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Ravine Erosion and Reclamation in India

MARTIN J. HAIGH,* Oxford, U.K.

Abstract: Ravine and gully erosion affects 1% of India's land area. Zones of severe ravine trenching are found along the margins of the Gangetic Basin and in the semi-arid northwest. Ravine reclamation is currently rated as a high national priority, and India has the Third World's leading soil conservation movement. This paper reviews the technical contributions made to the study of ravine origins and genesis by government soil conservation research workers in the light of the dissident views expressed by academic geoscientists. It also reviews the soil conservation establishment's major contributions to cost-effective ravine reclamation planning. However, it is emphasised that while great advances have been made towards technological remedies for ravine erosion, relatively little has been accomplished in the realm of social science. Successful ravine reclamation requires the support and involvement of the local cultivator and local community and, probably, reform of local land tenure and social arrangements. Towards this end, much experience has been accumulated in non-government circles through the activities of Gandhian *sarvodaya* groups. It is recommended that their ideas and methods are integrated into ravine reclamation activities.

Introduction

Gully erosion due to river channel trenching is a problem that threatens vast tracts of the world's agricultural land. The damage is greatest in the alluvial plains of the semi-arid and arid zones and most serious where it threatens precarious subsistence-oriented agricultural systems in the developing world.

Ravine-cut landscapes occur in many areas and have many names. The French call them *lavaka*, the Brazilians *vossoroca* or *bocoroca* (TRICART, 1972; PRANDINI, 1974; OKA FIORI and SOARES, 1976). They have been reported from Zimbabwe (STOCKING, 1978), Madagascar (PETIT and BORGEAT, 1965), Central Russia (BOGOLYUBOVA and KARAUSHEV, 1979) and many parts of the American Southwest, where they are associated with the name '*arroyo*' (COOKE and REEVES, 1976).

However, on reading the scientific literature, one might be forgiven for wondering if concern for gully erosion and land conservation were exclusively the province of the world's major scientific nations, their colonial extensions, and international organisations.

This paper seeks to redress the balance. Its concern is with India's internal struggle with the problems of ravine and gully erosion. Its goal is to award long-overdue recognition to the research and experience of India's small cadre of soil conservationists and geoscientists, and to the Third World's leading, non-colonial soil conservation movement. It is an attempt to collect and collate that material within India's internal publications which is of value to the global struggle against ravine and gully erosion.

Swaraj: Indian Approach to Science and Development

There is evidence of prejudice against Indian scientific publication in the west. Even in India there is growing concern about the quality of India's scientific publications (RAMASEHAN, 1982), and there is no doubt that this concern is sometimes justified.

In part, the problem results from India's overall

*Department of Social Studies, Oxford Polytechnic, Oxford OX3 0BP, U.K.

approach to self-reliant development. In business and technology it has been Indian policy to build internal capacity, even if that is initially of low quality, rather than to allow its own endeavours to be swamped by products from outside. Slowly, and against enormous odds, this economic strategy appears to be succeeding.

India's universities and research centres seem to be operating under the same principles. In many cases they lack the resources and facilities to compete effectively with institutes in the west. However, they are by no means colonial institutions. Foreign influence is restricted to a handful of 'returned' scholars. The shortage of funds for foreign travel and the limitations of institutional libraries, together with the magnitude of India's internal traditions of scholarship and culture, have helped enhance this isolation. India's science, like India's industry, develops in its own independent, insular world (EISEMON, 1982).

Soil Conservation Research in India

Indian work in soil conservation has origins which can be traced back before independence (RAMA RAO, 1970). However, the modern movement has followed an American lead (PANDE, 1981). The pioneering *Journal of Soil and Water Conservation in India* was launched in 1952 by workers in the Damodar Valley Corporation (Bihar), a scheme modelled on America's Tennesee Valley Authority and which absorbed much of its ethos.

During the 1960s the D.V.C. lead was superseded by the work of Central Government institutes, especially the Central Soil and Water Conservation Research, Demonstration, and Training Institute at Dehra Dun, U.P., though the fading impress of the American model remained. Indian soil conservation, however, like much Indian science, has become progressively more self-contained and introverted as the years have passed. The reasons for this are not wholly clear, though there seems to be a belief that India's own research is more relevant to its immediate problems and experience than that from elsewhere. Citation analysis of the *Indian Journal of Soil Conservation* 6–9, 1978–1981 reveals that two-thirds of the citations are drawn from Indian publications and one-quarter from American. The average age of the foreign sources is conspicuously greater than those from India.

The fact that 'ravine' erosion, as such, is not recognised elsewhere in the world has helped compound the isolation of Indian research. The literature on related phenomena: gully erosion, stream trenching and arroyo incision, is heavily dominated by American work, but this is scattered through a geoscientific literature which only partially penetrates the research libraries of India.

Ravine Lands of India

Land degradation by ravines and gullies is widespread in India. The NATIONAL COMMISSION ON AGRICULTURE (1976) estimated that 3.67 million ha (1% of India's land area) is damaged. NARAYANA and BABU (1983) claim 4,000,000 ha as a more reasonable estimate of land covered by gullies. In colonial days the problem was considered to be even worse. The NATIONAL PLANNING COMMITTEE (1943) believed that 3.8% of United India's land area suffered severe gully erosion and that 8% of the United Provinces, some 2 million ha, were barren ravines.

There are four major areas of severe ravine erosion (SHARMA, 1980; Figure 1). The largest is the Yamuna-Chambal Ravine Zone. Ravines flank the Yamuna river for nearly 250 km and in the Agra and Etawah Districts attain depths of more than 80 m. Nearly 389,000 ha are affected along the Yamuna in Southern Uttar Pradesh, but the area affected along the tributary Chambal River is still greater. The Chambal ravines flank the main channel in a 10 km wide belt which extends southward from the Yamuna confluence, some 480 km, to the town of Kota in Madhya Pradesh. Ravines infest the basins of several Chambal tributaries, notably the Mej and Morel-Dhund. Altogether some 5000 km^2 are affected. The whole region is so seriously eroded that the only remaining vestiges of the alluvial plain which antedated incision are the artificially protected islands on which villages are sited (SHARMA, 1980, pp. 20–21).

In arid Gujarat, the Ravine Belt covers 500,000 ha and extends from the southern bank of the Tapti River, along the banks of the Narmada and Watrak to the borders of Rajasthan in the Sabramati and Mahi basins. There are other areas of substantial ravine erosion in Chota Nagpur, Bihar, the Mahanadi and Upper Son Valley of Mirzapur, all on the southern fringes of the Gangetic Plain, and the Siwalik and *Bhabar* tract of the western Himalayan

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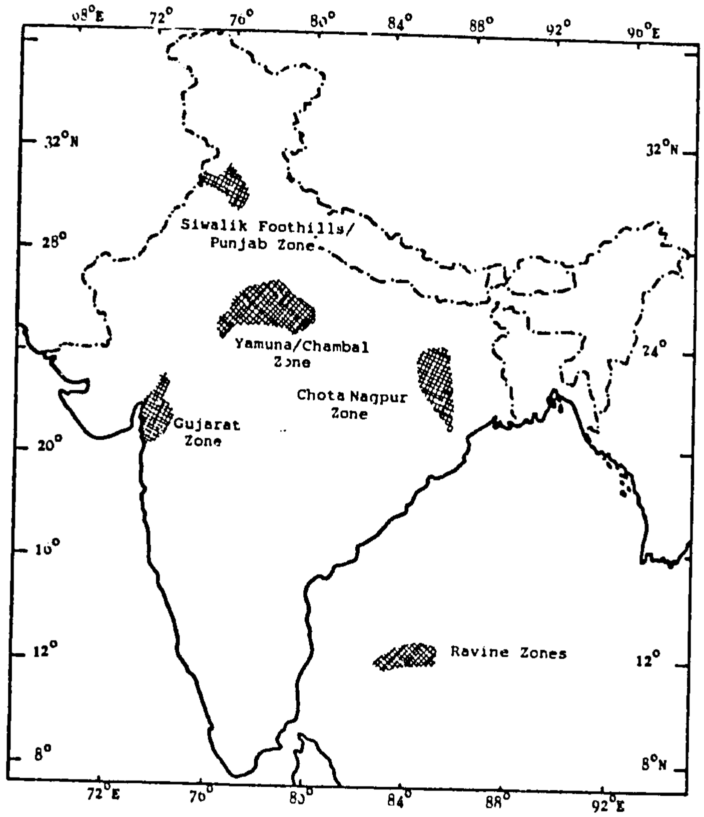

Figure 1. Distribution of ravine zones in India (SHARMA, 1980).

Figure 2. Ravine near Jaipur, Rajasthan [Type 4a: TEJWANI, 1968; D2: GUPTA and PRAJAPATI, 1983; SETH *et al.*, 1969: G2: BHULYAN, 1967 (see Table 2); reclaimability class I: BALI and KARALE, 1977 (see Table 3)].

foothills (SHARMA, 1980). Less extensive ravinous badlands can be found near Mathura in Uttar Pradesh, in the Upper Tapti Basin of Gujarat, near Jaipur in Rajasthan (Figure 2) and even in Kashmir (SINGH, 1958; Table 1).

Origin of India's Ravines

In the West there is much debate concerning the origins of ravine-like arroyos, trenched channels and badlands. Some workers prefer to relate these features to climatic changes which cause modification to ground cover, concentration of run-off and changes to the level of ground water tables. Others believe that they are caused by human activities which have induced the concentration of surface flow (HUDSON, 1971; COOKE, 1974; PATTON and SCHUMM, 1975; COOKE and REEVES, 1976; SCHUMM, 1977; GRAF, 1979). Certainly, in southern Arizona newspaper reports from the late Nineteenth and early Twentieth Centuries record the exact dates of channel trenching in this region (SHERIDAN, 1981; COOKE and REEVES, 1976). Further, there is at least one arroyo, Greenes Canal, which is completely artificial. It was created around 1910 as an irrigation canal. It evolved into an arroyo following floods in 1914 which carved a deep incision into the ditch's floor (COOKE and REEVES, 1976, pp. 53–54). The arguments on both sides of the arroyo debate are so well documented that the leading reviewers of the subject (COOKE and REEVES 1976, pp. 187–189) allow the possibility of convergence and conclude that both explanations are possible. Soviet workers, who face similar problems in the central Russian uplands and Dnieper Highlands, have independently reached the same conclusion (BOGOLYUBOVA and KARAUSHEV, 1979).

Indian soil conservation workers have, on the whole, preferred explanations couched in land-use terms (GUPTA, 1973; GUPTA and PRAJAPATI, 1983). Gullies and ravines are explained as due to surface run-off mismanagement (PRAJAPATI *et al.*, 1982; ALI, 1974), especially deforestation, overgrazing and ill-considered tillage in an environment which is particularly susceptible to erosion (KAUL, 1962a; TEJWANI, 1959). This susceptibility is in part due to the intensity and concentration of rainfall during the monsoon (SINGH *et al.*, 1976; BABU *et al.*, 1978; RAGHUNATH *et al.*, 1982) and in part due to the erodibility of the deep, alluvial soils where most of the ravines develop (MEHTA *et al.*, 1958, VERMA and PATEL, 1969; NARAIN *et al.*, 1979). The report of the NATIONAL COMMISSION ON AGRICULTURE (1976) points out that in India there are no historical records to indicate when ravine erosion started, though it is certainly pre-Mughal (HABIB, 1963, p. 14). However, the report agrees that indiscriminate land-use practices leading to a disturbance of the hydrological balance is one of the reasons. Certainly, ravine erosion on the Chota Nagpur Plateau in Bihar is closely associated with forest thinning (SHARMA, 1980, p. 28).

Western theories which relate ravine and gully erosion to climate find little support within the Indian scientific community. In India the main zones of ravine erosion have no obvious relation to climate. In Gujarat and Rajasthan the rainfall is only 500–

Table 1. Area affected by ravines in India (million ha)

	NATIONAL COMMISSION ON AGRICULTURE (1976) and MINISTRY OF HOME AFFAIRS (1972)
All India	3.669
Uttar Pradesh	1.230
Madhya Pradesh	0.683
Bihar	0.600
Rajasthan	0.452
Gujarat	0.400
Punjab/Haryana	0.120
West Bengal	0.104
Tamil Nadu	0.060
Maharastra	0.020

750 mm/year, but in the Yamuna-Chambal Ravine Zone it ranges upwards from 750 to 1330 mm/year. In the western Sub-Himalayan Zone the annual rainfall is 1125–1225 mm/year and in Chota Nagpur 1125–1500 mm/year (SHARMA, 1980).

India's geoscientists, however, prefer another explanation. They note that most of India's ravinelands are to be found on the margins of the Gangetic Plains. AHMAD (1968, 1973) argues for the possibility of peripheral uplift of the Peninsular Shield by pressure against the Himalayas and suggests that the discontinuous pattern of incision is due to differential rates of disturbance. PRAMILLA and RAI (1972) write of the rejuvenation of the Deccan Foreland. SHARMA (1968, 1979, 1980) extends the argument by pointing out that there is no easy correlation between intensity of human occupance or deforestation and the intensity of ravine erosion along the margins of the Deccan. In addition, he cites a number of geomorphological studies which illustrate the polycyclic character of river valleys in Peninsular India (SHARMA, 1979, 1980).

Certainly, the enormity of the Chambal and Yamuna ravines, which achieve depths of 60–80 m, lends weight to the geological argument. However, it is possible that the tectonically induced susceptibility to ravine trenchment has, in fact, been brought to realisation by human activities. In other words, neotectonics may have prepared the way for ravine erosion but, in most circumstances, the actual ravine erosion may have been triggered and exacerbated by human activities.

Classification of Gullies and Ravines

The international literature contains a substantial number of different approaches to the classification of gully and related channels (IMESON and KWAAD, 1980). The Indian approach is notable for its single-minded orientation towards the problems of erosion control and land reclamation. In such circumstances plan-form (cf. IRELAND *et al.*, 1939) is much less important than depth of incision and bed-width. It is unfortunate that the Indians have yet to agree on the details of a gully classification but several *ad hoc* variations have been

Table 2. Classification of channels based on dimensions

	Gujarat (TEJWANI, 1968)	Madhya Pradesh (GUPTA and PRAJAPATI, 1983)	Rajasthan (BHULYAN, 1967)	Chambal River Basin (SETH *et al.*, 1969)
Very small	G1: gullies up to 1 m deep and 18 m bed-width	D1: shallow ravines up to 1.5 m deep	G1: gullies up to 1 m (18% overall)*	D0: gullies less than 1.5 m deep and 3 m wide (10% overall)†
				D1: gullies less than 1.5 m and more than 3 m wide (60% overall)
Small	G2: gullies up to 3 m deep and more than 18 m bed-width	D2: medium ravines 1.5–5 m deep	G2: gullies, 1–5 m deep (39% overall)	D2: gullies between 1.5 and 5 m deep, more than 3 m wide (24% overall)
Medium	G3: gullies 3–9 m deep and not less than 18 m of bed width, side-slope 8–15%	D3: deep ravines, 5–10 m deep	G3: gullies more than 5 m deep (43% overall)	D3: trenches 5–10 m deep (6% overall)
Large	G4: (a) gullies 3–9 m deep and less than 18 m of bed-width (b) ravines, more than 9 m deep. Side-slopes steep to vertical and gullied	D4: very deep ravines, 10 m deep		

* Survey of 137,000 ha area of ravine land.
† Survey of 1570 ha area near Alnia River confluence, Chambal Command Area.

developed to meet the needs of individual projects (Table 2). (N.B. The dimensions selected reveal a great deal about the varying character of India's gully problems.) It is, however, agreed that gullies vary in size along a regular scale that can be expressed in terms of depth, bed-width and side-slope steepness (GUPTA and PRAJAPATI, 1983). These concepts are, at present, best encapsulated by the system devised by TEJWANI and DHRUVANARAYANA (1961) for the Gujarat Ravine Zone and which TEJWANI (1972, 1974/1975) believes should be extended to the description of all India's gullied lands. However, for the purposes of reclamation, the Tejwani system is in danger of being supplanted by rival schemes, notably a 5-class ravine land classification proposed by BALI and KARALE (1977; BALI, 1972 a, b and c, 1967/1968) which includes gully depth, width, slope with drainage density, soil texture, depth to caliche, hard pan or rock, especially on the inter-gully table-land, and depth to ground water (see Table 3).

Evolution of Gully Channels and Ravinelands

It has long been recognised that gully channels are the product of two types of flow concentration: surficial and subterranean. There are two types of gully channel: continuous and discontinuous (HEEDE, 1967, 1974). Continuous gully channels evolve at the ground surface as a result of the concentration of overland flow. As flow is concentrated its power to transport sediment increases exponentially. Continuous gully channels begin as a coalescence of rills and have channels which become deeper downslope until the point where this growth is limited by deposition or a local base-level (HEEDE, 1974). Discontinuous gullies are rather different: they begin as an abrupt headcut, tend to become more shallow downslope and often end as a midslope alluvial fan.

Discontinuous gullies are particularly associated with the subterranean concentration of flow in soil pipes (Figure 3). Frequently, this is caused by a local lowering of the water-table which increases the hydraulic gradient. JONES (1968) indicates that, in Arizona, hydraulic gradients as low as 3% can initiate piping, especially when the soil contains lines of structural weakness such as shrinkage cracks. SHARMA (1979, 1980) believes that the solution of calcareous layers in the soil is an important factor, but this idea does not seem to be widely accepted.

Once established, a soil pipe extends headwards up the hydraulic gradient and expands its sides and roof by collapse. Eventually, roof collapse exposes the pipe at the soil surface — initially as a steep-sided oval depression, then later as a trench. Further evolution is controlled by the parallel retreat of the gully side-walls and deposition on the gully floor.

In the Indian literature the soil conservation workers prefer to explain ravine evolution in terms of surface run-off (TEJWANI *et al.*, 1975; Table 4) and in this they are joined by the soil conservation textbooks of America and Russia (SOBOLEV,

Table 3. Ravine reclaimability groups (BALI and KARALE, 1977)

Class I	Very good; ravinous lands that can be reclaimed readily with minor reclamation operations of levelling and scraping. These lands include shallow ravines (G1) with widths up to 30 m or more, simple and compound bed-slopes of up to 5%, lack extremes of texture and do not have within a depth of 1.5 m a calcareous layer, hard pan, bed rock, salinity or alkalinity. Ground water level is below 2.5 m
Class II	Good; lands that can be reclaimed readily with minor reclamation operations but requiring more dozing work than class I. The depth and width specifications for this group are the same as class I, but bed-slopes range between 5 and 10%. They have a low frequency of gullies. They also lack extremes of texture, hard pans, caliche, salinity or alkalinity within the depth of 1–1.5 m
Class III	Moderate; lands that can be reclaimed with medium intensity reclamation measures. These lands have moderately deep ravines with narrow-to-moderate width, medium frequency with compound bed-slopes of 10–15%. Soil textures are moderately fine and fine, often demanding heavy draft. Soils have slight to moderate salinity and/or alkalinity and possess calcium carbonate, hard pan or bed rock within 0.5–1 m from the surface
Class IV	Poor; includes medium-to-deep gullies of narrow width. There are severe limitations due to complex and strong bed-slopes, a high frequency of gullies, extremes of textures, salinity and alkalinity, and the occurrence of hard layers, bed rock or pans within 0.5 m from the surface. These lands are very costly to reclaim or may not be suitable for agriculture after reclamation. Reclamation of such lands for horticultural uses is recommended
Class V	Unsuitable; there are severe limitations for reclamation of these lands for agriculture or horticulture, and the very high cost means reclamation is not desirable. Such lands would be best developed for forestry and grassland.

Table 3. Continued

Class	Property	Reclamation suitability groups: Very good	Good	Moderate	Poor	Unsuitable
1	Depth of the gully (m)	<2.5	<.2.5	2.2–5.0	2.5–5.0	>5.0
2	Width of the gully (m)	above 30	above 30	15–30	15–30	Up to 15
3	Bed-slope simple/ compound/ complex and steep gradient	simple compound up to 5%	simple compound 5–10%	compound 10–15%	complex 15–25%	complex 25%
4	Frequency of gullies (length in m)	<500	<500	500–1000	500–1000	>1000
5	Texture within 1 m of depth	si,* sli, without any hard pan, concretionary layer or bed rock	sl, sil, l,	sc, sil, l, scl, sic, clay	c, s, ls, concretary layer below 0.5 m	Sand or hard pan concretionary layer
6	Occurrence of calcareous layer/hard pan/bed rock/ salinity/ alkalinity	none or below 1.5 m	1–1.5 m surface followed by texture as in 4	0.5–1.0 m	none or any depth	lithic/ paralithic, strong salinity, severe alkalinity, contact within 0.5 m of the surface
7	Depth of the inter-gullied zones above lithic or paralithic contact (m)	>2.5	>2.5	1–2.5	0.5–1	<0.5
8	Ground water table (depth in m)	>2.5	>2.5	<2.5	<2.5	<2.5

* s, sand; sl, sandy loam; sil, silty loam; sic, silty clay; ls, loamy sand; l, loam; scl, sandy clay loam; c, clay.

1948; SCHWAB *et al.*, 1981). SHARMA (1979, 1980; Table 4), by contrast, emphasises the importance of pipe erosion (see also OLLIER and BROWN, 1971; OLLIER and MacKENZIE, 1974).

It has long been realised that discontinuous and continuous gullies are part of a continuum series, that discontinuous gullies may evolve into continuous ones by coalescence and that most gully channels are a hybrid of the two types (HEEDE 1967, 1974; OLLIER and BROWN, 1971). Similarly, in India observation suggests that both surficial and subterranean processes are at work in all gully systems. Nevertheless, the author's researches in ravine lands near Jaipur, Rajasthan, discovered vertical-sided, flat-floored ravines identical to those produced by soil-pipe exposure in Arizona.

Rates of Ravine Expansion

The problem of ravine erosion in India has attained the status of a national emergency because, in many

Figure 3. Vertical ravine sidewall (height 6 m) with soil pipes: Rajasthan.

areas, ravine systems are aggressively encroaching on agricultural lands (DAYAL, 1975). Unfortunately, few reliable studies have been directed to the evaluation of this problem. One notable exception is a study which compared the area given over to ravines in Badoh village, Kota District, Rajasthan, as represented on the maps of 1923/1924, with that identified on air photographs dated 1953/1954. In the 30-year period the ravined areas increased by 5.3% (KHYBRI, 1973).

It has been said, however, that the ravine lands across all Rajasthan increase their area by 500 ha each year; that is an increase of 1.75 ha/year for each 1000 ha of existing ravine land (G. SINGH *et al.*, 1966). Ahuja (in TEJWANI *et al.*, 1975), who appears to have pioneered this type of study, considered that each year around 810 ha of ravine land was added to the ravines of Madhya Pradesh's Morena, Bhind and Gwalior districts. Accepting the data quoted by SHARMA (1980), there are 419,000 ha affected by ravines in this area, which means that the annual rate of expansion is 1.93 ha for each 1000 ha of existing ravine land.

SHARMA (1976) has studied ravine extension in the Morel Basin of Rajasthan. The estimated rate of ravine extension ranged from 0.6 to 1.0 m/year, and was greater on sandy than on the clayey loam soils. SHARMA (1979) also conducted a study of ravine extension in the Lower Chambal Valley. Here analysis based on the comparison of Survey of India maps and interviews with local farmers indicated that the rate of ravine extension is between 0.25 and 0.45 m/year and that the rate of extension is a function of soil type and ravine size.

A case study conducted at the Soil Conservation Research Centre at Vasad, in the Gujarat Ravine Zone, which examined a 0.24 ha catchment with a 10% slope, found that gully erosion advanced at an accelerating pace during 2 years of observation. In August 1973 the gully-affected area was only 173 m^2. In 1974, after 1294 mm of rainfall, its area had expanded to 200 m^2. The following year supplied only 657 mm of rainfall, but by August 1975 the young ravine had expanded to 231 m^2 (SINGH and KAMANNAVER, 1975). So in 2 years, the gully had increased its area by more than one-third. In the second year of observation, despite receiving only a little over half the rainfall of the previous year the rate of expansion remained between 15 and 16% and the area added to the gully increased by 15%.

Table 4. Evolution of gully channels and ravine systems

(1) TEJWANI *et al.* (1975): India	(2) SHARMA (1980): India	(3) SOBOLEV (1948): U.S.S.R.
Stage 1: Rills form in a sheet-washed surface and cut through topsoil to subsoils beneath	Stage 1: Subterranean solution of calcium carbonate nodules creates a swallow hole	Stage 1: Rills form, often on a scarp face due to human activities, landsliding or differential slope retreat
Stage 2: Small gully cuts down into sandy layers below subsoil. These are readily washed out and the gully widens by undercutting and collapse, forming vertical headcut and side-walls	Stage 2: Swallow holes become linked to walls on incising master channel by soil pipes and a steepening of the local hydraulic gradient (cf: JONES, 1968)	Stage 2: Small gully forms on valley side slope, due to 'accidental' concentration of flow due to natural or artificial causes. Gully head cuts upslope
Stage 3: Incision stopped by encounter with stable horizon or water-table. Headcut and side-walls retreat laterally and become less steep	Stage 3: Subterranean pipe system is opened up by collapse	Stage 3: Gully deepens towards the development of an 'equilibrian' longitudinal profile involving no erosion or deposition beyond headcut advance and side-wall retreat
Stage 4: Either vegetation and shrubs colonise the side-walls, then stabilise the gully channel and/or the cycle is repeated on a bigger scale	Stage 4: Side-wall retreat causes the channel to get wider and more shallow as, and if, sediments accumulate on channel bed	Stage 4: Either the gully achieves a stable long profile and heals as its banks retreat to a gentle angle, or it continues to grow to become the size of a ravine

(4) OLLIER and BROWN (1971): New Guinea	(5) SCHWAB *et al.* (1981): U.S.A.
Stage 1: Rills begin 10–30 m from slope head. A rill is a small channel formed by downward erosion along the entire length of a watercourse	Stage 1: Channel created by incision into topsoil. This process may be quite slow where the topsoil resists erosion
Stage 2: Major rills grow into gully channels. Relict rills are left as small hanging tributaries	Stage 2: Gully channel enlarges in width and depth. Headcut advances upstream. Channel cuts into the C horizon and the weak weathered parent material is removed. A waterfall develops where flow plunges from the upstream segment to the eroded channel below.
Stage 3: Gully heads extend by 'particle extrusion'. Pore water causes particles to be extruded from a free-face in saturated porous material. This process is enhanced by gully wall undermining and collapse. The authors have no explanation for headcut origination	Stage 3: Healing begins with vegetation beginning to grow in the channel and on its margins
Stage 4: Colonisation by dense tropical vegetation fossilises the gully system. Erosional features persist, relatively unaltered (study based on a young volcanic cone of pumice and ash)	Stage 4: Gully is stabilised. The channel reaches a stable gradient, the gully walls a stable slope. Vegetation colonisation proceeds sufficiently to anchor the soil and permit the development of a new topsoil

Current wisdom prefers that gully systems undergo allometric, that is, proportional, growth. The UNITED STATES SOIL CONSERVATION SERVICE (1966) has developed a formula to predict headcut advance. This equation has the form:

$$R = a_1(W)^b a_2(P)^c,$$

where R is a headcut advance, W is drainage area above the headcut, P is the summation of daily rainfall totals greater than 12.7 mm, a_1 and a_2 are scaling constants, b is an exponent of value 0.46 and c is an exponent of value 0.20.

A detailed empirical study of allometric gully system expansion has been published by FAULKNER (1974). BHAN (1973, 1981) has modelled the growth of the Kamtari Basin ravines in the Yamuna belt as an exponential power function of area against time.

Land Capability Classification

The problem of spreading ravine-affected areas has had to be incorporated into agricultural planning for the ravine lands. TEJWANI (1974/1975) had produced a land capability classification which is based on two criteria: land-slope and distance from the gully rim (Table 5). For example, class 6(a) land is within 6 m of the gully rim. Studies of ravine-wall retreat along the Mahi River ravines near Baroda found annual retreat rates ranging from 1 to 5 m/year. Clearly, class 6(a) land has a very limited life expectancy.

BALI and KARALE (1977) present a more optimistic alternative. This is a 5-point classification of ravines based on degree of reclaimability. The scheme (Table 3) incorporates concern for gully depth and local slope, and for the problems discovered by past reclamation efforts. SONI (1968) discovered that a shallow calcareous pan will cause the roots of trees to spread horizontally, so that the trees planted for reclamation purpose die. Soil properties such as texture, the presence of saline/alkaline layers and ground water depth, as well as depth to caliche or rock, also affect the construction and subsequent behaviour of terraces, so these too are included. BALI and KARALE (1977) also mention that information on land ownership and land-use practices are important for project planning. Bali's previous ravine work was heavily oriented to air photograph interpretation, where social factors are more easily ignored (BALI *et al.*, 1969).

The professional soil conservationists, however,

Table 5. Land capability classification* in ravine lands (TEJWANI, 1975: 258)

Land capability class	Landform type	Slope angle (%)	Distance from gully rim (m)
1	table lands	0–1%	>60
2	table lands	1–3%	>60
3(a)	table lands and broad interfluves	0–3%	6–60
3(b)	table lands	3–5%	>6
3(c)	table lands	5–10%	>6
4†	table lands	10–15%	>6
6(a)	gully margins	0–15%	<6
6(b)	table lands	15–25%	<6
6)c)	beds of small (G1–G3)‡ gullies		
7(a)	table land	>25%	<6
7(b)	deep and narrow gully channels		

†No class 5 is identified.
‡See Table 2, column 1.
*Criteria for land capability classes are described in HUDSON (1971, pp. 169–175).

have a growing awareness of the complex problems of project implementation. They are currently engaged in several integrated reclamation schemes, in different contexts, which they call 'Operations Research' projects (JAISWAL *et al.*, 1977; TEJWANI *et al.*, 1975; GUPTA and PRAJAPATI, 1983).

Ravine Reclamation

Soil conservationists the world over spend a large part of their time reclaiming gullied lands, but nowhere is this an exact science (HEEDE, 1978, 1979). Practical soil conservationists also recognise that land conservation is as much a social scientific problem as a technological problem (HUDSON, 1983). Further, it is widely recognised that the societal pressures that encourage land degradation, and which restrict the effectiveness of soil conservation programmes, are often more intractable than the technological problems of erosion control. Despite this, soil conservationists tend to be trained first as technologists, second as environmentalists and last of all as applied social scientists. The situation is clearly reflected in the contents of the worlds top two soil conservation textbooks. SCHWAB *et al.* (1981) ignore the social aspects of soil conservation. HUDSON (1971) cites humankind as a cause, but describes only technical cures. By contrast, in 1982–1983, the world's premier conservation journal, *The Journal of Soil and Water Conservation*, carried one to two articles per issue on the broad political problems of conflict resolution and on the sociological problems of soil conservation implementation.

Despite some glimmerings of promise in the early days of soil conservation in India (BLACKMORE and HOLSCHER, 1957), the profession has preserved the blinkers of the standard textbooks. In 1975 India's Central Soil and Water Conservation Research, Demonstration, and Training Institute had a staff of 66, but there were only five posts in the newly created section of economics and extension. Central government institutes everywhere tend to be slow to react, but change has begun.

India, however, has the advantage of possessing a dynamic and vital environmentalist movement (AGARWAL *et al.*, 1982). This is further blessed by having been endowed with an indigenous and widely accepted political philosophy dedicated to people's action for development. The last decade has seen both a revival of interest in decentralised Gandhian approaches to rural development and new successes for environmentalist groups practicing Gandhian methods. The techniques of *Sarvodaya* have begun to turn the tide against deforestation in the Himalaya of Uttarakhand. Sooner or later, groups modelled on the Himalaya's *Chipko Andolan* (MISHRA and TRIPATHI 1978) will get round to tackling the ravine lands. The ravinous badlands of Chambal and elsewhere, with their infestations of bandits (BALI, 1972a), have an emotional and media attraction not far short of that of the Himalaya.

Meanwhile, establishment soil conservationists continue to conduct solid, if rather piecemeal, research into the technical problems of ravine reclamation. TEJWANI *et al.* (1975) stress the importance of regulating land use. Their first reclamation priority is closure to grazing and other biotic disturbance. Part of the reason is to allow the recovery of vegetation. Overgrazing is a major problem on the common lands of India and, in many areas, deforestation and desertification is being abetted by this process. In arid Rajasthan, Acharya *et al.* (in JAISWAL *et al.*, 1977) report that 80–90% of the rangeland is degraded and current livestock fodder requirements are an eighth larger than the land's productive capacity. Simple closure of a tract of ravine land at Vasad, Gujarat resulted in a 35% increase in tree cover in just 5 years (SINGH and DAYAL., 1974 a, b, 1975; TEJWANI *et al.*, 1975). Similar results were obtained in an experiment at Kota in the Chambal Region (KAUL, 1962 a, b; VERMA *et al.*, 1969).

Closure to grazing can also reduce soil loss by more than 80% (MIRCHANDANI *et al.*, 1958) and increase the development of the grass root systems by up to 184% (PANDEY *et al.*, 1967). This, in turn, would help stop gully incision by increasing soil strength. GRAF (1979) models ravine incision as a cusp catastrophe where the axes are vegetation cover/strength and run-off erosivity.

PATNAIK *et al.* (1974) afforested a 2 ha, 20% slope catchment in the Chandigarh Siwaliks. This measure reduced surface run-off by 54% and reduced flood peaks by 57%. RASTROGI and SHARMA (1970) note that control of surface water-flow is also necessary to restrict gully headcut advance and permit vegetation regeneration. They recommend water diversion by the construction of terraces.

Ravine Reclamation Engineering

Reclamation engineering is founded on the premise that re-contouring the land will stop erosion. It ignores the fact that re-shaped land tends to be inherently more erodible than that which is undisturbed. Worse, engineering structures require maintenance, which is expensive. They also can be positively harmful if they are not maintained properly, which requires an unusual degree of community involvement and support. Further, engineering structures tend to have a life expectancy which rarely exceeds that of the problem they are intended to counter. ALI (1974) epitomises the engineering philosophy. He noted that losses of soil, soil nutrients and moisture are increased by slopes of only 1–2%. His solution: level all land in the slope range 0.5–3%. The Indian soil conservation establishment has developed a range of treatments which range from ploughing out for minor gully networks to more complex schemes involving gully plugging and the terracing of gully sidewalls (TEJWANI *et al.*, 1975, Table 6). Most of this work has been conducted at the Vasad research station in Gujarat (e.g. PRADHAM *et al.*, 1976).

In economic terms, the success or failure of a physical reclamation project can often be expressed in terms of water conservation. Bunds and check dams in the desert concentrate water and silt. At Vasad, Gujarat conservation measures reduced run-off from 35 to 27% of the rainfall. The increase in available water resulted in increased agricultural production, the value of which was one-tenth that of the whole treatment (SINGH and DAYAL, 1974 a, b, 1975; SINGH, 1976; KAUL, 1957).

Table 6. Reclamation recommendations (GUPTA and PRAJAPATI, 1983) (structural measures after closure to grazing)

1. Small gullies (less than 3 m depth. Clearing, minor levelling, contour bunds with piped outlets, earthen checkdam with masonry spillway. Earth bunds and checkdam to be protected by vegetation with (*Cynodon dactylon*) grass
2. Medium gullies (3–9 m depth). Clearing, levelling, bench terracing of side-slopes, plugging of tributary gullies, earthen and brick checkdam at 1–2 m vertical intervals. Structures to be protected by grassing
3. Deep gullies (more than 9 m). Peripheral bunding and diversion of water to a masonry spillway. (In areas like Chambal, where the rainfall is heavier, graded bunds are preferred (cf. DAYAL, 1975.) The object is to starve the gully of water. Lateral earthen bunds at 120–150 m intervals guard against breach of the contour bund. Bunds are protected by grassing (*Dichanthium annulatum*, *Cenchurus ciliata*, *Panicum antidotale* (PRAJAPATI *et al.*, 1982; SINGH *et al.*, 1969). Afforestation, preferably with local species: *Dalbergia sissoo* (slopes), *Dendrocalamus strictus* (Bamboo) and *Eucalyptus camaldulenis* (beds); also *Acacia* spp., *Albizzia lebbeck*, *Azadirachta indica* and *Tectona grandis* (MAJUMDAR *et al.*, 1962; TAMHANE *et al.*, 1964; GIDWANI *et al.*, 1967; SINGH, and MONAPPA, 1968; SINGH *et al.*, 1973, 1977; PRADHAM *et al.*, 1976; PRADHAM, 1979). Bamboo may prove the most useful tree crop (PURI and KHYBRI, 1975).

AHMAD (1957) reports from Attock District, Pakistan that plants grow more effectively on bunds (also VERMA *et al.*, 1978). KAMANNAVAR *et al.* (1977) believe that the increased productivity of grasses and firewood can be used to offset the expense of bunding and soil conservation work, but adds the caution that the life expectancy of bunds is only about 20 years. Further, bund systems require maintenance, which can cost as much as 1% of the initial investment each year (KAMANNAVAR, 1975).

Physical reclamation measures, then, are at best a debatable economic proposition (KAUL, 1962 a, b). At worst, they can be a disaster. FARMER (1974) cites a case from Malwa, Madhya Pradesh where the 'Mysore System' of bunding, designed for the permeable soils developed on the Archaen rocks of South India, was employed in a region of less permeable 'black cotton' soils. The result was overloaded bunds which burst, causing major erosion and destruction.

Ravine Afforestation and Agricultural Development

Frequently, the best use for ravine-lands is to retire them from grazing and cultivation to grassland, or, better still, forest, and that "this is a must for deep and narrow ravines . . . throughout India" (TEJWANI *et al.*, 1975). In spite of this, India really cannot afford to retire much land from economic production (KAUL, 1962a, 1963; BALI, 1967/1968, 1972a, b, c; PRAJAPATI *et al.*, 1972). Ravine afforestation projects have a long-standing pedigree in India. These are the preference for economically useful tree species and for the development of food and fodder reserves. The 'Fisher Forest' project of Etawah, U.P. was undertaken in the late Nineteenth Century. The Gwalior ravine lands of Madhya Pradesh were forested in the early Twentieth Century. Today ravine land afforestative reclamation research continues at the Soil Conservation Centres at Vasad (Gujarat), Agra (Uttar Pradesh) and Kota (Chambal area of Rajasthan). (BHIMAYA and KAUL, 1960; BHIMAYA and GANGULI, 1964; JALOTE and MALIK, 1974; PRADHAM and VASAVA, 1974; PRADHAM *et al.*, 1976; PRAJAPATI *et al.*, 1968; PURI and KHYBRI, 1975; SINGH *et al.*, 1968 1969, 1977).

The report of the NATIONAL COMMISSION ON AGRICULTURE (1976) recommends the following species for forest, fuel and fodder development of steeply sloping ground, including river banks: '*ber*' (*Zizyphus* spp.), 'drum stick' (*Maringa pterigosperma*), '*khair*' (*Accacia cathechu*), '*sissoo*' (*Dalbergia sissoo*), '*siris*' (*Albizzia libbek*) and, possibly, bamboo (*Dendrocalamus strictus*) (KAUL, 1963). However, it is still Ministry of Agriculture policy that wherever possible, the ravine beds and adjacent table-lands should be reclaimed for agriculture. PRAJAPATI *et al.* (1974, 1975, 1978) have examined the problems of cultivating land reclaimed as level bench terraces within ravine channels. For a period of more than a decade, experiments have been undertaken on terraces constructed at Chhalesar in the Yamuna Ravine Zone near Agra. Early results (PRAJAPATI *et al.*, 1974) indicate that relatively large applications of nitrogen fertiliser were required to maximise the yields of rain-fed Karif Bajra (*Pennisetum typhoides*): 100 kg/ha was suggested. A decade or so later, the optimum treatment was found to be 80 kg/ha (PRAJAPATI *et al.*, 1975). More recently, however, the same research team has published the results of experiments with still lower applications of 50 kg/ha and less. They found that yields were greatest at the highest level of application (50 kg/ha) irrespective of the mode of application. Applications recommended by other workers in semi-arid north-west India have ranged from 50 to 60 kg/ha (PORWAL and MATHUR, 1973; RAM, 1973).

Research at the Soil Conservation Centre at Kota, in the Chambal ravine lands, has focused on the battle with waterlogging and salinity for agricultural development of the low-lying ravine beds. GAWANDE *et al.* (1980) have worked in an area adjacent to the Sultanpur Irrigation Canal. Here, seepage has created a high water-table. Open wells yield saline waters and salinity levels are increasing. The research workers have had some success with planting salt tolerant crops like IR 49 Paddy, *jaya*, *dhaincha* (*Sesbaina aculeata*), fig (*Ficus casica*), para grass and wheat. Experiments with *ber* (*Zizyphys* spp.) the date palm (*Phoenix dactylifera*), *Dendrocalamus strictus* and several fruit species have proved unsuccessful (VERMA *et al.*, 1978). *Ber* (*Zizyphys* spp., including *Z. mauritania*), however, is one of the most hardy fruit trees of India's arid ravine lands and it is both cultivated and grows wild in many areas. The problem with the species is its poor germination rate. PURI *et al.* (1976) have found that they can increase germination from 40 to 86% by soaking the seeds for a few minutes in sulphuric acid.

It is within the wild-plant communities of the ravine lands that many of the most useful reclamation species may be found. SAJWAN (1976) has reviewed the dominant species and their associate species in the Yamuna ravines *Dichanthium–Denchrus–Elyonurus* grassland. TEJWANI *et al.* (1975) have published details of the specific soil-holding properties of such species (see also SRINIVASAN *et al.*, 1962, 1970).

Ravine Reclamation as Applied Social Science

The worst enemies of soil conservation are ignorance and poverty. A problem which is not perceived is an impossible problem to cure. There can be few soil conservationists who have escaped that first great trauma which results from the realisation that the intended client does not believe that he has a problem.

While there is a relatively high degree of soil conservation consciousness in India, problems of poor perception are still widespread. CHAUHAN (1958, 1966), who worked at Chhalesar, Agra District, U.P., ranks as one of the few who have attempted to look at farmers' attitudes to ravine and gully erosion. Presently, two-thirds of Chhalesar village's area is ravine land and associated gullies. In places the ravines are up to 15 m deep and wide enough to allow cultivation in their beds. Land-use statistics, compiled from map data, chart a steady decline in the agricultural base. Between 1385/1886 and 1955/1956 the cultivated area declined from 53 to 37%. Records for the period 1922/1923–1955/1956 show a 45% decline in the area double cropped and a general reduction in crop yields.

CHAUHAN (1966) described the progress of environmental decline. Sheet erosion was not perceived by local farmers. Even small incisions and rills, as long as they could be obliterated by tillage, were treated as matters of no concern. Gullies

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received attention only when they became large enough to hinder agricultural operations but, in general, were then too large for the individual farmer to remedy. The loss of the land was reconciled as 'providential'.

Attitudes of fatalism or carelessness are often reinforced by land tenure factors. Many farmers are tenants for (often) absentee landlords. The land does not belong to the farmer who, in turn, is unlikely to worry about the state of another's property. Land holding problems also work against remedial soil conservation works. Tenant farmers are frequently reluctant to work on land improvement when the main end result will be that landlords will increase the rent. RUTTER (1984) reports a typical instance from Andhra Pradesh. Here a non-government development agency planted a small demonstration farm forest in a seriously deforested region. The response of the landowner was to triple the rent.

Y. P. SINGH (1961) examined farmers' attitudes to soil conservation work in the Chota Nagpur area, Bihar. Here poor attitudes were correlated with ignorance, illiteracy, poverty, small and scattered land-holdings and lack of credit facilities. PILLAI and NAIR (1978), working in Trivandrum District, Kerala, confirm that the farmers least willing to accept the necessity for soil conservation work tended to be older, poorer, less educated and less 'socially active' than average. SINGH (1961) confirmed that the prevalence of share cropping inhibited the acceptance of soil conservation measures, as did village factionalism, notably the friction between high and low caste.

TAMHANE (1964, 1968) stressed that community involvement is essential for successful reclamation. The British-sponsored Indore Dry Farming Project paid lip service to the ideal by involving local cultivators as paid labourers in their reclamation schemes. TAMHANE (1964) prefers that peoples' co-operatives and village panchayats should control the reclamation process. In practice, however, this does not get around the more serious problems which are built into the social and land-holding system.

Sarvodaya workers have long recognised that a more radical change is needed. Acharya Vinoba Bhave is associated with the bravest and most revolutionary approach to the problem through his campaign for *Bhoodan*, or land gift, and *Gramdan*, collective village living (DOCTOR, 1967). In the *Gramdan* village each man contributes his possessions to the village and continues to work according to the best of his ability. Each is asked 'to live in order to help others live'. The concept seems hopelessly romantic from a Western viewpoint. However, it makes a great deal more sense to the religious Hindu, where spiritual wealth is considered better than material wealth and renunciation is part of the life duty. The Sarvodaya philosophy appeals to the thoughtful and the educated, and it insists on leadership by example. Still, given the entrenched nature of the caste system and natural human possessiveness, what is really surprising is that voluntary *Gramdan* collectives have evolved in some village. The fact that some exist, of course, lends tremendous moral leverage to the Sarvodaya movement as a whole. Gandhian revolution thrives through moral pressure. Today this whole movement is undergoing revival and the seeds for future success in rural development and reform are sown.

Certainly, long-term success in soil conservation, as in all aspects of rural development, requires a radical re-orientation of rural attitudes. In the United States soil conservation extension has been successfully promoted by subsidised self-help and encouragement, but in India too many cultivators are too poor for this to be a wholly realistic option. BHATTACHAJEE (1965, p. 212) was of the opinion that in India, the state will have to play a central role in the instigation, financing and execution of projects. The government will have to bear the brunt of the cost, at least in the short term, in the name of future national prosperity. The NATIONAL COMMISSION ON AGRICULTURE (1976, pp. 268–269) advises that the preservation of the nation's economic base is a duty for central government to be executed by loans to state government and subsidies for appropriate projects. It is noted that ravine reclamation requires the treatment of the whole of the affected catchment and that it presupposes the existence of technical, financial and practical aid by local government, an appropriately educated farming community and a spirit of co-operation amongst the rural population (TAMHANE, 1966). Perhaps the inspiration that is needed to turn rural development into a self-reinforcing process is a policy which causes resources to be concentrated, conspicuously, in rural areas which have independently demonstrated their willingness to reshape their village economy and who are prepared to make themselves responsible for the necessary work. Recent experience in social forestry lights the way (MISHRA and TRIPATHI, 1978).

Discussion and Conclusion

India is engaged in a most serious struggle with environmental decline due to ravine and gully erosion. The NATIONAL COMMISSION ON AGRICULTURE (1976, pp. 191–192) notes:

> The problem of ravines has assumed urgency because they are fast spreading into cultivated lands . . . This deterioration has not only affected agricultural land but also habitations, roads, railways, and other public properties. The other problem is the presence of anti-social elements in the ravines which provide escape-routes and hideouts for dacoits [bandits]. The active erosion problem in ravine lands needs to be seen in the background of economic loss. It has been estimated that the production potential of ravine areas in Uttar Pradesh, Madhya Pradesh and Rajasthan alone would amount to 3 million tonnes of food grains annually. In addition, fruit, fodder, fuel, timber and industrial raw material could be produced.

This paper has attempted to outline the work of India's soil conservationists and other applied scientists towards ravine reclamation. It is a small group, perhaps dwarfed by the enormity of the problem, yet this small cadre of scientists has produced sound criteria for the management of the physical problems and has made great progress towards controlling their physical causes. Unfortunately, ravine erosion, ravine management and ravine reclamation are all, in part, social problems. It is in the study of the social problems of ravine management that the Indian research effort faces most problems. CHAUHAN (1966) has shown how the peasant farmer can become an accomplice to the destruction of his own land. In many instances this situation is exacerbated by the patterns of land-holding and privilege within the country. Many farmers are tenants who pay high rents for their land. If their land is improved by reclamation, these rents will rise and, for the tenant, the stakes are raised in the annual gamble of agricultural production, perhaps to unacceptable levels. If the land is being destroyed by erosion, then that is not the tenant's worry. Let the land-owner pay to stop the gullies if he cares!

Most of India's farms are small and land fragmentation continues with the expansion of population. SWAMINATHAN (1982) notes that in such circumstances, where the net 'take-home' income of the farmer is very small, the risks become correspondingly high as input costs rise. SWAMINATHAN (1982) adds "Since there is no crop insurance worth the name and since farming is the riskiest profession in the world, the poor farmer will not be able to derive benefits from the new technology . . . if the price is kept high". There is a great need for more applied research into the development of procedures to overcome the problems due to land fragmentation, patterns of land tenure and the problems of conservation technology financing within the agricultural community. In this, the works and ideas of Gandhian non-government organisations may have a leading role to play.

Is India winning the war against the depredations of its ravines? During India's first four Five Year Plans (the period between independence and 1971) ravine reclamation works were attempted on just 49,000 ha. Ninety-two percent of this area was reclaimed by afforestation while 7.8% (3880 ha) were returned to agricultural production (NATIONAL COMMISSION ON AGRICULTURE, 1976, 17.2.25, p. 193). No-one appears to have published a critique of the success or otherwise of these projects, though there are rumours of some upsets; and, indeed, it would be amazing if this were not the case.

What is certain, however, is that India's ravines have continued to grow, and that in each decade have added about 1% of their total area. In the first two decades after independence land reclamation work tackled an area equivalent to perhaps two-thirds of that newly claimed by the ravines. At that stage, the battle was clearly being lost.

During the 1970s India's ravine-lands will have added perhaps 37,000 ha to their area. However, in 1972 India launched its 7-year Plan for Ravine Reclamation (MINISTRY OF HOME AFFAIRS, 1972). This time, more than 1.1 million ha of ravine-land in Uttar Pradesh, Madhya Pradesh and Rajasthan have been scheduled for reclamation. The plan includes the ambition to reclaim 55,000 ha for agriculture, 27,500 for horticulture and provides for afforestation and the treatment of table-lands on the ravine margin. No-one has yet reported the final results of this project (cf. SHARMA, 1980). However, it may be that India is beginning to turn the tide of battle.

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