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Impact of agriculture land use change on the recharge and quality of groundwater in the northeastern region of India

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INTRODUCTION

The northeastern region of India, comprising seven states, lies between 21°57’ and 29°28’ N latitudes and 89°40’ and 97°25’ E longitudes. The region, with an area of 255,090 sq km, is predominantly hilly. Though endowed with such natural resource of water, its indiscriminate use and mismanagement has caused resource degradation to the extent that quality and quantity of groundwater has been affected. Fast growing population has pressurized the food production base and to satisfy their needs, the people have misused water resources. The region, though having sufficient water in aggregate, cannot boast of adequate quantity of water for its people at all the places and during all the seasons. Major factors affecting groundwater recharge in the region include; type, amount and distribution of precipitation, land use, initial soil moisture, soil infiltration and slope of the catchment. Hydrologists have considerable interest in land use change and its hydrological consequences, both from the perspective of field monitoring (Bosch, Hewlett, 1982) and from a modelling perspective (Niehoff, 2002). To understand effective eco-system management, there is need to use interactive models to simulate the hydrological processes, together with the meteorological and climatic variables and also with ecological behaviour of the eco-system. Changes in water regime are linked with climate fluctuations as well as environmental changes over time. So, precipitation, vegetation and groundwater quantity and quality are interlinked. The extent of inter-linkage has temporal and spatial variations. The important issue is to promote conservation and sustainable use of resources which allow long term economic growth and enhancement of production capacity, along with being equitable and environmentally acceptable. A study was, therefore, undertaken to see the effect of agriculture land use on the groundwater recharge and its quality.

MATERIALS AND METHODS

To manage water resources effectively, a long-term multidisciplinary study was undertaken on watersheds having slopes varying from 32% to 42% to see the effect of different land uses, and fertilizer use on the recharge and quality of groundwater (Tab. 1). The soil conservation measures followed were bench terracing, half-moon terraces, trenching and grassed water-ways. The land use systems have grasses, forestry, agro-forestry, agricultural crops, horticulture, agri-horticultural crops and shifting cultivation as control. The soil and nutrient losses were monitored through monitoring gauges fixed at the exit point of each watershed. The crops grown in different land use systems, soil conservation measures followed and animals kept as per farmer’s requirement are given in Tab. 1. The soil of the experimental area was loam in texture, The pH varied from 5.0 to 5.3 and E.C. from 0.30 to 0.35 dSm^{-1}.

The runoff (surface and base flows) and soil loss was monitored through gauges installed at the base of each micro-watershed. The runoff water as well as groundwater samples were taken from different crop land use systems and analysed for various constituents to ascertain quality. Potential groundwater recharge was estimated using the simple approach, which takes into account crop water requirement, soil type and evaporation from the bare soil viz.; Groundwater recharge (mm) = $P - Yw - E - T$; where P is the precipitation, Yw is the water yield through surface and base flow, E the evaporation from bare soil and T is the transpiration or crop water requirement to produce a particular crop yield. Soil and water samples analysis was done as per procedures mentioned by Jackson (1973).

Table 1. Vegetation cover in different land use systems.

Land use	Slope (%)	Crops/Trees	Livestock	Soil conservation measure
Fodders	32.0	*Zea mays, Stylosanthes guyanensis, Avena sativa, pisum sativum, Setaria sphaselata, Panicum maximum, Thysanolaena sphacelata*	Cows, pigs, rabbits	Contour bunds, trenches, grass water-ways
Forestry	38.0	*Alder nepalensis, Albziia lebbeck, Acacia auriculiformis*	None	None
Agro-forestry	32.2	*Ficus hookerii, Eucalyptus amygdalina, Pinus longaeva, Ananas comosus, Phaseolus spp., Psidium guajava*	Goats, rabbits	Contour bunds
Agriculture	32.4	*Phaseolus spp., Raphanus sativus, zea mays, Oryza sativa, Zingiber officinale, Curcuma longa, Arachis hypogaea, Avena sativa, Panicum spp.* on risers	Cows	Contour bunds, bench terraces grass water-ways
Agri-horti silvi-pastoral	41.8	*Phaseolus spp., Carica papaya, Citrus spp., Zingiber officinale, Solanum spp., Alder nepalensis, Ficus hookerii,Psidium guajava*	Pigs, goats	Contour bunds half-moon terraces, grass water-ways
Horticulture	53.2	*Prunus persica, Pyrus communis, Citrus spp., Citrus lemon, Psidium guajava* vegetables	None	Same as above
Shifting cultivation	45.0	*Mixed cropping*	None	None

RESULTS AND DISCUSSION

Effect of land uses on the water yield and soil loss

In the present study, the mean values of base flow and surface flow were 114.3 mm and 69.4 mm in the new land use systems as against 275.3 mm and 560.1 mm in shifting cultivation (Tab. 2).

Table 2. Water yield and soil loss from different land uses.

Parameters	Livestock based	Forestry	Agroforestry	Agriculture	Agri-hortisilvipas-toral	Horticulture	Shifting cultivation
Base flow(mm)	2.9	365.3	202.2	0.5	8.5	106.8	275.3
Surface flow (mm)	11.1	68.0	35.4	20.4	69.1	212.7	560.1
Total water yield (mm)	14.0	433.3	237.6	20.9	77.6	319.5	835.3
Per cent of rain-fall	0.6	17.7	9.6	0.9	3.1	13.0	34.1
In-situ rainwater Retention (%)	99.4	82.3	90.4	99.1	96.9	87.0	65.9
Soil loss ($t\ ha^{-1}$)	0.2	2.0	1.9	0.1	1.8	8.3	42.4
Benefit/cost ratio	2.1	1.2	1.5	1.8	1.9	1.7	0.6

By and large, more than 90% of rainwater was retained *in-situ* in the new land use systems compared to 65.9% in the shifting cultivation. More *in-situ* retention of rainwater helped in the availability of adequate moisture from the soil to the succeeding crops when the rainy season receded. It was interesting to note that while in shifting cultivation 34.1% of rain water escaped as runoff, it varied from 0.6% to 17.7% in the new land use systems. Maximum of 99.4% of rain water was retained in livestock based land use system, followed by agriculture (99.1%). It was reported earlier also that more than 95% of rain-water can be retained *in-situ* by following these land use systems (Singh, 1989). Annual soil loss due to erosion with runoff varied from 0.2 to 8.3 t ha^{-1} in new land use systems compared to 42.4 t ha^{-1} in the shifting cultivation. The soil loss was very low in newly tried land use systems due to reduced runoff because of proper vegetation cover and water and soil conservation measures undertaken.

Groundwater recharge

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. Most of the rainfall is confined to the period from May to October in the region. Water levels of aquifers in the region reach their peak from mid-August to mid-October. Heavy rainfall causes huge soil erosion through runoff from the hills and silting of river bed and flood in the plains (Sharma, 1990). Management solutions should aim at restoration of the more natural, dynamic behaviour of the water system, because this will minimize the volume of water discharged from the area and maximize water conservation. Dynamic surface water control implies that greater water level fluctuations are allowed within the constraints of agricultural activity and safety. Prevalence of shifting cultivation, fast increase in the population at, urban development free range grazing, land tenure system and deforestation have significant effect on the hydrological cycle in terms of both water quantity and quality in the region.

Effects of land use

Recharge is the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. The precipitation reaches the groundwater and depending on groundwater intensity and state of the soil, some rainfall runs away as runoff and some infiltrates into the soil zone (Hulme et al; 2001). The groundwater recharge was maximum in livestock based land use system, followed closely by agriculture, horticulture and forestry land use systems (average 32.5% of precipitation) as against only 8.3% in shifting cultivation (Table 3).

Table 3. Effect of land use, rainfall and their interactions on groundwater recharge (mm).

Land use	**Rainfall (mm)**						**Mean**
	2195	**2705**	**2770**	**2599**	**2288**	**1992**	
Livestock based	738	1212	1294	1101	835	555	956 (39.0)
Forestry	426	729	746	663	477	338	563 (22.9)
Agro-forestry	560	954	984	870	633	459	742 (30.2)
Agriculture	731	1219	1289	1102	831	570	957 (39.0)
Agri-horti-silvi-pastoral	679	1134	1198	1021	769	526	888 (36.2)
Horticulture	516	897	914	815	590	420	692 (28.2)
Shifting cultivation	152	260	274	231	168	125	202 (8.2)
Mean	543 (24.7)	915 (33.8)	957 (34.5)	829 (31.8)	615 (26.8)	426 (21.4)	

The low groundwater recharge in the shifting cultivation was due to minimum land cover and higher slope, resulting in high runoff mainly as surface flow. The affect of precipitation on the groundwater recharge was significant ($r = 0.831$) as also on base and surface flows. During the six years of study, the rainfall varied from 1992 mm to 2770 mm per annum and groundwater recharge varied from 426 to 957 mm, respectively. The groundwater recharge was 21.4% of the precipitation during the year when the annual fall was 1992 mm and 34.5% when the rainfall was 2770 mm. Though, the runoff was higher at higher rainfall, the groundwater recharge was also higher. The results were validated at other two sites receiving rainfall of 1350 mm and 1060 mm. Application of the simple model; Groundwater recharge (mm) = $P - Yw - E - T$, showed that the groundwater recharge was only 16.6% and 1.5% of rainfall, respectively, at above sites. On ground situation at second site above has revealed that in most of the dug-wells the water table has considerably gone down due to over-exploitation of these wells and their recharge was almost negligible. It showed that groundwater recharge is negligible at lower rainfall when the evaporation is high. When the annual rainfall is below 1000 mm, no groundwater recharge can be expected. The model gave significant predictability and reliability as verified from the ground situation and predicted and observed values agreed relatively well. Maximum rain water could be retained *in-situ* and the soil can retain sufficient moisture for growing winter crops (Sharma, 2001, Sharma and Sharma, 2003, 2005). This would also helps in reducing runoff and soil loss and, improved environmental conditions could be assured.

Groundwater quality

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. The use of fertilizers, pesticides and other agricultural chemicals in an effort to increase crop productivity, results in pollution of groundwater. The ground water is vital form of earth's capital and is easy to deplete and pollute because it is renewed very slowly. The pH of groundwater varied from 5.1 to 5.6 and conductivity from 0.08 to 0.19 dSm^{-1} in various land use systems (Table 4). The variation in 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. The use of fertilizers, pesticides and other agricultural chemicals in an effort to increase crop productivity, results in pollution of groundwater. The ground water is vital form of earth's capital and is easy to deplete and pollute because it is renewed very slowly. pH and conductivity was non-significant among various land uses. The NO_3-N is the most widespread contaminant affecting the groundwater quality in the aquifers in the region. The NO_3-N in the groundwater crossed the critical limit of 45 mgl^{-1} for drinking water in fodder/grasses, agriculture, agri-horti-silvi-pastoral and horticulture land uses. This may be attributed to the application of inorganic fertilizers in these land uses (Sharma, 1990, 1999). The nitrate may be derived from natural and anthropogenic sources such as application of inorganic fertilizers, septic systems, animal manure, atmospheric deposition and transformation of soil organic matter to nitrate. Nitrate is highly soluble and can be readily transported to groundwater. Sulphates, chlorides, calcium, zinc, Mn, Fe and magnesium concentrations in the groundwater varied from 12.9 to 45.6, 11.6 to 26.2, 30 to 70, 4.2 to 11.8, 0.4 to 1.7, 0.8 to 6.4 and 10 to 33 mg/L, respectively. The sulphates, chlorides, calcium zinc and magnesium were within the critical limits for drinking as well as irrigation purposes. However, manganese and iron concentration was higher than critical limit for drinking water in some samples. This may be attributed to the soil acidity and higher concentrations of manganese and iron in the soil.

Table 4. Effect of land use (vegetation) on the range of pH, conductivity (dSm-1) and elements in groundwater (mg/L).

Land use	pH	Conductivity	NO_3-N	SO_4	Cl	Ca	Zn	Fe	Mn	Mg
Fodders	5.1–5.4	0.13–0.19	25–47	15.1–26.2	11.2–16.0	46–63	4.3–9.5	1.4–3.3	0.5–1.4	16–28
Forestry	5.0–5.2	0.11–0.15	18–26	12.6–21.3	11.0–15.6	36–50	4.7–8.2	0.8–2.4	0.4–1.2	13–23
Agro-forestry	5.1–5.3	0.14–0.18	20–35	14.3–26.8	14.5–19.5	36–58	4.9–10.1	1.0–2.8	0.7–1.3	13–25
Agriculture	5.3–5.6	0.12–0.19	36–55	19.2–45.6	16.8–26.2	48–70	5.6–11.8	1.9–6.4	0.6–1.4	12–33
Agri-horti-silvi-pastoral	5.2–5.4	0.10–0.18	28–48	17.3–32.9	16.8–23.0	46–72	5.2–11.1	1.8–5.5	0.5–1.3	12–30
Horticulture	5.1–5.3	0.14–0.19	27–50	18.1–33.2	17.5–23.6	40–68	4.9–12.2	1.6–5.6	0.9–1.7	20–28
Shifting cultivation	5.2–5.4	0.08–0.09	18–27	12.9–20.0	11.6–15.0	30–49	4.2–7.4	1.2–2.5	0.4–1.2	10–17

CONCLUSIONS

The results of the study undertaken showed that the introduction of new land use systems, with suitable water and soil conservation measures, significantly reduced runoff from the watersheds on hill slopes and helped in more *in-situ* retention of rainwater, thereby increasing the groundwater recharge. The land use and precipitation significantly affect the groundwater recharge and the sediment yields. While the rainfall is a natural phenomenon and its amount and intensity cannot be controlled, judicious management and use of rainwater and proper land use can be controlled. Proper land use and soil and water conservation measures need to be undertaken for higher *in-situ* rainwater retention and reduction in runoff to increase groundwater recharge. The interface between runoff and ground water is signified by gradient, geology of the area and physical and chemical properties of the soil. Heavy rainfall and the anthropogenic interventions are important factors affecting GWR in the northeastern region. An understanding of the mechanisms that control groundwater interactions with surface water is crucial for the effective management of water resources and the conservation of its associated ecosystem.

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