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MICHAEL MÄRKER (*), SANDRO MORETTI (**) & GIULIANO RODOLFI (*)

ASSESSMENT OF WATER EROSION PROCESSES AND DYNAMICS IN SEMI-ARID REGIONS OF SOUTHERN AFRICA (KWAZULU/NATAL, RSA, AND SWAZILAND) USING THE EROSION RESPONSE UNITS CONCEPT (ERU)

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Land resources management is becoming an important issue in regions affected by natural hazards. The sustainable development of land resources depends on the understanding of the processes and dynamics active within the landscape. In southern African countries soil erosion and the related problems such as water quality issues or decreasing soil productivity are the main problems affecting the inhabitants of rural and urban areas. Therefore increasing attention has been focussed on the problems related to soil erosion over the last few years. This can also be seen from the increasing number of erosion studies and the development and application of erosion models. This study deals with the identification of spatially distributed erosion forms and processes in the Mkomazi-river catchment (KwaZulu/Natal-South Africa) and the Mbuluzi-river catchment (Kingdom of Swaziland). The study was carried out within the framework of an interdisciplinary EU-funded Project aimed at developing an Integrated Water Resources Management System (IWRMS) for water resources analyses and prognostic scenario planning in semi-arid catchments of Southern Africa. Within this more general framework, a concept was drawn up, that integrates the information about the spatial and temporal distribution of soil erosion phenomena. Once the areas subject to different erosion processes and dynamics have been identified, this information can be used in the erosion modelling process, thus providing a fully distributed modelling structure. This structure consists of entities with the same behaviour in terms of their erosion process dynamics and therefore they are called Erosion Response Units (ERUs). Consequently the concept of Erosion Response Units can be utilized to identify the distribution of erosion processes in a river catchment and to model the different erosion processes active within the catchment. The examples from Southern Africa show the methods used to delineate these erosion response units. Furthermore the concept was successfully applied for modelling the soil erosion processes in the catchment.

KEY WORDS: Erosion Response Units (ERUs), Erosion, Erosion modelling, Regionalisation, Swaziland, Southern Africa.

INTRODUCTION

The study presented herein deals with the delineation of erosion response units in the Mkomazi-river catchment (KwaZulu/Natal- South Africa) and in the Mbuluzi river catchment (Kingdom of Swaziland) and is part of the interdisciplinary EU-funded project «Integrated Water Resources Management System (IWRMS)» for semi-arid catchments of Southern Africa. A central objective of *IWRMS* is to enable managers and decision makers to improve the regional strategic planning of catchment water resources by optimising water use, thus satisfying the demands of competing stakeholders while protecting water and land resources. Since soil erosion is directly related to water quality issues the erosion processes have to be considered in water resources management. Apart of the damages due to the sediments itself, such as reservoir sedimentation, the sediments are working as storage medium and catalyst for chemical, physical and biological pollution. Consequently the sediments in a river network are directly related to water quality.

The erosion processes and forms caused by water are mainly influenced and interlinked by the hydrological dynamics of a drainage basin. The response of three dimen-

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(*) *Dipartimento di Scienza del Suolo e Nutrizione della Pianta, Università di Firenze (Italia).*

(**) *Dipartimento di Scienze della Terra, Università di Firenze (Italia).*

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sional terrain units to erosion can be delineated by modifying the concept of areas with hydrological catchment response. Naturally this is only valid for erosion processes caused by water. The concept of Hydrological Response Unit (HRU) was applied by several authors in the past (see Beran & *alii*, 1990; Falkenmark & Chapman, 1989; Flügel, 1995, 1996; Plate, 1992, Bongartz, 1999). An innovative approach to characterize erosion processes caused by water and their integrated dynamics was introduced by Märker & *alii* (1999) and Flügel & *alii* (1999) with the concept of «Erosion Response Unit» (ERU).

In this study the ERUs are used on the one hand to identify areas subject to different erosion processes and dynamics and as modelling entities for erosion simulations on the other. Remote sensing techniques were applied to get information about the distributed physiographic and anthropogenic catchment characteristics (land use, settlements, digital elevation models, etc.). Furthermore this information was used for the parameterisation of the different erosion process models. Remote sensing techniques provide information which is normally difficult to obtain, especially in developing countries such as South Africa and Swaziland. By reclassifying and overlaying the relevant information layers, using GIS, one obtains Response Units, which take into account the physiographic and anthropogenic heterogeneity of the river basin. The response units have the same behaviour in terms of their erosion process dynamics and they are therefore called Erosion Response Units. In this way the different spatial and temporal scales of the erosion processes and dynamics are incorporated into the concept. Consequently the concept of Erosion Response Units can be utilized to identify the distribution of erosion processes and to model the different erosion processes active within a river catchment.

GENERAL FEATURES OF THE STUDIED CATCHMENTS

Physiography of the Mbuluzi river catchment

The Mbuluzi river basin originates in the Ngwenya hills in Swaziland and runs through the North-Central part of the country into Mozambique. It runs through all the physiographic regions of Swaziland and drains an area of about 3100 km^2, from the border with Mozambique upwards (fig. 1). The Highveld area (1066-1500 meters a.s.l.) is characterized by steep slopes with average gradients exceeding 18 percent. The Middleveld altitude ranges from 610 to 760 meters a.s.l. with median slopes of 12%. Gentle relief and median slopes of 3% were observed in the Lightveld (125-364 m a.s.l.). The mean annual rainfall ranges from 700 to 1200 mm (905 mm, Kwaluzeni), with the main rainfall in summer (October to March). Kiggun-

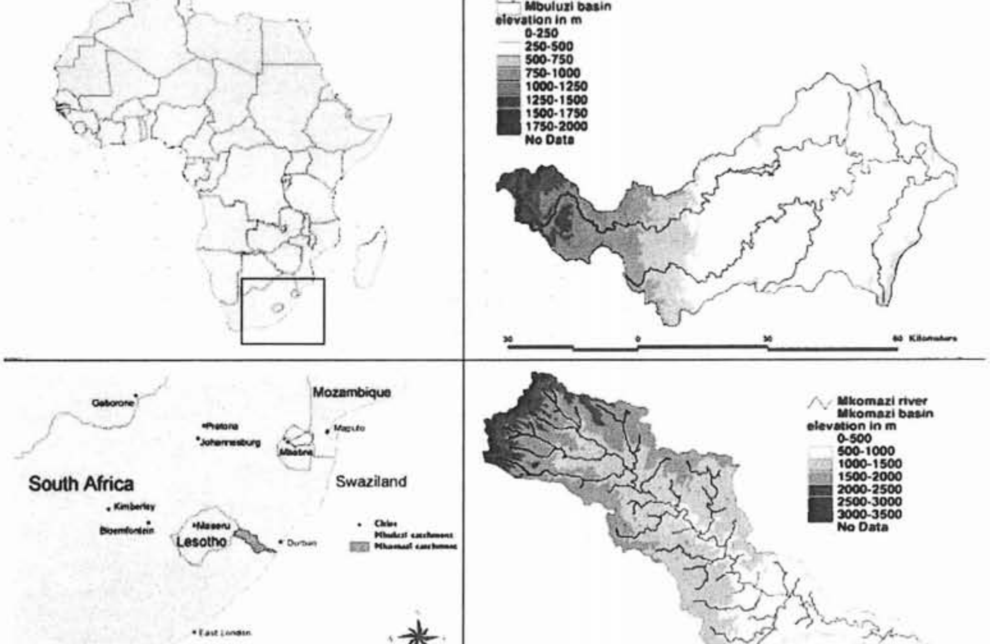


FIG. 1 - Location of the Mkomazi river and Mbuluzane river study catchments.

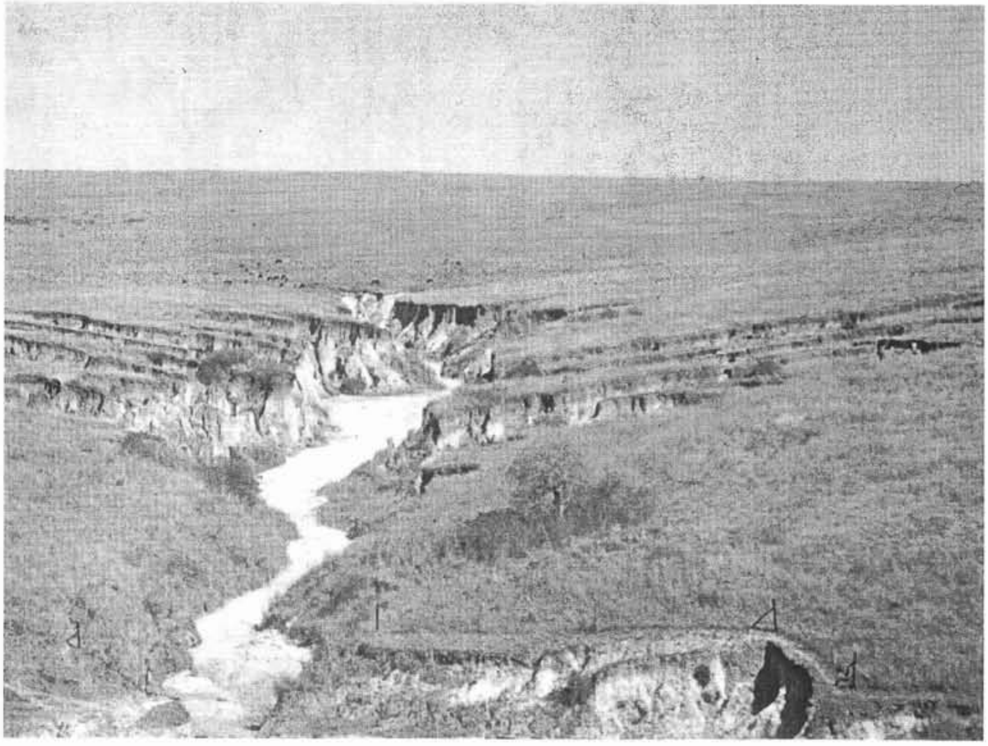


FIG. 2 - Mbothoma gully ca. 15 km north of Manzini (Swaziland) (Photo, Märker).

du (1986) calculated a rainfall erosivity (EI_{30}) of 450 kJmm/m hr (after Wischmeier & Smith, 1978).

Granites and some areas of precambrian sediments and volcanic outcrops dominate the geology of the upper Mbuluzi catchment. Granite and granitic gneisses with outcrops of dolerite and gabbro were found in the Middleveld. The Lowveld area is composed of sedimentary and volcanic rocks of the Karroo sequence.

The main soil types in the Highveld and Middleveld are deep, acid and well drained red and yellow ferrisolic and ferralitic soils, often with stone lines. In the lower Middleveld grey or red light textured soils from granite and gneiss were generally found. The Lowveld is characterized by weathered red, brown and black clays originating from basalt rocks (Murdoch, 1970). The land cover in the upper parts of the Mbuluzi river basin is mainly rangeland and bushland, with some small-scale farms and subsistence cultivations. Intensive sugar cane plantations dominate the lower part, with irrigation and bush lands in the Lebombo region.

The test catchments are drained by the upper Mbuluzane River (contributing area: 221 km^2) and the Mhlambanyoni River (contributing area: 42 km^2). Both rivers are tributaries of the Mbuluzi River (fig. 1). It is a densely populated area and overgrazing is widespread. The dominant land use on this subsistence/small-scale farming land is pasture. The lithology is composed of a thick granodioritic saprolite layer and a system of amphibolite and serpentite dykes (Felix-Henningsen & *alii*, 1993; Hunter & *alii*, 1984; Mushala & *alii*, 1994; Scholten & *alii*, 1995). Fig. 2 shows a deep gully developed in saprolite material in the Mbothoma area.

Physiography of the upper Mkomazi river catchment

The upper Mkomazi river catchment in the KwaZulu/Natal province (Republic of South Africa) stretches from the Drakensberg escarpment to the Indian Ocean. The sources of the Mkomazi river are sited at altitudes of approx. 3300 m a.s.l. in the upper Drakensberg area. The flow length is about 160 km from Northwest to Southeast. The mouth of the Mkomazi river is located 40 km Southwest of Durban. Tributary rivers in the upper part of the catchment are the Nzinga, Loteni, Mkomanzana and Elands rivers (fig. 1).

The Mkomazi river drains an area of about 4400 km and can be subdivided into four physiographic zones: i) the coastal lowlands up to 500 m a.s.l.; ii) the interior lowland area («middle berg area») from 500 to 2000 m a.s.l.; iii) the mountain area up to 2500 m a.s.l.; iv) the highlands, with elevations up to 3300 m a.s.l. However, the climatic conditions in the semi-arid catchment are characterized by high seasonality with dry winters and rainy summers. The mean annual precipitation varies between 1000 mm and 1800 mm in the upper Drakensberg down to values of less than 700 mm in the central areas, which are the most arid ones in the catchment (Seuffert & *alii*, 1999; Tyson & *alii*, 1976). The maximum rainfall occurs in the summer months, i.e. February and March. In the upper catchment the mean January temperature reaches 21 °C versus 24 °C on the coast (Durban). The monthly minimum temperatures vary between 10 °C in the «High Berg» area of the Drakensberg and 16,5 °C in the coastal parts. In the winter months, July to September, frost can occur especially in the mountain areas.

The geology of the Mkomazi river catchment is dominated by the Drakensberg escarpment (fig. 3). The oldest materials outcropping in the upper Mkomazi are the Permian dark grey shales, siltstones and sandstones of the Escourt Formation. The successive formation, which also belongs to the Beaufort group, is the Triassic Tarkstad Formation, consisting of fine to medium grained sandstones and mudstones. Various sand and mudstones of the Triassic Molteno, Elliot and Clarens formations build up the next layers. A thick sequence of basaltic lava of the Drakensberg formation was deposited on top of this sedimentary series during the Jurassic period. All the above mentioned formations were disturbed by injections of dolerite as both dykes and sills. Some partly consolidated colluvial deposits (Masotcheni formation) and alluvial material of the Quaternary age were found in the middle and lower parts of the hill slopes (Linstrom, 1979). These colluvial-alluvial materials are the result of several «cut-and-fill» cycles, probably due to climatic fluctuations of short duration (Botha, 1996). Botha (1996) developed a model of landscape cyclicity for the northern KwaZulu/ Natal based on geochronological analysis of palaeosols. The models shows three mayor cycles in the last 135 ka. Gully erosion is widespread in this colluvial material.

The vegetation in the upper Mkomazi valley is mainly influenced by the altitude and the long history of burning (Garland, 1987). Three belts of vegetation can be distinguished: the montane, subalpine and alpine belts. All the belts are dominated by *Themeda* species with pockets of shrub and woodland or *Protea* savanna (Killick, 1963). The main land use in the upper part is unimproved grassland with scarce patches of agriculture and forest plantations.

METHODS AND MATERIALS

In order to describe the erosion processes and their dynamics at catchment level, many of the parameters that characterize the physiographic properties of the catchment, as well as the human activity in this catchment, have to be taken into consideration. All the erosion processes are not as yet fully understood (e.g. subrosion, suffusion etc.) so it is still difficult to calculate the effects of erosion at catchment level. Therefore erosion processes on various temporal and spatial scales have to be considered. These processes may be on small spatial scales such as rill-interrill erosion processes or suffusion processes (e.g. tunnel erosion), or large-scale erosion features such as gullies. We are also working on different time scales: from short term processes to long term ones (raindrop impact, storms, climate change). Tab. 1 shows the characteristic time and spatial scales adopted for studying water erosion processes and landforms.

Soil erosion modelling is only one method of describing the erosion processes we are dealing with on a catchment scale. In order to integrate as many erosion processes as possible into the erosion modelling of an entire catchment a method is needed that is able to handle different erosion models for different erosion processes on different spatial and temporal scales.

In this study a concept was developed that integrates the different erosion process scales (temporal and spatial). Furthermore the concept allows the identification and location of different erosion forms and processes. The concept is based on three-dimensional terrain units called Erosion Response Units (ERU).

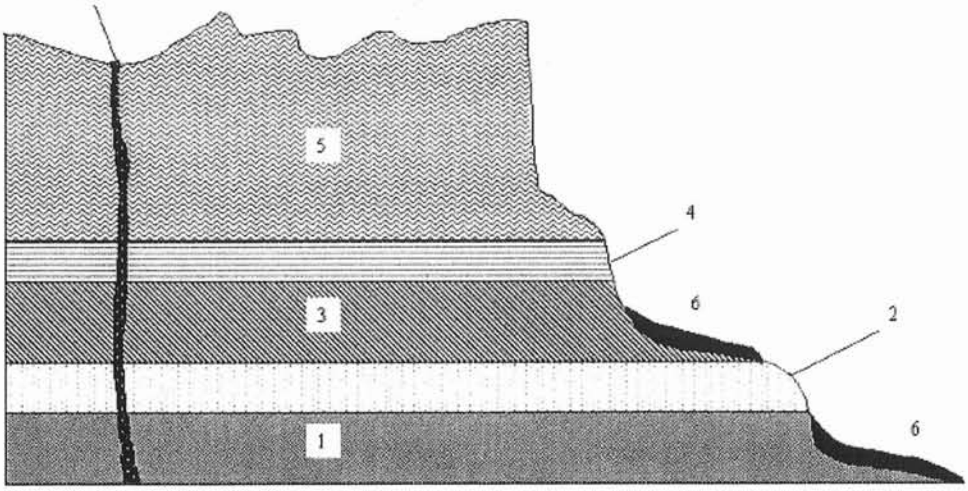


FIG. 3 - Stratigraphy of the Mkomazi river area; Drakensberg escarpment (after Pickles 1985): 1 - sandstones and red/green mudstones of the Tarkastad subgroup; 2 - coarse grained sandstones of the Molteno formation; 3 - red mudstones and sandstones of the Elliot formation; 4 - fine grained sandstones of the Clarens formation; 5 - amygdaloidal lava of the Drakensberg group; 6 - partly consolidated colluvial deposits of the Masotcheni formation; 7 - Dolerite dykes.

TABLE 1 - Characteristic time and spatial scales adopted for studying water erosion processes and landforms (source: various)

Erosion forms and processes	time scale	spatial scale
Gully erosion	Single event-continuous	Slope - catchment
Rill erosion	Single event	Plot - slope
Interrill erosion	Single event	Plot - slope
Tunnelling and piping	Single event-continuous	Slope - catchment
Badlands	Continuous	Slope - catchment
Mass movement	Single event-continuous	Slope - catchment

The application of the Erosion Response Units concept allows the discrimination of erosion modelling entities. These units have to be small enough to include the small scale erosion processes, and at the same time big enough to be handled, e.g. by computers.

Once the spatial distribution of the different erosion processes in the catchment is known it is also possible to apply specific erosion models or algorithms in the right places and for the right processes. This means that different erosion models can be applied at the same time on different spatial and temporal scales. Next chapter will describe this concept; the following ones will go on to explain the delineation of ERUs and the derivation of the parameters used; finally, the application of these units in regionalisation and erosion modelling will be illustrated.

The concept of Erosion Response Units

Erosion processes and landforms caused by water are mainly influenced and interlinked by the hydrological dynamics of the drainage basin. Therefore modifying the concept of areas with hydrological catchment response can delineate the response of three-dimensional terrain units to erosion. Naturally this is only valid for erosion processes caused by water. The concept of «Hydrological Response Units» (HRU) has already been proposed and applied by several authors in the past (see Beran & *alii*, 1990; Falkenmark & Chapman, 1989; Flügel, 1995, 1996, 2000; Plate, 1992; Bongartz, 1999). If we consider the «Soil-Vegetation-Atmosphere Transfer interface» (SVAT) as an ecosystem with certain characteristics, it is obvious that an input to this system must be followed by a specific system response. The way in which the system reacts depends on the system's characteristics. To get more information about the sensitivity of the system one has to separate the system into components. Different erosion process dynamics are linked to certain associations of system component properties. Entities with the same erosion process dynamics (i.e. with the same system response) consequently consist of certain associations of system characteristics and system inputs (fig. 4).

ERUs are defined as «distributed three-dimensional terrain units, which are heterogeneously structured; they each have homogeneous erosion process dynamics characterized by a slight variance within the unit, if compared to neighbouring ones, and they are controlled by their

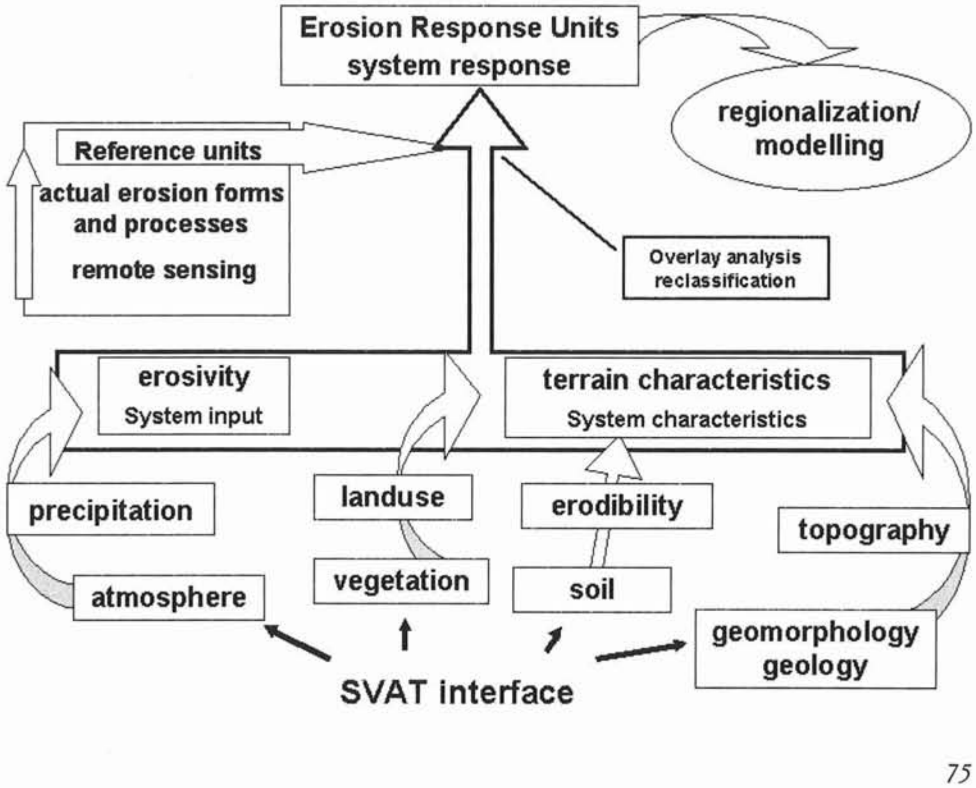


FIG. 4 - Erosion Response Units Concept (Märker).

physiographic properties, and the management of their natural and human environment».

The Erosion response units are based on the finite element concept and therefore they do not have a fixed scale such like raster based approaches.

The *ERUs* contain information on the morphologic features resulting from the erosion process dynamics. When applied as homogeneous erosion modelling entities, they transform the precipitation system input into a corresponding runoff (surface, subsurface) and thereby generate specific erosion and sediment transport as system output.

According to this definition the drainage basin is conceived as an assembly of spatial process entities with different erosion potentials. The latter are in turn determined by the configuration of their natural capital and the respective human management. Once the *ERUs* have been delineated, these entities can be used for spatial scale transfer in regional erosion modelling as they conserve their properties.

In this study the *ERUs* have been applied to characterise the distribution of erosion features and processes, and for the regionalisation in order to get information about the entire river basin susceptibility to erosion. Furthermore the *ERUs* were used as modelling entities.

Starting with characteristic parameters, which describe the physiographic and anthropogenic attributes influencing the erosion processes, we can distinguish two major parts of the entire system: on one hand the system's erosivity, that depends on rainfall, and on the other hand the terrain characteristics (system characteristics) such as land use, erodibility and geomorphology. This information was inserted into overlay analysis and reclassification procedures, using reference units, delineated by remote sensing, that contain the present erosion processes and forms in order to arrive at the Erosion Response Units, already defined as three-dimensional entities with the same erosion response to a given system input. Once the ERUs in the test catchments have been delineated, this information can be regionalized for the entire basin, as we did for the Mkomazi catchment. Furthermore the ERUs were used as base information and base entities for the modelling process (fig. 5). The erosion modelling is in the final stage of elaboration and the publication of the results is in preparation.

Depending on the dominating erosion process within the ERU, an erosion model capable of modelling this specific process can then be chosen. In this study the erosion processes identified were the gully erosion and rill- interrill erosion. As far as gully erosion is concerned, two models for different gully development stages can be applied (Sidorchuk & *alii*, 2001). These models were adapted for the special conditions in the catchments (Sidorchuk 1999, 1998, 1996,). For the rill- interrill erosion the Revised Universal Soil Loss Equation (RUSLE) was chosen (see Renard & *alii*, 1987). These models were run for each single ERU. The sediment loss produced in an ERU then has to be routed down the catchment or is used as input for ERUs further downslope as shown in fig. 5.

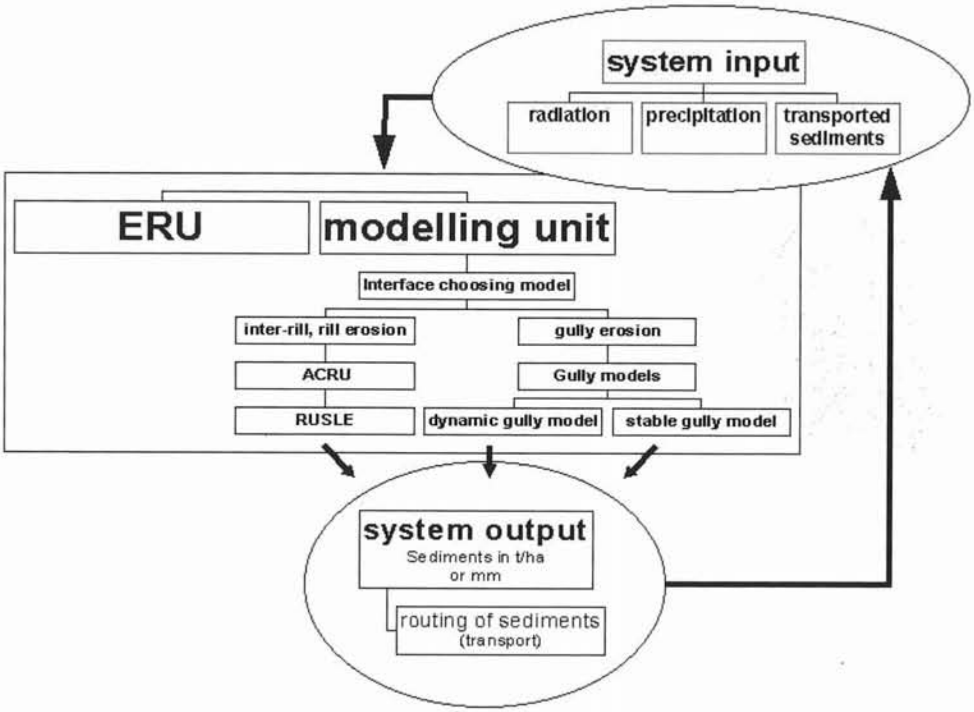


FIG. 5 - Erosion Modelling using the ERU Concept (Märker).

Identification of present erosion sites and forms as Erosion Reference Units (ERefUs)

Reference units describing the existing erosion processes and landforms are needed for the final delineation of ERUs, as mentioned in the previous chapter. The derivation of these «Erosion Reference Units» (ERefUs) was achieved with the analyses of stereo-aerial-photographs, orthophotos and GIS. The background for these analyses was a field mapping campaign and photo documentation, conducted during the first field trip in February and March 1998. For the classification of the erosion features and the subsequent delineation of the *ERefUs*, the erosion type, the degree and extent of erosion, as well as the density of the erosion features, were mapped based on 1996 (Mkomazi river catchment) and 1990 (Mbuluzi river catchment) aerial photographs at 1:30,000 scale. For the analyses the adapted method of van Zuidam (1985) was applied. Tab. 2 shows the classification of erosion intensity based on the depth and spacing of rills and gullies.

The final classification of erosion types and erosion intensities with respect to vegetation cover is shown in tab. 3. The degradation was estimated as a function of the vegetation cover density.

The criteria determining this classification are on one hand the density/frequency of the erosion type (tab. 2) and on the other hand the erosion type itself, as well as the percentage of vegetation cover (tab. 3). The results of these analyses are terrain units subject to different levels (classes) of erosion intensity (ERefUs) and they were worked out for the two test catchments. These units were transformed into digital format using the topographical map, 1:50,000 scale, that was scanned and georeferenced. Fig. 6 shows the erosion intensity map at 1:50,000 scale for the KwaThunzi area in the upper Mkomazi catchment. In the subsequent delineation of ERUs these entities were used as reference units (ERefUs).

TABLE 2 - Frequency and density of erosion features (after van Zuidam, 1985)

Depth (cm) of rill and gullies	Spacing (m) between rills and gullies				
	<25	25-50	50-150	150-500	>500
5-50	Moderate	Slight			
50-150	Severe	Moderate	Slight		
150-500	Severe	Severe	Moderate	Slight	
>500	Severe	Severe	Severe	Moderate	Slight

TABLE 3 - Classification of erosion types and intensities with respect to vegetation cover (modified after van Zuidam, 1985)

Class	Erosion	Erosion type	Vegetation Cover in %	Degraded areas in %	Colour
1	None		>90	<10	green
2	Slight	slight rill-interrill	>75	<25	light-green
3	Slight-moderate	Rill-interrill; shallow gully	>75	<25	yellow
4	Moderate	Rill; medium-deep gully	51-75	25-49	brown
5	Severe	Rill, medium-deep to deep gully; landslides	26-50	50-74	red
6	Very severe	Rill, deep gully; badlands; sever mass movement	<25	>75	dark red

Reclassification of available physiographic parameters for the ERU overlay analysis

The land components such as topography, geology, land use, soils and erosion features, etc., characterized by their attributes, were converted into digital raster format with a specified pixel length of 200 m for the Mkomazi river catchment and 25 m for the Mbuluzi river catchment. The pixel scale was chosen on the basis of the available grid cell size of the digital elevation models, which have an area of 4 ha (Mkomazi) and 0.0625 ha (Mbuluzi). Consequently the physiographic information on a more detailed scale was generalised taking into account only the main components of the physiographic characters within that pixel.

All the information layers were reclassified in order to reduce the number of classes within each information layer. Table 4 shows the parameters used in the overlay and reclassification procedure. The national land cover classification (Council for Scientific and Industrial Research - CSIR, Pretoria) (Thompson & *alii*, 1996) was revised and reclassified into 6 land cover classes (tab. 4). Digital elevation models were then analysed to obtain information about the mesorelief (Köthe, 1988). One of the factors delineated from the DEM is the slope aspect subdivided into four classes. The terrain morphology is characterized by a combination of slope gradient, slope length and curvature. The first derivation of the DEM is the slope gradient, here in degrees. The second derivation of the DEM is the terrain curvature, which provides information about the longitudinal profile. Erosive slope length was calculated following Lorentz & Schulze (1995):

The erosive slope lengths were subdivided into three classes according to the cumulative frequency of the values: < 30 m; 30-60 m and >60 m. The second derivation of the DEM (slope curvature) was classified in two groups because of the scarce DEM information (4 ha; 0,0625 ha pixel area): i) concave slope, ii) convex slope.

One of the most important items of information is soil texture. For the Mkomazi river basin soil texture has been delineated from the land types information (Institute of Soil Water and Climate, Pretoria). Because of the high correlation between soil texture and geology in the Mkomazi river basin these two parameters were combined in a single layer of lithology and soil texture information (tab. 4). For the Mbuluzi river catchment soil texture and lithologic information was obtained from the Swaziland Soil

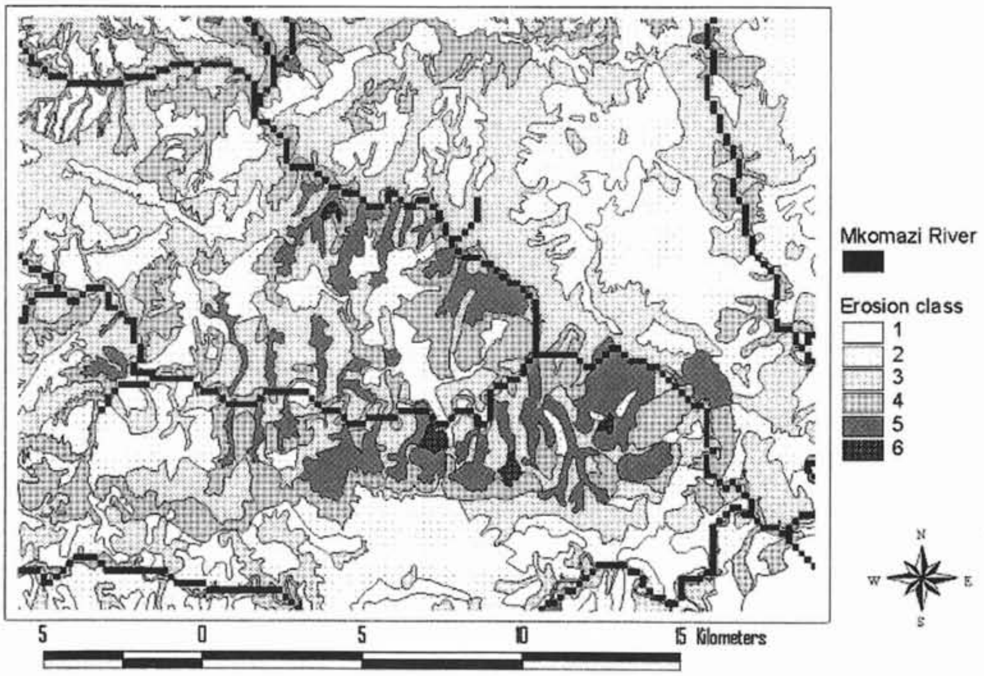


FIG. 6 - 6 class erosion map at 1:50.000 scale for the KwaThunzi area in the upper Mkomazi catchment (legend based on tab. 3) (Märker).

TABLE 4 - Parameter classification and overlay sequence used for the delineation of ERU combinations (Märker)

Layer Class	EREFU	1 Aspect	2 Land use	3 Slope morphology	4 Geology & Soils
1	no erosion	North	Unimproved grassland	Convex/ concave slope <1° & > 60 m	Alluvium Sand Loam Clay
2	Slight rill-interrill erosion	east	Shrub bush & forest	Convex slope 1-5° & > 60 m	partly consolidated Sediments (Masotcheni Formation)
3	Rill-interrill; shallow gully erosion	South	Wetland & waterbodies	Concave slope 1-5° & > 60 m	Basalts Dolerite Shales Mud-, Siltstone Diamectites Loam/Clay
4	Rill; medium-deep gully erosion	West	Cultivated commercial/ subsistence	Convex slope 5-10° & > 30 m	Basalts Dolerite Siltstone Shales Mud-, Diamectites Sand
5	Rill; medium-deep to, deep gully erosion		Urban	Concave slope 5-10° & > 30 m	Gneiss Diorite Sandstone Loam
6	Rill, deep gully erosion; badlands; sever mass movement		Degraded unimproved grass- & bushland	Concave/ convex slope >10° < 60 m	Granite Granite Diorite Sandstone Sand/ Clay

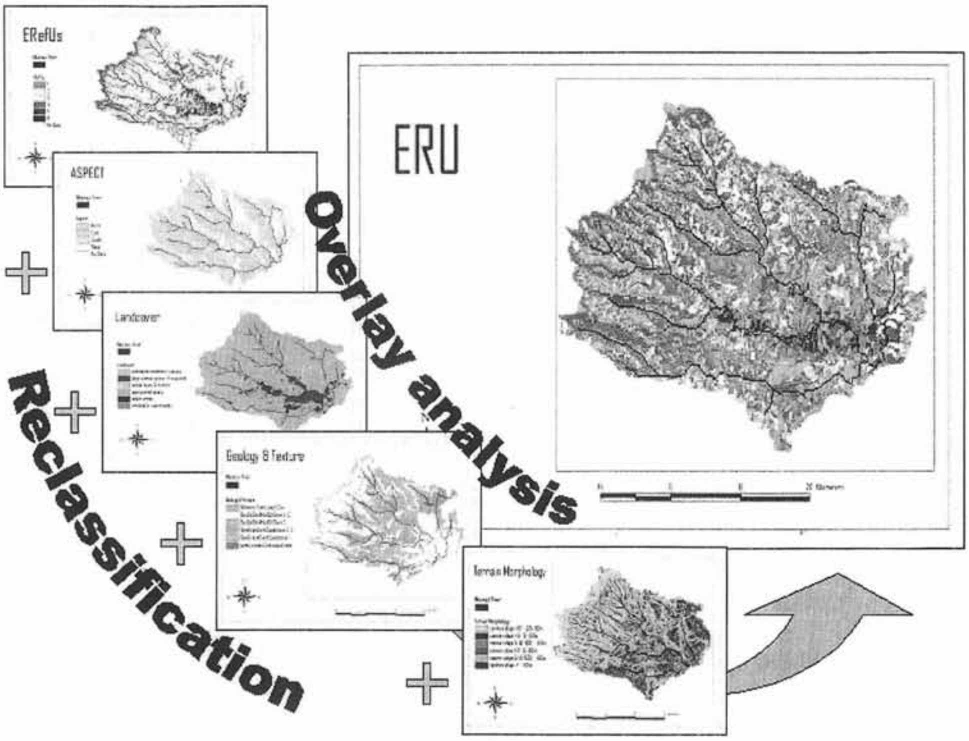
Map (Murdoch, 1970). Contrary to the Mkomazi classification, here only five classes i) alluvium, ii) clay, iii) loam, iv) rock outcrops and v) sand, were identified. These reclassified physiographic layers were combined with the ERefUs using overlay analyses, according to the scheme shown in tab. 4. The procedure consists in adding one layer after another, reclassifying the result after each process (fig. 7 and tab. 4). The reclassification was done by normalising the result by the area of the ERefUs, eliminating all classes under 2%. The resulting complex information sequence contains combinations of different input information layers. Fig. 7 shows the different layers used for the ERU delineation for the upper Mkomazi catchment.

The resulting combinations are considered as Erosion Response Units (ERUs) because they consist of specific combinations of physiographic information related to erosion. Consequently the ERUs correspond to the present erosion and contain a defined combination of parameters (system characteristics) that influence the erosion response in each unit. Furthermore the morphology of the erosion features is also described by the response units.

Regionalisation of ERU information

By regionalising the ERU information of the test areas, it is possible to identify the erosion processes and dynamics that affect or could affect areas in the entire Mkomazi and upper Mbuluzane river catchments (fig. 8). The catchment's susceptibility to erosion is obtained by using the already existing information (ERU) on the upper part

FIG. 7 - Overlay procedure and parameters used for the ERU delineation in the upper Mkomazi river catchment (Märker).



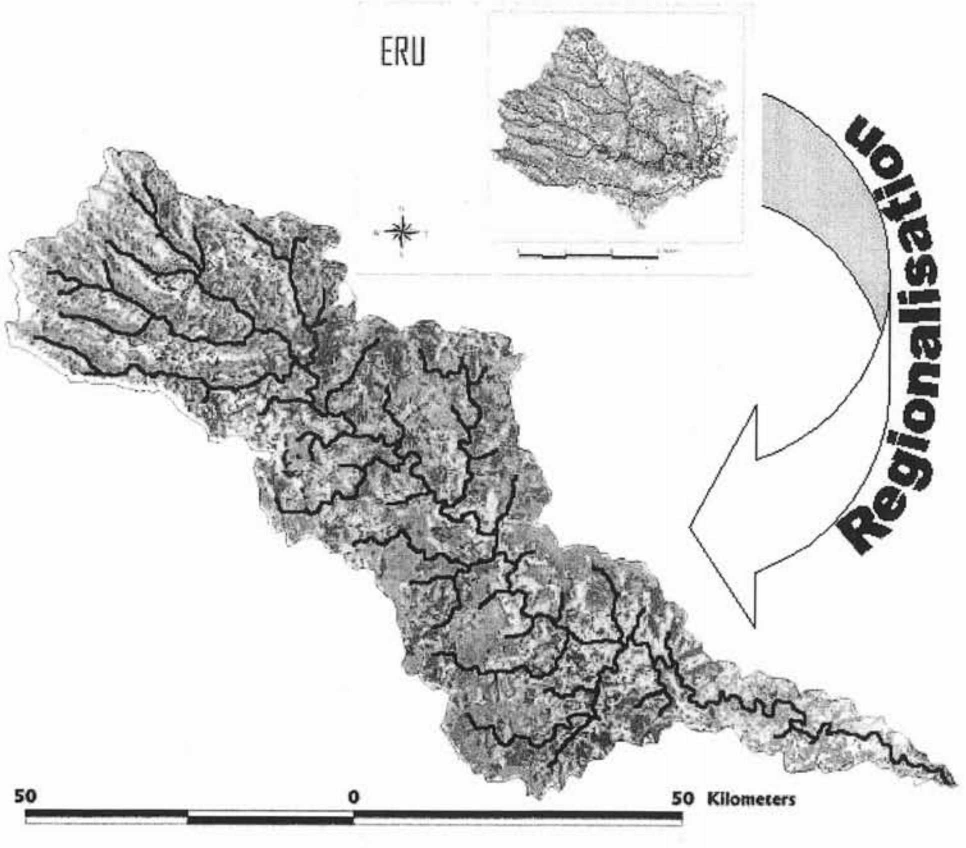


FIG. 8 - Regionalizing ERU information for the Mkomazi river catchment (Märker).

of the catchment and extending it to the entire catchment. Therefore the same overlay procedure was carried out for the entire catchment without the reference information. The resulting combinations were then combined with the specific ERU combinations we had found in the upper part of the catchment. With these regionalised ERUs it is finally possible to arrive at the catchment's susceptibility to erosion (fig. 9). The ERU information on erosion intensity, worked out in six classes, was therefore used (tab. 3).

RESULTS

The distribution of the different erosion types and their intensities was provided for the Mbuluzane river catchment as well as for the Mkomazi river catchment with the six class erosion map (map of ERefUs). In the upper Mbuluzi basin severe gully erosion was identified mainly in the upper part of the Mbuluzane river catchment and in the Mhlambanyoni catchment. The Mbothoma gullies appear in the highest erosion class and they are clearly visible at this scale (1:50,000). About 8% of the Mhlambanyoni basin is directly affected by severe erosion (classes 4, 5 and 6), whereas 40% of the area shows signs of erosion (deep linear and rill-interrill erosion: classes 2-5). It should be noted that the zone of intensive erosion is situated along a North-South running system of amphibolite/serpentite and dolerite/granophyre dykes. The main lithology consists of highly erodible saprolites (Mushala & *alii*, 1994; Scholten & *alii*, 1995). It is a densely populated area with a high livestock concentration. Consequently overgrazing occurs, especially on communal land like the Mbothoma area. Cattle tracks and pathways are visible in the aerial photographs and analyses of different time series show that gullies often develop along these pathways and tracks (WMS Associates 1988).

The upper Mkomazi catchment shows severe erosion mainly in the densely populated areas where the lithology consists of partly consolidated sediments of the Masotcheni formation or shales, siltstones and mudstones (fig. 9). Severe deep gully erosion (classes 4, 5, 6) affects about 13% of the entire upper basin. Whereas 90 % of the upper Mkomazi river area is affected by erosion (classes 2-6).

The physiographic parameters for both catchments were identified and reclassified (tab. 4). Finally, combining this information with the ERefUs, the Erosion Response Units were delineated. Fig. 7 shows the overlay procedure with the selected parameters for the upper Mkomazi river basin. The same was done for the upper Mbuluzi river catchment. In the first one 57 characteristic ERU combinations were obtained. Table 5 show some examples of Erosion Response Units combinations with the highest frequency for both catchments. The ERU combinations correspond to the sequence of layers in table 4.

From the 57 ERU combinations delineated in the upper Mkomazi catchment 30 combinations can be asso-

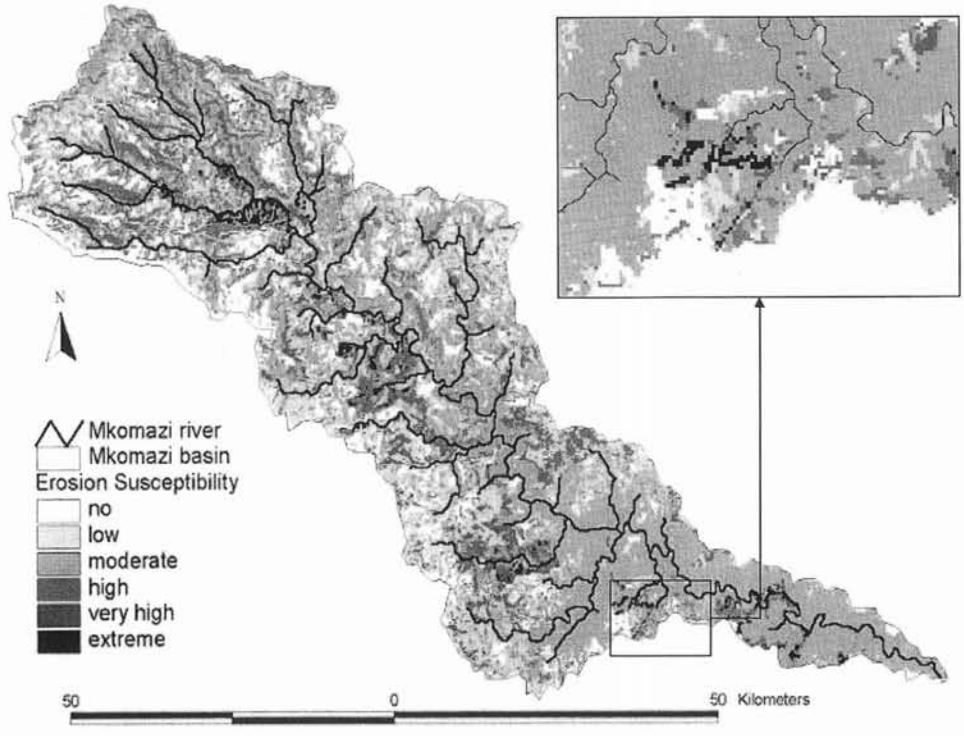


FIG. 9 - Erosion susceptibility delineated from the regionalized ERU information (Märker).

TABLE 5 - Examples of ERU combinations with high frequency and erosion classes for the upper Mkomazi and the upper Mbuluzi catchments (Märker)

ERU combination	Counted pixel	Erosion class	Erosion susceptibility
	Upper Mbuluzane river catchment		
2615	26652	1	No
4265	43378	1	No
3253	7135	2	Light
3264	6616	2	Light
2255	3976	3	Light - Medium
2623	5747	3	Light - Medium
3113	2147	4	Medium
4253	1298	4	Medium
1233	1200	5	High
4133	670	5	High
4653	358	6	Very High
4663	371	6	Very High
	Upper Mkomazi catchment		
1115	66	1	No
2133	103	1	No
2123	1221	1-2	Light
3123	992	1-2	Light
2163	2915	2-3-4	Light - Medium
3163	2853	2-3-4	Light - Medium
1166	1472	3-4	Medium
2166	1025	3-4	Medium
1155	273	4-5	High
1623	294	4-6	High
2653	140	5-6	Very High
2655	72	5-6	Very High

ciated with only one erosion class whereas 19 ERU combinations are characteristic for two erosion classes and 8 ERU combinations describe three erosion classes. In the Mbuluzane river catchment 40 ERU combinations were obtained. Here 31 combinations occur in only one erosion class, 7 ERUs appear in two different erosion classes and 2 ERUs describe three erosion classes (see examples in table 5). Both classifications show that the number of ERUs in a river catchment is limited. This can be explained with the genesis of the process structure within the Erosion Response Units that is influencing on their physiographic properties. Generally it can be stated that a low erosion risk exists for southern expositions. Very high erosion risk only occurs in unimproved grassland. Whereas the slopes showing high erosion risk are steeper than 10° and have an erosive slope length shorter than 60 m in the Mkomazi catchment, in the Mbuluzi catchment the slopes prone to erosion are 5-10° and have an erosive slope length longer than 30 m. The differences in the ERU combinations observed in the two catchments are due mainly to the relief, the soils and the geology respectively. The Mbuluzi catchment shows a high erosion risk for soils with loamy texture, often over saprolite, whereas in the Mkomazi river catchment the partly consolidated sediments of the Masotcheni formation have a high erosion risk. Loamy clay sediments and basaltic lithologies, as well as sandy granodioritic material, are also prone to erosion.

The ERUs were also used in the regionalisation of the erosion information in the Mkomazi river basin. Overlay analysis was therefore carried out for the entire basin. Finally, an ERU map with combinations was produced for the entire basin, shown in fig. 8. An erosion type and intensity can be attached to each ERU in order to derive the erosion susceptibility for the entire basin (fig. 9). This was done for the Mkomazi catchment. The relative values of the upper part of the basin naturally correspond completely to the erosion classes of the ERefUs (figg. 6 and 9). The analyses were visually validated comparing the erosion susceptibility map with the observations of the present erosion processes in the field. The erosion sites identified in the lower basin are mainly located in areas with dense informal settlements and pedologic conditions characterised by high k-factors (erodibility, after Wischmeier & Smith 1978). Some exceptions of the general good fitting of the erosion susceptibility map are due to the quality of the DEM and the chosen pixel size which was not detailed enough to identify areas such as rockoutcrops or escarpments correctly. As a result the susceptibility delineated from the ERUs was greater than the one actually observed.

The little window in figure 9 shows a structure interpreted as having high erosion susceptibility with the associated erosional forms: medium-deep to deep gully erosion. Indeed this structure was found during field validations (fig 10). This example shows that the erosion susceptibility of a river basin derived using ERU information not only provides the relative values of erosion but also information about the erosion features and landforms.

CONCLUSIONS

The example of the two southern African test catchments shows that areas subject to different erosion processes and intensities can be identified using the Erosion Response Units concept. Furthermore ERUs can be used in the regionalisation of erosion processes to provide information about the catchment's susceptibility to erosion. The latter analysis was successfully carried out for the Mkomazi river catchment.

The ERU combinations were delineated in a characteristic test area using reference entities containing information about the existing erosion processes and intensities. Detailed information about topography and lithology, as well as land cover information, normally obtained by a great amount of fieldwork, was derived with remote sensing techniques such as the API methods. Finally GIS was used to integrate all the information and delineate characteristic combinations, thus describing the erosion process dynamics of single terrain entities. The combinations are therefore called erosion response units. This ERU information was then used to delineate the erosion susceptibility for the entire basin

In this study the ERU concept was applied to identify the spatial and temporal distribution of erosion process dynamics in a river basin. Furthermore the concept of us-

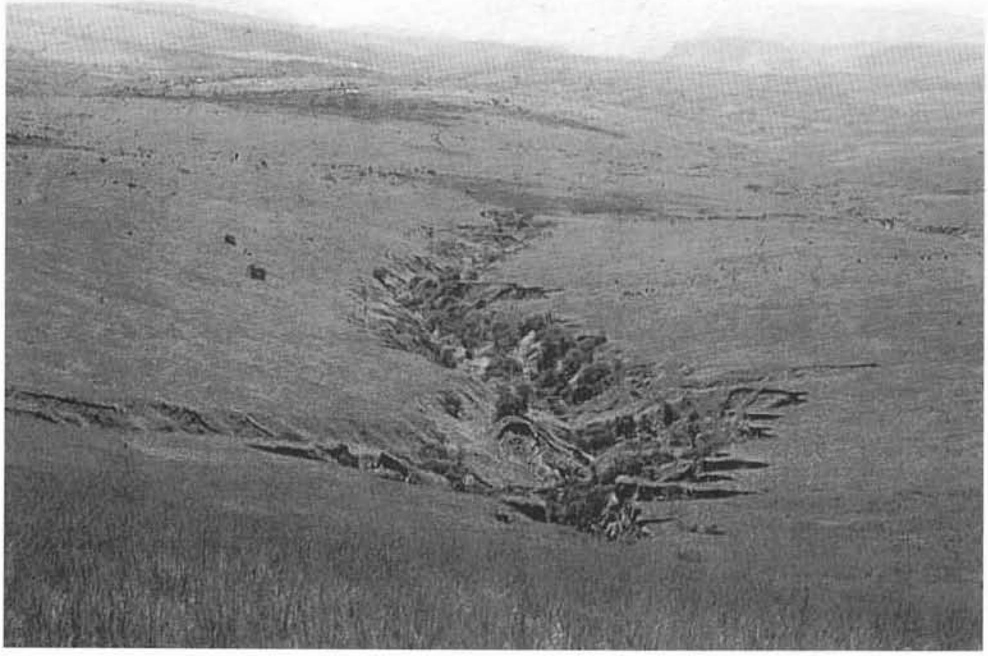


FIG. 10 - Gully system 20 km east of Ixopo (RSA) detected with the ERU method (Photo: Märker).

ing the ERUs as modelling entities too, was also proposed. The erosion processes considered in this study were interrill-rill erosion processes as well as deep linear erosion processes such as gully erosion. The distribution of gully erosion in the study areas clearly shows that gully erosion must be included in the calculation of sediment yield, especially where the lithology (saprolites) is highly vulnerable to erosion or land use is inadequate. Nevertheless in traditional models such as the RUSLE or MUSLE (Williams & Berndt, 1977) gully erosion is almost completely neglected. The integration of different erosion models for specific erosion processes using the ERU concept will lead to a higher degree of accuracy in the estimation of the total sediment yield of a catchment.

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