fig 1: Kandi region in the state of Jammu & Kashmir, India

soils is increasing as a result of the reuse of reclaimed sewage water for irrigation, municipal refuse and atmospheric fallout. The samples were analysed for TDS, HCO_3^-, NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}, K^+, Ca^{2+}, Na^+ and Mg^{2+}, by the methods as suggested by Jackson [13].

RESULTS AND DISCUSSION

Arid Zones in the World: The area under different zones in continents of the world is given in Table 1. Asia has highest area under semi-arid and arid zones, while Africa has maximum area under hyper-arid conditions [14]. Maximum area of 1689 million ha under arid situation is in Africa, followed by Asia (1596 million ha).

The Kandi Region: Due to high evapotranspiration and surface and sub-surface flows in the Kandi region, the groundwater recharge is poor. Biophysical features, such as fragility, marginality, low accessibility and resource heterogeneity, are constraints in groundwater management in the region. Due to complexity of the

Table 1: Aridity zones by region (million ha).

	Region						
Zone	Africa	Asia	Austral-Asia	Europe	N. America	S. America	Total
Cold	0	1082	0	28	617	38	1765
Humid	1008	1224	219	623	838	1188	5100
Dry	269	353	51	183	231	207	1294
Semi-arid	514	693	309	105	419	264	2305
Arid	503	626	303	11	81	45	1569
Hyper-arid	672	277	0	0	3	26	978
Total	2966	4256	882	950	2191	1768	13011

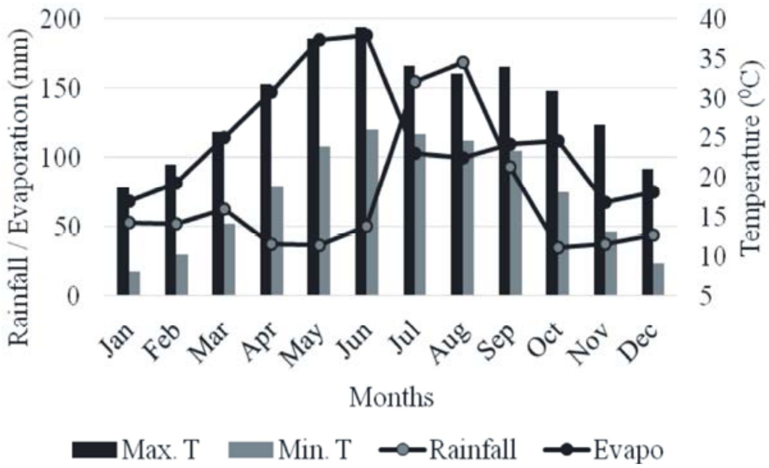

Fig 2: Rainfall, evaporation and minimum and maximum temperature in Kandi region.

Table 2: Annual loss of soil (Mt) and nutrients (000' t) from the region.

Parameters	Annual loss	Parameter	Annual loss
Soil loss	11.04	Mn	0.34
N	12.22	Zn	0.23
P	1.46	Ca	0.85
K	9.23	Mg	0.66

sustainability of groundwater and associated causes, it is also difficult to ascertain the exact behavior of many sustainability indicators. Uncontrolled disposal of urban wastes into water bodies, open dumps and poorly designed landfills cause ground water contamination and has become one of the most important toxicological and environmental issue in India [15]. Major factors affecting groundwater recharge in the *kandi* region of Jammu include; type, amount and distribution of precipitation, evapotranspiration, land use, initial soil moisture, soil infiltration and slope. Meteorological factors as amount and duration of rainfall, temperature, *in-situ* retention of rain water, rate of infiltration and amount of run-off as well as aquifer recharge capacity are important indicators of ground water sustainability in the region. Annual rainfall in the region is below 800 mm and the average temperature during summers goes above 40 °C and around 20 °C in winters. This results in high evaporation and the groundwater recharge is only possible during July and August during the rainy season (Fig. 2). About 41.16 $km^3$of rainwater is received annually in *kandi* region. The water supply in the region is constrained by natural water scarcity, conflicting demands, intensive development, sudden spurt in population growth, dilapidated infrastructure, allocation among users in time and space, aquifer recharge capacity, contamination and land subsidence. The runoff water goes untapped from the denuded hill slopes instead of infiltrating in the soil to recharge aquifers. About 11.04 million tonnes of soil and 12.22, 1.46, 9.23, 0.34, 0.23, 0.85 and 0.66 thousand tonnes of soil, N, P, K, Mn, Zn, Ca and Mg is displaced every year from the region (Table 2). Changes in land use over time coupled with their impacts on water holding capacity of soils have affected GWR (groundwater recharge) in the region. Increase in the population at a faster rate and urban development as well as human activity and land use changes have significant effect on the hydrological cycle in terms of both water quantity and quality. Groundwater contamination has affected the health of the people, particularly women and children suffer from malnutrition. Since the women constitute the main working force, their poor health affects the socio-economic milieu of the society as a whole.

Arid Soils and Their Problems: The fragile ecosystems and their limited water resources are threatened by Global Warming, risking the livelihood of hundreds of millions of inhabitants of the arid belts. A key issue is to understand the risks of toxic trace and heavy elements released into the soils by increased human activities in arid environments. Important trace elements of significance in arid soils are Cd, Cu, Co, Cr, Ni, Pb, Hg, Mn, As, Se, Mo and B. Limited work has been done on trace elements in the soils of arid regions. High soil pH and high CO_3 in the arid regions further lower solubility of most trace elements, such as Cu, Ni, Pb, Cd, Zn, Mn and many other cations. The Kandi region receives heavy dust storms during April to mid-July, with about 5 to 6 heavy dust storms, annually.The dust remains in the atmosphere for few days and settles everywhere, including agricultural lands and with it trace elements like Pb, Cd, Cu, Se, Zn. Agricultural activities such as the application of fertilizers, organic compost and farm wastes increased the concentrations of trace elements. Ground water usually has the great advantage over surface water, as it is free from pathogenic organisms. However, the study showed that the quality of groundwater was dependent on the soil content of major, minor and trace elements. Moreover, in the arid and semiarid regions, surface water evaporates at a faster rate, leaving concentrated salts on the surface. It was concluded that major sources of trace element pollution in semi-arid/arid soils is due to; nature of the parent material, irrigation water, application of agricultural chemicals, including inorganic fertilisers, soil organic matter and human interference.

Trace Element in Arid Soils: The uptake of trace elements by plants is regulated by active and passive mechanisms at the soil-root interface. Nickel and Cd^{2+} can be readily taken up by plants, while Pb^{2+} tends not to be taken up by most plants. The role of organic matter in controlling the bioavailability of trace elements was found to depend upon the nature of organic matter and trace elements, soil pH, redox potential and other competing ions and ligands [6, 16]. However, soil pollution with toxic trace elements including heavy metals may be virtually "permanent" [9]. Soil is a perfect sink for toxic trace elements which may rapidly accumulate in soils, but they are only slowly depleted by leaching, plant uptake and erosion. There are various types of pollutions in Kandi region but most important is the pollution due to the use of agricultural chemicals, city wastes, plastic bags and human excreta as still many people in rural areas defecate in the open. Pollution can have various effects on the environment as pollution provides a breeding ground for germs causing diseases. These are especially detrimental to health of environment because sandstorms can carry germs across vast areas.

Agricultural Management: Agricultural activities such as the application of fertilizers, organic compost and animal wastes, as well as pesticide or herbicides increase the concentrations of many trace elements. Also, some phosphate rocks from the western U.S. contain as much as 130 mg/kg Cd^{2+} [17]. The transfer of trace elements in phosphate rocks to P fertilizers is dependent upon the manufacturing processes. Triple superphosphate fertilizer contains 60-70% of the Cd^{2+} present in phosphate rocks [18]. The addition of $Cd^{2+}$to soils as a contaminant from P fertilizers at these rates does not appear to result in increased Cd^{2+}levels in plants as a result of long-term P fertilization [17]. On the other hand, the long-term application of pesticides and other agricultural chemicals containing trace elements, such as As, Pb and Cu, increase their concentrations in soils [19]. Concentration of Mn, Zn and Co in soil solution of limed soils decreased as the pH increased [20]. Widespread increases of trace metals including Cd, Hg and Pb have been estimated to be on the order of 10-15% since the turn of the century in agricultural soils in Europe [16].

Sewage Water: The sewage water, both grey (domestic water from bath and clothes washings) and black water (carrying human excreta), were analysed for various elements (Table 3). The black water was found to be highly nutritive as against grey water and when applied to soil for irrigation enhanced the crop productivity tremendously. Sodium was higher in grey water. The sewage effluents were analysed and found to have 25, 3 and 12 mg L^{-1} in grey water and 54, 14, 28 mg L`$^{-1}$ in black water of N, P and K, respectively. The average values of Cd2+, Cu^{2+}, $Pb^{2+}$and Zn $^{2+}$were; 0.02, 0.03, 0.04 and 0.8 mg L^{-1}, respectively. Sewage sludge is another potential source of heavy metals in soils. Arid and semi-arid soils are low in organic carbon and other plant nutrients. Sewage sludge when applied,

Table 3: Average concentration of different elements in sewage water (mg L^{-1})

Element	Grey sewage water	Black sewage water	Element	Grey sewage water	Black sewage water
N	25	54	Sulphate	32	31
P	3	14	Ca	1.5	2.1
K	12	28	Mg	2.2	2.3
Cd	0.02	0.02	Zn	0.80	1.15
Cu	0.03	0.03	Mn	0.20	0.23
Pb	0.04	0.06	Na	5.6	4.2
NO_3	34	47	CO3	3.7	3.8
Chlorides	135	202	TDS	510	702
Arsenic	0.03	0.03	TOC (%)	2.5	18.6

improves soil fertility as well as physical condition and water retention. Soil biological quality (soil biomass carbon, basal respiration and others) was improved by the organic amendment of arid soils with sewage sludge and other municipal solid waste [21].

Groundwater Pollution: Assessing groundwater quality it isimportant to know for what purpose the water is to be used that is, for drinking or irrigation. Water suitable for irrigation may not be fit for drinking. For instance the presence of waterborne microbes can make a drinking water supply unfit for human consumption, but it may be good for irrigating crops. The ground water is a vital form of earth's capital and is easy to deplete and pollute because it is renewed very slowly [11]. The use of fertilizers, pesticides and other agricultural chemicals in an effort to increase crop productivity has polluted the ground water in the *kandi* region [22]. Precipitation causes large scale soil, nutrient and heavy metal ions losses through leaching, resulting in contamination of ground water in the region [12]. Fertilizers, pesticides and fungicides use for crop nutrition and to control pests and diseases in agriculture contaminate the groundwater as these enter the deep soil with infiltrating water. Pesticides detected in surface and ground water were usually at low concentrations, well below drinking water guidelines in most of the samples but their concentration was higher in a few cases (Fig. 3). Phosphorus was higher in surface water while nitrates, sulphates and chlorides were more in groundwater. Low concentrations of P in groundwater were due low solubility of this element in the soil solution. Proper pesticide selection and management is required to avoid contaminating groundwater. Most pesticides break down at the ground surface or in shallow soil. Pesticides contaminate groundwater after breakdown and dissolution in soil moisture. Shallow aquifers with only limited protection from soil are most vulnerable to contamination. Water is an essence of life and its conservation, development and planned utilization is of prime concern for resource conservation and food security [23]. The soil taxonomy system uses soil water potential to define moisture regimes as a criterion for classifying soils [24]. The agricultural chemical contamination of groundwater is a growing concern. It was mentioned that elevated NO_3 levels in wells could result from agricultural chemical contamination as well as point source contamination in poorly constructed and poorly sited and managed wells [26]. Nitrate, harmless in small amounts, buthigh levels of nitrates can affect humans and animals. Nitrates infiltrate drinking water through fertilizers and from improperly disposed sewage [26].

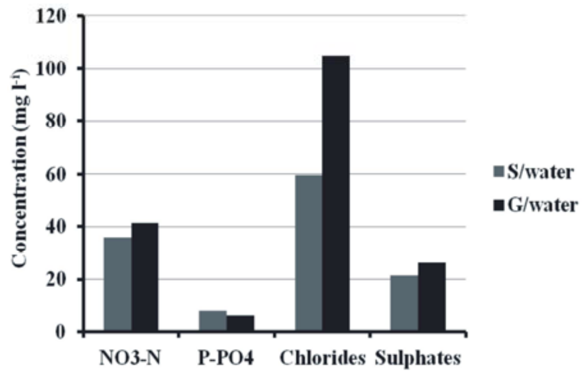

Fig 3: Elemental concentration in surface and groundwater.

The work on sewerage treatment plant in Jammu, being funded by the Asian Development Bank, has been delayed due to certain constraints and bottlenecks [27]. The treatment system being not in place, has caused pollution of soil and water bodies. The NO_3-N, sulphates and chlorides in the groundwater in Kandi region varied from 19 to 51 mg L^{-1}, 132 to 275 mg L^{-1} and 145 to 550 mg L^{-1}, respectively, while pH was from 6.9 to 8.7. The evaporation losses are more from March to June when sun-shine hours vary from 7.3 to 11.2 hours per day on an average. Heavy metals may enter soils through irrigation with reclaimed sewage water. This is especially important in arid and semi-arid areas where water supplies are limited and fresh water is very valuable. Irrigation with reclaimed sewage water is the most readily available and economically feasible way to supplement the fresh water in these areas. Heavy metals may enter soils through irrigation with reclaimed sewage water. This is especially important in arid and semi-arid areas where water supplies are limited and fresh water is very valuable. The agricultural sector is the largest user of water in the arid and semi-arid areas. Irrigation with reclaimed sewage water is the most readily available and economically feasible way to supplement the fresh water in these areas.

CONCLUSIONS

In the present study, it was observed that the chemical composition of the groundwater in the aquifers near the areas where sewage water was used for irrigation, changed drastically. There was tremendous increase in crop nutrients like N, P, K Zn, total organic carbon in the soil where black water was used as irrigation. The crop productivity was also substantially increased. However, there was anincrease in certain elements crossing the safe limits for drinking; particularly the nitrates, Cd, Mn and Cu. Soil water potential is another way of defining boundaries of arid and semi-arid soils. Uncontrolled disposal of urban wastes into water bodies, open dumps and poorly designed landfills cause ground water contamination and has become one of the most important toxicological and environmental issue in *Kandi* region. The use of fertilizers, pesticides and other agricultural chemicals in an effort to increase crop productivity has polluted the ground water. It is important to carefully select an agricultural chemical or fertilizer looking into the nature of the soil and source of irrigation.

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