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The distribution of erosion in the Mfolozi drainage basin – implications for sediment yield control

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Abstract The Mfolozi drainage basin covers 10% of the province of KwaZulu Natal. Its mean annual sediment load is extremely high and deposition on its flood plain during exceptional events has caused very serious financial losses. Poor land-use practices by peasant farmers in former KwaZulu "homeland" areas are generally perceived to be responsible for most of the sediment production from the basin. There is concern that this production will be substantially increased by land-use changes incumbent on the land redistribution programme of the post-apartheid government. This paper attempts to provide a preliminary assessment of the efficacy of a methodological approach used to identify land types which are inherently potentially major sediment sources and/or susceptible to erosion. A map showing the location of 19 categories of potential sediment sources was produced from extensive field surveys and air photo interpretation. The number of each of these sources within each of the 16 land types within the 43 sub-basins was recorded and correlated with the dominant biophysiographic variables of the land types. The method proved capable of identifying land types which are potentially susceptible to erosion and which should therefore not be allocated to land users lacking the technical and financial means to implement appropriate soil conservation measures. In order to identify major sediment production land types reliably, however, the method needs to be revised to include a system of weighting the spatial extent and production potential of the sediment sources.

INTRODUCTION

The most widely accepted estimate of the mean annual sediment load of the River Mfolozi, viz., 2.75×10^6 m^3 (Fleming & Hay, 1983), is extremely high. During the exceptional flood triggered by tropical cyclone Domoina in 1984, 80×10^6 m^3 of sediment was deposited on the flood plain (van Heerden & Swart, 1986) resulting in very serious financial losses as detailed by Watson (1993). Over a decade later the major sediment production areas of the drainage basin still await elucidation. As noted by Watson (1993), the most popular and persistent view is that poor land-use practices are primarily responsible for the overcrowded and overstocked former KwaZulu "home-

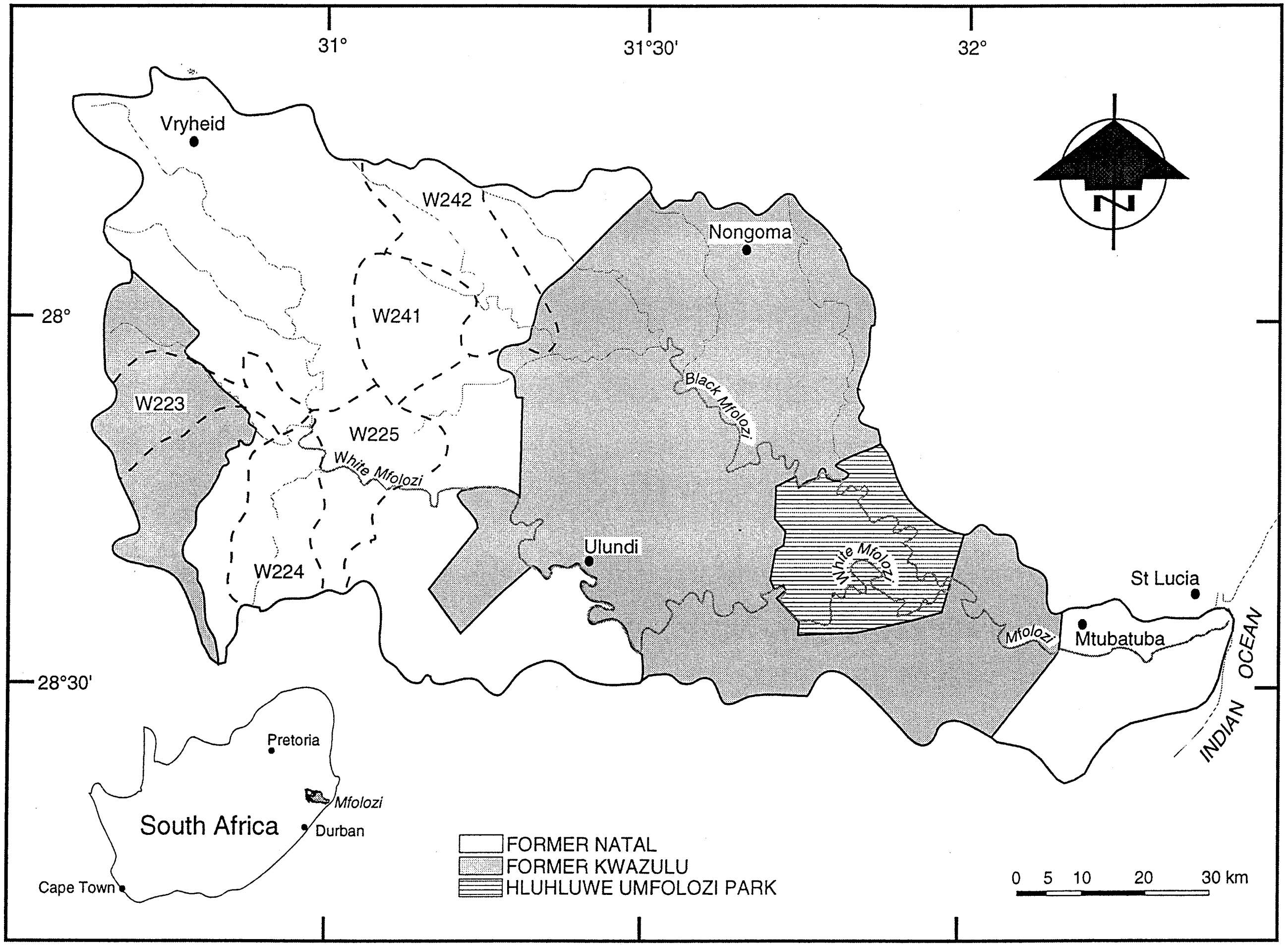

Fig. 1 The Mfolozi drainage basin.

land" areas being the principal source of sediment. The findings of Schulze (1981); Looser (1984 cited in Kovacs *et al.*, 1985); Looser (1985); Berjak *et al.* (1986); Liggitt (1988); and Liggitt & Fincham (1989) in former KwaZulu areas within the low lying region of the middle reaches of the basin, support this view. However, those of Looser (1985); Venter *et al.* (1989) and Watson (1990, 1996) in equivalent areas in the lower reaches, do not. The southern portion of the Hluhluwe Umfolozi Park is also located in the low lying region of the middle reaches of the basin (Fig. 1). While the findings of Stewart (1965); Mentis (1969); Porter (1972); and Smuts (1980) suggest that it is an important sediment production area, those of Venter (1988) and Watson (1990) indicate that this is unlikely. The sediment yield map of southern Africa by Rooseboom *et al.* (1992) depicts the upper, middle and lower reaches of the basin as having a predominately moderate, high and low yield potential, respectively.

Discrepancies in the findings reviewed above are no doubt due to the extreme biophysiographical diversity of the basin as well as variations in (a) the techniques used to identify and assess the severity of sediment production areas; (b) the type of source areas included in the studies; and (c) the size of areas examined. Watson (1996) found that settlement by peasant farmers in an area that had been virtually uninhabited for a long period, caused a dramatic 25 and 11 fold increase in eroding and sparsely vegetated surfaces, respectively. Faced with the imminent delivery of the land redistribution programme of the post-apartheid government, there is a very real and urgent need to identify land types which are inherently potentially significant sediment sources.

DESCRIPTION OF THE MFOLOZI CATCHMENT

Extending over 10 075 km^2 (Pitman *et al.*, 1981), the Mfolozi is the second largest drainage basin in the province of KwaZulu Natal. The White and Black Mfolozi rivers rise at altitudes of 1620 and 1524 m a.m.s.l. respectively in the northwest portion of the catchment and flow over nearly 400 km on their course to the Indian Ocean (Begg, 1988). The rivers converge east of the Hluhluwe Umfolozi Park (Fig. 1). At present three distinct categories of land-use activities are carried out in the basin, viz.,

(a) privately owned commercial farming in former Natal;
(b) subsistence use of communal lands in former KwaZulu; and
(c) wildlife conservation in the Hluhluwe Umfolozi Park.

The basin contains 11 physiographic, 14 geological, 11 soil, 10 vegetation and eight bioclimatic type categories as identified by Turner (1967, cited in Phillips, 1973); Kent (1980); Fitzpatrick (1978); Acocks (1988); and Phillips (1973), respectively. Given this very high land type diversity, the sediment production potential is obviously tremendously variable.

METHODOLOGY

Data obtained during extensive field surveys conducted and detailed by Looser (1988, 1989), and extracted from 1:50 000 topocadastral maps, 1:10 000 orthophoto maps produced from 1:30 000 aerial photographs taken in 1983 and 1:30 000 aerial photographs taken in 1986 were integrated to produce a 1:100 000 map showing the location of 19 categories of potential sediment sources over the entire drainage basin. The boundaries of the 43 Quaternary sub-basins delimited by Pitman *et al.* (1981), and the boundaries of 16 broad soil patterns delimited by Land Type Survey Staff (1986, 1988) were superimposed on this potential sediment source map. On the 1:250 000 land type series maps the coincidence of terrain form and macroclimate zone boundaries delimit land types within each broad soil pattern. As this research did not require such a detailed land type depiction, the broad soil pattern boundaries were accepted as land type boundaries. Data on the characteristic topography, geology and pedology, veld type, and bioclimate and land use of each land type were extracted from Land Type Survey Staff (1986, 1988), Acocks (1988), and Phillips (1973), Begg (1988) and Rooseboom *et al.* (1992), respectively.

The number of each of the 19 potential sediment sources present within each broad soil pattern within each sub-basin was recorded. The semi-logarithmic frequency distribution plot technique described by Fisher & Yates (1983) was used to verify the parametric nature of all data sets. The standard analysis of variance test was used to assess at a 99% confidence level, the significance of differences (a) between the 19 potential sediment source data sets and (b) between the 10 land type characteristic data sets. The absence of significant differences between several of the potential sediment source data sets enabled them to be regrouped into eight categories as follows:

(a) four gully length classes viz., < 125 m, 126-250 m, 251-375 m, 376-1375 m;
(b) unconfined erosion viz., sheet/rill erosion, cattle tracks and bare areas in loose material;
(c) mass wasting viz., stepped, slumped and slipped slopes;
(d) badlands viz., both active and inactive badlands; and
(e) mine dumps viz., mine dumps, sites excavated for fill material, waste disposal etc.

The standard Pearsons product moment correlation coefficient was used to measure the degree of association between the potential sediment source and land type characteristic data sets. As the number of inputs for each data set was in excess of 100, a coefficient of 0.19 was the threshold for significance at a 95% confidence level.

RESULTS AND DISCUSSION

This paper attempts to provide a preliminary assessment of the efficacy of the methodological approach described above in identifying the land types in the Mfolozi drainage basin which are inherently potentially significant sediment sources. In order to achieve this, the five sub-basins in which the highest overall density of potential sediment sources was recorded were analysed. As noted earlier, studies carried out in the drainage basin to date indicate that these sources are best represented in the former KwaZulu areas of its middle reaches. Indeed, this is also the casual visual impression gained from the data base map. Contrary to this expectation however, Fig. 1 shows that all five of these sub-basins are located in the upper reaches and only one of them falls in former KwaZulu.

The dominant biophysiographic characteristics of the five sub-basins depicted in Table 1 clearly indicate why they are potentially so susceptible to sediment production processes. Their very large altitudinal range suggests that both long and steep slopes play a significant role in these processes. According to Schulze (1985) and Rooseboom

Table 1 Dominant biophysiographic characteristics of the five Quaternary sub-basins with the highest density of potential sediment sources.

Number	W223	W224	W225	W241	W242
Name	Lower Mvunyana	Ntinini	Nsubeni	Hlonyana	Upper Black
Size (km^2)	320	300	355	340	415
Altitude (m a.m.s.l.)	1526-840	1598-780	1542-700	1524-564	1560-426
Annual rainfall mean (mm)	738	745	840	849	922
Annual rainfall range (mm)	900-600	900-600	1200-600	1000-700	1200-700
Mean annual runoff ($\times 10^6$ m^3)	17	16	31	30	53
Rainfall erosivity index (EI_{30})	601-700	601-700	701-800	>800	>800
Geology	Karoo dolerite & Dwyka tillite	Archaean granite & Dwyka tillite	Archaean granite	Dwyka tillite	Vryheid sandstone & Dwyka tillite
Soil uplands	Yellow & grey hydromorphic, mesotrophic sands & loams	Yellow & red apedal, freely drained dystrophic	Yellow & red apedal, freely drained dystrophic	Weakly developed (litho-cutanic B), plinthic &	Yellow & red apedal, freely drained dystrophic
Soil lowlands	Weakly developed (litho-cutanic B), red clays & duplex	Weakly developed sandy or plinthic	Weakly developed sandy or plinthic	some red-black clays & duplex	Weakly developed (litho-cutanic B) plinthic & red-black clays & duplex
Veld type	Natal sand sourveld	Highland sourveld & Dohne sourveld	Lowveld	Northern tall grassveld	Northern tall grassveld
Bioclimatic sub-region	Tall grassveld – drier fasciation	Tall grassveld – drier fasciation	Tall grassveld – drier fasciation	Tall grassveld – drier fasciation	Midlands mist belt
Formerly	KwaZulu	Natal	Natal	Natal	Natal
Land use	Subsistence use of communal lands	Unused – held in trust by Dept Land Affairs	Private & state owned *Pinus* & *Eucalyptus* plantations	Privately owned commercial cattle ranching	Privately owned commercial beef and maize farms

et al. (1992) respectively, their potential mean annual runoff and rainfall erosivity values are very high. It is interesting to note that with the exception of sub-basin W224, the order of increasing overall potential sediment source density in these sub-basins viz., W224 < W223 < W225 < W241 < W242 corresponds with the order of increasing altitudinal range, mean annual runoff and rainfall erosivity. According to MacVicar (1984), the most common soils represented in these sub-basins viz., yellow and red apedal freely drained sands and loams, red-black clays and duplex soils, are all highly erodible. All five sub-basins are predominately grass covered. According to Roux (1981), compared to woodland, grassland is more resistant to sheet erosion processes and more susceptible to gully erosion processes. Although seven bioclimatic sub-regions are represented in the upper reaches of the drainage basin, four of these five sub-basins occur within the drier fasciation of the tall grassveld which has a potential climax of mixed short thicket and woodland (Phillips, 1973). In his overview of the 11 such sub-regions in the province, Scotney (1978) rated this sub-region amongst the four most seriously eroded. It is unfortunately beyond the scope of this paper to assess the inherent potential susceptibility to sediment production processes of these five sub-basins, relative to that of the other 38 sub-basins in the Mfolozi basin. Suffice it to say that their altitudinal extent, potential mean annual runoff and rainfall erosivity are all substantially greater. Their geological, pedological, vegetal and bioclimatic characteristics are however, well represented elsewhere in the drainage basin.

The four land types in which the highest overall density of potential sediment sources was recorded and which were present in at least four of the five sub-basins, were analysed further. Their dominant biophysiographic characteristics and the densities of the potential sediment sources in them are shown in Tables 2 and 3, respectively. Significant correlations between the potential sources and the biophysiographic variables

Table 2 Dominant biophysiographic characteristics of the four land types with the highest density of potential sediment sources.

Land type	BA	CA	IB	EA
Proportion of sub-basin (%)	<10	<60	<20	<40
Mean range in slope length (m)	700-1700	300-3000	500-750	250-500
Mean slope shape	convex to concave	convex to straight	convex to straight	convex to straight
Mean range in slope angle (°)	2-5	5-10	10-25	5-10
Geology	Pietermaritzburg shale	Vryheid sandstone	Dywka tillite	Archaean granite
Soil	Doveton	Longlands	Mispah	Bonheim/ Glengazi
Most erodible soil series	Swartland	Longlands	Cartref	Rensburg
Veld type/s	Northeastern mountain sourveld	Natal sand sourveld Highland sourveld Dohne sourveld	Natal sand sourveld Highland sourveld Dohne sourveld	Lowveld Northern tall grassveld Natal sand sourveld
Bioclimatic sub-region	Midlands mist belt	Tall grassveld (drier)	Tall grassveld (drier)	Tall grassveld (drier)

Table 3 Density of sources in the four land types with the highest density of potential sediment sources.

Land type	Gullies: 1	2	3	4	Unconfined erosion	Mass wasting	Badlands	Mine dumps	Total
BA	0.66	0.10	0.14	0	6.23	3.5	0	0.25	10.9
CA	1.85	0.27	0.02	0.43	2.18	0	1.46	0	6.21
IB	3.08	0.18	0.09	0.02	0.49	0	0	0	3.86
EA	0.25	0.16	0.08	0.05	0.31	0	0.23	0	1.08

are shown in Table 4. Despite being the least susceptible of the four land types, type BA has the highest overall density of potential sediment sources. Its long, gentle slopes are covered by low to moderately erodible fine sandy clay loams. It is most susceptible to unconfined erosional processes which appear to be predominately regulated by the slope shape and vegetal cover. Mass wasting processes are only represented in this land type. In addition to vegetal cover, they appear to be regulated by substrate and slope length. Gullies are best represented in land type IB which is characterized by short, steep to very steep slopes covered by very highly erodible very shallow sandy clay loams. Although gullies are most dense, unconfined erosion and badlands are also well represented on land types CA and EA. Both have gentle to moderately steep slopes. The overall density of potential sediment sources in land type CA is, however, six times greater than that of EA. This difference may be explained by the fact that the slopes in land type CA are long and covered by very highly erodible sandy loams, whereas those of land type EA are short and covered by moderately erodible cracking blocky clays. Although potential sediment sources in CA, IB and EA are significantly associated with numerous variables, their coefficients are not strong enough to support speculation about the extent of their influence. There is obviously a high degree of multi-collinearity between them. In order to identify the variables regulating sediment production processes in these land types, a multiple regression analysis will be carried out as soon as use of a computer that can cope with this massive data base is secured.

The methodological approach used in this study has satisfactorily identified land types which are potentially susceptible to erosion. Such information is of value to the land redistribution programme as it indicates the potential on-site constraints of these land types e.g. land types heavily dissected by gullies pose a bigger constraint to peasant farmer use than those actively influenced by unconfined fluvial and/or mass sediment transfer processes. This approach however, has not reliably identified major sediment producing land types which have off-site as well as on-site implications. Land types with high overall densities of potential sediment sources or of particular categories of erosion cannot reliably be assumed to be major sediment production areas.

Firstly, only the number of each of the 19 potential sources present within each land type within each sub-basin was recorded. A land type for example, with one sheet/rill eroded surface covering a substantial portion of its area is obviously potentially a more significant sediment source than one with several small such surfaces. The method used overestimates the contribution of the latter land type, at the expense of the former. It therefore needs to be revised so that the number recorded is weighted to take into

Table 4 Significant correlations between sources and biophysiographic variables in the four land types with the highest density of potential sediment sources.

Land type	Potential sediment source	Slope length	Slope shape	Slope angle	Dominant soil	Erodible soil	Dominant geology	Least common geology	Veld type	Rainfall	Bioclimate	Land use
BA	Gullies 1	0.90	0.90		−0.44	0.24	0.47	0.80	0.93		0.91	0.47
	Gullies 2	0.47	−0.20	0.29	0.39	1.00	−0.38	0.55		−0.49		−0.34
	Gullies 3	0.88	0.92		−0.47	0.19	0.50	0.78	0.95		0.93	0.49
	Gullies 4											
	Unconfined erosion	0.71	0.99	−0.28	−0.62		0.64	0.58	0.99	0.25	1.00	0.62
	Mass wasting	0.93	0.75		−0.29	0.48	0.32	0.87	0.81		0.77	0.33
	Bad lands											
	Mine dumps	0.69	1.00	−0.29	−0.63	−0.20	0.65	0.55	0.99	0.27	1.00	0.63
CA	Gullies 1	−0.49			0.58					−0.31		
	Gullies 2		0.31									−0.23
	Gullies 3		0.30		−0.22	−0.56		−0.19				−0.28
	Gullies 4			0.64		−0.31						
	Unconfined erosion	−0.19		0.72		−0.30						
	Mass wasting					−0.42						
	Bad lands			0.62		−0.22						
	Mine dumps											
IB	Gullies 1	0.42	−0.32		−0.27	0.44		0.51	−0.35			
	Gullies 2		−0.23	0.24	−0.60		0.51		0.48		−0.24	
	Gullies 3		0.21	0.31	−0.49	0.21		0.32			0.22	0.37
	Gullies 4	0.31	−0.77		−0.61	0.61	−0.57				−0.45	
	Unconfined erosion			−0.29	−0.33	−0.40	−0.63	−0.66	0.54		0.32	−0.37
	Mass wasting											
	Bad lands	0.40	−0.34		−0.24	0.44		0.51	−0.39			
	Mine dumps											
EA	Gullies 1		0.26	0.38	−0.34	−0.27			0.23			−0.21
	Gullies 2	−0.19	0.19	0.44	−0.45		−0.20	0.44	0.23	−0.24		−0.26
	Gullies 3		0.24	0.35	−0.32	−0.31						
	Gullies 4				−0.20	−0.24		0.38		−0.27		
	Unconfined erosion			0.30	−0.26							
	Mass wasting				0.34	0.22						
	Bad lands	−0.35		−0.29				0.41		−0.28		
	Mine dumps											

account the proportion of the land type affected. Secondly, the level of accuracy with which these 19 potential sediment sources were mapped may have varied over the basin. The procedure commenced in the upper reaches where small sources were no doubt meticulously mapped. In the middle reaches however, such sources may have been overlooked because of their apparent insignificance relative to the generally much larger potential sediment sources. A sample transect of this map will need to be checked to establish if this is indeed a significant source of error and if so, a correction factor devised. Finally, the sediment production potential of the five groups of sources examined in this study obviously varies e.g. that of a terraced slope is much less than that of a sloped bare area in loose material. To derive the overall density of these five groups within a land type or sub-basin, they should not simply be summed as was done in this preliminary assessment. The density of each should be weighted to take into account their differing sediment production potentials.

CONCLUSION

The methodological approach used in this study has proved capable of identifying land types in the Mfolozi drainage basin which are potentially susceptible to confined and unconfined fluvial and mass sediment transfer processes. In order to identify those land types that serve as major sediment sources reliably, however, a system of weighting the spatial extent and production potential of the sediment sources needs to be devised. It is hoped that information gleaned from and discussions generated at this conference will indicate the best means of carrying out this weighting.

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