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Original Research Paper

Impact of Mountain Cropping Systems on Groundwater Quality and Soil Accumulation of Heavy Metals in Mid-hills of Himachal Pradesh in India

C. K. Ndungu† and S. K. Bhardwaj
Department of Environmental Science, Dr. Y S Parmar University of Horticulture and Forestry, Nauni (Solan) India
†Corresponding author: Ndungu C. K.

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ABSTRACT

The impact of the mountain cropping system on groundwater quality and soil heavy metal accumulation was studied in mid-hills of Solan and Kullu districts of Himachal Pradesh. To assess the impact of dominant cropping systems, the four commonly occurring systems, namely vegetable, fruit, cereal crop and agroforestry were selected in the area ranging from 800-1800m. Uncultivated land in the region was considered as control. In total, there were five treatments which were replicated six times under randomized block design. The study was conducted for two years, i.e. during 2014 and 2015. The study indicated that the mountain cropping systems varied significantly with respect to their impact on groundwater quality and soil heavy metal accumulation. The pH, electrical conductivity, chlorides, nitrates and sulphates in groundwater were within drinking water permissible limits prescribed by Bureau to Indian Standards (BIS). The concentration of zinc, arsenic and nickel in groundwater was also within drinking water critical limits prescribed by BIS but lead and cadmium exceeded the limits. The concentration of lead and cadmium ranged from 0.12 to 0.27 mg L^{-1} and 0 to 0.02 mg L^{-1}, respectively, and followed similar crop system-wise trend, i.e. vegetable > fruit > agriculture > agroforestry > control. The soil accumulation of zinc, arsenic and nickel was within permissible limits prescribed by WHO but lead and cadmium violated the limits. Interestingly, soil accumulation of lead exceeded WHO permissible limits under all cropping systems, including the control. The accumulation of lead and cadmium in soil ranged from 0.16 to 0.44 mg kg^{-1} and 0.02 to 0.12 mg kg^{-1}, respectively, and had a similar crop system-wise trend they had in groundwater. Therefore, to maintain the quality of the important natural resources like groundwater and soil in mid-hills of Himachal Pradesh, necessary steps need to be taken.

INTRODUCTION

Cropping systems are vital means through which agriculture meets the rising demand of food from the exponentially growing human population. However, commercialization of agriculture in the contemporary world has led to adoption of short duration, high yielding crop varieties, intensive use of land and the prolific use of chemicals such as fertilizers and pesticides. This trend has resulted into soil and water resources degradation, thus impairing the flow of ecosystem services of these vital resources.

Groundwater is an extremely valuable ecosystem service resource and its pollution by anthropogenic activities is a matter of serious concern. Though a high input commercial agriculture is a viable venture for increasing agricultural production, it is becoming a major threat to groundwater quality. The leachates from agricultural farms containing pollutants such as nitrates, chlorides, sulphates, high biochemical and chemical oxygen requiring organic matter and heavy metals among others are causing significant groundwater pollution.

Generally, the natural concentration of heavy metals in agricultural soils derived from soil parent materials is not sufficiently high to affect soil health. However, anthropogenic sources such as agrochemicals can greatly increase heavy metal concentration in agricultural soils and impair its ecological conditions. Application of chemical fertilizer and manure on commercial agricultural farms has been reported as source of heavy metal accumulation in agricultural soils (Guo et al. 2013). Application of lime and superphosphate fertilizer leads to soil accumulation of heavy metals such as cadmium, lead and arsenic among others.

In the recent past, dramatic changes in the agricultural land use and associated management practices have happened in mid-hills of Himachal Pradesh. Increasing commercialization of agriculture and the spread of market oriented horticulture has led to the adoption of high input demanding cropping systems on steep and sloppy areas, thereby exposing the region to various environmental problems. Consequently, the current study was conceived with the objective of exploring the impacts of cropping systems on groundwater quality and soil heavy metal accumula-

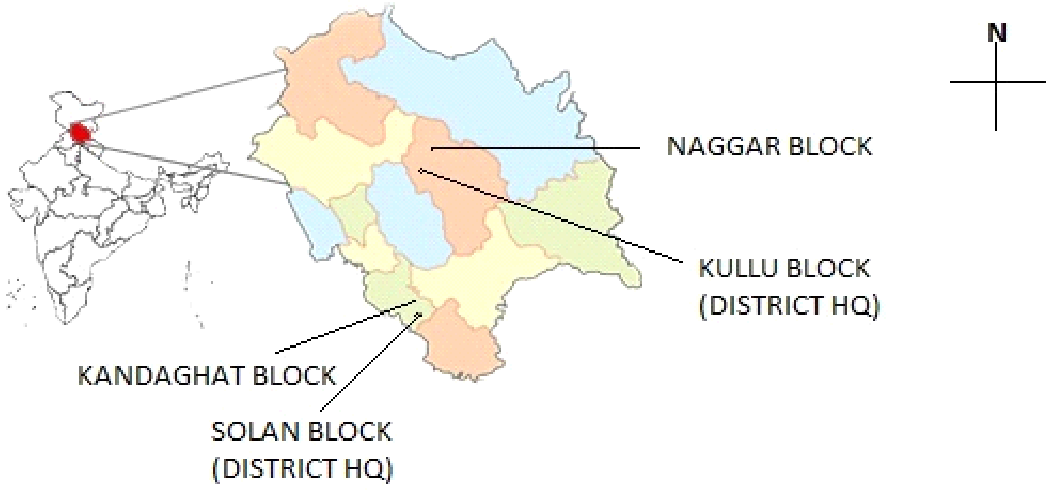

Fig. 1: Map of the study area showing the selected sites in mid-hills of HP.

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MATERIALS AND METHODS

Study area: The study area consisted of mid-hill (800-1600 m above mean sea level) regions falling in two districts namely Kullu and Solan of Himachal Pradesh in North Western Himalayas. The region has a mild temperate climate with annual average rainfall of about 1150 mm. The soils vary from sandy loam to loam in texture. The area has a steep and rugged terrain which amplifies biophysical and socioeconomic vulnerability of the communities. The mid-hills cover an area of about 33% of the total geographical area and 53% of the cultivated area of the state. The study area selected in mid-hills of Kullu and Solan districts of Himachal Pradesh is depicted in Fig. 1.

Cropping systems and experimental details: The four cropping systems, i.e. fruit, vegetable, cereal and agroforestry based were selected in mid-hills of Kullu and Solan districts of Himachal Pradesh. The fruit farming system was composed of apple, apricot, pomegranate or peach crops. The vegetable farming system was composed of cabbage, capsicum or potato crops. Cereal based farming system was maize and wheat based, while the agroforestry system was composed of agri-silviculture or agri-horticulture. The total area under vegetable, fruit, cereal and agroforestry system was 51102.1, 70809.42, 370199 and 144001.4 ha, respectively. Whereas, uncultivated land was 53426.88 ha in mid-hills of Himachal Pradesh (Anonymous 2012b). Amongst the four dominant cropping systems in mid-hills of Himachal Pradesh, the cereal based and agroforestry were the oldest systems and are being followed by the mountain people for the last 50 years. On the other hand, fruit and vegetable based cropping system are being practised for the last 30 and 15 years, respectively. Vegetable cropping system was noticed to be the recent one, having been followed by the farmers for the last 15 years. Among the selected cropping systems, fruit and vegetable systems were noticed to be high input based, wherein, farm yard manure is applied at a rate of 900-1000 kg ha^{-1} and 1000-1100 kg ha^{-1}, respectively, and NPK at the rate of 700:350:700g per tree- 200:112.5:75 kg ha^{-1}, respectively.

The experiment was conducted by taking a total of five treatments composed of four cropping systems and uncultivated land as control. The treatments were replicated six times under a randomized block design.

Water sampling and analysis: Water samples from groundwater sources adjoining the selected cropping system were collected during the year 2014 and 2015. The water samples were preserved for quality analysis by adding 1 mL concentrated nitric acid to avoid microbial utilization of heavy metals. Electrical conductivity and pH were determined by use of electrical conductivity meter, model 1601 of EIA make and pH meter, model 510 of EIA make, respectively. Biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrates and chlorides were determined following standard methods (APHA 1998). Determination of heavy metals was done by use of Inductively Coupled Plasma Emission Spectrometer (ICP-6300 Duo) af-

Table 1: Indian standards for drinking water.

Water chemical properties (mgL^{-1})	Maximum Limit
pH	6.5-8.5
Chloride	250
Fe	0.5
Nitrate	45
Sulphate	200
Zinc	5
Cadmium	0.01
Lead	0.10
Nickel	0.02
Arsenic	0.05
Electrical conductivity	2000

Source: Anonymous (2012a) and Kumar & Puri (2012).

Table 2: Permissible limits for heavy metals in soil (mg kg^{-1}).

Metal	Highest permissible level	Maximum permissible level
Pb	0.05	0.1
Cd	0.005	0.01
Zn	5.0	15
Cu	0.05	1.5
Fe	0.1	0.3
Cr	0.02	0.05
Ni	0.5	6.5
As	-	20

Source: Ekpete (2013) and Rahaman et al. (2013).

ter filtering the water with Whatman filter (No. 1).

Soil sampling and analysis: Composite soil samples from surface and sub-surface layers were taken from each cropping system during year 2014 and 2015 and transported to the laboratory for processing and analysis. Soil samples were air dried, ground and sieved (2mm) before laboratory examination. The soil was digested in nitric acid and hydrogen peroxide mixture following US-EPA 3050 B method (APHA 2005).

Permissible standards: The drinking water standards prescribed by Bureau to Indian Standard (BIS) and Central Pollution Control Board (CPCB) were used to discuss results on impact of cropping systems on groundwater quality (Table 1). Similarly, the results of soil accumulation of heavy metals under different cropping systems were discussed following WHO standards prescribed for soil (Table 2).

Statistical analysis: Analysis of variance (ANOVA) was used to evaluate the influence of cropping systems on groundwater quality and soil accumulation of heavy metals in mid-hills of Himachal Pradesh. The means were separated and compared through critical difference at 5% level of significance. In order to depict the long term impact of cropping systems on groundwater quality and soil accumulation of heavy metals, the data with respect to the various parameters were pooled for both the years.

RESULTS AND DISCUSSION

Effects of cropping systems on groundwater quality: In mid-hills of Himachal Pradesh, the commonly followed cropping systems have been found to exert significant influence on groundwater quality (Table 3). The pH of groundwater ranged from 6.76 to 7.48 and was within the normal range and permissible limits prescribed by BIS (Table 1) for drinking water. It followed the trend; control (7.53) > agriculture (7.48) > agroforestry (7.48 > fruit (7.23) > vegetable (6.76) under the different cropping systems. Although the pH of groundwater under the different cropping systems was within the normal range and permissible limits prescribed by BIS for drinking water, it tended to be comparatively lower under the vegetable based system. The relatively lower pH of groundwater under the vegetable based cropping system as compared to the others and control may be ascribed to regular application of acid forming chemical fertilizers under the high input commercial system. The results are in conformity with findings of Kaown (2009) who attributed low pH in groundwater to application of acid forming chemical fertilizers in the catchment.

The electrical conductivity of groundwater ranged from 0.46 to 0.99 dSm^{-1} which was within the permissible limits prescribed by CPCB (Table 1) for drinking water. The crop system-wise order was; vegetable (0.99 dSm^{-1}) > fruit (0.69 dSm^{-1}) > agriculture (0.54 dSm^{-1}) > agroforestry (0.52 dSm^{-1}) > control (0.46 dSm^{-1}) under the different cropping systems. Although the electrical conductivity in groundwater among the cropping systems was within permissible limits prescribed by CPCB for drinking water, it tended to be higher in groundwater under vegetable based cropping system. The higher EC in groundwater under vegetable cropping systems as compared to the others and control can be attributed to accumulation of salts under regular application of fertilizers and pesticides and further their percolation into groundwater. The results corroborate findings of Abida (2008) who attributed high salts in groundwater to high input based systems.

The groundwater concentration of chlorides, nitrates and sulphates ranged from 7.33 to 15.50 mg L^{-1}, 1.39 to 9.98 mg L^{-1} and 19.75 to 58 mg L^{-1}, respectively and the crop system-wise trend was; vegetable (15.50 mg L^{-1}) > fruit (10.50 mg L^{-1}) > agriculture (9.17 mg L^{-1}) > agroforestry (8.92 mg L^{-1}) > control (7.33 mg L^{-1}), vegetables (9.98 mg L^{-1}) > fruits (4.35 mg L^{-1}) > agriculture (3.25 mg L^{-1}) > agroforestry (3.27 mg L^{-1}) > control (1.39 mg L^{-1}) and vegetable (58 mg L^{-1}) > fruit (49.25 mg L^{-1}) > agriculture (26.33 mg L^{-1}) > agroforestry (24.50 mg L^{-1}) > control (19.75 mg L^{-1}), respec-

Table 3: Effect of mountain cropping systems on groundwater quality in mid-hills of Himachal Pradesh.

Cropping system	Groundwater quality parameter						
	pH	EC(dSm^{-1})	Cl(mg L^{-1})	NO_3(mg L^{-1})	SO_4(mg L^{-1})	BOD(mg L^{-1})	COD(mg L^{-1})
Vegetable	6.76	0.99	15.50	9.98	58.00	2.33	17.33
Fruit	7.27	0.69	10.17	4.35	49.25	2.03	15.33
Cereal	7.48	0.54	9.17	3.25	26.33	1.72	12.67
Agroforestry	7.53	0.52	8.92	2.98	24.50	1.51	10.33
Uncultivated land	7.48	0.46	7.33	1.39	19.75	1.33	7.67
$CD_{0.05}$	0.1	0.06	0.72	0.39	1.22	0.02	0.17

Table 4: Effect of mountain cropping systems on heavy metal status of groundwater in mid-hills of Himachal Pradesh.

Cropping system	Heavy metal (mg L^{-1})				
	Cd	Zn	Pb	As	Ni
Vegetable	0.02	0.19	0.27	0.04	BDL*
Fruit	0.02	0.17	0.14	0.03	BDL
Cereal	0.01	0.07	0.09	0.02	BDL
Agroforestry	0.00	0.06	0.08	0.02	BDL
Uncultivated land	0.00	0.04	0.06	0.01	BDL
$CD_{0.05}$	0.004	0.005	0.004	0.006	-

*BDL- below detectable limit

Table 5: Effect of mountain cropping systems on heavy metal accumulation in surface and sub-surface soils in mid-hills of Himachal Pradesh.

Cropping system	Heavy metal (mg kg^{-1})									
	As		Cd		Ni		Pb		Zn	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
Vegetable	0.49	0.44	0.12	0.04	0.13	0.09	0.44	0.40	3.88	3.43
Fruit	0.47	0.42	0.11	0.04	0.13	0.08	0.43	0.38	3.87	3.38
Cereal	0.28	0.27	0.07	0.01	0.08	0.03	0.27	0.25	2.69	2.43
Agroforestry	0.27	0.25	0.06	0.00	0.08	0.02	0.26	0.23	2.73	2.38
Uncultivated land	0.26	0.21	0.02	0.00	0.04	0.01	0.16	0.14	1.72	1.48
$CD_{0.05}$	0.009	0.009	0.007	0.005	0.007	0.008	0.012	0.010	0.09	0.113

tively. The results indicated that among all the selected cropping systems, vegetable based system tended to increase the contents of chloride, nitrate and sulphate in groundwater, although the values were within the permissible limits prescribed by BIS for drinking water (Table 1). The tendency of increasing chloride, nitrate and sulphate under vegetable cropping system may be attributed to continuous injudicious use of chemical fertilizer and pesticides under this agricultural system, and their further leaching into groundwater. Similarly, the relatively high values of chloride, nitrate and sulphate in groundwater under fruit based cropping system as compared to cereal, agroforestry and control may be ascribed to regular application of chemical fertilizers and pesticides in such high input agricultural commercial systems. The results are in consonance with findings of Khound et al. (2012) and Jeyaruba & Thushyanthy (2009) who attributed high content of chlorides, nitrates and sulphates in groundwater to high input agricultural commercial systems.

The range of BOD and COD in groundwater was from 1.33 to 2.33 mg L^{-1} and 7.67 to 17.33 mg L^{-1}, respectively and the crop system-wise trend was; vegetable (2.33 mg L^{-1}) > fruit (2.03 mg L^{-1}) > agriculture (1.72 mg L^{-1}) > agroforestry (1.51 mg L^{-1}) > control (1.33 mg L^{-1}) and vegetable (17.33 mg L^{-1}) > fruit (15.33 mg L^{-1}) > agriculture (12.67 mg L^{-1}) > agroforestry (10.33 mg L^{-1}) > control (7.67 mg L^{-1}), respectively. Though the values of both BOD and COD in groundwater were within the permissible limits prescribed by WHO for drinking water (WHO 1993), they were comparatively high under vegetable among the cropping systems. This is probably due to regular application of organic and chemical fertilizers under the high input system which ultimately find their way into groundwater. The results are in line with findings of Adekunle et al. (2007) and Jinwal & Dixit (2008) who also reported high BOD and COD values in groundwater whose catchment was characterised by high input commercial agricultural system.

Status of heavy metals in groundwater: With exception of nickel, which was below detectable limits, all the other heavy metals had their concentration in groundwater significantly influenced by cropping systems in mid-hills of Himachal Pradesh (Table 4). The concentration of cadmium, zinc and lead in groundwater ranged from 0 to 0.02 mg L^{-1}, 0.04 to 0.19 mg L^{-1} and 0.12 to 0.27 mg L^{-1}, respectively and the crop system-wise was; vegetable (0.02 mg L^{-1}) > fruit (0.02 mg L^{-1}) > agriculture (0.01 mg L^{-1}) > agroforestry (0 mg L^{-1}) > control (0 mg L^{-1}), vegetable (0.19 mg L^{-1}) > fruit (0.17 mg L^{-1}) > agriculture (0.07 mg L^{-1}) > agroforestry (0.06 mg L^{-1}) > control (0.04 mg L^{-1}) and vegetable (0.27 mg L^{-1}) > fruit (0.14 mg L^{-1}) > agriculture (0.09 mg L^{-1}) > agroforestry (0.08mg L^{-1}) > control (0.06 mg L^{-1}), respectively. Whereas the concentration of arsenic in groundwater ranged from 0.01 to 0.04 mg L^{-1} and followed the trend; vegetable (0.04 mg L^{-1}) > fruit (0.03 mg L^{-1}) > agriculture (0.02 mg L^{-1}) > agroforestry (0.02 mg L^{-1}) > control (0.01 mg L^{-1}) under the different cropping systems. The results further indicated that the concentration of cadmium and lead in groundwater under the fruit and vegetable cropping systems exceeded the permissible limits prescribed by BIS (Table 2) for drinking water. The higher concentration of cadmium and lead in groundwater under fruit and vegetables cropping systems as compared to the others and the control, may be attributed to regular application of chemical fertilizers and pesticides, which further percolate into groundwater under the high input commercial agriculture in mid-hills of Himachal Pradesh. The results are in conformity with the findings of Ghanem et al. (2011) and Sankar et al. (2010), who have also attributed high concentration of heavy metals in groundwater to regular application of chemical fertilizers and pesticides in such high input systems.

Status of heavy metals in soil: Perusal of data presented in Table 5, indicates that the heavy metal concentration in the soil was significantly influenced by cropping systems in mid-hills of Himachal Pradesh. The concentration of arsenic, cadmium, nickel and lead in surface soil ranged from 0.26 to 0.49 mg kg^{-1}, 0.02 to 0.12 mg kg^{-1}, 0.04 to 0.13 mg kg^{-1} and 0.16 to 0.44 mg kg^{-1}, respectively and followed the trend; vegetables (0.49 mg kg^{-1}) > fruits (0.47 mg kg^{-1}) > agriculture (0.28 mg kg^{-1}) > agroforestry (0.27 mg kg^{-1}) > control (0.26 mg kg^{-1}), vegetables (0.12 mg kg^{-1}) > fruits (0.11 mg kg^{-1}) > agriculture (0.07 mg kg^{-1}) > agroforestry (0.06 mg kg^{-1}) > control (0.02 mg kg^{-1}), vegetables (0.13 mg kg^{-1}) > fruits (0.13 mg kg^{-1}) > agriculture (0.08 mg kg^{-1}) > agroforestry (0.08 mg kg^{-1}) > control (0.04 mg kg^{-1}) and vegetables (0.44 mg kg^{-1}) > fruits (0.43 mg kg^{-1}) > agriculture (0.27 mg kg^{-1}) > agroforestry (0.26 mg kg^{-1}) > control (0.16 mg kg^{-1}), respectively under the different cropping systems. Whereas the range of zinc concentration in surface soil was from 1.72 to 3.88 mg kg^{-1} and the cropping system-wise trend was; vegetables (3.88 mg kg^{-1}) > fruits (3.87 mg kg^{-1}) > agriculture (2.69 mg kg^{-1}) > agroforestry (2.73 mg kg^{-1}) > control (1.73 mg kg^{-1}). In sub-surface soil, the concentration of all the heavy metals investigated in the study was lower as compared to their corresponding value in surface soil but followed the same trend.

The results further indicated that zinc, nickel and arsenic concentration in soil was within permissible limits prescribed by WHO (Table 2) for soil but lead and cadmium exceeded the limits. Interestingly, the soil accumulation of lead exceeded the WHO permissible limits under all the cropping systems including the control while the accumulation of nickel exceeded the limits under all the systems except the control. The highest soil accumulation of heavy metals under the vegetable cropping system as compared to the others and control may be ascribed to regular application of chemical fertilizers and pesticides under such highly remunerative systems in mid-hills of Himachal Pradesh. Similarly, the relatively high soil accumulation of heavy metals under fruit cropping system as compared to cereal, agroforestry and control is probably due to injudicious application of chemical fertilizers and pesticides under such high input system. The results are in conformity with findings of Muhammad et al. (2011), Chao et al. (2014) and Nazir et al. (2015) who attributed the soil heavy metal accumulation to application of chemical fertilizer and pesticides. Accumulation of lead in all the cropping systems including the control beyond the permissible limit may be ascribed to increased development and transportation activities in the region. The results are in line with findings of Ekpete (2013) who attributed gasoline as a source of lead in the environment. The decrease in concentration of heavy metal elements with increase in soil depth can be attributed to adsorption of metal ions in the surface soils, thus resulting in less leaching to the sub-surface soils.

CONCLUSION

The study has indicated that the mountain cropping systems in mid-hills of Himachal Pradesh have started impacting the quality of groundwater by increasing lead and cadmium contents beyond the permissible limits prescribed by BIS. The cropping systems of the region have also enhanced the accumulation of lead and cadmium in the soil beyond the permissible limit prescribed by World Health Organization. Further, other development activities have also started influencing the soil health of the region. Therefore, to maintain the quality of the important natural resources like groundwater and soil in mid-hills of Himachal Pradesh, necessary steps need to be taken.

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