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Problems of monitoring erosion and sediment yields in southern Africa

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ABSTRACT The paper describes, in general terms, the problems associated with the monitoring of soil erosion and sediment yield in southern Africa. The problems identified are related to the following four areas: 1. Temporal variations, that is, seasonal variations in the operation of the processes of erosion and sedimentation in the region, coupled with the lack of long-term and continuous data collection and analysis. 2. Spatial/sampling problems, namely, choice of representative spatial units and the need for well designed instrumentation networks. 3. Lack of well developed institutional infrastructure to operate monitoring systems efficiently in terms of manpower and availability of resources. 4. Financial constraints in the procurement of equipment and materials required for a monitoring system, for instrumentation and for data analysis. However, work by individual institutions and researchers in the region have continued to produce results which still need to be coordinated into a regional or national framework.

INTRODUCTION

Monitoring of erosion and sediment yield are related problems and form part of the environmental monitoring system initiated within the Southern African Development Coordination Conference (SADCC) region as a follow-up to the SADCC Workshop on Monitoring Systems for Environmental Control held in Gaborone, Botswana, in 1986 (SADCC-SWCLU-CU, 1987). The monitoring system sub-programme of the SADCC Environment and Land Management Sector (ELMS) is designed to address the interdependence that exists between environment and development as well as to meet the needs for environmentally sound socio-economic programmes that will achieve sustainable development. The programme includes, among other aspects, land systems analysis, water quality assessment and their implication in the development process (ELMS, 1991). The basic programme focuses on land degradation, soil erosion, surface water resources, water quality and sediment transport. The overall objective of the monitoring system is "to bring about coordinated and purposeful sharing of experience, data, information, knowledge and techniques"(ELMS, 1991). It is in this context that the problems of monitoring of soil erosion and of sediment yield will be reviewed in order to enable insights into the problems facing the monitoring system for environmental management and planning.

This paper aims to give a short description of some of the problems related to the monitoring of soil erosion and sediment yield within the SADCC Region as a part of the environmental monitoring system to form a basis for the design of a monitoring system for resource use and planning for sustainable development production. In addition, a presentation will be made of some of the steps undertaken to improve and strengthen the monitoring system both at regional and at the national levels.

The problems in monitoring erosion and sediment yield in the region are related to four major areas:

1. Temporal variations, that is, seasonal variations in the operation of the processes of erosion and sedimentation in the region, coupled with the lack of long-term and continuous data collection and analysis.
2. Spatial/sampling problems, namely, the choice of representative spatial units and the need for a well designed instrumentation network.
3. Institutional infrastructural problems - lack of well developed Institutional infrastructure to operate monitoring systems efficiently in terms of man-power and availability of resources.
4. Financial constraints - insufficient funds to enable procurement of equipment and materials required for monitoring system instrumentation and data analysis.

In the following sections these four problems will be treated under two headings, namely, monitoring of soil erosion and monitoring of sediment yield. Under each monitoring system the following will be highlighted: institutional constraints, funding and methodological problems and design. Although the two monitoring systems are related in nature, the presentation makes a convenient subdivision of the attendant problems, mainly to highlight problems specific to each monitoring system.

MONITORING OF SOIL EROSION

Institutional Constraints

One of the essential prerequisites of a monitoring system is the availability of a reliable institution to house it and to coordinate the activities of the programme. Regionally the SADCC ELMS sector provides this home, but because of the nature of the way the sector operates, it can only be effective in monitoring as an initiator and coordinator and as a back-up system that links together well developed monitoring system units in each country. The national monitoring units should in turn be effective in coordinating monitoring at the national level. The administration of soil erosion monitoring activities in the region varies from country to country. The institutions entrusted with these activities include Soil and Water Conservation Departments of Ministries in each SADCC country, and Research Institutes and Departments of University Faculties or Regional Research Institutions supplemented by individual researchers undertaking independent studies within each country. In some cases the monitoring of erosion is related to donor-funded development programmes.

The activities include baseline assessment of the degree of land degradation resulting from soil erosion at different levels (national, regional or by ecological zone), assessment of soil loss from different land management units, overall assessment of the degree of erosion within a given drainage basin, and qualitative assessment of the status of erosion as a basis for the formulation of projects and to identify constraints in land management strategies. In some cases, individual institutions have embarked on long-term assessment of changes in erosion as part of their development strategies, in order to evaluate the effects of planned land uses at the end of projects or as a way of getting information to introduce changes in management.

The local institutions entrusted with the monitoring of soil erosion are in most countries inadequately supported in terms of the quality and quantity of staff. The countries are also characterised by a lack of well-equipped data collection networks and of facilities for rapid data processing and analysis. In addition, the nature of the organization of these institutions is mostly to implement a policy of land management; while monitoring is often relegated to a secondary role. Furthermore, the staff turnover within the SADCC region is very high resulting in a lack of continuity in the work of the monitoring units and in the high cost of manpower training.

The SADCC-ELMS and other donor agencies have realized these short-comings, and, as a result, support programmes, in terms of short workshops and seminars organised either at regional or national level, have been initiated to assist the member countries in order to improve the quality of their technical staff. In addition Donor agencies have assisted the member countries in institution building through staff development programmes and initiation of sustainable transfer of technology into the region. The seminars and training workshops have included training of local staff to use already available local facilities and expertise to improve and build up a system of rapid methods of data collection and analysis, and the introduction of joint training programmes based on a common methodolgy. The strategy here is to enable the local institutions to improve their efficiency and upgrade the technical level of their staff members without inccurring the large cost normally associated with training courses in formal education institutions. Furthermore, the ELMS has initiated research networks to look specifically at the relationship between soil loss and loss of agricultural productivity by producing a common research design for the region (Stocking, 1986, 1987; Strömquist et al., 1989; ELMS, 1991).

Methodological problems

In soil erosion monitoring the major problems relate to the definition of what to measure. Three related data collection techniques have been used in the region:
1. the study of soil erosion processes;
2. production of inventories of erosion features and their spatial distribution;
3. assessment of soil erosion risk or hazard (the likelihood of erosion occurring given certain environmental and climatic conditions).

In the first instance the emphasis is on the study of the processes of erosion in terms of their magnitude, frequency and their rates of operation. This provides an understanding of soil erosion process dynamics and also information on the overall effects of erosion processes. In an inventory of soil erosion features (forms) the emphasis is on the overall degree of land degradation caused by different erosion processes, in terms of their types, extent and degree of severity. The third group of techniques are models for erosion classification and prediction of erosion potential. In all groups, the scale factor is a major constraint. This, coupled with the erratic seasonal variation in the operation of the processes of soil erosion, gives rise to one of the major monitoring problems in the region. The problem can be viewed in three ways. First, there is the temporal variation problem related to the time frame over which the measurement of soil erosion has been undertaken in the region. In most countries, these measurements have only started recently. Thus even where data are available, the very short time series available commonly hampers proper understanding of the dynamics, magnitude and frequency of the processes and their results. Secondly, the measurements are discontinuous in time. There exist large gaps in the data records. Most of these gaps are related to the intermittent nature of donor projects and institutional constraints. Thirdly, the problems are related to the choice of spatial sampling frame and instrumentation network. Most of the data collection systems are manually operated, and in a region with varying degrees of accessibility and lack of well trained manpower, data collection is carried out inefficiently, limited to areas of ease of access and over limited periods. Therefore, there is a likelihood of missing rare events that may be important for good monitoring.

The design problems involve selection of suitable times and spatial units to be able to arrive at manageable data collection systems which are representative of the erosion status in the region; and also generation of a data base that will be useful for management, decision making and planning of strategies.

Financial and Budgetary Constraints

Most of the countries in the region have low budgets to run the monitoring systems and therefore these systems are normally poorly equipped in terms of the instruments and manpower required for carrying out soil erosion monitoring activities. Relatively few of the research institutions have sufficient budgetary allocations to run and equip soil erosion research and monitoring. The donor dominace in the erosion surveys related to specific projects is another factor that contributes to the problem of continuity, because most often the project phases of the monitoring have high budgets and use sophisticated equipment which at the end of the projects cannot be maintained efficiently or replaced because of the dearth of funds. To minimize the negative effects of this legacy, ways are being sought to involve local staff at the planning stages of the projects and to include counterpart staff in the project team to ensure minimal loss of continuity at project termination.

APPROACHES TO SOIL EROSION MONITORING

Despite the above mentioned constraints and problems, monitoring of soil erosion in the region has been undertaken since the 1940s. The methods used range from plot studies to regional assessments of the severity of erosion in the region.

A methodology for the assessment of regional severity of soil erosion was initiated within the framework of The Southern African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS) which culminated in a soil erosion classification system based on the combined score system of sheet, rill and gully erosion. The system enables the delineation of erosion classes over a given area in a qualitative manner ranging from slight erosion to very severely eroded areas (Anon, 1981). The system relies heavily on aerial photo-interpretation combined with sound knowledge of the local environment, the causal factors and underlying processes. It has been used in a modified form in Lesotho (Chakela et al. 1986; Strömquist et al., 1988, 1990) to produce erosion maps of the Lesotho Lowlands using both conventional aerial photography at the catchment level and satellite imagery at the regional level. Whitlow (1985, 1986) has used aerial photography to produce an erosion map of Zimbabwe. It is clear, therefore, that in the presence of good coordination, the methodology can be used to monitor erosion rapidly over large areas, provided the financial and staffing constraints are alleviated.

The erosion hazard mapping project of the SADCC is another means of assessing erosion potential in the area. This methodology is based on the Soil Loss Estimation Model for Southern Africa (SLEMSA) developed in Zimbabwe (Elwell & Stocking, 1973) and modified for the region as described by Chakela, Stocking & Elwell (1988). This methodology has been used to produce national erosion hazard maps of most of the SADCC countries on a qualitative scale (low to high risk) and in semi-quantitative units (erosion hazard units). Although this gives only a potential erosion risk, the maps provide a basis upon which an efficient monitoring system can be developed at low cost.

Measurements of soil erosion at the plot level have been carried out in several areas by different researchers within the region. These researches include studies carried out as early as 1934 by Staples in Tanzania; Zimbabwe studies started by Hudson and others in the 1950s which have culuminated in the development of the SLEMSA model for prediction of soil erosion from agricultural lands; studies carried out in Tanzania as part of the Dar es Salaam/Uppsala Universities Soil Erosion Research (DUSER) Project (Rapp et al., 1972). The plot studies supply soil erosion information that is very site specific and thus offers limited scope for the understanding of the dynamics of soil erosion over large areas in the region. However, the availability of erosion plot data enables understanding of the factors that control the rates of soil erosion and thus permits the design of a monitoring system with minimal modifications.

At the catchment level, soil erosion studies have been carried out using catchment field surveys along specific transects (Rapp et al., 1972; Chakela, 1974, 1981; Strömquist et al., 1985; Rydgren, 1984, 1990); sequential aerial photography (Chakela, 1984; Lunden, Strömquist & Chakela, 1986; Stocking, 1984; Thwaites, 1986); and instrumented experimental basins (Amphlett, 1984; Rydgren, 1986, 1990). In addition to these, several workers have used wash-traps and erosion pins to assess interfluve sediment production and loss of sediment from different land use types (le Roux & Roos, 1982; Rydgren, 1984, 1990; Kulander 1986). The aim here is to provide supplementary information on sediment production by overland flow and to assess the spatial distribution of sediment production in the catchment area.

The most rewarding approach, in my opinion, which is amenable to the design of an efficient soil erosion monitoring system is the multi-level and multi-technique approach using all of the four above mentioned approaches (plot studies, field surveys, wash-traps and catchment surveys). The approach was first used in the SADCC region in Tanzania within the framework of the DUSER Project and was extended to Lesotho, where in 1986, satellite imagery was added to the techniques of soil erosion monitoring. In conclusion, although monitoring of soil erosion in the region is imbued with several problems, with the improvements that are being made in the coordination of techniques and strategies through the ELMS and the available experience in the region, an efficient soil erosion monitoring system can be achieved if the major financial constraints are removed and this seems to be a possibility in view of the awareness of the need for such a system as part of the development of sustainable land resource management in the region.

MONITORING OF SEDIMENT YIELD

Institutional constraints

The institutional constraints on the monitoring of sediment yield are not as great as those related to the monitoring of soil erosion. This is mainly because sediment yield monitoring is part of the activity of water resources management institutions in the region. Although in most countries in the region, departments entrusted with water resources management are relatively new and understaffed, the operational framework exists. The major problem is still financial and lack of adequately trained personnel and lack of modern facilities for data collection, processing and analysis which often results in poor access and retrieval of collected data and too many delays in the data processing and publication of data for it to be useful in resource management.

Methodological Problems

Sediment monitoring within the SADCC region is not carried out in all the countries. Where it is undertaken the standard techniques for the monitoring of sediment are employed. These include the measurement of sediment in main rivers using standard water sampling techniques for sediment load assessment (Makhoalibe, 1984; Watson, 1984). In some cases these are complemented by measurements of sediment accumulation in reservoirs and river deposition in bottom land (Chakela, 1981; Rapp et al., 1972; Bolton, 1984).

Most of the problems associate with the monitoring of sediment yield with the SADCC countries were reviewed in detail in a paper presented by Walling at the SADCC Seminar on Monitoring Systems for Environmental Control (Walling, 1987). In this paper only the essential problems pertaining to the region will be highlighted.

In the first instance sediment yield data in the region are very meagre and have been obtained from drainage basins of varying size (10 - 200 000 km^2). The bulk of the sediment yield values are based on suspended sediment load with very few incorporating bedload and dissolved load. Other shortcomings in the available data include the lack of information on the particle size characteristics of the sediment.

Secondly, the estimation of sediment load relies heavily on rating curve procedures, which have not been tested for accuracy in the region. Such reliance might lead to very different results because of insufficient understanding of the relationships between changing river flows and sediment regimes in these environments (Temple & Sundborg, 1972).

Thirdly, there are the problems associated with the accurate measurement of sediment yield. These can be separated into two groups. First, are the problems of obtaining representative measurements of the instantaneous suspended sediment discharge in the river. Secondly, the problems in the extension of such instantaneous measurements to annual sediment yield.

The fourth set of problems are those associated with the interpretation of obtained sediment yield data. The data may not give an accurate long term mean if measurements are taken over a short period. The other problem is the sediment residence time and delivery from upstream areas of the catchment to the point of measurement (Chakela et al., 1986). In addition, the interpretation might be complicated by temporal discontinuities in the sediment delivery system resulting from presence of sediment storage sinks in the catchment areas. This is more so in a region where rainfall variations are large with periodic drought cycles such as southern Africa.

Estimation of sediment yield based on reservoir sedimentation suffers from similar problems to those associated with sediment yield monitoring in rivers in terms of sediment residence time and delivery to the reservoir. The other problems are those related to the trap efficiency of the reservoirs, accurate measurement of sediment accumulation and conversion of the volume of sediment deposits into values of sediment yield for the catchment. Therefore the problems can be grouped into catchment characteristics, and reservoir characteristics. The size of the reservoirs and its operational management poses further problems in the use of reservoir sedimentation for assessment of sediment yield from catchment. The catchment characteristics include topography, land use and soils.

The amount of sediment stored in any reservoir will depend on the rate of inflow into the reservoir, the size of the reservoir, the calibre of the sediment delivered to the reservoir and the rate of outflow. Estimation of sediment yield through reservoir sedimentation will also depend on the operational characteristics of the reservoir. Because the techniques used for measurement of sediment yield within the region follow more or less standard procedures, I am not going to discuss these. The major strategies for improving sediment yield monitoring could be developed along the following lines. First, the sediment measurement network needs to be improved by following a hierarchical system that will minimise the delivery problems and overcome those posed by catchments topographic characteristics. The majority of drainage basins used for the assessment of sediment yield in the region are biased towards large basins covering several geomorphic and vegetation units which are likely to respond differently in the mobilisation and transport of sediment. The approach used in Lesotho and South Africa (Lunden et al., 1986; Kulander, 1986; Rydgren, 1990; Le Roux & Roos, 1982, 1991) allows one to understand the sediment delivery problem and with improvements this approach could be applied to calibrate sediment yield data from larger catchment areas.

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