

# Erosion Hazard Mapping in the Runde Catchment: Implications for Water Resources Management

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**Abstract** Soil erosion not only makes agricultural lands unproductive, it also contributes to sedimentation of water bodies leading to the eventual filling up of these water bodies. The control of sedimentation in reservoirs requires that the potentially significant sources of sediments be known and characterised. Knowledge of the spatial variations in the erosion hazard of a catchment is a good starting point. Using the Soil Loss Estimation Model for Southern Africa (SLEMSA) within a Geographic Information System (GIS), we characterized the spatial variations in erosion hazard in the Runde catchment in Zimbabwe. Results from this study show that the greater part of the catchment (around 64%) is in the moderate to negligible erosion hazard classes. Around 17% of the total catchment is in the moderately high to extremely high categories. We concluded that under the current land cover and land use regimes, water bodies in the Runde catchment are not at risk from abnormal rates of sedimentation.

**Keywords:** SLEMSA, erosion modelling, Runde catchment, GIS

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## 1. Introduction

Soil erosion is a geomorphologic process of landscape development [1]. It is a complex dynamic process by which productive surface soil is detached, transported and deposited at a distant place resulting in exposure of subsurface soil at the origin and siltation in reservoirs and natural streams elsewhere [2]. There are basically two natural forces causing soil erosion, and these are wind and water [3]. Soil erosion by rainfall and runoff, has been recognized as the major cause of land degradation worldwide and is increasingly becoming a major problem in many communal lands of Southern Africa [4].

Problems associated with soil erosion, movement and deposition of sediment in rivers, lakes and estuaries have persisted throughout the geologic ages in almost all parts of the earth. However, the situation has been aggravated in recent times as a result of man's increasing interventions in a number of natural environmental processes. The increasing soil erosion rates in Southern Africa can be ascribed to the increased clearing of forests for cultivation, poor farming practices and encroachment into marginal lands [5].

The impacts of land degradation caused by soil erosion directly increase the poverty levels in Southern Africa, which largely relies on rain water for its agricultural production [6]. The erosion intensity in many parts of Southern Africa is most likely to increase due to climate change which is predicted to increase rainfall intensities, which will lead to increases in soil erosion rates in the

future [7]. Therefore, planning of land and water conservation is essential. This requires knowledge of the potential erosion hazard and an understanding of the factors that cause soil erosion. The knowledge will contribute to the development of specific guidelines for the selection of the control practices best suited for the particular needs of each site. In addition, control of sedimentation in reservoirs requires that all the potentially significant sediment sources be known and characterized. To be able to prevent or at least reduce the erosion to the level of what would naturally occur demands a thorough understanding of the processes that cause erosion. This understanding will then make it possible to adopt the correct strategies for soil conservation.

Soil erosion assessment methods are generally divided into three approaches; field research, surveying and modelling. Generally, field research is suitable for small-area studies only, while modelling has been used both in small and large-area studies. Surveying has normally been used in medium-scale projects, often in combination with the two other approaches.

For some time now, mathematical modelling has been an attractive method of studying erosion. Soil erosion models are divided into two categories that are empirical models based on knowledge gathered through field experiments under statistically controlled conditions, and physical models based on the knowledge of the physical relationships between different parameters influencing erosion. The following are some of the most widely used soil erosion assessment models: the 1965 Universal Soil Loss Equation (USLE) by Wischmeier and Smith which was modified and adapted to other conditions through

modified versions such as MUSLE [8] and RUSLE [9] for sediment yield and the Soil Loss Estimation Model for Southern Africa (SLEMSA) [10]. All these models can be fully integrated into a Geographic Information System (GIS) environment to produce spatial erosion potential over large areas [11]. A number of studies have been done using these models [12,13,14] and for Zimbabwean conditions the SLEMSA proved to be a better tool compared to the alternatives because it requires few input data [15,16,17], which can be readily available, therefore, it is the model that was used in this study.

Although the SLEMSA model was developed especially for the Zimbabwean Highveld, it has found wide applications in areas that have either similar or different climate regimes [18,19,20]. This has resulted in the model gaining popularity as a soil loss estimation method which has often been juxtaposed with the (Revised) Universal Soil Loss Equation (RUSLE/USLE) in comparing soil losses in regions beyond Southern Africa [3,12,21,22]. Despite its popular use in soil loss estimation, SLEMSA has not been widely utilized in applications that require soil loss estimation such as integrated catchment management. It is the aim of this study to use SLEMSA within a GIS to come up with a map showing the spatial variations in soil erosion hazard for Runde catchment in Zimbabwe with an application towards integrated catchment management.

SLEMSA has various advantages for developing countries like Zimbabwe as noted by [22] these are:

- it combines reasonable accuracy without the need for excessively elaborate and expensive field experiments.
- iflexibility is maintained by the use of rational and easily-measurable parameters such as rainfall interception.
- irefinement and up-dating of information can be incorporated as and when new data become available.

## 2. Materials and Methods

### 2.1. Study Area

The Runde catchment is located at geographical coordinates 20<sup>0</sup>S and 30<sup>0</sup>E. It occupies the central to south-eastern parts of Zimbabwe, and is one of the seven hydrological catchments within the country. The Runde Catchment covers 41 000 km<sup>2</sup> and is one of the three catchments that lie in the driest parts of the country. Runde catchment is made up of all river systems that eventually drain into the Runde River. The catchment is divided into five major sub catchments which are: Upper Runde, Lower Runde, Mutirikwi, Chiredzi and Tokwe sub catchments (Figure 1).

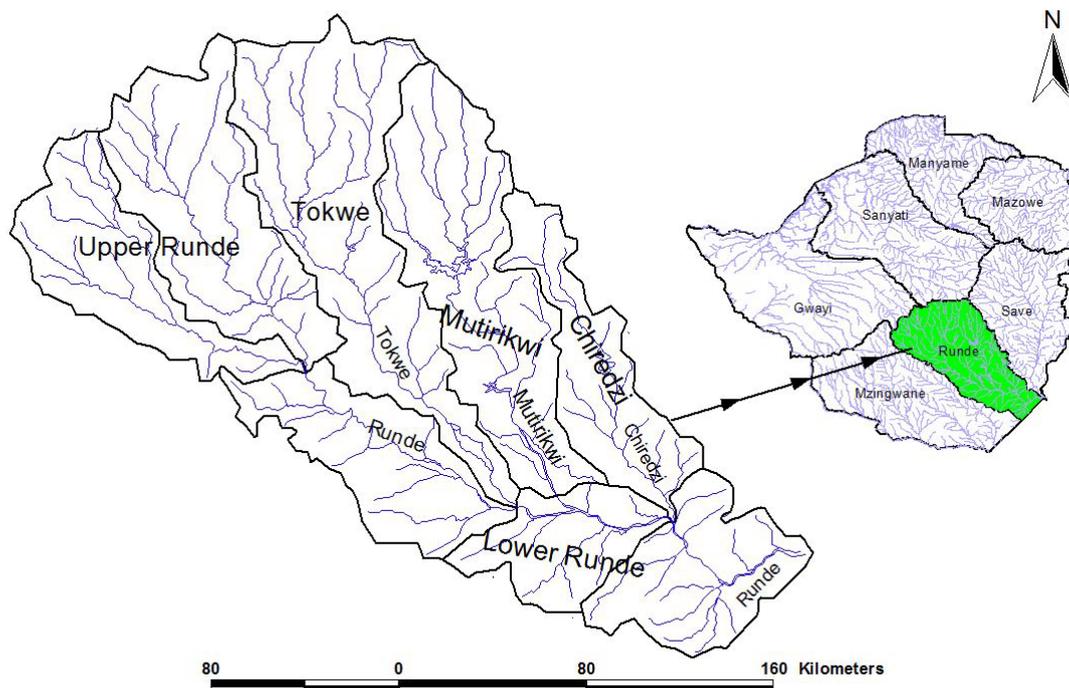


Figure 1. The location of Runde Catchment in Zimbabwe

Runde catchment is of much importance to Zimbabwe because it houses a number of the country's largest surface water bodies. These are Lake Mutirikwi which is currently Zimbabwe's largest inland water reservoir and the Tokwe-Mukorsi dam which is set to become the largest inland water reservoir in the country when construction is complete. The Catchment also has big and perennial rivers like the Runde, Tokwe, Mutirikwi, Chiredzi and Shagashe rivers. These water bodies mostly provide drinking and irrigation water to the sugarcane

plantation in the south east lowveld of Zimbabwe. In addition, the water bodies offer the greatest potential in mitigating the negative impacts of climate change in the catchment which receives on average 600 mm of rainfall per year. Therefore, the monitoring of erosion intensity is very important since it potentially can affect the life and the water holding capacity of the numerous water bodies. A proactive stance, and where necessary remedial action, will definitely be in order to prolong the lifespan of the water bodies.

Runde catchment is also home to a number of overcrowded communal areas that makes it vulnerable to erosion. These communal areas include Shurugwi, Chivi, Zaka, Zimuto, and Chiredzi. Farmers within these communal areas depend mostly on dry land farming for their livelihoods, making land conservation a priority within the catchment. Erosion has got the potential to reduce soil fertility and eventually crop yields thereby exacerbating the poverty level with the area. This will result in people clearing up the land and increasing the chances of erosion.

## 2.2. Soil Loss Estimation

Figure 2 shows a conceptual framework for the model, while the detailed description can be found elsewhere [22,23,24]. There is generally little knowledge on the state of erosion hazard within Zimbabwe's catchments. For the purposes of landuse planning and water resources management, there is a need to provide a spatially explicit map of soil erosion hazard at the catchment scale. To assess the spatial variation of erosion hazard in using an improved method for erosion hazard mapping based on the empirical model SLEMSA. For this study the SLEMSA Model was used because it ensures that

curvilinear relationships such as erosion and vegetation cover are accommodated and it provides a more realistic way of combining factors, other than by simple addition. It also gives adequate relative weighting to the factors and thus addressing the more important interactions [16,23]. There have not been any quantitative measures that have been implemented, especially at the sub-catchment level. However the main limitation of the SLEMSA model is that it assumes that each factor in erosion has equal weight and importance, which is not true because under tropical conditions erosion rates are far more sensitive to changes in vegetation than to changes in soil type [23]. Secondly, the technique uses the ordinal or ranking scale of measurement where erosion is implicitly linearly related to the rank of the variable. This ignores, for example, the important exponential relationship between vegetation cover and erosion [22,23].

The main objective of this paper is therefore to make an environmental erosion hazard assessment in order to identify parts of the Runde Catchment where the land is threatened by soil erosion. The aim is to divide the Runde Catchment into areas or regions that have a similar degree of erosion hazard as a basis for a plan for soil conservation.

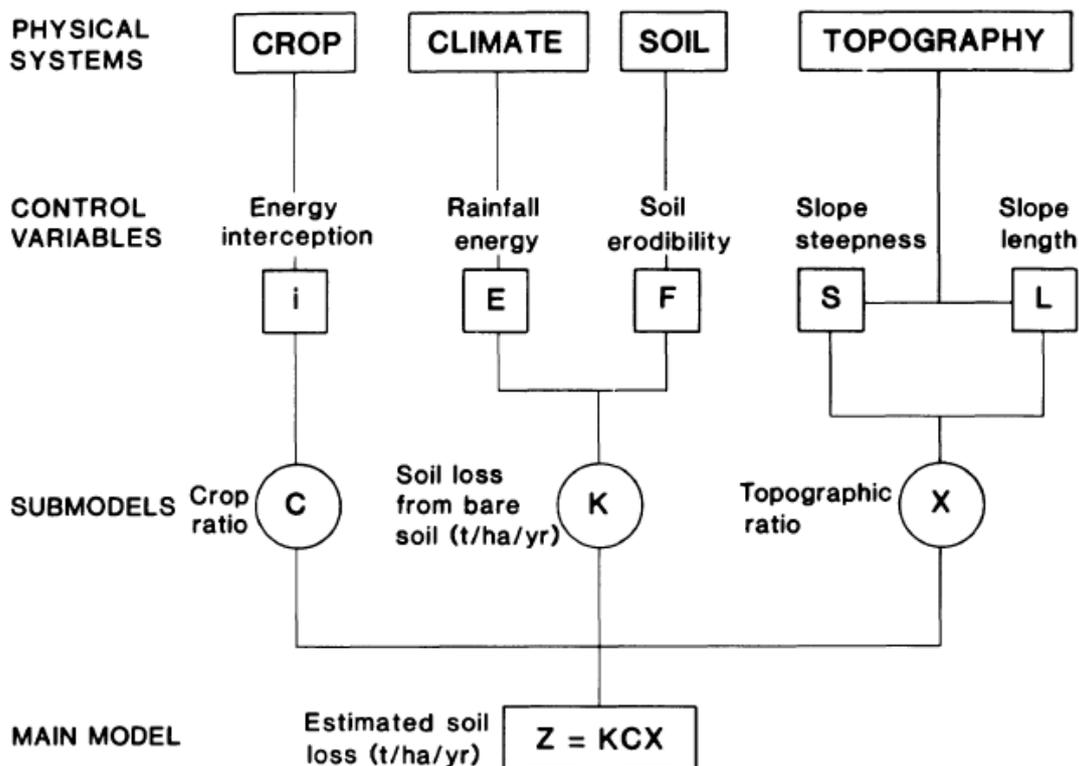


Figure 2. The SLEMSA Model – [23]

SLEMSA uses four broad factors to summarize erosion hazard within an area. These factors are: (1) rainfall, (2) soil, (3) vegetation and (4) relief. These broad factors are described by five control variables which can be expressed numerically. These are seasonal rainfall energy,  $E$  ( $J/m^2/y$ ); soil erodibility,  $F$  (as an index); seasonal energy intercepted by the crop,  $I$  (in %); slope steepness,  $S$  (in %); and slope length,  $L$  (in m). These control variables are further arranged into three submodels: a principal submodel,  $K$ , yielding estimates of soil losses from bare fallow land at a specified slope steepness and slope length,

a crop canopy cover model,  $C$ , giving a ratio to adjust from bare fallow to a specific crop type; and a topographic model,  $X$ , giving another ratio which enables soil losses to be estimated from slopes other than those specified in the  $K$  submodel. The first two sub models were developed from a limited amount of field plot data supplemented by expert opinion. The third submodel was derived from the slope factor relationship of the Universal Soil Loss Equation [23]. According to [16], the sub-models for the Zimbabwe Highveld are formulated as follows

$$C = \exp(-0.06 * i) \text{ for } i < 50 \text{ for } i < 50$$

$$K = \exp(0.4681 + 0.7663 * F) * \ln(E) + 2.884 - 8.2109 * F$$

$$X = L * (0.76 + 0.53 * s + 0.076 * S) / 25.65$$

The soil erodibility rating, F, according to Stocking *et al* was adopted. This factor is based on taxonomic data and soil properties such as texture and depth. The full scheme used for Zimbabwean soils can be found in [10], while the soil erodibility ratings are given in Stocking [24].

Mean annual rainfall (mm) data was obtained from the meteorological services department. From these data, a mean seasonal rainfall energy (E) rounded to the nearest 100 J/m<sup>2</sup> was calculated using the method of [23].

$$E = 18.846p,$$

Where p is the mean annual rainfall (mm)

The vegetation factor is measured by the mean seasonal interception of rainfall by vegetation, giving the proportion of the erosive rainfall, I (in %). This is the amount of rainfall that is intercepted by a growing crop or vegetation in a growing season. The value of I takes into account the influence of crop type, planting date, plant density and management [25].

The main model, which expresses the relationship between the three sub-models takes the form of their product:

$$Z = KCX,$$

where Z: predicted mean annual soil loss (t/ha/y);

K: mean annual soil loss (t/ha/y) from a standard field plot 30 m x 10 m at a 4.5% slope for a soil of known erodibility, F under a weed-free bare fallow surface;

C: the ratio of soil lost from a cropped plot to that lost from bare fallow land;

X: the ratio of soil lost from a plot of length L under slope percent S, to that lost from the standard plot.

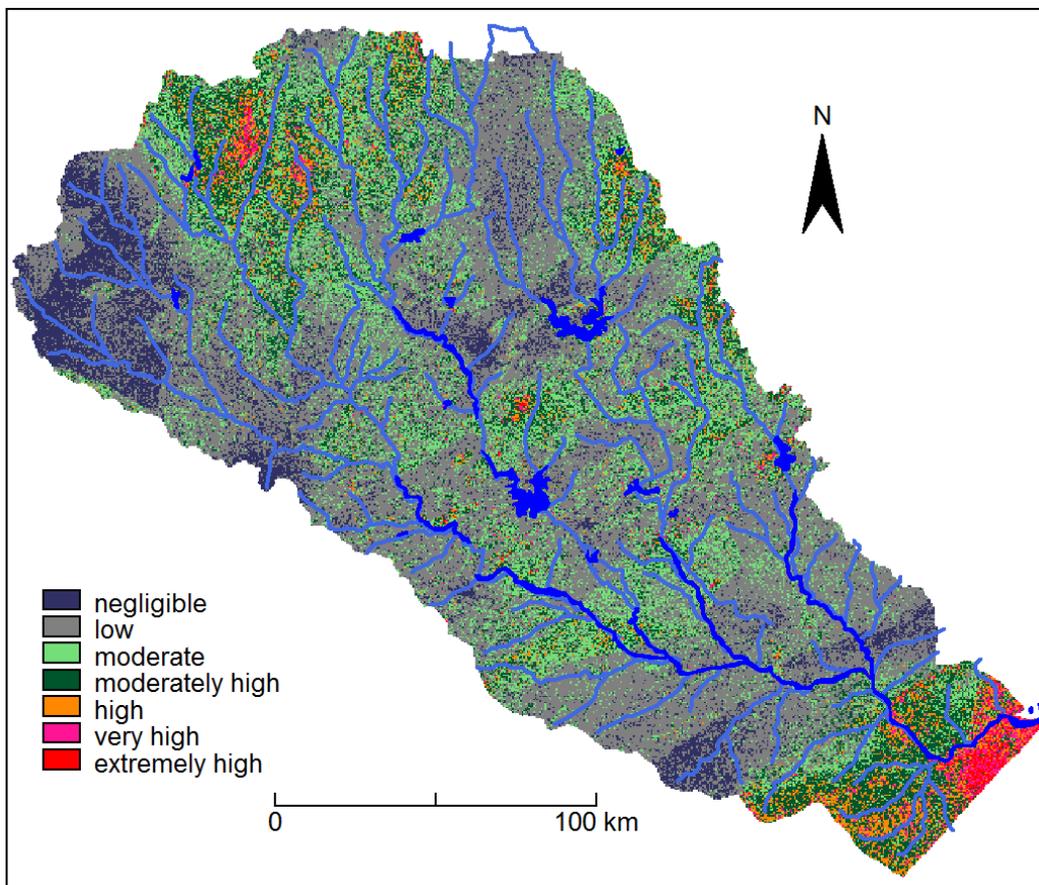
Although the above equation provides estimates of annual soil loss in t/ha, [23] strongly cautions for quoting the results in these units. Instead, they suggested expressing the results in dimensionless Erosion Hazard Units (EHU) on a scale of 1-1000. The EHU's will then give a relative idea of the degree of soil loss that might be expected on a field under the mean conditions used for the calculations. The erosion hazard units (EHUs) used in this study are given in Table 1.

**Table 1. The erosion hazard units used for soil hazard quantification in Runde catchment**

Soil loss in tones/hectare/year(t/ha/yr)	Erosion Hazard Class
0-10	Negligible
10.1 - 50	low
50.1-100	moderate
100.1-250	Moderately High
251-500	High
501-1000	Very high
>1000	Extremely high

### 3. Results

Figure 3 shows the spatial variations in the erosion hazard in Runde catchment.



**Figure 3.** Spatial variation of erosion hazard and water bodies on Runde catchment

Results from this study show that the greater part of the catchment is in the moderate to negligible erosion hazard classes. Figure 3 shows that the largest proportion of the catchment is actually in the low erosion hazard, where soil losses of between 10.1 to 50 tons per hectare per year are recorded. A small proportion of the catchment (around 17%) is in the high to extremely high categories (Table 2). These areas are mostly found in the Gonarezhou National Park (The southeastern part on the map) because this area is dominated by Ferralic arenosols. Arenosols are very

loose and friable, making them very vulnerable to erosion especially in the aftermath of a significant precipitation event. Other significant pockets of high erosion hazard include upper Gweru, on the northwestern part of the map. This area is communal land to the north of Masvingo town and is mostly dominated by bare ground culminating from either overgrazing or open fields from cultivation. Figure 4 shows the amount of hectares under different erosion hazards.

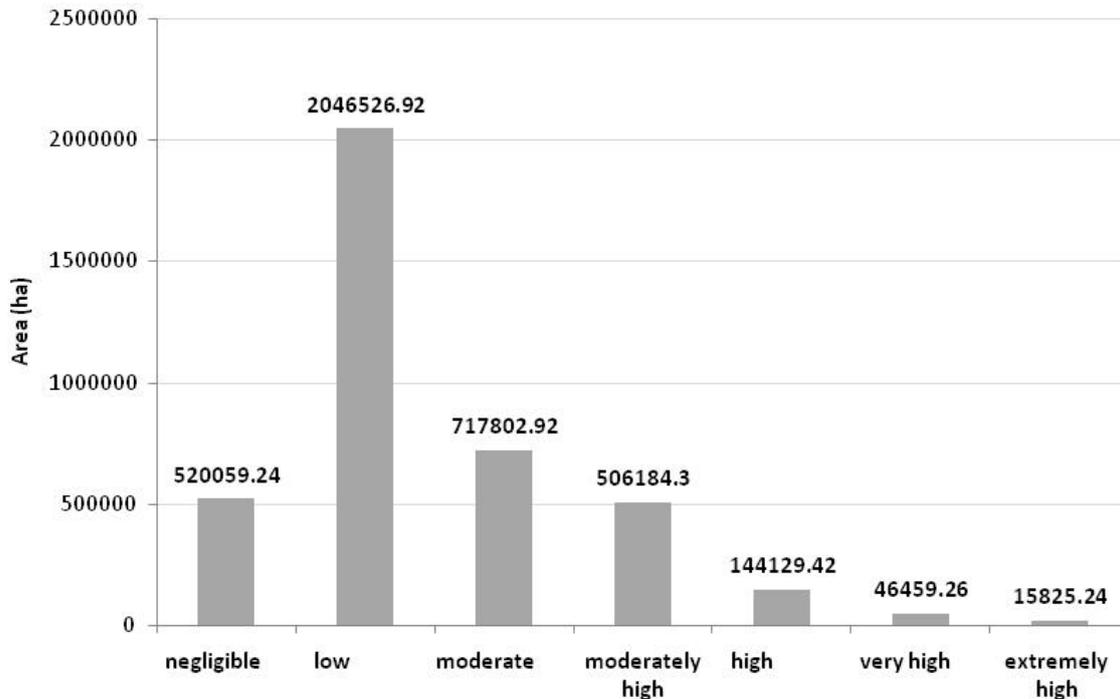


Figure 4. Distribution of different erosion hazards

Table 2. Erosion hazard unit as a percentage of the total catchment area in Runde

Erosion Hazard Unit	Percentage
negligible	13.01
low	51.20
moderate	17.96
moderately high	12.66
high	3.61
very high	1.16
extremely high	0.40

Despite the foregoing, an important aspect worth noting is that significant proportions of the catchments for the water bodies are in the moderate to moderately high categories (Figure 3). Numerically, this transforms into between 50 and 250 tons of soil per hectare per year lost into the nearby streams and water bodies. This has a bearing on the lifespan of the water bodies in this region. These water bodies are the mainstay of livelihoods in this dry region as significant agricultural projects such as the Hippo Valley and Triangle sugarcane plantations and Mwenezi irrigation schemes draw their water from these water bodies.

## 4. Discussion

An accurate validation of the soil loss rates obtained is challenging, as there is a dearth of empirical investigations

covering soil loss in Zimbabwe and absence of calculated soil loss data from run-off plots in the catchment. It is beyond the scope of the study to develop a set of field data to assess the accuracy of the SLEMSA model but rather to give a general quantitative assessment of soil erosion on the Runde catchment in order to determine if any of its water bodies are at risk from siltation. However, the SLEMSA model as used by many scientists in Zimbabwe and South Africa like [26,27] has been applied at catchment scales and these studies have demonstrated that the model is capable of adequately predicting soil loss under different land use, despite being applied to conditions beyond the original database [21].

The spatial scale with which the SLEMSA model has been applied in the study is not the spatial scale for which it was conceived. The mismatch between the small spatial and temporal scales of data collection and model conceptualisation, and the large spatial and temporal scales of most intended uses of the model [28] is a major challenge in soil erosion modeling.

Figure 3 shows that the water bodies on Runde catchment are relatively safe from siltation under the current landuse-landcover and rainfall regimes. Siltation is a serious hydrological problem which can cause the drying up of reservoirs and reduction of their water storage capacity. A number of dams in Australia have been choked by silt since the first dam was built in 1888 [29]. Human modifications within catchments have been

observed to have a direct positive correlation with erosion hazard and consequently sedimentation of reservoirs [30]. In the study by [30] in Puerto Rico, construction sites and dryland crop fields were observed to have sediment yields many times higher than the natural woodlands and grasslands. Thus sound management principles are the key to longer reservoir lives [31]. Further studies can include calibration of the SLEMSA model using ground control data so that the actual amount of sediments being transported into water bodies can be estimated. This can enable an estimate of the life span of the reservoirs to be made and consequently forward planning in terms of land use and water availability.

## 5. Conclusion

In conclusion, the use of GIS and remote sensing enabled the determination of the spatial distribution of the SLEMSA parameters. In this study tedious and costly field methods of obtaining landcover [20] have been replaced by the use of remote sensing derived landcover from satellite imagery. In this regard remote sensing and GIS can play a significant role in developing management scenarios and provide options to policy-makers for handling the soil erosion problem in the most efficient manner through prioritisation of conservation at the Catchment scale.

Integrated catchment management targeted at soil and water conservation is recommended to focus on areas with high settlement and cultivation, especially if cultivation is expanding into fragile lands. For planning purposes, ideally highly erodible soils could be allocated to land uses which do not reduce vegetation cover such as wildlife. Expansion of agricultural practices into soils with low erodibility values may have to be avoided if feasible. Identification of the degree of hazard and the reasons for that hazard may be useful in broad-scale planning for the conservation and utilisation of Runde Catchment land and water resources.

This study has shown that Runde catchment has a generally low erosion risk. However, it can be noted that there are pockets of extremely high erosion rates, which may give rise to siltation of the available water bodies. There is need to practice good land husbandry to ensure that the erosion rates will maintain the low levels. Overall, SLEMSA is an invaluable model that can be utilized in watershed management.

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