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Effects of farming system type on *in situ* groundwater recharge and quality in northeast India

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Abstract A long-term study of the effects of land use on groundwater quantity and quality was conducted. Groundwater recharge was highest in newly developed land-use systems consisting of livestock-based, forestry, agri-pastoral, and agri-horti-silvi-pastoral; recharge as a percentage of annual precipitation was 99.4%, 95.3%, 98.8% and 97.2%, respectively. In contrast only 82.3% and 77.4% of the annual precipitation was recharged in the traditional systems, the *bun* method and shifting cultivation, respectively. Groundwater quality exceeded permissible limits for pH, and nitrate, iron and aluminium concentration in some farming systems. The new systems retained more water *in situ* resulting in low movement of water and nutrients out of the system. Average soil loss was 0.74 t ha^{-1} in new systems compared to 27 t ha^{-1} in traditional ones. The nutrient load in groundwater discharged from the system was 0.73, 4.2, 2.0 and 0.79 in the new systems and 27 and 21 kg ha^{-1} in the traditional systems, respectively. The quality of the groundwater was affected by the land use, deforestation, and nutrient and pesticide application.

Key words farming systems; groundwater quality; India; *in situ* groundwater; recharge

INTRODUCTION

The northeast region of India has an area of 255 090 km^2 and is predominantly hilly. Although the region receives an average annual precipitation of about 2500 mm, *in situ* retention of water is very low and soil moisture during winter (November–April) is not sufficient for crop seed germination. Most of precipitation is lost through the surface and as base flows. The prevalence of shifting cultivation and *bun* methods of cultivation has further aggravated the problem causing land and environmental degradation. Precipitation causes large nutrient losses through leaching and runoff, resulting in poor crop productivity (Sharma, 1990, 1991, 1999). Groundwater recharge by rainfall depends on the infiltration rate, which is either downward or lateral. The infiltration characteristics of the soil are affected by the soil porosity, vegetative cover and the method of cultivation. A long-term study, based on a micro-watershed approach, was conducted to see the effects of various newly evolved and traditional land-use systems on the *in situ* retention of rainwater and the quality of groundwater.

MATERIALS AND METHODS

An experiment was conducted on micro-watersheds on hillslopes with four newly developed land-use systems, which include livestock-based, forestry, agri-pastoral, and agri-horti-silvi-pastoral, and two traditional farming systems, which include the *bun*

method and shifting cultivation, to study the quality and quantity of groundwater. The quantity of surface and groundwater, including *in situ* recharge of groundwater, was measured. The crops that were planted/sown in different land-use systems are listed in Table 1. The soil texture, pH, and conductivity are listed in Table 2. Measurements were taken over eight years, i.e. from 1984 to 1991. The annual mean rainfall during the period was 2470 mm.

Table 1 Vegetation cover on different micro-watersheds.

Land use	Vegetation cover
Livestock based	Maize, rice-bean, oats, pea, guinea grass, broom grass, tapioca
Forestry	*Alder exbucklandia, Albizia lebbeck, Acacia auriculiformis*
Agri-pastoral	Rice, ginger, maize, guinea grass, french beans, turmeric, oats
Agri-horti-silvi-pastoral	Sweet potato, radish rice bean, guava, pineapple, lemon, guinea, grass, *Ficus hookerii*
Bun method	Potato
Shifting cultivation	Mixture of crops like rice, maize, jobs tear, beans

Table 2 Physico-chemical characteristics of the soil (0–20 cm depth).

Characteristics	Livestock-based	Forestry	Agri-pastoral	Agri-horti-silvi-pastoral	*Bun*	Shifting cultivation
Sand (%)	51.2	52.5	51.6	52.1	52.4	51.1
Silt	30.6	30.8	29.9	30.5	31.6	32.0
Clay(%)	18.2	17.7	17.5	16.4	16.0	16.9
Texture	Loam	Loam	Loam	Loam	Loam	Loam
pH	5.1	5.0	5.2	5.1	5.3	5.2
EC (dS m^{-1})	0.32	0.30	0.32	0.35	0.31	0.32

RESULTS

In situ restoration of groundwater

The average water yield from surface flow, baseflow and *in situ* recharge was 2.33%, 0.87% and 96.80% in new farming systems and 20%, 13% and 67% in traditional farming systems, respectively (Table 3). *In situ* recharge of groundwater was significantly higher in the new land-use systems, which helped the germination of *rabi* (winter) after the rainy season. *In situ* groundwater recharge amounted to 99% of the total rainfall in the livestock-based land-use system. This might be due, in part, to the grassy vegetation and to the addition of organic matter, e.g. manure. The traditional land-use systems resulted in excessive surface and subsurface discharge, resulting in depletion of soil moisture.

Quality of groundwater

The nutrient load in the groundwater discharged from the traditional land-use systems was significantly more than from newly developed systems (Table 4). This was mainly due to high ground water discharge from these systems. The nutrient load was highest from the bun cultivation system (27 kg ha^{-1}) followed by the shifting cultivation system

Table 3 Water yields from different micro-watersheds.

Land use	Surface flow:		Baseflow:		*In situ* recharge:	
	Mean	% of total water yields	Mean	% of total water yields	Mean	% of total water yields
Livestock-based	14.8	0.6	7.5	0.3	2400	99.1
Forestry	116.0	4.7	60.6	2.4	2390	92.9
Agri-pastoral	29.5	1.2	12.7	0.5	2430	98.3
Agri-horti-silvi-pastoral	69.1	2.8	8.5	0.3	2390	96.9
Bun	437	17.7	359.9	14.8	1670	67.5
Shifting cultivation	560	22.6	275.3	11.1	1630	66.3

Table 4 Nutrient loading in groundwater for different land-use systems (kg ha^{-1}).

Land-use systems	N	P	K	Al	Mg	Mn	Fe	Zn	Total
Livestock based	0.319	0.009	0.180	0.092	0.023	0.003	0.097	0.002	0.725
Forestry	1.280	0.060	1.096	0.756	0.192	0.018	0.760	0.024	4.186
Agri-pastoral	1.289	0.016	0.370	0.166	0.039	0.005	0.158	0.004	2.047
Agri-horti-silvi-pastoral	0.337	0.010	0.160	0.112	0.028	0.025	0.097	0.025	0.794
Bun	8.280	0.396	11.16	2.916	1.220	0.180	2.592	0.108	26.852
Shifting cultivation	6.475	0.302	9.083	2.257	0.935	0.137	1.982	0.082	21.253

(21 kg ha^{-1}) and lowest from the livestock-based land-use system (0.7 kg ha^{-1}). The average nutrient loads of N, P, K, Al, Mg, Mn, Fe and Zn were 0.83, 0.02, 0.45, 0.28, 0.07, 0.01, 0.28 and 0.01 kg ha^{-1} from the new land-use systems, respectively, whereas the loads were 7.4, 0.35, 10., 2.6, 1.1, 0.16, 2.3 and 0.10 kg ha^{-1} from the traditional land-use systems, respectively. The comparison indicates that *in situ* recharge of precipitation was better in the new land-use systems than the traditional ones. The soil loss also exceeded the permissible limit of 10 t ha^{-1} from the traditional land-use systems, averaging 27 t ha^{-1}.

The highest N concentration was in the agri-pastoral system (45 mg l^{-1}), where large amounts of N were applied for agricultural crops. Significantly, low N concentrations were observed in the forestry, *bun* method, and shifting cultivation because in each of these systems no inorganic fertilizer N was applied. Also, Al and Fe concentrations in groundwater were high and relatively constant.

CONCLUSIONS

The watershed land-use systems that provide adequate vegetative cover have higher *in situ* recharge of precipitation and less soil and nutrient loss than traditional systems, which involve deforestation and burning of forest material.

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