Erosion processes and their implications in sustainable management of watersheds in Nepal Himalayas

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Abstract The problem of soil erosion due to human and natural processes, and its consequences in terms of sedimentation and changes in hydrological regimes in downstream areas in the Himalayas in general and in Nepal in particular, has been a subject of national and global concerns. Considering the lack of long-term pertinent data the uncertainty that surrounds this debate has already been well highlighted. Recently some works at plot level, micro and meso watershed level erosion processes have been carried out in different physiographic and elevation zones in Nepal Himalaya which have been used to examine the role of land management in modifying the runoff and soil loss from the hillslopes in this area. The paper is based on secondary data and information on runoff and soil erosion processes reported from different parts of the country. Significant differences were observed in the rate of soil loss and the percentage of runoff to total precipitation with time, physiographic regions and different land cover/use and land management practices. The data so far available are limited in time and space and it is difficult to generalize these processes. However, it appears that there is a possibility of minimizing the loss of soil and enhancing productivity upstream through simple and innovative land use and land management practices which could also contribute significantly to reduce flood hazards in downstream areas of the watershed.

INTRODUCTION

Nepal Himalayas is one of the high energy environments mainly because of very active tectonic activities, high relief and seasonal concentration of precipitation. The altitude ranges from only 60 m in the south to more than 8848 m in the north within a short distance of 160 km. The recorded mean annual precipitation ranges from only 163 to 5244 mm with a weighted average of 1630 mm. More than 80% of the total precipitation occurs during the monsoon season between June and September. Daily precipitation exceeding 300 mm occurs frequently in the country and produces simultaneous disturbances of both the slopes and channel equilibrium on the regional scale (Chalise *et al.*, 1995; Khanal *et al.*, 1996; Khanal, 1995). Due to very high relief and seasonal concentration of precipitation with frequent high intensity precipitation events and frequent seismic activities, natural hazards in the form of surface erosion and landslides are common. Moreover, the high rate of growth of human and livestock population, subsistence land-based economy and scarce land resources have also caused to accelerate natural erosion processes. The total population of the country has more than doubled from 8.3 million in 1952–1954 to 18.5 million in 1991 with an annual growth rate of more than 2% and more than 90% of the total population engaged in subsistence farming (Manandhar *et al.*, 1994). Livestock population in relation to arable land and animals per person is large by Asian standards (HMG/ADB, 1993). About 21% of the total area of the country is under agricultural use whereas only 17% of the total land with slopes less than 5° is suitable for seasonal crops. Forest lands have been brought for agricultural use in order to meet the increasing demand of food and fodder (Bajracharya, 1983). Similarly, due to the increasing demand for fuel wood which shares more than 83% of the total energy consumption in the country (HMG/ADB, 1993), the pressure on non-agricultural land has also been increasing and consequently accelerating the rate of surface erosion and environmental degradation.

Much of the discussion regarding environmental degradation in Nepal Himalayas which started in the mid 1970s have focused primarily on ecological concerns particularly on deforestation caused by fast growing human and animal population and its consequent impact on local and regional ecology and economy (Eckholm, 1975, 1976; Ives & Messerli, 1989). This paper attempts to discuss spatial and temporal variation in runoff and soil loss, its relation with land use and the implication for the sustainable management of watersheds in Nepal Himalayas.

METHODOLOGY

Present discussion on rainfall-runoff and soil loss processes is based on secondary information reported from different physiographic regions and land use types in different periods. On the basis of geology, relief and climate, Nepal is divided into five physiographic regions namely the Terai, the Churia Hills, the Middle Mountains, the High Mountains and the High Himal from south to north (Gurung & Khanal, 1987; LRMP, 1986). The Terai in the south with elevation ranging from 60 to 330 m is the extension of the Indogangetic plain. It represents about 13% of the total area of the country. The Churia (200–1500 m) including Inner Terai are similar in area and are composed of tertiary sandstone, siltstone, shale and conglomerates. The Middle Mountain with altitude between 800 and 2400 m is composed of phyllites, quartzite, limestone and isolated pocket of granites and occupies about 29% of the total area. The High Mountain between 2000 and 4000 m with relief of 3000 m is composed of gneiss, quartzite and mica schists and comprises 20% of the total area. The High Himal (>4000m) is composed of gneiss, schist, limestone and Tethys sediments and comprises about 24% of the total area of the country (LRMP, 1986). Seasonal and annual rainfall-runoff and soil loss data from erosion plots, micro, and meso watersheds have been analysed in order to understand the processes quantitatively and identify an intervention strategy for the sustainable management of land and water resources. Data on soil erosion from the High Himal used in this study are from Langtang and Khumbu (Watanabe, 1994; Byers, 1987). Rainfall-runoff and soil loss data reported from Bamti-Bhandara representing the High Mountain region (Ries, 1993) from Jhikhu khola, Chisapani, Chyandanda in Sindhupalchok district, Kulekhani and Pokhara representing the Middle Mountain and Subakuna (Surkhet district) representing the Churia hills have been analysed. In addition, sediment discharge data from some selected watersheds have also been analysed in order to understand the process at different levels—from erosion plot to micro; and meso-watersheds in the country. The data on runoff and soil loss from plot to watershed levels referred to in this paper are not for individual events. Although these data do not represent the annual figures in all cases, all of them cover monsoon period which is critical for runoff and soil loss in Nepal.

DISCUSSION

Runoff

Data so far available on the percentage of precipitation which runs off is presented in Table 1. There is a wide variation in the percentage of runoff by time, place and land use types. The percentage of runoff from agricultural terraces ranges from only 0.5 to 33. Study on Bamti-Bhandara (the High Mountain) indicates that the runoff from agricultural terraces varies significantly by types of cultivation. Very high runoff of more than 20% was recorded from Buckma under shifting cultivation compared to only 3% from natural forest, 13% from used forest and 15% from pasture land (Ries, 1993). Studies in Dandapakhar and Bonch area showed that runoff ranges from only 5% from overgrown plots to 25% of the total rainfall from bare (weeded) plots (Schaffner, 1987). It varies from only 0.5 to 11.6% in Jhikhu khola from agricultural plots and such differences in runoff in Jhikhu khola were mainly due to the differences in soil properties and intensity of rainfall rather than slope and cropping (P. B. Shah, personal communication). At the micro-watershed level, the percentage of runoff so far reported ranges from only 12.2 to 35%. The percentage of runoff in paired catchments in Phewa (the Middle mountain) ranges from 22.4 to 29.6 whereas it is only 12.2–14.4 from Kulekhani. Study of the water budget in Likhu khola watershed (the Middle and High mountain) indicates that 35% of the total

Table 1 Percentage of runoff to total precipitation.

Places	Annual precipitation (mm)	Plot level: Agriculture	Pasture	Degraded forest/ shrubland[1]	Forest	Micro-watershed
High mountain						
Bamti-Bhandara (Ries, 1993)	1000–2200	0.2–33 (14.4)	14.8	12.6	3.2	
Dandapakhar (Schaffner, 1987)	3125		5–19			
Bonch (Schaffner, 1987)	3661		7–25			
Likhukhola (Boorman *et al.*, 1996)	4970					35
Middle mountain						
Pakribas (Sherchan & Chand, 1991)	1261	22–31 (29)				
Jhikhu khola	1393	0.5–11.6 (2.9)				
Chyandanda (Maskey & Joshi, 1991)	2104	15–24 (20.6)				
Chisapani (Maskey & Joshi, 1991)	2047	4–9 (6)				
Kulekhani (Upadhaya *et al.*, 1991 and DSC, 1995a, 1996)	1387	6–30 (16)				12.2–14.4
Phewa (DSC, 1996)						24.4–29.6

Note: Figure in parentheses indicates annual average.

[1] It also includes used forest and shrublands.

precipitation is discharged annually in the form of runoff, 34% is lost due to evaporation and the remaining 31% is lost by other processes (Boorman *et al.*, 1996).

Soil erosion

There is a wide variation with time, space and land use in the rate of soil erosion (Table 2). The annual loss of soil from agricultural plots ranges from only 0.1 to

Table 2 Annual soil erosion (t ha^{-1}).

Places	Annual precipitation (mm)	Altitude (m)	Plot level: Agriculture	Pasture	Degraded forest/ shrubland[1]	Forest	Micro-watershed
High Himal							
Khumbu (Byers, 1987)	807–1071	3300–4415		2.22–16.93		0.25–4.87 (0.6)	
Langtang (Watanabe, 1994)		3000–4900		0.43–2.95			
High mountain							
Bamti-Bhandara (Ries, 1993)	1000–2200	1995–2453	0.2–12.7 (5.8)	0.4	1.4	1.4	2.08–29.85
Dandapakhar (Schaffner, 1987)	3125	1730		0.4–18.7			
Bonch (Schaffner, 1987)	3661			3.7–66.6			
Middle mountain							
Pakribas (Sherchan & Chand, 1991)	1261		16.9–36.7 (32.9)				
Jhikhu khola (Carver & Nakarmi, 1995)	1393	1230–1260	0.1–42 (12.3)				
Chyandanda (Maskey & Joshi, 1991)	2104	1385	53.9–104.8				
Chisapani (Maskey & Joshi, 1991)	2047	1940	0.2–0.6 (0.6)				
Kathmandu (Laban, 1978)						8	
Kulekhani (Upadhaya *et al.*, 1991 and DSC, 1995a)	1387	1620–1800	0.3–3.98 (1.4)				0.2–0.3
Phewa (Mulder, 1978 and DSC, 1996)	3700			9–35		0.34	15.2–15.4
Dailekh (Carson, 1985)			2–7	20	15	5	
Churia							
Chatra (Laban, 1978)				36.8	7.8		
Lothar (Laban, 1978)				31.5–420			
Surkhet (DSC, 1995b)	923	720	1.06–2.74 (1.87)				
Nepal (Laban, 1978))							
Well managed level terraces			0–15		40–200	0–5	
Poorly managed sloping terraces			20–100				
Nepal (LRMP, 1986)							
Irrigated terraces (khet)			0				
Level terraces (pakho)			5				
Sloping terraces (pakho)			20				
Shifting cultivation			100				

Note: Figure in parentheses indicates annual average.

[1] It also includes used forest and shrublands.

104.8 t ha^{-1}. The average soil loss from different types of agricultural fields is reported to be 1.4 t ha^{-1} (10-years) in Kulekhani area, 12.27 t ha^{-1} (4-years) in Jhikhu khola and 32.9 t ha^{-1} (2-years) in Pakhribas in the Middle Mountain region. Relatively high rates of soil loss are reported from outward sloping terraces as compared to level terraces. Comparatively very high rate of soil erosion was reported from pasture and heavily utilized forest and shrubland as compared to the rate of erosion from protected and natural forest except at Bamti-Bhandara. Annual loss of soil from pasture land ranges from 9 to 35 t ha^{-1} in the Middle Mountain, 0.4–66.6 t ha^{-1} in the High Mountain and 0.43–16.93 t ha^{-1} in the High Himal region. Very high rates of soil loss from overgrazed or weeded bare ground (16.9–66.6 t ha^{-1}) were also reported from Khumbu, Danadapakhar and Bonch areas compared to the locally managed or overgrown pasture plots (Byers, 1987; Schaffner, 1987). The rate of soil loss from highly utilized degraded forest including *shrub*land ranges from 1.4 to 420 t ha^{-1} whereas it is between 0.25 and 7.8 t ha^{-1} from well managed or natural forest. Studies in micro-watersheds (less than 6 ha) show this rate to be less than 1 t ha^{-1} in Kulekhani to 15 t ha^{-1} in Phewa (the Middle Mountain) and 2–30 t ha^{-1} in Bamti-Bhandara. The estimated soil loss ranged from 0 to 15 t ha^{-1} from well managed level terraces to 20–100 t ha^{-1} from poorly managed sloping terraces, 40–200 t ha^{-1} from overgrazed degraded shrub and pasture land and

Table 3 Seasonal and annual loss of soil (t ha^{-1}).

Id	River	Station	Area (km^2)	November–February		March–June		July–October		Total
				Soil loss	%	Soil loss	%	Soil loss	%	Soil loss
Watersheds (Shankar, 1989)										
170	Surnagad	Patan	188							12
240	Karnali	Asarghat	19260	0.179	2.1	1.802	20.9	6.64	77.0	8.621
260	Seti	Banga	7460	0.43	1.5	2.537	9.1	25.051	89.4	28.018
280	Karnali	Chisapani	42890	0.372	1.9	2.699	13.4	17.034	84.7	20.105
286	Sarada	Sarada	816	0.105	2.1	0.104	2.1	4.861	95.9	5.070
290	Babai	Bargadha	3000							37
350	West Rapti	Bayasoti	3512	0.718	1.5	6.732	14.2	39.856	84.3	47.306
360	West Rapti	Jalkundi	5150	0.311	1.1	1.754	6.3	25.891	92.6	27.956
410	Kaligandaki	Setibeni	7130	0.197	0.5	4.013	9.6	37.518	89.9	41.728
430	Seti	Pokhara	582	0.632	1.2	18.793	35.6	33.434	63.3	52.859
447	Trisuli	Betrawati	4640	0.128	1.3	1.114	11.5	8.459	87.2	9.701
450	Narayani	Narayanghat	31100	0.295	0.5	4.359	7.7	52.184	91.8	56.838
470	Lothar	Lothar	169	0.1956	0.5	0.991	2.7	35.184	96.7	36.370
550	Bagmati	Chobhar	585	0.122	0.8	1.463	9.9	13.183	89.3	14.768
570	Kulekhani	Kulekhani	126	0.044	2.5	0.413	23.8	1.278	73.7	1.735
590	Bagmati	Karmaiya	2720	0.122	0.8	1.463	9.9	13.183	89.3	14.768
598	Kamala	Kamala	1550							32.3
690	Tamur	Mulghat	5640	1.217	1.2	11.954	11.7	88.881	87.1	102.052
695	Saptakosi	Chatra	59400							24.4
795	Kankaimai	Mainachuli	1148	0.263	0.5	6.071	12.6	42.021	86.9	48.355
	Average									31.1
Erosion plots										
	Dandapakhar (Schaffner, 1987)						74		26	
	Bonch (Schaffner, 1987)						71		29	
	Jhikhu khola (Carver & Nakarmi, 1995)						82		18	
	Kulekhani (Upadhaya *et al.*, 1991 and DSC, 1995a)				6		39		55	

0–5 t ha^{-1} from natural forest. The annual rate of soil loss within agricultural land ranges from 0 to 100 t ha^{-1} depending upon types of terraces.

The annual discharge of sediment from 20 watersheds is presented in Table 3 and Fig. 1. The rate of soil loss from these watersheds ranges from only 1.74 to 102.05 t ha^{-1} with an average of 31.1 t ha^{-1}. The annual loss of soil is comparatively low in the northern and middle part of the country except in Pokhara area (Setibeni and Pokhara) where the average annual precipitation is very high (more than 3700 mm) compared with other parts of the country (Fig. 2). The annual loss of soils from watersheds within the High and the Middle Mountain ranges from 1.73 t ha^{-1} in Kulekhani to 52.86 t ha^{-1} in Seti watershed (Pokhara) with an average of 19.39 t ha^{-1}, whereas it is between 14.77 t ha^{-1} in Bagmati at Karmaiya and 102.5 t ha^{-1} at Mulghat in Tamur with an average of 43.26 t ha^{-1} in the southern part of the country (the Mahabharat and Churia) and 20.11 t ha^{-1} at Chisapani in Karnali to 56.8 t ha^{-1} at Narayanghat in Narayani and 24.4 t ha^{-1} at Chatra in Saptakosi with an average of 33.8 t ha^{-1} (Fig. 1). Average annual soil loss from small watersheds with areas less than 200 km^2 is 16.7 t ha^{-1}, from watersheds with areas between 500 and 1000 km^2 is 24.23 t ha^{-1}, from watersheds with areas between 1000 and 5000 km^2 is 31.57 t ha^{-1}, from watersheds with areas between 5000 and 20 000 km^2 is 41.67 t ha^{-1} and from macro- watersheds with areas more than 20 000 km^2 is 33.78 t ha^{-1}. Average annual loss of soil in these watersheds increases with the increase in the size of watershed upto 20 000 km^2 and begins to decrease as the size becomes larger.

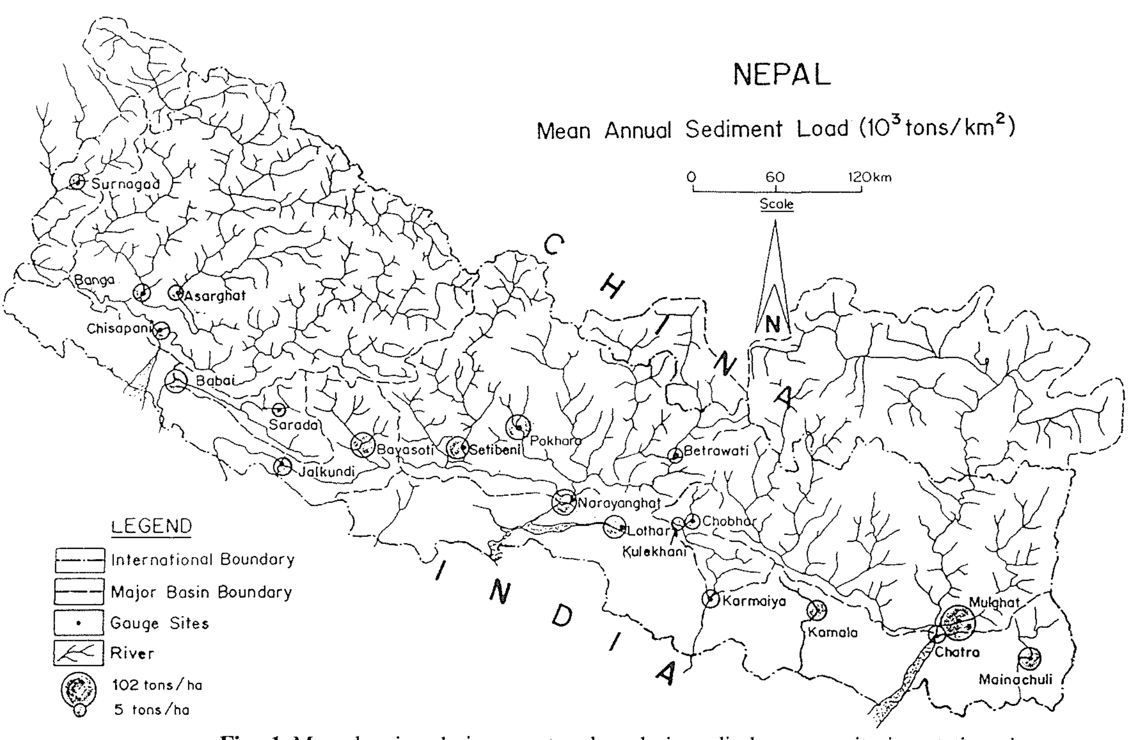

Fig. 1 Map showing drainage network and river discharge monitoring stations in Nepal and annual sediment discharge.

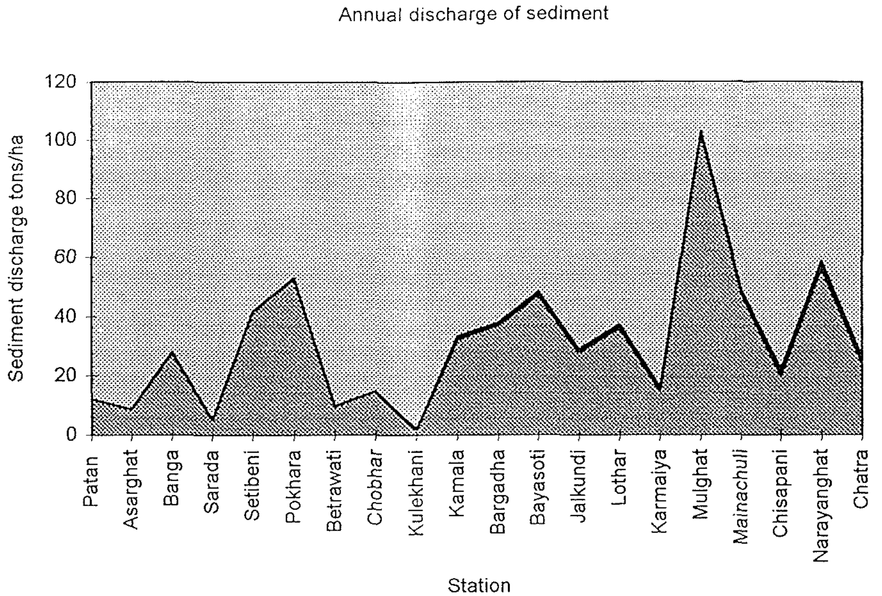

Fig. 2 *Annual sediment discharge from selected watersheds in Nepal.*

Annual sediment discharge from watersheds is higher than the average loss of soil from agricultural plots. Similarly, there are differences in the timing of soil loss in plots and watersheds. About 68% of the total soil loss occurs in the pre-monsoon and early monsoon period in agricultural plots whereas more than 86% of the total loads in the river is discharged during the later part of the monsoon period (Table 3). The comparatively very high loss of soil in the late monsoon period from watersheds compared to the amount of soil lost from agricultural fields indicates that the major sources of sediments in the rivers are not agricultural fields. The source of the high loss is surface erosion from degraded pasture, shrub and forest areas, and from landslides, river bank cutting and reworking of deposited materials along the gullies and river channels. The rate of soil erosion from degraded forest, shrubland and overgrazed pasture land is more than double that from agricultural fields. Several other studies also indicate that agricultural fields are well managed by the farmers and the loss of soil from these fields is less than was generally assumed in the past (Chalise, 1986; Ives & Messerli, 1989). Tree cutting alone is considered not to lead to increase in surface erosion, nor to the decrease in water resources, nor any negative consequences in the timing and distribution of water resources. However, overgrazing and the collection of litter from forest land does contribute to high runoff and soil loss (Hamilton, 1987). Since grazing of animals and collection of litters and grasses for farm manure and fodder from common lands (shrubland, forest and pasture) are commonly practised in the country, one can expect high surface runoff and sediment yield from these common lands. Studies of the soil hydraulic properties in Sindhupalchok also reveal that short term rainfall events are likely to cause more surface runoff on heavily grazed, trampled grassland than on well protected forest areas (Gilmour *et al.*, 1987).

Studies of landslides in Kakani by Caine & Mool (1982) indicate that 1% of the total area is occupied by landslides resulting in a denudation rate of 14 mm $year^{-1}$ (approximately 250 t ha^{-1}). In Lele watershed near Kathmandu, a single precipitation event of 1981 caused many landslides (47 landslides per km^2) removing hillslope materials of more than 160 t ha^{-1} (Manandhar & Khanal, 1988). In Kulekhani watershed the estimated volume of materials removed from landslides by a single event of 1993 was more than 2000 t ha^{-1} from agricultural fields and 10 000 t ha^{-1} from degraded forest, shrubland and pasture (Khanal, 1995; Dhital *et al.*, 1993). Significantly high rates of sediment discharge from Tamur (50 $m^3 ha^{-1} year^{-1}$) as compared to other watersheds such as Arun (9.7 $m^3 ha^{-1} year^{-1}$), Sunkosi (28 $m^3 ha^{-1} year^{-1}$) and Saptakosi (19.5 $m^3 ha^{-1} year^{-1}$) were reported to be due to a higher density of landslides in Tamur (13.8% of the total area) than in other watersheds (less than 3% of the total area covered by landslides) (HMG/JICA, 1986). Though the dominant causes of deep and large scale landslide occurrences are natural, it has been reported that large scale mass wasting (landslides) had increased by 26% as a result of human activities (Laban, 1979).

Table 4 Land use (000 ha).

Land use types	Existing area	Additional area suitable for trees
1. Total land area	14 748	
2. Total cultivated land:	3 052	
(a) Hillslope cultivation level terraces	774	
(b) Hillslope cultivation sloping terraces	511	
(c) Terai/valley cultivation	1 767	
3. Non-cultivated inclusion within cultivated land	998	789
4. Grazing land	1 745	829
5. Forest/plantation	5 518	5 518
(a) Forest with crown density 10–40%	1 417	
(b) Forest with crown density 40–70%	3 186	
(c) Forest with crown density >70%	821	
6. Shrub/degraded forest	706	706
7. Others	2 729	

Source: HMG/ADB/FINNIDA (1988) and LRMP (1986).

Land use

Earlier discussions on runoff and erosion processes have shown that the major source of sediments are other than privately owned agricultural fields. It is poorly managed common lands e.g. pasture, shrubland and used forest area which contribute to high sediment yield. Though reduction in soil and nutrient loss from the agricultural fields particularly from outward sloping terraces is essentially required to maintain the productivity, it is the common lands which should be managed from the ecohydrological view point. Table 4 shows the existing land cover/land use condition of the country. It indicates that greater attention should be paid to improving the management of about 511 000 ha of sloping terraces, 789 000 ha of non-cultivated inclusions (which include mainly grazing and shrublands), 829 000 ha of grazing land, 1 417 000 ha of thinly covered forest with crown densities between 10 and 40% and 706 000 ha of shrub and degraded land which altogether represent about 29% of the total area for the sustainable economic and ecological development of the country.

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