Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation
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CHANGING PATTERNS OF EROSION IN A PERI-URBAN CATCHMENT, MASERU, LESOTHO

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ABSTRACT The Maqalika catchment on the periphery of Maseru, has been subjected to rapid and ill planned urban development, since the 1970s. The catchment is badly eroded, with an estimated sediment yield of 18.1 t ha^{-1} $year^{-1}$ for the five years since 1983. The erosion and land use history of the catchment was reconstructed using sequential aerial photography of 1961, 1979 and 1985, orthophoto maps and field surveys. A hand factor analysis was performed to determine the dominant factors or factor combinations influencing erosion at each date. Whilst soil erodibility persisted as the dominant natural factor, road density and housing density became increasingly important as urban development ensued. The effects of urban development on sediment sources, transport mechanisms and sediment sinks is discussed with a view to promoting sound control related to the realities of peri-urban development typical of developing countries such as Lesotho.

INTRODUCTION

Urban areas have been recognized as significant sources of sediment for more than twenty years (Wolman, 1967; Walling & Gregory, 1970). The conversion of land from rural to urban use modifies the land surface and hydrological characteristics, initiating erosion locally and increasing sediment yields from the urbanized area. The effect of urbanization on runoff and sediment yield varies as urban development proceeds (Douglas, 1983), whilst the degree of erosion and sedimentation also reflects the effectiveness of planning controls designed to mitigate degradation.

Studies of urban sediment problems have focussed mainly on western cultures where urbanization is planned. In many developing countries the problems are exacerbated by lack of planning controls and poor development of an infra-structure designed to alleviate sediment problems. Unplanned roads and road drains and a high density of footpaths are examples of features which promote erosion and sediment movement in these areas.

The present study describes changing patterns of erosion in a small catchment experiencing rapid and ill-planned urban residential development on the outskirts of Maseru, the capital of Lesotho (Ntsaba, 1989). Soil erosion research in Lesotho to date has focussed on rural areas where problems are related to agricultural activities. However, the exploitation of land for agricultural purposes has decreased, with a subsequent increase in urban residential land use. The study thus serves to draw attention to the changing nature of erosion as society changes, in particular the increasing importance of urban development and settlement evolution as factors influencing erosion.

TABLE 1 Erosion classes adapted from the sarccus classification.

EROSION CLASS	DESCRIPTION	SARCCUS EROSION CLASS
1	No erosion	S1
2	Slight sheet erosion without rilling	S2
3	Severe sheet erosion with slight rilling	S2R2 S3R2
4	Severe sheet and rill erosion without gullying	S3R3 S4R3 R4R4
5	Sheet and rill erosion with low density first order gullying (extension of gully network)	S2R2G2 S3R2G2 S4R2G2 S4R3G2 S3R3G2 S4R4G2
6	Sheet and rill erosion with high density second order (and above) gullying (incision of gully network)	S3R2G3 S3R3G3 S4R2G3 S4R3G3 S4R4G3 S4R3G4 S4R4G4

THE STUDY AREA

The Maqalika catchment is situated on the outskirts of Maseru and drains into the Maqalika Reservoir which was completed in 1983 (Fig. 1). This reservoir acts as a trap for sediment originating from the catchment which has an area of 11.04 km and a relief ranging from 1500 to 1820 m. The geology comprises shales, sandstones and siltstones of the Stormberg Series (Stockley, 1947). The Cave sandstone formation forms scarps bordering the upper plateau whilst Red beds and Molteno formations underlie the lower slopes. Soils are mainly duplex and semi-duplex, ranging in erodibility from 0.24 to 0.79 (k factor (Conservation Division Team, 1979). The mean annual rainfall is 682mm, and comprises high intensity short duration thunderstorms, occurring in the summer. The natural vegetation, Themeda grass, has been removed by urban development which has been extensive since about 1976.

The residential development and growth are unplanned, with planned development being hindered by the unauthorized and arbitrary building in the area. Few roads are tarred, unplanned earth roads have developed from farm tracks, while storm water drains and road ditches are largely unlined and badly designed. Footpaths are common along roads, across

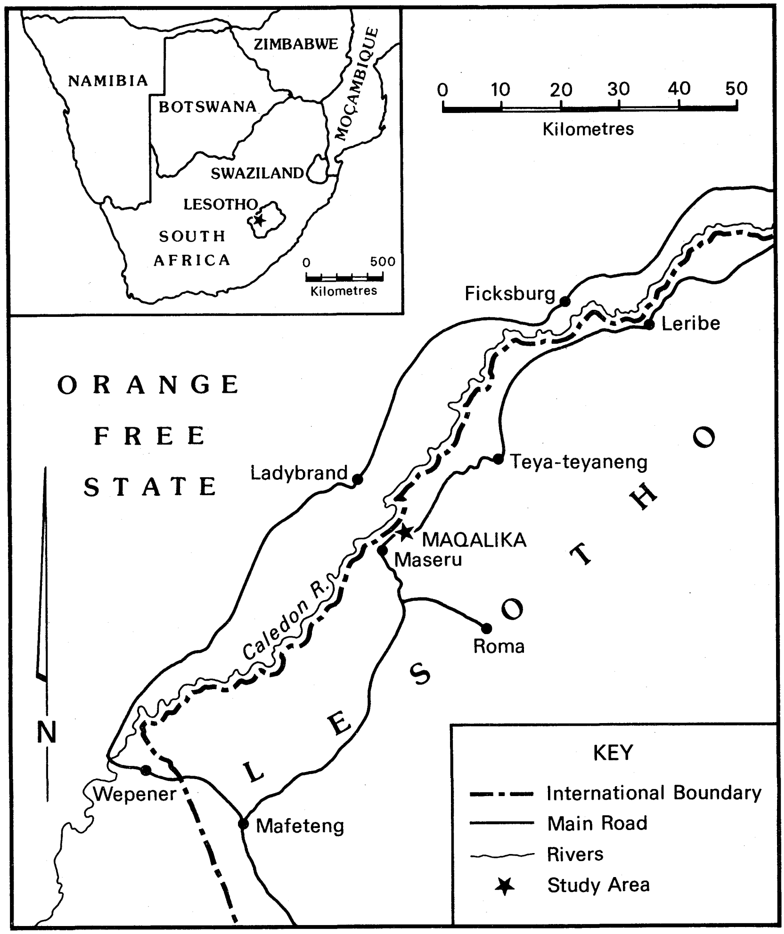

FIG.1 Location of the study area.

unfenced areas and around public amenities such as communal taps and boreholes. Extraction of raw materials in the form of quarrying, sandstone crushing and borrow pits for brick-making add to the disturbance of the land surface and provide local sediment sources.

The absence of planning control in this area can be related to the lack of both political will and an effective administrative structure. Although the Land Act of 1979 was designed to create orderly urbanization, it was opposed and ignored by the local chiefs who lost their powers to allocate land. The resulting development was both illegal and unregulated. The 1980 Town and Country Planning Act did little to improve the situation due to lack of resources, skilled manpower, finances, and the absence of local authorities who would prepare and enforce the plans.

METHODOLOGY

The net sediment yield from the catchment for the years 1983 to 1988 was determined from reservoir survey data. The present study employs a bathymetric survey of the Maqalika reservoir based on methods described by Rausch & Heinemann (1984). The initial reservoir capacity was determined by applying to pre-construction orthophoto maps the area-depth integration technique of Linsley & Franzini (1972); the 1988 capacity was similarly determined using a contour map derived from field transects of the reservoir. The difference between the original capacity and that for 1988 gave the capacity loss which can be equated to the volume of deposited sediment. Sediment bulk density, estimated from its particle size distribution and reservoir operational characteristics (Braune, 1983), was used to convert sediment volume to the sediment mass derived from the catchment for the five year period.

Catchment sediment yield does not give a direct measure of catchment erosion rates due to the complex interplay of sediment sources, transfer mechanisms and sinks which determine the sediment delivery ratio (Lunden *et al.*, 1986). Furthermore, sediment yield does not show the spatial distribution of erosion within the catchment. The major part of the research reported in this paper was therefore directed at mapping the distribution of erosion by type and degree at three different dates in relation to contemporary land use change.

The catchment was surveyed using black and white panchromatic aerial photographs for 1961, 1979 and 1985. Aerial photo interpretation was followed by ground truthing and aided by a series of aerial oblique photographs. Erosion was mapped at each date using the system developed by the Southern African Regional Commission for the Conservation and Utilization of Soil (SARCCUS, 1981). The observed SARCCUS classes were further grouped into six erosion classes (Table 1).

Variables used to explain the temporal and spatial changes in erosion were geology, slope class and soil erodibility (time independent), land use and road density (time dependent). The first three variables were extracted from published maps, land use and road density were mapped off the aerial photographs for the three dates. A rainfall erosivity factor was not included because no measure of its spatial variability was available.

A non-parametric hand factor analysis (Potter & Coshall, 1986) was applied to data obtained at each date to determine the relationship between erosion distribution and the erosion causing variables. It has been noted that erosion is not necessarily controlled by individual variables, but by a combination of interrelated variables acting together (Stocking, 1972). The use of hand factor analysis enabled these inter-correlations to be related to the erosion distribution. Full details of the procedure are given in Ntsaba (1989). An assessment of present day sediment sources, sinks and transport pathways was made from the 1985 aerial photographs supplemented by field surveys. Each erosion unit identified on the aerial photographs was described in terms of physical characteristics, land use, SARCCUS soil erosion class, and sediment erosion, deposition and transport features. This information allowed an evaluation of the effect of urban development on erosion processes and sediment movement through the catchment.

DISCUSSION OF RESULTS

Sediment yield

The average sediment yield from the Maqalika catchment between 1983 and 1988 was estimated at 18.1 t ha^{-1} year. This is in line with previous estimates for the Lesotho lowlands which lie between 3.4 and 61 t ha^{-1} $year^{-1}$ (Chakela, 1981; Lunden *et al.*,1986), but are one to two orders of magnitude higher than available estimates for the geological erosion rate under similar natural environments (Murgatroyd, 1979). Human activities in the catchment therefore appear to have exacerbated erosion rate well above natural limits. Kirkby (1980 has recommended a maximum permissible soil loss value of 25 t ha^{-1} for construction sites. Given that 18.1 t ha^{-1} $year^{-1}$ is an under estimate of on-site erosion rates, rates of soil loss from urbanized areas in the Maqalika catchment are unacceptable.

Erosion and land use history

The distribution of erosion by type and degree for the three dates is shown in Fig. 2. Erosion features identified in the catchment were sheetwash, rills, gullies and pipes. All parts of the catchment were eroded to varying degrees throughout the three study periods, save for the airport and sportsground, but the degree of erosion has increased through time. Sheet erosion was widespread throughout the catchment at all dates, but was most pronounced on the upper plateau, the footslope pediments, formerly cultivated land in the valley bottom and homesteads and communal taps. Rill erosion tended to be associated with intense sheet erosion and was concentrated along footpaths, downslope of roads and around homesteads. Gully erosion was concentrated on the valley bottom colluvium and on the steep bedrock slopes. Pipe erosion was often associated with the gullies and is not shown separately on Fig. 2. The main gully network was initiated prior to 1961, since when headward extension of main gullies has been resisted due to bedrock near to the surface. Gully erosion since 1961 has been largely through the erosion of tributaries or lateral erosion and widening of existing gullies. The change in erosion distribution is closely associated with changes in land use (Fig. 3). In its rural condition of cultivation, grazing and traditional low density settlements the catchment exhibited low intensity erosion. The period 1979 to 1985 was marked by a drastic decrease in cropland, which coincided with the period when the population was doubled, and there was a 'scramble' for residential land. Initially, grazing land decreased, but, by 1985, grazing land increased replacing former cropland.

The relationship between the spatial distribution of erosion and land use change is shown by the results of the hand factor analysis. This was used to identify variable groupings which are spatially associated with the mapped distribution of erosion classes. A number of trial factors can be derived for each date, but for simplicity Fig. 4 shows the results of the first trial only. This isolates the factor with the highest explanatory significance.

Results from the 1961 analysis show that the dominant erosion classes are 2, 3 and 6 as defined in Table 1. These erosion classes can be related through the first trial factor to the following catchment characteristics: Red beds, low slope class, moderate slope class, high erodibility, cropland and low road density. The key variables promoting erosion are probably cropland and high erodibility; geology probably indirectly effects slope class and soil erodibility while slope class, in turn, will influence the distribution of cropland. Low road density probably is characteristic of cropland and therefore is incidental.

In 1979, the dominant erosion classes were 3, 5 and 6, indicating a shift from a relatively low erosion status to a higher status which combines rill erosion with both gully network extension and incision. The trial factor responsible for this erosion distribution is associated with the following catchment characteristics: Molteno Formation, Red Beds, high erodibility, grazing, medium density housing, high density housing and high road density. The influence of urban features in promoting erosion at this date is clear.

In 1985, the dominant erosion classes were again 3, 5 and 6, but the relative degree of domination by classes 5 and 6 had increased. The observed erosion distribution was associated with the following catchment characteristics: Molteno formation, high soil erodibility, low and medium density housing, and high road density, whilst there was a negative association with low erodibility and low road density.

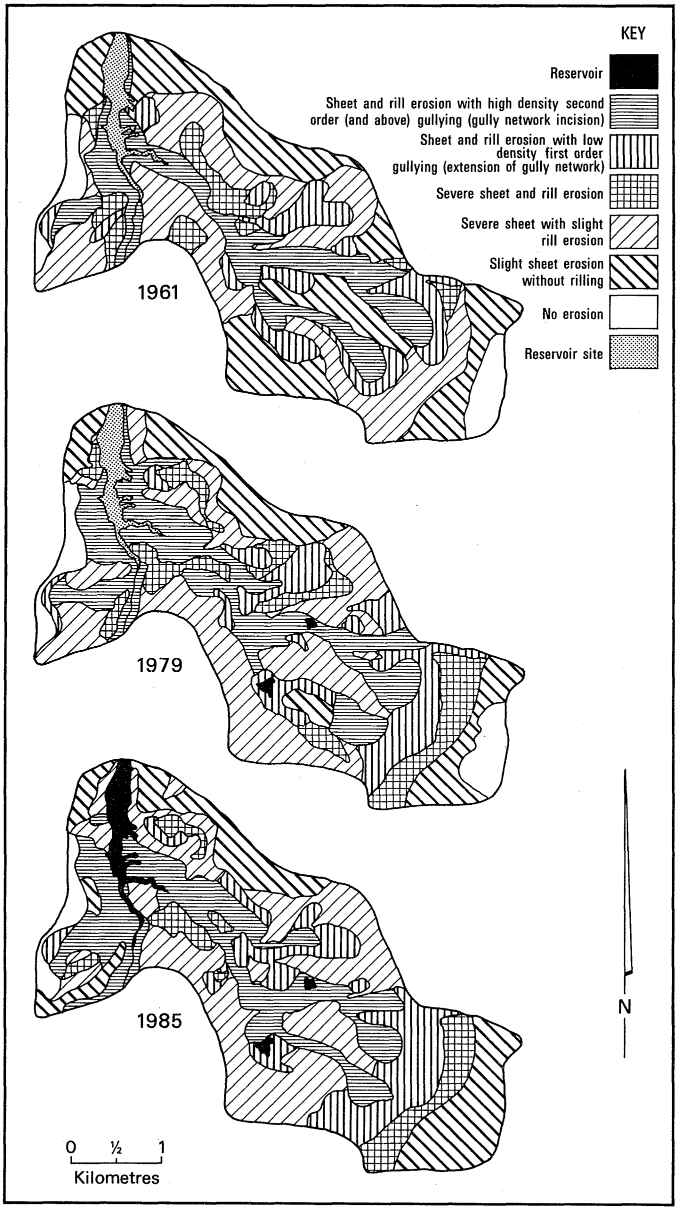

FIG.2 Distribution of erosion by type and degree, 1961, 1979 and 1985.

Of the natural, time independent catchment variables, soil erodibility and geology persisted as erosion promoting factors at all dates. The significance of a high soil erodibility is obvious. Geology may act both through its effect on soil erodibility and its spatial coincidence with erosion promoting land uses in the lower parts of the catchment: cropland in the first instance and urban development in the second and third.

Indices of urban development include housing density and road density, both of which

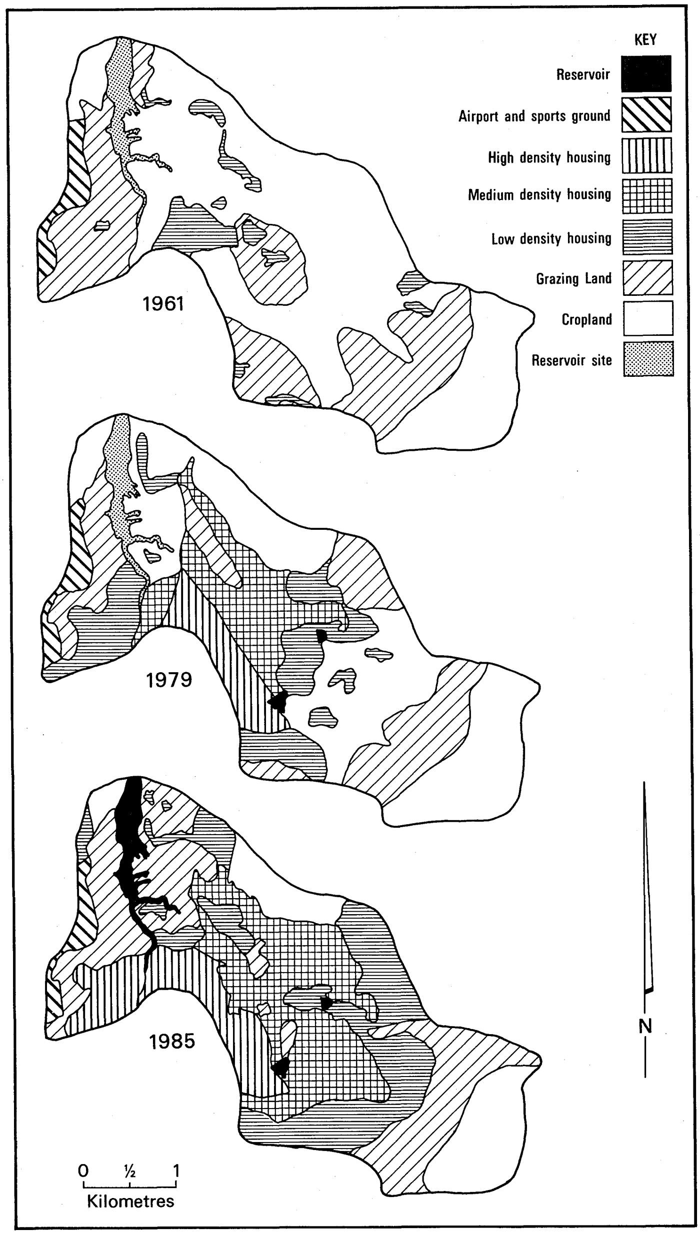

FIG.3 Catchment land use 1961, 1979, and 1985.

become important variables in 1979 and 1985. The effect of housing development varies between the two dates. In 1979 both medium and high density housing were associated with severe erosion, whereas in 1985 low density housing becomes important whilst high density housing no longer contributes to the first trial factor. Construction activity probably plays an important part in inducing erosion. It is a short term, high intensity activity that changes location, being most pronounced in the early stages of site development. It is pos-

		1961	1979	1985
Soil erodibility	low			0
	medium			
	high	■	■	■
Slope gradient	low	■		
	medium	■		
	high			
Geology	Molteno f.		■	■
	Red beds	■	■	
	Clarence f.			
Land use	grazing land		■	
	cropland	■		
housing:	low density			■
	medium density	n.a.	■	■
	high density	n.a.	■	
Roads	low density	■		0
	medium density			
	high density		■	■
Airstrip				
Dominant erosion class		2 3 6	3 5 6	3 5 6

■ positive association
0 negative association
n.a not applicable

FIG.4 Results of the hand factor analysis showing which catchment characteristics contributed significantly to the observed erosion distribution in each year.

sible that the present high density settlements were in the process of construction in 1979; by 1985 construction had stabilized. Thereafter construction activity and associated erosion problems were transferred to lower density settlements. Recognition of the changing location of construction activity is important therefore to the application of erosion control measures which should be applied both where and when they are needed, that is in phase with construction activity.

Medium and high road densities are seen to promote severe erosion following urban development. As noted above, unpaved roads and poorly designed road drains are prime sites for rills and gullies. Road erosion becomes especially pronounced on duplex soils whose sub-strata are vulnerable to undercutting.

As early as 1954 the problem of roadways and footpaths in Lesotho was recognized by Sheddick (1954): "there exists a virulent form of erosion which occurs all over the country. It may generally be ascribed to 'public convenience'. Under this head, by far the most destructive item is roads. In time these earth roads and paths become too deep for comfortable use and the traffic moves further over on to the grassland. It is a common site to see metalled roads paralleled by a dozen or more such tracks, the oldest of which may already be erosion gullies" (Sheddick, 1954 pp 49-50).

As both road density and the traffic use increase with urbanization, the erosion associated with unplanned and poorly designed road development will be greatly exacerbated.

Sediment sources, sinks and transport mechanisms

Major areas of sediment production (sources) were identified as construction sites, road sides and surfaces, gully walls and sites for extraction of raw materials. Borrow pits used in brick making are a particular problem. Although they cover only a small area of the catchment, their impact as sediment sources is substantial. The brick making area is severely eroded and has turned into a badland. The absence or removal of vegetation from these sites further elevates their potential as sediment sources.

Major sediment sinks are gully bottom fills in the lower reaches of the gully system, reservoirs constructed along certain channels, stockwatering ponds and depositional areas at slope breaks. Off-channel sinks are not as extensive as sinks that occur within channels and reservoirs. Two reservoirs constructed as sediment traps on the two main channels no longer act as sinks as they are almost filled with sediment.

Transportation of sediment from sources to sinks follows three routes. Firstly there is off-channel transportation whereby sediment is entrained by overland flow. Secondly there is transportation within discontinous channels that link sources to local sinks. Thirdly there is transportation in continuous channels such as gullies and road drains which are directly connected to the drainage network delivering sediment into Maqalika reservoir. The upper reaches of the gully system have been found to be the most efficient form of transport, while the lower reaches are poor transporters. The dense road network in the valley bottom, however, enhances the efficiency of the lower gully reaches. Thus although much of the eroded sediment does not at present reach the catchment outlet due to deposition in gully bottom fills, urban development and its associated structures, may reactivate the sediment and enhance transportation in the near future.

IMPLICATIONS FOR SOIL CONSERVATION AND SEDIMENT CONTROL

It has been demonstrated that the distribution and intensity of erosion changes through time as urbanization proceeds. The construction phase has been identified as a critical period when erosion and sediment control measures should be most carefully applied. Roads and their associated drains and culverts are seen as a persistent problem acting as both sediment sources and transport Pathways. Construction techniques and road alignment both need to be addressed. Extraction sites for raw materials are further source areas for sediment. Legislation pertaining to control of excavation and land restoration is required for brick making and quarrying. Control measures are clearly needed to alleviate problems of erosion and sedimentation, but their application is complicated by the fact that the development of sites is illegal and unrecorded in land planning projects. The socio-economic consequences of erosion and sedimentation must be made clear to both planners and developers so that the application of control measures is seen to be in their best interest.

Maqalika reservoir has an estimated life span of over 100 years given the continuation of the sediment input estimated for 1983 to 1988. This does not represent a significant problem. If, however, urban development acted to further increase erosion of the upper slopes, or to convert present sediment sinks to sediment sources through activation of gully floors, then the sediment yield could increase and significantly shorten the life of the reservoir.

Another concern is the effect of erosion on land values and development costs. Sheet erosion reduces the value of cropland and grazing land through loss of top soil. Sheet erosion was the dominant erosion form of erosion in 1961, constituting 65.7% of the catchment. The effect of urbanization has been to increase the area affected by gully erosion from 29% to 43% of the total catchment. Large gully systems deprive land of its value; severely eroded land requires methods of reclamation in the form of land levelling and revegetation, road maintenance costs are significantly increased.

A major cost of urban development is thus seen to be a degradation of land values through accelerated erosion. It is important that this cost be made known to land developers and urban residents so as to create the political will to encourage planned and orderly urban development.

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