Farmers' Survival Strategies and Soil Erosion in the Lake Malawi/Niassa/Nyasa Basin – in the Context of Biodiversity Conservation in the Lake; the Case of Linthipe River Catchment

by

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Table of Contents

List of Figures....ix
List of Tables....xii
List of Abbreviations....xvii
Acknowledgements....xviii
Abstract....xx

Chapter 1 Introduction....1
1.1 Rationale....1
1.1.1 Threat to the Biodiversity of Lake Malawi....5
1.1.1.1 Lessons from Lake Tanganyika and Other Lakes....9
1.2 Thesis Organization....10
1.3 Summary....12

Chapter 2 Statement of the Problem....13
2.1 Introduction....13
2.2 Human Influences on Soil Erosion in Malawi....14
2.2.1 Population Trends in Malawi....17
2.2.1.1 Effect of Population Growth on Arable Land....18
2.2.1.2 Influence of Agricultural Systems on Soil Erosion in Malawi....23
2.2.1.2.1 Smallholder Farming....24
2.2.1.2.2 Estate Farming....27

2.2.1.3	Effect of Population Growth on Forest Cover	29
2.2.1.4	Effects of Soil Erosion	31
2.2.1.4.1	Effects of Soil Erosion on Crop Yields	32
2.3	**Soil Conservation on Agricultural Land: Successes and Failures**	**33**
2.3.1	The Colonial Period	33
2.3.2	The Post-Independence Period	38
2.4	**Research Hypothesis and Objectives**	**42**
2.5	**Summary**	**44**
Chapter 3	**Processes and Physical Determinants of Soil Erosion, with Reference to the Lake Malawi Basin**	**46**
3.1	**Introduction**	**46**
3.2	**Basic Mechanics of Soil Erosion**	**47**
3.2.1	General Review of Influences of Physical Factors on Soil Erosion	48
3.3	**Influence of Physical Factors on Soil-erosion Processes in the Lake Malawi Basin**	**52**
3.3.1	Topography	52
3.3.1.1	Influence of Topography on Rainsplash Erosion, and Sediment Transport by Sheet flow, Rills, and Gullies	54
3.3.1.2	Influence of Topography on Sediment Deposition	55
3.3.2	Rainfall	56
3.3.3	Soil Erodibility	60
3.3.4	Vegetative Cover	62

3.4 Summary **65**

Chapter 4 Description of Physical and Anthropogenic Determinants of Soil Erosion in the Linthipe River Catchment **67**

4.1 Introduction **67**

4.2 Physical Factors of the Linthipe Catchment **68**

4.2.1 Slope 68

4.2.2 Rainfall 70

4.2.3 Soils 72

4.2.4 Vegetative Cover 74

4.3 Some Anthropogenic Activities in the Linthipe Catchment **77**

4.3.1 Human Population 77

4.3.1.1 Farmer Characteristics 82

4.3.1.2 Type of Farmer by Geographic Region 82

4.3.1.3 Cropping Practices 84

4.4 Soil-Erosion Control Measures **87**

4.5 Summary **89**

Chapter 5 Geographic Distribution of Soil-Erosion Risk in the Linthipe River Catchment **91**

5.1 Introduction **91**

5.2 Methods **92**

5.2.1 Description of the original SLEMSA 93

5.2.2 The Modified SLEMSA 97

5.2.3 Rationale for Validation of Predicted Soil Losses 98

5.2.4 Modelling the Geographic Distribution of Soil-Erosion Risk 100

5.2.4.1 Calibration of the Modified SLEMSA 101

5.2.4.1.1 Calibration of the Crop Ratio (C) Submodel 102

5.2.4.1.1.1 Measurement of Vegetative Cover and Rainfall-Energy Interception 106

5.2.4.1.1.2 Assigning Cover Values to Land-cover Classes 109

5.2.4.1.2 Calibration of the Climate and Soil (K) Submodel 115

5.2.4.1.3 Calibration of the Topographic Ratio (X) Submodel 125

5.2.4.1.4 Prediction of Soil Loss 129

5.2.4.2 Potential Changes in Distribution of Erosion Risk in Response to Alterations in Land Cover 129

5.2.4.2.1 Worst-case Scenario: Traditional Management and Deforestation 131

5.2.4.2.2 Best-case Scenario: Improved Traditional Management and Reforestation 133

5.2.4.2.3 Moderate-case Scenario: Agriculture and Reforestation 135

5.2.5 Validation of Soil Losses Predicted by the SLEMSA 135

5.2.5.1 Sediment Sampling 136

5.2.5.2 Comparison of Observed and Predicted Soil Losses 137

5.3 Results and Discussion 138

5.3.1 Predicted Soil Losses 139

5.3.2 Validated Soil Losses 147

5.3.3 Observed Versus Predicted Soil Losses 148

5.4 **Summary** 152

Chapter 6 **Principal Socio-economic Factors that Contribute to Soil Erosion in the Linthipe River Catchment** 155

6.1 **Introduction** 155

6.2 **Methods** 157

6.2.1 Questionnaire Design 158

6.2.2. Data Collection 159

6.2.3 Data Analysis 161

6.2.3.1 Perceived Degree of Soil Erosion and Awareness of Effects of Soil Loss 161

6.2.3.2 Identification of Principal Socio-Economic Factors 163

6.2.3.2.1 Multiple Regression Analyses 168

6.2.3.3 Determination of Reasons the Principal Variables Contributed to the Degree of Soil Erosion as Perceived by Farmers 168

6.2.3.3.1 Farmers' Background 169

6.2.3.3.1.1 Sources of Farming Knowledge 169

6.2.3.3.2 Farm Characteristics 170

6.2.3.3.2.1 Sizes of Cultivated Farmland 170

6.2.3.3.2.2 Shapes of Cultivated Land 170

6.2.3.3.3 Farm Inputs 171

6.2.3.3.3.1 Fertilizers 171

6.2.3.3.3.2 Farm Labour 172

6.2.3.3.3.4 Farm Equipment 174

6.2.3.3.4 Farm Outputs 174

6.2.3.3.4.1 Crop Yields 174

6.2.3.3.4.2 Farm Income 175

6.3 Results and Discussion........ 176

6.3.1 Perceived Degree of Soil Erosion and Awareness of Soil-Loss Effects.... 177

6.3.2 Contribution to Soil Erosion by the Principal Variables 182

6.3.2.1 Background Factors 184

6.3.2.1.1 Sources of Farming Knowledge........ 184

6.3.2.2 Farm Characteristics 186

6.3.2.2.1 Sizes of Cultivated Farmland........ 186

6.3.2.2.2 Shapes of Cultivated Land 191

6.3.2.3 Farm Inputs 194

6.3.2.3.1 Fertilizer Applications for Maize........ 194

6.3.2.3.2 Fertilizer Applications for Tobacco 197

6.3.2.3.3 Farm Labour........ 200

6.3.2.3.4 Farm Equipment........ 203

6.3.2.5 Farm Output 205

6.3.2.5.1 Maize Yields 205

6.3.2.5.2 Tobacco Yields 207

6.3.2.5.3 Farm Income 209

6.4 Summary........ 210

Chapter 7 Conclusions and Recommendations........ 213

7.1 Introduction **213**

7.2 Conclusions **214**

7.3 Recommendations **217**

7.3.1 Retaining Natural Vegetative Cover 218

7.3.1.1 Promote Ecotourism 222

7.3.1.2 Strengthen Law Enforcement in Protected Areas 224

7.3.2 Improving Cover on Arable Land 224

7.3.2.1 Removal of Socio-Economic Constraints 225

7.3.2.1.1 Alleviation of Labour Constraints 227

7.3.2.2 Reducing the Need to Open Up Uncultivated Arable Land 230

7.3.2.3 Research into Possible Mixed-cropping of Tobacco 231

7.3.3 Restoration of Cover on Cultivated Land of Marginal Quality 232

References **233**

Appendix A: Geographic Regions of the Linthipe River Catchment 248

Appendix B: Questionnaire for a Socio-economic Survey on Soil Conservation Practices in the Linthipe Watershed, Malawi, 1998/99 Farming Season 250

Appendix C: Cartographic Models and Calibration Procedures of the Modified SLEMSA using Idrisi32 258

Appendix D: Rainfall Data used in Generating Data Layers for Calibration of the Soil and Climate (K) Submodel of the Modified SLEMSA 266

Appendix E: Location and Characteristics of Validation Plots, Linthipe River Catchment, 1998/99 269

List of Figures

1.1 The Lake Malawi Basin: its major riverine inflows; administrative regions; districts covered by the Linthipe River Catchment (hatched); and locations of other places mentioned in the text. 2

1.2 Sediment plume at the mouth of the Linthipe River, Lake Malawi, during the 1998/1999 rainy season 6

2.1: Malawi population and annual-growth rate trends, 1966-1998 18

2.2: Early signs of gullying in a maize field on a steep slope in Malawi 21

2.3 Main sources of fuelwood in Malawi 31

3.1: A profile of the geomorphological zones of the Lake Malawi Basin from the Malawi side. 53

3.2: Rainfall intensities and duration for different return periods for the whole of Malawi 59

4.1 Slope-gradient categories in the Linthipe River Catchment 69

4.2: Mean annual rainfall in the Linthipe River Catchment based on data from 1988 to 1999 71

4.3: Soil Groups in the Linthipe River Catchment 73

4.4: Major land-cover types of the Linthipe River Catchment resampled from 1991 Landsat TM images 76

4.5 Population density in Linthipe River Catchment in 1998; extrapolated from 1998 population and average annual growth rates of the administrative districts that cover the area 81

5.1 The Soil Loss Estimation Method for Southern Africa framework 93

5.2: Rainfall-interception factors (*i*) based on the 1991 land-cover data of the Linthipe Watershed 110

5.3: Average vegetative-cover trend in two plots of *Brachystegia* woodland in the 1998/99 rainy season; Linthipe River Catchment 113

5.4 Crop-ratio based on field data and values from the modified SLEMSA look-up tables (high values represent poor interception); Linthipe River Catchment...... 114

5.5: Determining coordinates of a validation plot using differential GPS 116

5.6: Rainfall energy, 1998/99 rainy season; Linthipe Drainage Basin 118

5.7 Final soil erodibility; Linthipe River Catchment 123

5.8: Soil loss (t ha^{-1} yr^{-1}) from bare land, as predicted by the Soil and Climate (***K***) submodel; Linthipe Watershed 124

5.9: Slope-length determined from 1991 land-cover classes; Linthipe River Catchment..127

5.10: Topographic-ratio; Linthipe River Catchment 128

5.11 Geographical distribution of soil-erosion risk based on 1991 land cover/use data; Linthipe River Catchment 140

5.12 Geographical distribution of soil-erosion risk under the worst-case scenario (traditional management and continued deforestation); Linthipe River Catchment..141

5.13. Geographical distribution of soil-erosion risk under the best-case scenario (improved traditional management and reforestation); Linthipe River Catchment 142

5.14. Geographical distribution of soil-erosion risk under the moderate-case scenario (*status quo* on agricultural land, and reforestation); Linthipe River Catchment.......143

5.15: Relationship between predicted and observed soil-loss estimates for each validation site in the Linthipe River Catchment 149

6.1 Scree plot used to determine the number of factors to retain from the principal factor analysis of socio-economic variables that influence soil erosion in the Linthipe River Catchment....... 166

6.2 Correspondence Analysis of perceived degree of soil erosion by geographic region: Linthipe River Catchment. Clusters of soil-erosion degree and region indicate close association between these variables. 179

6.3 Response frequencies of on-site effects of soil erosion in 1998; Linthipe River Catchment 181

6.4 Correspondence Analysis of shape of cultivated land by region in 1998; Linthipe River Catchment 193

List of Tables

1.1: Families of fish, number of species, and percentage of endemism in Lake Malawi 3

1.2: Sediment discharge into Lake Malawi by major rivers 6

1.3: Soil loss in catchments with similar characteristics except land use; Bvumbwe, Southern Malawi 1984/85..........7

2.1: Arable land or nutritional densities by administrative region in Malawi, 1987 and 1998 19

2.2: Comparison of Malawi's cropland per capita with neighbouring riparian states; figures in parenthesis are for 1994..........20

2.3: The land balance in Malawi 24

2.4: Soil loss on gross arable land and crop yield loss by ADD 33

2.5: Summary of different soil-conservation methods advocated by the GoM..........39

3.1: Surface runoff and flow data of some major rivers draining into Lake Malawi...54

3.2: Some characteristics of rainfall from selected sites in the Lake Malawi Catchment, 1995/96 rainy season 57

3.3: Erodibility factors of different soil groups in Malawi; low values indicate highly erodible soils 61

3.4: Ecological resource distribution in Malawi as of 1991..........63

3.5: Rainfall energy interception factors (*I*) of various cover types in Malawi 64

4.1: Some characteristics of soil groups in the Linthipe River Catchment, Malawi....74

4.2: Distribution of farmers by region, Linthipe River Catchment, Malawi, 1998......83

4.3: Crops commonly grown by estate farmers; Linthipe River Catchment, Malawi, 1997/98 85

4.4: Crops mainly grown by smallholders; Linthipe River Catchment, Malawi, 1997/98 86

4.5: Soil-erosion control measures commonly used by farmers; Linthipe River Catchment, Malawi, 1998 88

5.1: Details of runoff/sediment collection plots; Linthipe River Catchment, 1998/99 104

5.2: Distribution of sampling plots by geographic region and land cover/use; Linthipe River Catchment, 1998/99 104

5.3: Rainfall-energy interception-factors assigned to the major land-cover classes (1991) of the Linthipe River Catchment 111

5.4: Comparison of observed vegetative-cover values (%) with those in the SLEMSA look-up tables 111

5.5: Comparison of interpolated (1988-98) and *in situ* rainfall data; Linthipe River Catchment 117

5.6 Comparison of observed soil depth and texture of soil groups with descriptions in LREP reports 121

5.7: Summary of initial elevation differences between DEMs generated from topographic maps and validation data using two scales; Linthipe River Catchment 126

5.8: Minimum and maximum annual changes in precipitation and energy by 2050 in the Linthipe River Catchment, predicted using outputs of three General Circulation Models 130

5.9: Rainfall-energy-interception factors assigned to the major land-cover classes under different scenarios; Linthipe River Catchment 133

5.10: Area of land in different soil-loss categories under different vegetative-cover scenarios; Linthipe River Catchment 146

5.11: Observed soil loss (t ha^{-1} y^{-1}) by cover type and geographic region in the 1998/99 rainy season; Linthipe River Catchment 147

5.12: Comparison of predicted and observed soil loss based on 1991 land-cover and 1998/99 field data; Linthipe River Catchment 148

6.1 Ranks assigned to perceived degree of soil erosion and effects of soil loss; Linthipe River Catchment 162

6.2: Ranking of socio-economic variables that significantly contribute to soil erosion in the Linthipe River Catchment; an example of the manner in which all responses employed in the factor analyses were ranked 165

6.3 Retained factors and loadings of variables related to perceived degree of soil erosion among estate farmers; Linthipe River Catchment, 1998 167

6.4: Retained factors and loadings of variables related to perceived degree of soil erosion among smallholders; Linthipe River Catchment, 1998 167

6.5: Recommended blanket application rates (kg ha^{-1}) of fertilizers applied to maize and tobacco varieties in Malawi. Figures in parenthesis are averages for tobacco (burley and Malawi western), and maize (local and hybrid maize), as calculated by the author 172

6.6 Proclaimed maize and tobacco yields in Malawi 175

6.7: Degree of soil erosion as perceived by farmers in 1998; Linthipe River Catchment 178

6.8 Principal socio-economic variables that contribute to the degree of soil erosion perceived by farmers in 1998; Linthipe River Catchment 183

6.9: Sources of farming knowledge among smallholders and estate farmers; Linthipe River Catchment, 1998 185

6.10 Farm size, cultivated and uncultivated land, and number of fragments by farmer category; Linthipe River Catchment, 1997/98 187

6.11: Number of farmers cultivating land of different shapes in 1998; Linthipe River Catchment 192

6.12: Mean fertilizer-application rates (kg ha^{-1}) of basal and top-dressing fertilizers used by farmers in maize; Linthipe River Catchment, 1997/98 195

6.13: Number of farmers that applied different types of basal-dressing fertilizers in maize; Linthipe River Catchment, 1997/8 195

6.14: Number of farmers that applied different types of top-dressing fertilizer in maize; Linthipe River Catchment, 1997/98 195

6.15: Estimated mean rates of basal and top-dressing fertilizer (kg ha^{-1}) used in tobacco by farmers in the 1997/98 season; Linthipe River Catchment 198

6.16: Number of farmers that claimed to have applied basal-dressing fertilizers in tobacco in the 1997/98 season; Linthipe River Catchment 198

6.17: Number of farmers that claimed to have applied top-dressing fertilizers in tobacco; Linthipe River Catchment, 1997/98 199

6.18: Total farm labour (hired and family) among estate farmers and smallholders; Linthipe River Catchment, 1997/98 201

6.19: Number of labour sufficient or deficient farmers; Linthipe River Catchment, 1997/98 201

6.20: Mechanized and non-mechanized equipment used commonly by farmers; Linthipe River catchment, Malawi, 1998 204

6.21: Estimated maize yields among smallholders and estate farmers categories; Linthipe River Catchment, 1997/98 206

6.22: Number of farmers insufficient or sufficient in maize; Linthipe River Catchment, 1997/98 206

6.23: Estimated yield of tobacco among smallholders and estate farmers; Linthipe River Catchment, 1997/98 208

6.24: Number of farmers that were deficient or sufficient in tobacco yield; Linthipe River Catchment, 1997/98 208

6.25: Ranges and means of farm income by farmer category; Linthipe Drainage Basin, 1997/98 209

6.26: Number of farm-income deficient and sufficient farmers; Linthipe River Catchment, 1997/98 209

List of acronyms used in the dissertation

Acronym	Meaning
ADD	Agricultural Development Division
AIDS	Acquired Immune Deficiency Syndrome
ADMADE	Administrative Management Design for Game Management Areas
ADMARC	Agricultural Development and Marketing Corporation
CAMPFIRE	Communal Areas Management Programme for Indigenous Resources
CAN	Calcium Ammonium Nitrate
CBNRM	Community-Based Natural Resources Management
CIDA	Canadian International Development Agency
CCC	Canadian Climate Change
DAP	Diammonium Phosphate
DFis	Department of Fisheries
DFor	Department of Forestry
DNPW	Department of National Parks and Wildlife
DoM	Department of Meteorology
DREA	Department of Research and Environmental Affairs
GFDL	Geophysical Fluid Dynamic Laboratory
GDP	Gross Domestic Product
GEF	Global Environment Facility
GoM	Government of Malawi
LIFE	Living in a Finite Environment
LMBCP	Lake Malawi Biodiversity Conservation Project
LREP	Land Resources Evaluation Project
MAFE	Malawi Agroforestry and Extension
MEMP	Malawi Environmental Monitoring Programme
MH12	Malawi Hybrid 12
MoA	Ministry of Agriculture
NEAP	National Environmental Action Plan
NSCM41	National Seed Company of Malawi 41
PRA	Participatory Rural Appraisal
PROSCARP	Promotion of Soil Conservation and Rural Production
RRA	Rapid Rural Appraisal
SADC	Southern African Development Community
SARCCUS	Southern African Commission for Conservation and Utilisation of the Soil
SLEMSA	Soil Loss Estimation Method for Southern Africa
UKMO 98	United Kingdom Meteorological Office 98

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Without the co-operation of the 360 farmers in the various geographic regions of the Linthipe River catchment, an understanding of the soil-erosion problem would have remained a mere illusion. These farmers provided important socio-economic data that explains why high rates of soil erosion are observed from agricultural land despite the fact that the GoM advocates different soil-conservation measures. The contribution of these farmers was, therefore, extremely valuable. For purposes of confidentiality, however, I will keep them anonymous.

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Abstract

This dissertation provides an understanding as to why soil losses on agricultural land in the Lake Malawi/Niassa/Nyasa Basin are excessive notwithstanding the various soil-conservation methods that the Government of Malawi prescribes. These soil losses result in a decline of soil fertility and crop yields thereby reducing the nation's self-sufficiency in food supply. Additionally, high rates of sediments are being discharged into the Lake where they are potentially detrimental to its socio-economic importance and ecological integrity. Soil erosion is, therefore, negatively affecting two important socio-economic sectors in Malawi, i.e., agriculture and fisheries.

To provide the necessary understanding, the study assesses the distribution of soil-erosion risk in the Linthipe River Catchment in relation to physical and socio-economic factors. The Linthipe is used as a case study because it is a large catchment (about 8640 km^2) with a high human-population pressure, steep gradient, high rainfall, and poor vegetative cover thereby providing an ideal opportunity for examining what happens to a large catchment when it is intensively developed for agriculture and human settlement. Distribution of erosion risk is assessed using the modified SLEMSA model, while field data, measured from erosion plots, are used to validate the predicted soil losses. Land-cover change scenarios are used to determine the type of land use that would minimize soil loss. To examine the socio-economic aspects of soil erosion, in order to identify the principal factors that inhibit farmers from employing conservation measures optimally, the study uses socio-economic data and multivariate statistical methods.

In terms of distinguishing between areas of low and high erosion risk, soil losses estimated from erosion plots agree with the predicted results, thereby giving confidence in the use of the model. Results also indicate that the whole catchment is generally vulnerable to soil erosion on account of steep gradient, intense rainfall, and poor vegetative cover. Approximately 63% of the Linthipe has an erosion risk that is moderate to severe (between 3.1 and 19.0 t ha^{-1} y^{-1}). Geographic regions of the highest erosion risk are the Dowa Hills and Scarp regions because of steep slopes, and removal of natural vegetation for agriculture and settlement. In contrast, the Lilongwe and Lakeshore Plains are potentially less susceptible, although intensive settlement and agricultural cultivation also exacerbates the erosion potential. Use of land-cover change scenarios further highlights the importance of vegetation in the study area. Predicted soil losses suggest that the proportion of the catchment that could experience low erosion-risk (< 3.0 t ha^{-1} y^{-1}) might increase up to about 81% by increasing cover through use of improved crop management on cultivated land, and reforestation of land of marginal quality that is presently under cultivation.

Socio-economic data reveal that farmers are aware of erosion degree and its impacts on their land. Therefore, the occurrence of high rates of erosion is not due to ignorance; a fact clearly supported by farmers' use of different soil-conservation methods in the study area. Rather, it is factors such as farm characteristics, and deficiency in inputs, namely labour, fertilisers, and low returns in the forms of crop yields and farm income, that force farmers to adopt survival strategies that lead to ineffective implementation of the recommended soil-conservation practices. Consequent upon these survival strategies, excessive erosion occurs in the catchment, and high rates of sediment are discharged into Lake Malawi, where they have ramifications for biodiversity conservation. The study, therefore, concludes that both agricultural productivity and Lake Malawi's biodiversity are under continued threat unless measures are taken to ameliorate the socio-economic constraints.

To safeguard against further soil loss and its consequences, it would be appropriate for the Malawi Government to prescribe recommendations that will, hopefully, not only sustain agricultural productivity, but also conserve the Lake's biodiversity. These recommendations include retaining natural vegetation, improving cover on agricultural land, and restoring cover on cultivated land of marginal quality. Successful implementation of these recommendations would involve changing public perception of protected areas and other natural vegetation positively because they are presently considered to be locking up resources that would otherwise have been exploited. Consequently, there is vegetative cover removal through encroachment, which is one way that the public manifests its negative attitudes towards protected areas. Adoption of appropriate technology that simultaneously saves labour and conserves soil, and elimination of the need to increase farmland, by means of agricultural intensification that incorporates appropriate soil-conservation measures, could improve cover on arable land. Lastly, reforestation may restore cover on marginal land that is presently under cultivation.

Chapter 1

Introduction

1.1 Rationale

This dissertation provides an understanding of the relationship between agricultural practices, soil conservation, and soil erosion in the Linthipe River Catchment (one of the important catchments in Lake Malawi/Niassa/Nyasa Basin[1], Fig. 1.1) on one hand, and associated downstream effects of sedimentation on fish communities of the Lake, on the other. This understanding will contribute to the development of a biodiversity-management strategy, which is the ultimate goal (Ribbink, Barber, and Hecky, 1996, p 6) of the LMBCP, under whose auspices this study falls. The project involved the three riparian states, namely Malawi, Tanzania, and Mozambique with development of a biodiversity atlas, and a fish identification guide, as the principal objectives. To this end, various studies were undertaken, mainly in the fields of taxonomy, ecology, limnology, and geography.

[1] The terms "Lake Malawi Basin", "Lake Malawi Catchment", and "Lake Malawi Drainage Basin" will be used interchangeably to avoid monotony.

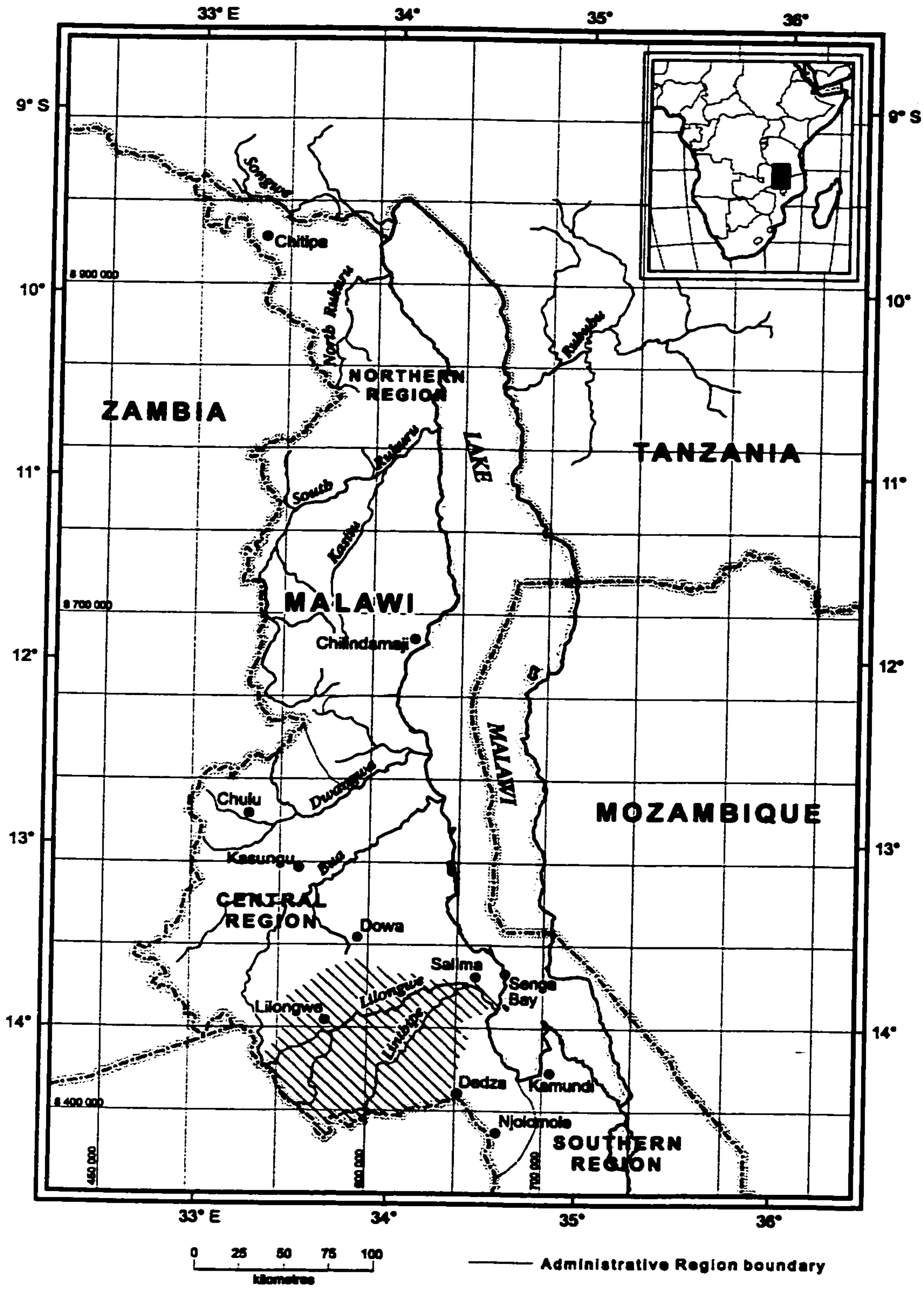

Fig. 1.1 The Lake Malawi Basin: its major riverine inflows; administrative regions; districts covered by the Linthipe River Catchment (hatched); and locations of other places mentioned in the text.

The need for a management strategy is underpinned by three compelling reasons. First, Lake Malawi/Niassa/Nyasa (hereafter referred to as Lake Malawi) is one of the richest and most diverse in terms of fish species in the world (Hecky, 1993). Although all the fish have not been fully described taxonomically, different authors present high estimates of species; for example, 500+, 600+, and 700+ (Lowe-McConell, 1993; Ribbink, 1994; Bootsma and Hecky, 1999, p 1 respectively). This variation notwithstanding, these data do indicate that the Lake is rich ecologically. The majority of the fish belong to the Cichlidae family (Table 1.1), 99% of which are endemic, an indication that speciation took place within the Lake (Ribbink, 1994). Furthermore, the Lake's endemic species flocks are hotspots of biodiversity for the planet, and that they have played an important role in understanding evolutionary processes (Cohen, Kaufman, and Ogutu-Ohwayo, 1996, p 580). Other predominant families are the Clariidae, Mormyridae, and Cyprinidae (Table 1.1).

Table 1.1: Families of fish, number of species, and percentage of endemism in Lake Malawi

Family	Number of species	Percent endemism (excluding stream and river species)
Mormyridae	6	17
Characidae	2	0
Cyprinidae	16	56
Amphiliidae	1	100
Bagridae	1	0
Clariidae	14	86
Mochokidae	2	50
Cyprinodontidae	1	0
Cichlidae	600+	99
Anguillidae	1	0
Mastacembelidae	1	100
Protopteridae	1 (introduced)	0

Source Ribbink (1994)

Second, not only do fish provide nearly 75% of the animal protein intake by Malawians (Ribbink, 1994), fishing is a significant source of employment to 32,000 fishers and 200,000 fish-processors and -mongers (Munthali, 1997). Third, the Lake has a thriving ornamental fish trade that has accounted for as much as 66% of the earnings from fish export (GoM, 1988, p 100). Although there is paucity for recent data on this trade, it has been, and continues to be a source of foreign exchange. In total, the fisheries sector contributes about 4% to Malawi's GDP (Nsiku, 1999, p 15). Undoubtedly, the Lake is an ecological and socio-economic asset for Malawi, Mozambique and Tanzania; one that must be conserved not only for the benefit of the people who depend upon it, but also as a scientific resource in studies of evolutionary processes. This important resource, however, is under pressure from overfishing and the impacts of human activities in the Lake's catchment, e.g., agriculture and deforestation (Hecky, 1993; Bootsma and Hecky, 1993; Munthali, 1997).

It is necessary to stress from the outset that although this dissertation stems from the concerns about conservation of biodiversity in Lake Malawi, its focus is on soil erosion in the Lake's basin. Also, it is appropriate to emphasize that notwithstanding the fact that overfishing is one of the threats to the Lake's biodiversity, that concern was beyond the mandate of the LMBCP; hence it is not addressed in this study. Lastly, there are other important issues related to conservation of aquatic biodiversity, for example, water quality and impacts of sedimentation on fish and their habitats. These topics are also not considered because they have either been covered, or are being addressed, by other studies (refer to Bootsma and Hecky, 1999, pp 1-15; Duponchelle, Ribbink, Msukwa, Mafuca, and Mandere, 1999, p 111; Kingdon, Bootsma, Mwita, Mwichande, and Hecky, 1999, p 29; McCullough, 1999, p 70; Cooley, 2000, p 17; Sululu, 2000, p ix).

To provide background information and establish a scientific rationale for the study, this Chapter describes the threat that sediment discharges from excessive soil erosion in the Lake's catchments pose to the biodiversity of Lake Malawi. Evidence from the Lake itself is used to depict the nature of the threat, but lessons of relevance to Lake Malawi are drawn from another African Great Lake[2] (Tanganyika in Tanzania), and other freshwater lakes. These lessons render weight to the concerns about sustainability of the biodiversity in the Lake. The Chapter then concludes with an outline of the entire dissertation to illustrate the flow of subsequent Chapters.

1.1.1Threat to the Biodiversity of Lake Malawi

As indicated in the preceding section, the most apparent problem facing the biodiversity of Lake Malawi is that of increased suspended sediment input (Hecky, 1993; Fig. 1.2; Table 1.2) as a result of high soil-erosion rates occurring principally on agricultural land in the catchments (also refer to Chapters 2 and 4). Earlier studies have also shown deposition of sediments in the Lake (Crossley, 1984; Pilskaln and Johnston, 1991, Halfman and Scholz, 1993; Kalindekafe, Dolozi, and Yuretich, 1996, p 443).

[2] The African Great Lakes include Malawi, Tanganyika, and Victoria

Fig.1.2 Sediment plume at the mouth of the Linthipe River, Lake Malawi, during the 1998/1999 rainy season (photo by courtesy of G.K. McCullough)

Table 1.2: Sediment discharge into Lake Malawi by major rivers

River Catchment	Size ('000 ha)	Sediment discharge (t ha^{-1} yr^{-1})
Linthipe	864	3.28
North Rukuru	209.1	0.45
Songwe	880	2.59
Ruhuhu	1723	4.97
Bua	1065.4	0.18
Dwangwa	770	0.40
South Rukuru	1190	0.26

Source Kingdon *et al.*, (1999, p 52)

Although other geomorphological processes, such as mass movements, especially landslides, and fluvial processes (bank and channel erosion) are also sources of sediments (Crossley, 1984; Begin, 1981), existing studies in Malawi have focused on surface soil erosion by water (e.g., rainsplash, sheet, rill, and gully) on agricultural land. For this reason, this study also focuses on the surface-erosion processes because the fact that they have received more attention implies that are considered more significant than the other sources of sediment. Available evidence of soil loss on land under different management practices in fact helps to clarify why occurrence of soil erosion on agricultural land is of concern. On sites with similar slope, rainfall, and soil characteristics, soil loss was higher on cultivated land than under a *Eucalyptus* plantation (Table 1.3). Since the aggregate rate of soil loss from arable[3] land is about 20 t ha^{-1} yr^{-1} (WB, 1991, p 13), which is almost twice as high as the maximum permissible limit[4] of approximately 5 ton $acre^{-1}$ yr^{-1} or 12.7 t ha^{-1} yr^{-1} (Shaxson, 1970), soil is being removed at a faster rate than it is being formed. The long-term sustainability of agriculture in the catchment is, therefore, being undermined, while sediment deposition in Lake Malawi threatens the value of the aquatic biodiversity.

Table 1.3: Soil loss in catchments with similar characteristics except land use; Bvumbwe, Southern Malawi 1984/85

Parameter	**Catchment**			
	Bvumbwe[a]	Mindawo[b]	Mindawo II[c]	Mphezo[d]
Rainfall (mm)	1334	1191	1207	1137
Runoff (mm)	62.2	154.5	85.6	8.4
Soil loss (t ha^{-1})	0.13	14.32	5.11	0.06

Adapted from Amphlett (1986, p 34)
[a] Full land use, complete physical or mechanical conservation measures and land-use plan set out in accordance with the GoM's Land Husbandry Manual
[b] Traditional cultivation, intensive uncontrolled arable farming for subsistence crops, without conservation
[c] Mechanical conservation works, but without a planned system of land use
[d] *Eucalyptus* plantation with very good ground cover

The fate of a pollutant entering a lake depends on a variety of processes, including degradation, sedimentation, volatilisation, resuspension, and flushing (removal by outflow). The relative importance of each process depends on the nature of the pollutant and physico-chemical conditions, but flushing rate is the dominant factor (Bootsma and Hecky, 1993). These authors have estimated that Lake Malawi has a flushing time of about 750 years, while Pilskaln and Johnston (1991) have calculated that sediments

[3] Land that is fit for planting crops
[4] This figure is balanced the rate of soil formation from below (Shaxson 1970).

accumulate at about 1 mm yr^{-1}. The implication of these estimates is that sediments stay in the Lake for a long period before they are removed.

Effects of sediment on the aquatic environment of Lake Malawi are not yet fully understood, but the increased sediment input and its long flushing period provide a basis for the concern about the sustainability of biodiversity. Moreover, there is evidence that the sediments could be impacting fish habitats. Suspended sediments cause turbidity thereby limiting the penetration of light, which is essential for primary production (Bootsma and Hecky, 1999, p 1). Actually, a decline in rock-algae production has been observed in sites where sediments cover the rock sub-strata in the Lake (Munthali, 1997). Generally, the temporal effect of such a decline is to disrupt the littoral food web (Worthington and Lowe-McConnell, 1994). Additionally, sediments seal holes where most of the rock-dwelling cichlids such as the *Mbuna*, which comprise almost 50% of all fish species in the Lake, breed (Reinthal, 1993; Munthali, 1997). Thus, sedimentation has a negative effect on the feeding and breeding behaviour of fish in the Lake.

Additionally, destruction of habitats of gravel spawners by large silt loads, washed down from cultivated steep marginal lands and catchment areas after heavy rains, has been reported by Tweddle (1992). Consequently, most popular fish species found in the rivers and streams of the Lake Malawi Catchment are in decline, e.g., *Opsaridium microlepis, O. microcephalus, Barbus johnstoni, B. eurystomus, B. litamba and Labeo mesops*. Since fish communities of Lake Malawi predominantly occupy major habitats such as rocky zones, vegetated areas, and open waters in the near shore (Ribbink, 1994), they are inevitably impacted by the increased sediment discharge because these habitats are frequently near the mouths of rivers (Fig. 1.2).

1.1.1.1 Lessons from Lake Tanganyika and Other Lakes

The relevance of Lake Tanganyika is that there is high human population pressure in its basin (as will be seen in Chapter 2), and steep-slope cultivation is as common as in Malawi. Excess sedimentation from the cultivated steep slopes of the Lake Tanganyika Basin has resulted in local reductions in species diversity of up to 60% for ostracode crustaceans (Cohen, Bills, Cocquyt, and Caljon, 1993). Fish-species diversity is also showing large magnitude of reductions. It has been observed that the biodiversity indices of the fish community on sandy beaches were lowest in front of the mouths of heavily loaded rivers (Bennett, Cocquyt, Coveliers, Downey, Duck, Holland *et al.*, 1996, p 55). Specialized benthic-algal browsers have been disproportionately reduced compared to other trophic groups, suggesting that light intensity and habitat quality are having a direct impact on the benthic fauna. If the impacts of human activities, such as steep slope cultivation, caused sedimentation and reduction of aquatic biodiversity in Lake Tanganyika where the population pressure on land is higher than in Malawi, then the increasing human-population pressure (Chapter 2) can also produce similar effects in Lake Malawi.

Besides the impacts observed within Lake Malawi, other biological consequences have been observed to result from excess sedimentation in other parts of the world. These include reductions in the nutritional value of detritus (Graham, 1990), physical damage or abrasion to organisms (Bruton, 1985), interference with respiration (Cairns, 1968), and loss of the spatial heterogeneity required by habitat specialists (Cohen *et al.*, 1993). Sedimentation also causes the foraging success of zooplanktivores, and of the early stage of fish development, to decline, while increased turbidity may restrict visibility for zooplanktivorous fish and affect predator size selectivity (Gardiner, 1981; Vinyard and O'Brien, 1976). Although the impacts that have been observed in other lakes are yet to be studied in Lake Malawi, it is prudent to speculate that they could occur; hence there is a need to safeguard against their occurrence. If they are already occurring, then it is equally important to prevent their escalation.

1.2 Thesis Organization

This dissertation consists of 7 Chapters, each one comprising an introduction, the main body, and a summary. This Chapter has described the ecological integrity and socio-economic importance of, and threats to, the biodiversity of Lake Malawi thereby providing a rationale for the dissertation. Chapter 2 is a description of the nature of the problem, i.e., excessive loss of soil, principally from agricultural land, which is an indication of the strong influences that human activities in the Lake's catchment have on soil-erosion processes. It also illustrates the underlying cause of soil erosion and the resultant sediment fluxes in the catchments; this is a high human-population density and its resultant effects on arable land and forest resources. Furthermore, the Chapter describes the two types of farming systems, both of which contribute to soil erosion. An account of various attempts that have been used, and continue to be employed, to control excessive soil loss in Malawi is given. Based on the background information, a hypothesis and study objectives are established.

Chapter 3 is a literature review of soil-erosion processes in relation to their physical determinants, i.e., soil characteristics, topography, rainfall, and vegetative cover. It renders credence to the observation made in Chapter 2 that the intrinsic potential of the Lake Malawi Basin is on account of physical factors such as steep slopes, high rainfall and soil erodibility. Chapter 4 describes the study area, i.e., the Linthipe River Catchment in terms of physical and human factors. Specifically, it qualitatively assesses the vulnerability of the different geographic regions to soil erosion on account of soil characteristics, rainfall, topography, vegetation, and socio-economic variables, for example farmers' background, income, farming practices.

Chapters 5 and 6 address objectives (i) and (ii) respectively. These Chapters, therefore, describe the methods that were used to determine the distribution of soil-erosion risk in the study area and those that led to the identification of the primary socio-economic variables that influence soil erosion. Chapter 6 also interprets and discusses the results in support of the research hypothesis. An abridged version of these two Chapters, entitled *Contribution by Farmers' Survival Strategies to Soil Erosion in the Linthipe River Catchment: Implications for Biodiversity Conservation in Lake Malawi/Nyasa,* has been accepted for publication in the *Biodiversity and Conservation* journal. This acceptance gives additional scientific merit to this dissertation.

Chapter 7 forms conclusions and provides recommendations for ameliorating the soil-erosion problem in order to sustain both agricultural productivity and the aquatic biodiversity. While the recommendations are specific to the Linthipe River Catchment, they may also be applicable to the other catchments, considering the similarity of geology and land-use activities around the Lake (Bootsma and Hecky, 1999, p 3).

1.3 Summary

The purpose of this Chapter was to set the stage for this dissertation. In this regard, it has described the ecological and socio-economic importance of the fish of Lake Malawi thereby rationalizing the study in the context of conserving this important resource. Issues that are also pertinent to conserving the biodiversity of Lake Malawi are multi-disciplinary, for example overfishing, water quality, and impacts of sediments on the aquatic environments. Every study has limitations, and this one is no exception. Therefore, the other issues pertinent to the conservation of biodiversity are excluded. Moreover, other authors have covered or are examining these topics. Being cognisant of this situation, this Chapter has defined the particular area that is of concern to this study. However, due recognition of the existence of the other studies that are relevant to conservation of the biodiversity of Lake Malawi has been made. The Chapter has ended with an outline of how the entire dissertation is organised in order to illustrate the sequential flow of succeeding Chapters.

Chapter 2

Statement of the Problem

2.1 Introduction

As indicated in Chapter 1, the observed sediment input into Lake Malawi is a result of excessive rates of soil erosion in its basin. Although the Lake Malawi Basin is potentially vulnerable to soil erosion on account of steep topography, intense rainfall, and soil erodibility[5] (Kettlewell, 1965; GoM, 1983, p 40; Shaxson, 1970; Paris, 1990, p 5), human activities, e.g., deforestation and agriculture, exacerbate this potential. One of the largest changes of land use in Malawi arises from the conversion of dry deciduous forest into agricultural land (Calder, Hall, Bastale, Gunston, Shela, Chirwa, and Kafundu, 1995). In fact, the decline of forest cover is about 3.5% per annum; that exclusively associated with agricultural clearing over the past fifty years has come at a rate of 1.5% per annum, while the rest is attributed to other activities such as fuelwood gathering, and local construction (Orr, Eiswerth, Finan, and Malembo, 1998, pp 28 and 29).

This Chapter provides a scientific rationale for examining the problem of soil erosion in the Lake Malawi Basin. Specifically, it describes the impact of human influences on the environment, especially soil erosion from past to present. Attention is given to the effect of human pressure on arable land and forest resources because these two are important to the livelihood of the people around the African Great Lakes (Cohen *et al.*, 1996, pp 578 and 579). Furthermore, it discusses the various attempts that have been used, and are still being

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[5] Vulnerability of soil to erosion.

used to combat soil loss in Malawi. From these descriptions, the key question, on which this study's hypothesis and study objectives are established, becomes apparent.

2.2 Human Influences on Soil Erosion in Malawi

Classical literature, e.g., Wilson (1941) and Harper and Gibson (1959), indicates that human influences on soil erosion became evident with the arrival of European settlers in the 1890s. It is possible that literacy, and prior knowledge of the soil-erosion problem by these settlers, brought about this awareness. Documented evidence, however, claims that the land-use practices that were introduced by the settlers triggered the occurrence of excessive soil loss on agricultural land in Malawi (the then Nyasaland).

Prior to the arrival of European settlers, soil erosion was not a serious threat to environmental degradation in Nyasaland. Several reasons have been advanced for such a situation. First, the indigenous population was low, the total population[6] in 1901 being 737,153. This low population was primarily because of poor medical care and hence a high mortality rate (Pike and Rimmington, 1965, p 134). Second, the people practiced shifting cultivation, which allowed vegetative cover to regenerate and soil fertility to be replenished. The traditional method of growing crops was on the flat, or in separated circular mounds locally known as "matuto". The methods of cultivation employed by the indigenous people were fairly standardized throughout the country, and had no doubt evolved through a long course of experience and adaptation to their natural surroundings (Wilson, 1941).

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[6] *De jure* (by right according to the law) population (GoM, 2001)

The main crops grown by the local people were for subsistence, e.g., maize (*Zea mays*) and finger millet (*Eleusine coracana*,). Beans (*Phaseolus vulgaris*) were intercropped with the main crops (Wilson, 1941). The salient feature was to retain soil fertility by using a maize-legume (groundnuts *Arachis hypogea* or beans) rotation (Wilson, 1941).

When cultivating, farmers used to select appropriate methods depending on soil type and fertility, which was identified by its colour. Farmers would open bush-fallow land using three methods: *chisoso* (new land); *magadi* (fallow land); and *mphuma*. Wilson (1941) explained that the *chisoso* cultivation, for example, was the method *par excellence* for infertile regions where long-term habitation was not expected. The soils in such regions were *msokolowe*, i.e., white sandy infertile or stony infertile soils of hilly slopes. Hoeing was very shallow, merely sufficient to make seedbeds for the *Eleusine* crop. *Magadi* cultivation was done on *katondo* (red fertile soils) or on *chigandasi* (strong black soils including seasonally saturated alluvial soils). Hoeing was deep, and it took place during the early rainy season in December and January. This was a definite adaptation to the fact that the months before the rains (October to November) are the hottest of the year. Moreover the soils become baked hard during the long dry season, so the early rains have a softening effect. While hoeing, the main idea was to turn the sod and bury the grass and crop residue to enhance decomposition. The *mphuma* method was subsidiary to the two systems of *chisoso* and *magadi*, and it was regarded as a hurried emergency approach used to enlarge existing maize gardens. To be successful, it demanded good soil, so its use in *chisoso* was limited (Wilson, 1941). Harper and Gibson (1959) have claimed that these practices meant that soil-erosion problems rarely confronted the indigenous population.

Third, the level of mechanisation did not involve heavy machinery that is responsible for soil-structure deterioration in today's agriculture (Mwendera, 1989, p 1). Fourth, pastoralism among most tribes did not involve large numbers of livestock, except amongst the Ngoni (Wilson, 1941). Therefore the effects of overgrazing were rarely evident. Harper and Gibson (1959) reported that this pastoral economy prevailed for numerous generations until the arrival of European settlers.

With the arrival of settlers, a change in land use and modern methods of conservation began, thereby changing the old ways of the indigenous people subtly. First, land was alienated to European settlers. Second, the attitude of colonial experts was that there was nothing to be learnt from the African traditional farming methods. Writing on the period 1890-1915, Vaughan (1977-78) cited by Mlia (1987, p 4) stated that both Europeans and Africans viewed this period, for different reasons, as a time of ecological crisis. The former condemned the traditional farming methods of the latter for causing extensive soil erosion among other things, while the latter blamed the former for disrupting their whole way of life through their intrusion, land alienation, and various restrictions on economic activities. The European perception of the "ecological crisis" led to "a colonial conservation mania" that led to setting aside of land as Native Reserves in 1902. Harper and Gibson (1959) noted that the setting aside of reserves was the first mistake that was to result in general land misuse in many areas. Under the more settled conditions, the population pressure of local people on land increased.

Third, with better medical facilities, there has been generally higher natality than mortality. For instance, the crude birth rate[7] in 1901 was about 55.2 while crude death rate was 34.1, and in 1998 these rates were 37.9 and 21 respectively (House and Zimalirana, 1992; GoM, 2001). A combination of the rapid population increase and land alienation to European settlers upset the original balance between people and their environment (Mlia, 1987, p 3). Apart from the ecological imbalance on reserves, use of machinery in areas farmed by the settlers, injudicious bush fires, monocultural agriculture, and persistent overgrazing also brought about soil erosion on a large and ever increasing scale (Harper and Gibson, 1959).

2.2.1 Population Trends in Malawi

Four post-World War II censuses have been undertaken in Malawi, and they reveal that since 1966 the population has more than doubled from about 4.4 to 9.9 million (Fig. 2.1). With the exception of 1998, the mean annual intercensal growth rate has been above 2.6%, the average rate for Africa (World Resources Institute, 1998, p 244). The decline in growth rate to 2.0% in 1998 (Fig. 2.1) is attributed to an increase in crude death rate from about 15 to 21 (Kalipeni 1992a; GoM, 2001). House and Zimalirana (1992) consider this decline as a temporary interruption by the speed and intensity of AIDS. The natural rate of increase may, therefore, rise again once AIDS has been brought under control. The

[7] Birth occurring for every 1,000 people in the country (Plane and Rogerson, 1994, p 81).

increase in human population is unquestionably having an effect on the static arable land, and forest resources, as will be seen in the succeeding subsections.

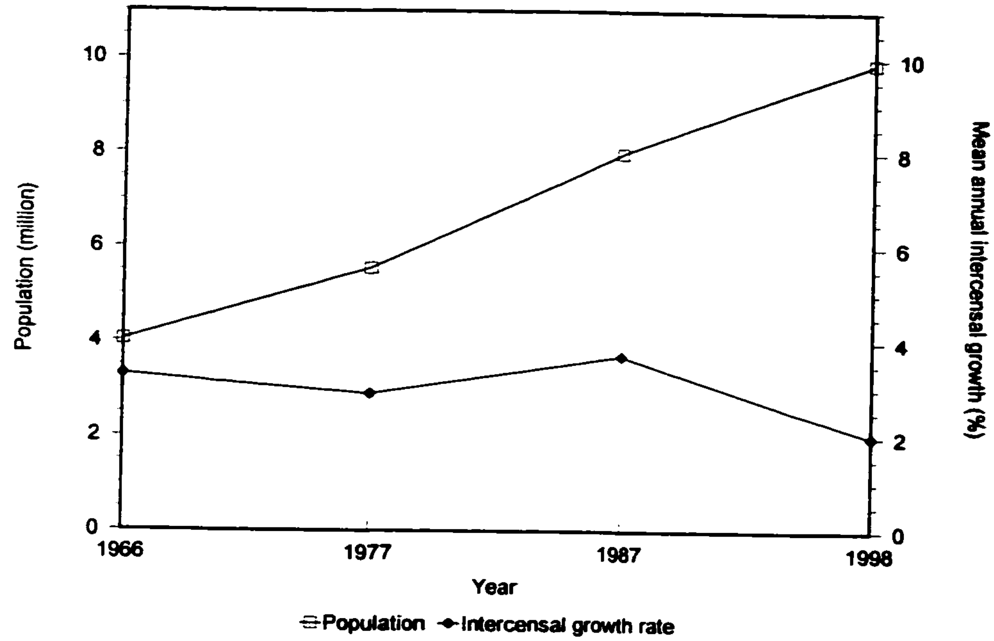

Fig. 2.1: Malawi population and annual-growth rate trends, 1966-1998 (GoM, 2001)

2.2.1.1 Effect of Population Growth on Arable Land

The most recent data (Table 2.1) are used to depict the effect of population pressure on land. At approximately 7.98 million people in 1987, Malawi's arithmetic density of population was about 0.85 persons ha^{-1}. Densities of administrative regions were, however, variable: 0.34; 0.87; and 1.25 persons ha^{-1} for the Northern, Central and Southern regions (Fig. 1.1) respectively, which occurred because of differences in land area and population distribution (Table 2.1). By 1998, the national arithmetic density had increased to 1.05 persons ha^{-1}. Similarly, the regional arithmetic densities rose to 0.46 persons ha^{-1} in the North, 1.14 (Centre), and 1.46 (South).

Table 2.1: Arable land or nutritional densities by administrative region in Malawi, 1987 and 1998

Region	Total land ('000 ha)[a]	Arable land ('000 ha)[a]	Population ('000) 1987[b]	Arable density[c]	Population ('000) 1998[b]	Arable density[c]
North	2693.1	1236.0	911.8	0.7	1233.6	1.0
Centre	3559.2	2249.0	3110.9	1.4	4066.3	1.8
South	3175.3	1822.0	3965.7	2.2	4633.9	2.5
Total	9427.6	5307.0	7988.5	1.5	9933.9	1.9

[a] GoM (1988, p 77)
[b] GoM (2001)
[c] Persons ha^{-1} of arable land

A refined measure of population pressure is arable or nutritional density, which is the number of people per unit area of arable land, and a measure of a nation's self-sustainability in terms of food (Kalipeni, 1992a; Plane and Rogerson, 1994, p 27). Since an increasing population requires larger amounts of resources to satisfy both tangible and intangible needs, most particularly food production (Shaxson 1970), there has been concomitant increase in arable density (Table 2.1). Conversely, there is a decline in per capita size of holdings. For instance, the equivalent of Malawi's arable density of 1.5 persons ha^{-1} in 1987 was a mean area of 0.7 ha per capita, which had decreased to 0.5 ha per capita by 1998.

Another way of depicting human population pressure on land is by expressing it as cropland per capita (World Resources Institute, 2000, p 273). Availability of data from Tanzania and Mozambique enables this study to compare population pressure, in terms of cropland per capita, between these two riparian countries and Malawi (Table 2.2). Cropland is defined as land under temporary and permanent crops, temporary meadows, market and kitchen gardens, and temporary fallow (World Resources Institute, 1998, p 302). From the definitions of arable land (Chapter 1) and cropland, it must be obvious that the latter may vary annually depending on an individual farmer's decision, while the former is static. According to Table 2.2, Malawi's cropland *per capita* was the same as Mozambique's in 1997, but higher than Tanzania's. The implication of the data in Table 2.2 is that the cultivation intensity is higher in Tanzania than in Malawi and Mozambique. However, Malawi's urbanization rate (13%) is slower (Orr *et al.*, 1998, p 17) than that of Tanzania (22%), let alone when compared to Mozambique (30%). A higher proportion of the human population is, therefore, directly dependent on the land for a longer period in Malawi than in the other riparian states. Compared to the neighbouring countries, Malawi's land is, therefore, cultivated continuously thereby limiting opportunities for use of fallow as a soil-conservation method.

Table 2.2: Comparison of Malawi's cropland per capita with neighbouring riparian states; figures in parenthesis are for 1994

Country	**Total ha ('000,000)**	**Cropland per capita (ha)**	
		1987	1997
Malawi	1.7 (1.4)	0.21	0.17
Mozambique	3.18 (3.1)	0.23	0.17
Tanzania	4.0 (2.89)	0.15	0.13

Source World Resources Institute (1998, p 286; 2000, p 273)

The increasing arable density in this case suggests that Malawi's self-sustainability in food requirements is being eroded. Therefore, more land has to be brought under cultivation. Bootsma and Hecky (1993) stated that catchment-basin morphology is one of the major determinants of the potential for human habitation and basin development. This is obviously because land of gentle relief is preferred for settlement and cultivation than steep slopes. However, as land that is suitable for cultivation becomes scarce, people resort to cultivating steep slopes, thereby dramatically increasing the potential for soil erosion (Fig.

2.2). Once under cultivation, these steep slopes generate very high sedimentation rates in precisely those areas that when undisturbed, are typically sediment free (Cohen *et al.*, 1993). Steep land is potentially more vulnerable to water soil erosion than flat land for the obvious reason that erosive forces such as splash, scour, and transport, all have a greater effect on steep slopes (Hudson 1995, p 98). Consequently, there is markedly greater soil erosion on slopes of 5-10% than on gentler gradient (Evans 1980, p 122). The problem is particularly acute within the steeply sloping rift basins where catchments often give way to steep, rocky lake bottoms at the shoreline. The present cultivation of marginal land in Malawi (Fig. 2.2), therefore illustrates why high soil-erosion and sediment-discharge rates are being recorded.

Fig. 2.2: Early signs of gullying in a maize field on a steep slope in Malawi (MAFE, 1995, p 2)

The second ramification of a decline in size of holdings is that farmers are unable to practice sound soil-conservation practices such as crop rotation, which helps to minimise soil erosion (GoM, 1974, p 2-2). Limitation of cultivated farmland in soil-erosion control has been well articulated by Douglas (1988, p 216) who stated that farmers with small size holdings are rarely able or willing to adopt improved conservation and land-use practices solely for the sake of soil conservation. Most of the standard soil-conservation recommendations require farmers to forego short-term benefits for the sake of long-term sustainability. For example, the priority of farmers with only 1 or 2 ha of land, is to grow food for the family, not crop rotation. In the case of class C arable land[8], which is obviously cultivated in Malawi (Fig. 2.2), at least 40% of the land would be required to be under perennial crops at any one time (Douglas, 1988, p 216). The requirement to conserve such land, however, diminishes the farmers' capacity to produce food. Mechanical conservation structures such as artificial waterways and storm drains, if installed, would similarly remove some land from food production. Farmers would rather commit as much land as necessary to food-crop production. Under such circumstances soil-erosion occurs with less than optimal conservation measures in place.

Another problem with the small size of holdings is that it limits access to cultivable land, especially under the customary tenure[9] system where a chief may reallocate uncultivated land, away from a household that is unable to cultivate it, to those in need of more land (Chipande, 1988, p 163). The consequence of this practice is that subsequent generations inherit very small pieces of land that may neither provide enough subsistence in a situation of static technology (Chipande, 1988, p 163), nor offer opportunities for soil conservation.

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[8] Class C arable land is equivalent to Land Capability Class III in the American system. This class has an increasing erosion hazard, hence recommended for limited or moderate cultivation (Brady and Weil 1999, p. 713).

[9] Land that is held, used, or occupied under customary law (Mkandawire *et al.*, 1990, p 8), and its nomenclature is associated with communal type of tenure.

The fourth problem of shrinkage in holding size is that it impinges upon farm mechanisation, which is one of the agricultural aims of the GoM because it reduces drudgery experienced by farmers (GoM, 1992, p 16). The approach to mechanization is to adopt use of draught animals and appropriate farm machinery in order to increase land and labour productivity. Achievement of this aim has been frustrated by the small size of holdings, in addition to an inadequate supply of draught animals (GoM, 1992, p 16). It has been observed by Stocking and Abel (1992, p 213) that farm labour is one of the critical socio-economic constraints in agriculture because its availability is a principal factor in the acceptance or rejection of soil conservation. Therefore, it can be speculated that farmers who are unable to mechanize farm operations, due to the small area of their cultivated land, experience drudgery. Consequently, they allocate most of their labour to food production as opposed to soil conservation. Under such circumstances, soil erosion occurs with very minimal measures in use.

2.2.1.2 Influence of Agricultural Systems on Soil Erosion in Malawi

While the increase in human population (Fig. 2.1) is without any doubt causing pressure on arable land, there are also specific agricultural practices that contribute to soil erosion and discharge of sediment from the catchments. Agriculture is the backbone of Malawi's economy and the mainstay of its population since it comprises about 33-45% of the nation's GDP, employs 80% of the labour force, and generates 90% of export earnings (Sahn and Arulpragasam, 1991; FAO, 2000; WB Group, 2000). Agriculture's prominence in Malawi's economy is further illustrated by the amount of land under estate[10] and customary

[10] Primarily by leasehold tenure (WB, 1991, p 11)

tenure (Table 2.3). Smallholder farming under customary tenure and estate farming characterise Malawi's agricultural systems, which are also distinguished by cropping emphasis, and size of holdings (WB, 1991, pp 10-12). What follows is a review of issues surrounding the central focus of the dissertation from the perspectives of the two primary agronomic systems currently used in Malawi, both of which contribute to soil erosion (WB 1991, p 12).

Table 2.3: The land balance in Malawi

Tenure type	Status	Land (000 ha)	Total (000 ha)	% of Malawi's land
Public				
Protected areas	Suitable	185		
	Unsuitable	1,665		
Agricultural schemes	Mostly suitable	150	2,000	21
Estate	[a]Cultivated	600		
	Available, suitable	360		
	Unsuitable, uncultivated	220	1,180	13
Customary	[1]Cultivated	1,900		
	Available, suitable	2,600		
	Unsuitable, uncultivated	1,600	6,100	65
Urban	4 major cities	85		
	Other urban	35	120	1
Total	-	-	9,400	100

[a] Includes 30,000 ha of unsuitable estate land and 266,000 ha of unsuitable customary land respectively (Orr *et al.*, 1998, p 19)

2.2.1.2.1 Smallholder Farming

This category of farming is undertaken on land under customary tenure. It provides 70% of domestic food production (FAO, 2000). Lorkeers and Venema (1991, p 54) state that smallholders can be subdivided into three groups. Farmers owning < 0.7 ha grow subsistence food crops especially maize (*Zea mays*), but they also depend on off-farm income. Individuals that have 0.7-1.5 ha grow mainly subsistence food crops, and they are able to sustain themselves, while those owning > 1.5 ha grow cash crops such as tobacco (*Nicotiana tabaccum*) in addition to subsistence food crops. Farm inputs and yields are higher among the latter than in the other two groups. In 1991, smallholder farming comprised 1.6 million families (WB, 1991, p 10). With the increase in human population, there must have been corresponding increases in the number of households practicing this type of farming.

The WB (1991, p 10) stated that land-use practices by smallholders are dominated by several factors. First, farmers cannot effectively practice soil-conservation measures because the holding sizes are small. Second, crop yields are extremely low, with averages ranging only from 1.3 t ha^{-1} to 3.0 t ha^{-1} for local and improved (hybrids and composites) maize varieties respectively (GoM, 1992, p 41). The low yields attained are attributed to the limited adoption of fertilizer and high yielding varieties (Chipande, 1988, p 163; WB, 1991, p 10). Using optimal agricultural methods, yields of these varieties can range from 3.0 t ha^{-1} to 8.0 t ha^{-1}. Potential yield of burley tobacco, which is most commonly grown in Malawi, is 4 t ha^{-1}, yet the proclaimed average yield is approximately 1.5 t ha^{-1} (GoM 1992, p 75). In light of low crop yields, farmers have to cultivate additional land in order to achieve their farming goals (food sufficiency and profit optimisation). Chipande (1988, p 166) reported that the annual growth rates of 1% and 11.1% attained in the agricultural sector by smallholder and estate sectors between 1964 and 1978 were more a result of expanding the area of cultivation rather than intensifying production. Since this practice usually involves cultivation of land of marginal quality, often with steep slopes, rates of soil erosion are accelerated.

Third, maize dominates smallholder farming, occupying about 75% of the cropped area (WB, 1991, p 10). The problem with cereals is that they rarely cover more than 90% of the ground surface (Stocking and Elwell, 1976). Even with good ground cover, in tall crops such as maize, more soil erosion might take place than expected. The height from which large coalesced raindrops fall is sufficient to enable them attain high terminal velocity[11] and cause soil erosion by rainsplash (Stocking and Elwell, 1976). The higher the impact velocity of raindrops, the greater will be the amount of soil loss (Evans, 1980, p 114).

Lastly, many smallholders are constrained by labour inputs in light of the large labour demands within the household. There is also limited availability of labour-saving technologies, particularly at the peak of labour demand/food deficit period at the beginning of the growing season (Chipande, 1988, p 170). During this period, it is common for smallholders to supplement their income and dietary needs by hiring out family members as labourers to better-off farmers in return for payment-in-kind or cash (Chipande, 1988, p 170). The necessity to hire out family members is especially acute between December and January, which is also the critical period for soil erosion because crops do not have enough cover to protect the soil against raindrop impact. Weil (1982) showed that on a maize farm at Bunda College of Agriculture in Lilongwe, soil loss and

[11] The speed at which a body continues to fall after gravitational force is in equilibrium with the frictional resistance of the air (Hudson 1995, p 62).

cumulative runoff increased from about 0 to 9.5 t ha^{-1} yr^{-1} and 0 to 18 cm^3 respectively at the onset of the rainy season (between November and December). Thereafter, both runoff and soil loss levelled off because maize and weed cover provided protection against raindrop impact. As this is the period that farmers' hire out their labour, the few family members who are left, if at all, to cope with demands on their own farms fail to implement soil-erosion control measures effectively. The consequences are the observed high rates of soil erosion and subsequent sediment fluxes.

2.2.1.2.2 Estate Farming

Upon attaining independence in 1964, the GoM's agrarian policy was largely geared towards the support of smallholder agriculture (Mkandawire, Jaffee, and Bertoli, 1990, p 18). A shift towards estate agriculture, however, began towards the end of the 1960s when the 1968 Economic Report raised doubt as to the ability of smallholder farming to generate economic growth and provide sufficient government revenues for investment purposes. Estate farming was, therefore, viewed as a potentially more reliable source of growth and revenues than smallholder agriculture (Mkandawire *et al.* 1990, p 18).

Estate farming is principally concerned with tobacco (*N tabaccum*), tea (*Camellia sinensis*, and sugar production (WB, 1991, p 11), but estate farmers also grow maize (*Z mays*) as a food crop for labourers (Lorkeers and Venema, 1991, p 61). It controls about 90% of the export trade (MAFE, 1995, p 3). This farming system is generally exemplified by larger holdings than those owned by smallholders. The estate sub-sector has been classified by Mkandawire *et al.*, (1990, p 15) as small-scale estates (< 30.0 ha), medium-scale (30.0 -

100.0 ha), and large-scale (> 100.0 ha). Given this distinction, it is feasible for the smallest estate to occupy less land than the largest smallholder.

Estate farming is heavily dependent on 'visiting tenants' and hired labour. The visiting-tenant system is a sharecropping arrangement under which some families obtain land on estates on the condition that they grow a cash crop that is sold to the estate at a price determined by the estate owner (Kydd and Christiansen, 1982). Under this type of arrangement, the visiting tenants cannot be expected to be committed in implementing soil-conservation practices because they do not own the land. Lee (1980) found significant differences in average rates of soil erosion between tenure groups. Land ownership can, therefore, influence the degree of importance that farmers attach to land-use practices. Moreover, visiting tenants and hired labourers frequently change jobs in light of low wages and difficult working conditions; hence commitment by these workers to conserve soil on the land that they work is limited.

Part of the strategy to accelerate estate agriculture's role as a revenue source involved conversion of about 1.1 million ha from customary land into leasehold burley (sun/air-cured tobacco) estates. Following this conversion, a new group of small, less-experienced estate owners emerged. This group has relatively poor knowledge of land management. In contrast, previous estate farming was solely associated with large-scale investment by corporations or prominent businesspersons, and better implementation of a conservation farm plan (Douglas 1988, p 216; Mkandawire *et al.* 1990, p 13). The emergence of this new group of estate farmers has resulted in the use of poor soil-conservation measures that include inadequately graded bunds, ridges not aligned with contours, drainage ridges at 45° angles to bunds irrespective of slope, and failure to maintain conservation bunds (WB 1991, p 12). In fact, despite intensive campaigns, only about 12% of the cultivated land in Malawi can be considered to have adequate ridges on contours (GoM, 1998, p 33).

By 1991 there were about 15,000 estate farms (WB, 1991, p 11). Given the economic importance of this sector, it is also likely that there has been an increase in the number of estate farmers. The implication is that the number of farmers (including smallholders) that manage their landholdings suboptimally has also increased.

2.2.1.3 Effect of Population Growth on Forest Cover

Rates of deforestation that have been reported by different studies for varying periods, but all show the general trend is one of decline of forest cover in Malawi. For example, Calder *et al.*, (1995) reported that the forest cover decreased by 13% between 1967 and 1990. Orr *et al.*, (1998, p 28) stated that forest-cover loss was about 50% over 45 years (1946-91). Since the role of agricultural land as a source of sediment has already been elaborated in the previous sections, the succeeding paragraph only explains how demand for fuelwood causes the removal of vegetative cover and subsequent soil erosion. Abbot and Homewood (1999) have demonstrated that use of construction poles seems to be sustainable because of their extended durability; hence this activity is not as detrimental as vegetation removal for agriculture or fuelwood. A discussion of the contribution to deforestation, of the effect of pole cutting for construction, is therefore excluded.

The main source of energy in Malawi is biomass, which provides about 93% of the total energy that is used by 96% of Malawi's population (GoM, 1998, p 42). The total wood consumption for 1990 was estimated at 8.5 million m^3 (WB, 1991, p 32), about 68% of which represented rural demand for fuelwood. The balance comprised urban fuelwood for cooking, heating and industrial requirements (14%), building poles (7%), tobacco and tea estate curing and building requirements (7%), and other miscellaneous uses (4%). The main sources of fuelwood are indigenous forests on customary land and forests reserves (Fig. 2.3). Although the rural population uses the majority of fuelwood, it is mostly in the form of dead wood that does not require cutting down of live trees. The cause of tree cutting for fuelwood, therefore, is the urban demand for charcoal, and industrial requirements; especially curing of tobacco which consumes about 30% of the wood energy in Malawi (Hudak and Wessman, 2000). By the year 2000, the demand for wood products was expected to increase to about 10.5 million m^3 (WB, 1991, p 32). The implication of this increase in demand for fuelwood, obviously as a result of the increases in population, is further deforestation, and concomitant accelerated rates of soil erosion and sediment yields. Cohen *et al.*, (1996, p 579) stated that the use of fuelwood (particularly charcoal) as a primary energy source among rural people in the African Great Lakes region is a contributing factor to acceleration of deforestation.

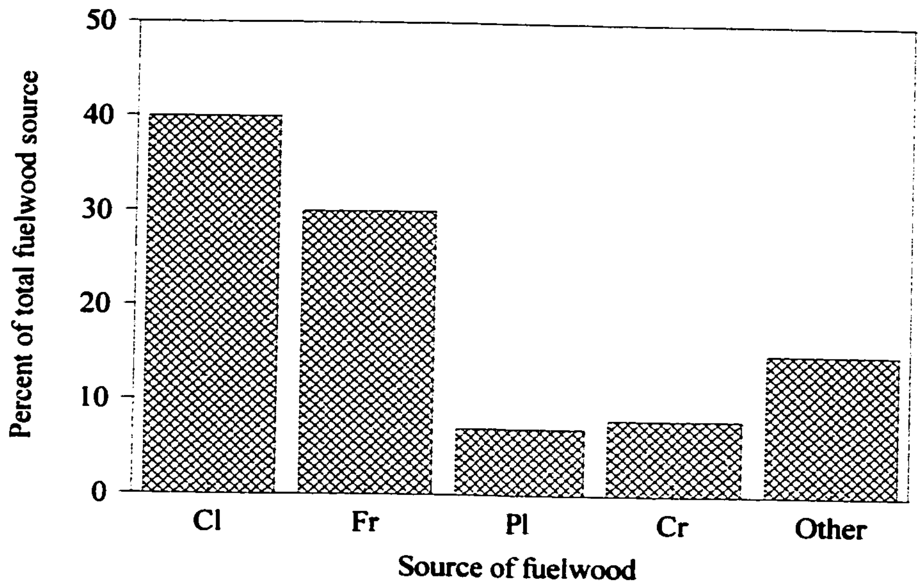

Fig. 2.3 Main sources of fuelwood in Malawi (after GoM, 1998, p 42). Explanations of the codes are as follows: Cl = customary land, Fr = forest reserves, Pl = plantations, Cr = crop residue

2.2.1.4 Effects of Soil Erosion

The decline in food self-sufficiency due to an increasing nutritional or arable density is compounded by low crop yields, which is one consequence of soil erosion. Other effects include energy costs, on-site, and off-site (Pimentel, Harvey, Resosurdarmo, Sinclair, Kurz, McNair *et al.,* 1995). Energy costs can be surmised as the amount of fossil energy expended on agricultural production activities, on-site effects occurring within the catchment boundary, while off-site impacts affect the environment outside the catchment boundary. Changes in landscapes, which are of interest to geomorphologists and geologists, are the other impacts of soil erosion (Troeh *et al.*, 1991, p 41). In view of the available evidence of soil erosion in Malawi, it is possible that there are accompanying subtle changes in the landscapes of the Lake Malawi Basin, neither can it be refuted that there is loss of energy in agricultural production. However, this study is principally concerned with on-site and off-site impacts of soil erosion because they directly affect economic sectors of importance in

Malawi, which are agriculture and fisheries respectively. Off-site impacts, however, have been thoroughly covered in Chapter 1; therefore, on-site effects are the focus of the next sub-section.

2.2.1.4.1 Effects of Soil Erosion on Crop Yields

Soil erosion adversely affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, organic matter, soil biota, and soil depth (Pimentel *et. al.*, 1995; Troeh *et al.*, 1991, p 69). Research on soil erosion-soil productivity relationships indicates that, generally, crop yields on severely eroded soils are lower than on protected soils. The losses in crop yields (Table 2.4) converted to a mean annual loss of income between MK 10.00[12] and MK 29.00 ha^{-1} (WB, 1991, p 15). This, in turn, aggregated to a national loss of between MK 18 million and MK 52 million y^{-1}, equivalent to 0.5 and 1.5% of the GDP. It is the rural poor, who consist of one-half of the smallholder population, that feel these economic impacts mostly because the loss of productivity arising from soil erosion may reduce the already limited household income by almost 10% y^{-1} (WB, 1991, p 15). Low income implies that farm inputs such as labour and fertilizers will also be low, resulting in poor crop cover and yield, thereby not only creating a need for expanding the amount of land under cultivation, but also exposing the land to forces of soil erosion.

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[12] US$ 1.00 was about MK 2.70 in 1991

Table 2.4: **Soil loss on gross arable land and crop yield loss by ADD**

ADD	Arable land ('000 Ha)	Soil loss (t ha^{-1} yr^{-1})	Weighted average yield loss (%)	
			Low impact	High impact
Karonga	188.1	29	5.5	15.6
Mzuzu	884.6	22	4.3	12.2
Kasungu	955.3	20	3.9	11.1
Lilongwe	788.4	22	4.2	12.1
Salima	577.9	16	3.1	8.8
Liwonde	739.1	13	2.6	7.4
Blantyre	636.5	29	5.6	15.7
Ngabu	244.7	17	3.2	9.3
Aggregate	-	**20**	**4.0**	**11.3**

Source WB (1991, p 13)

2.3 Soil Conservation on Agricultural Land: Successes and Failures

The soil-conservation efforts that began during the colonial period have continued to the present day, albeit with some modifications. Different approaches, such as policies, mechanical structures, extension and education, have been, and continue to be used. As it will be seen in the succeeding sections, these approaches have had their share of successes and failures in combating soil erosion, not only during the colonial era, but also the post-independence period.

2.3.1 The Colonial Period

The colonial period, which began towards the end of the nineteenth century, reached its peak in 1953 when the Federation of Rhodesia (Northern Rhodesia, now Zambia, and Southern Rhodesia, Zimbabwe) and Nyasaland was declared. This period came to an end in December 1963 when the Federation was dissolved, and Malawi became self-governed.

The priority during this period was not only to address the soil-erosion problem allegedly caused by the traditional farming methods, but also to respond to the problem of soil erosion that was precipitated by the concentration of human populations in reserves, and use of machinery and monocultural agriculture in areas farmed by the settlers. In this regard, the colonial administration introduced a soil-conservation policy, which arose in search of solutions. This search was accompanied by the appointment of the first soil-conservation officer in 1936 (Harper and Gibson, 1959). Ten years later, the first Natural Resources Ordinance was enacted in 1946 with the sole purpose of prescribing soil-conservation methods and encouraging judicious use of natural resources (Kettlewell, 1965). Natural Resources Boards were appointed under this ordinance at a local, regional, and national level. The role of these boards was to enforce the prescribed practices.

Kettlewell (1965) recognizes three overlapping phases in the colonial government's attempts to address the problem of soil erosion. The first phase (1945-49) sought to introduce contour-ridge cultivation to replace the traditional system of planting all crops on the flat and circular mounds. The second phase (1949-56) aimed to promote the reinforcement of the ridges by contour bunds or banks in the areas most susceptible to soil erosion. Some progress was made throughout the second phase. It was estimated that contour and box ridging protected about 750,000 acres or 303,525 ha. Gross soil erosion was halted because virtually all arable land on slopes was cultivated using contour ridges. For this reason, Nyasaland had a reputation of being one of the countries in Africa most notable for soil conservation (Kettlewell, 1965).

The third phase (1956-60), involved the use of more sophisticated methods of conservation such as planning techniques and use of mechanical equipment to build dams in areas of greatest agricultural potential. Kettlewell (1965) reported that about 1 million acres or 404,700 ha were protected from soil erosion by contour bunds or more sophisticated measures. This phase also brought in special schemes, for example, the Master Farmer Scheme that aimed at promoting good land use. Under this scheme, the government identified progressive indigenous farmers to set examples of soil conservation in their own areas. A master farmer had to own enough land, a minimum of 8 acres or 3.23 ha, for effective implementation of the recommended soil-conservation measures. In other words, it was part of a policy of helping the receptive to progress. This scheme, however, was not as successful as had been expected because of the minimum farm-size requirement and difficulty of consolidating fragmented[13] plots, an exercise that involved difficult negotiations with neighbours (Kettlewell, 1965). The Smallholder Scheme, for which the minimum holding size was 5 acres or 2.02 ha, was then introduced as an alternative. The essence of this scheme was the replanning of an area (preferably a catchment) to convert it from its haphazard scatter of fragmented plots into an orderly arrangement providing for arable, forestry, and grazing needs of the inhabitants in accordance with the natural properties of the area.

Apart from encouraging use of mechanical measures, agricultural extension and education constituted the primary means of imparting natural-resource conservation

[13] Fragmentation is a land ownership pattern where a single farm consists of numerous discrete parcels, often scattered over a wide area (Bentley, 1987). It is the result of people's desire to maintain an equitable distribution of land types (that have soil quality differences) among them independent of the amount of land each controls (Bellon, 1996).

knowledge to the public. Agricultural-extension work began as oral advice, and evolved into more sophisticated propaganda media, such as pamphlets, posters, press articles, films and magazines (Kettlewell, 1965). Institutional teaching of agriculture was given to the African staff of government departments, selected farmers and their families, and schools. Several farm institutes were established for the purpose of bringing together community leaders, teachers, chiefs, and progressive farmers for brief practical courses (Kettlewell, 1965).

In spite of the Nyasaland Government's good intentions to conserve soil, the attempts largely ended up as failures, with the exception of the wide acceptance of ridges, which are an alternative to planting on mounds or on the flat. Mlia (1987, p 11) acknowledged that this acceptance was the most tangible and permanent result of the conservation campaign of the colonial government. Three reasons are advanced for the overall failure; these are ecological, socio-economic, and political.

Ecologically, it was self-defeating to force the local farmers to continue living in reserves where a condition that was conducive to land degradation had been created. Second, emphasis on mechanical structures was largely due to the misconception that soil erosion was caused primarily by surface runoff. To the contrary, the primary cause of soil erosion in Malawi is raindrop splash (Douglas, 1988, p 216). Third, mechanical-conservation measures were more appropriate for European farmers that were growing estate crops such as tea, tung, coffee and rubber than the indigenous farmers growing subsistence crops. These commercial crops are generally grown in high rainfall areas, which are mostly at high elevations with steep slopes, and hence vulnerable to soil erosion. Under such farming conditions, mechanical measures were a necessity. However, the measures applied to all land users.

Socio-economically mechanical measures were alien to, and inconsistent with, the circumstances in which indigenous farmers operated; they were therefore in conflict with the traditional means of cultivating crops. In developing countries where farms are mostly small, low-cost agronomic methods of soil improvement are appropriate (Stocking, 1995, p 239). In developed countries, on the other hand, there is large-scale estate and commercial production, both machinery and conservation structures are, therefore, the obvious first choice of land managers. Kettlewell (1965) admitted that the measures were unquestionably misplaced for the small-scale African farmer equipped with hand tools. Most of the work to construct mechanical structures had to be done during the dry season when the ground was hard. This was contrary to the traditional practice of hoeing during the rains. Clashes between approaches occur where an attempt is made to force a conservation strategy developed in one set of resource, human and environmental circumstances on quite another situation (Dregne, 1990; Stocking, 1995, p 239). Therefore, it is not surprising that the local people resented these methods (Kettlewell, 1965). The colonial government, however, pressed its policy firmly. Incorrigible offenders were fined, and those who deliberately or persistently opposed its implementation or incited others to resist were, in some cases, given short prison sentences. For these reasons, the great majority of the farmers complied thereby explaining why contour and box ridging were incorporated into the traditional farming system.

Politically, the anti-conservation rhetoric expressed by nationalists struggling for political independence from colonial rule also contributed to the resistance against the adoption of the new conservation measures. Mlia (1987, p 11) reported that African nationalists fighting for independence turned conservation into a political issue, using it as a powerful weapon for attacking the colonial administration.

2.3.2 The Post-Independence Period

As an indication of its commitment to combat soil erosion, the GoM continues to implement soil-conservation measures during the post-independence period. One example of this commitment has been the formulation and implementation of an agricultural policy that stresses, as one of its aims, conservation of the natural resources, especially soil, water, and trees, in order to improve and maintain the productivity of the land (GoM, 1992, p 7). With the new policy in place in the 1970s, the Government reviewed its activities, including soil-conservation measures (Douglas, 1988, p 217). If rainsplash is responsible for 90% of the soil erosion, while surface flow processes account for the remaining 10% (GoM 1974, p 1-2), then the limitations of mechanical measures should have been evident. Consequent upon review of its activities, the MoA currently advocates use of various conservation measures to address the soil-erosion problem (Table 2.5).

Table 2.5: **Summary of different soil-conservation methods advocated by the GoM.**

Practice	Aim	Examples	Remarks
Land-use planning	To optimise use of the land in accordance with the land's capabilities for sustained production (GoM, 1974, p 2-1)	Land capability classification, correct land selection; cultivating on flat land, and prohibition of cultivation near watercourses	Considered as the second crucial step in soil conservation (Morgan 1986, p 166)
Agronomic or biological practices	To provide increased ground cover, thereby diminishing the amount of bare ground exposed to rainfall impact (Shaxson, 1981, p 389)	Early field preparation, timely planting, crop selection, mixed cropping, correct spacing, appropriate intercropping, crop rotation, planting fallow grass	Strong control over detachment and transport by splash and runoff (Morgan, 1986, p 165)
Agroforestry[14]	To improve soil fertility, and enhance crop yields (MAFE, 1995, p 9; Leach, 1996, p 5; Management Unit 1998, p 3; GoM, 1998, p 33)	Involves alley cropping[15], contour-vegetation strips using Vetiver (*Vetiveria zizanioides*)	Other benefits include water retention, and improved availability of fuelwood
Soil management	To improve soil structure so that it is more resistant to soil erosion and promote dense vegetative growth (Morgan, 1986, p 164)	Mulching, use of crop residue, organic or inorganic manure	Moderate effect against detachment by rainsplash and runoff, but strong against transport by runoff (Morgan, 1986, p 165)
Mechanical or physical measures	To supplement agronomic measures by controlling the flow of any excess water and wind that arise (Morgan, 1986, p 164).	Conservation structures such as contour ridging, box ridging, bunds, raising field boundaries, terraces, storm drains, and waterways	Moderate effect against transport by splash, and detachment by runoff, but strong against transport by runoff (Morgan, 1986, p 165)
Integrated land use	To integrate fully the production of annual crops, pastures, livestock and trees with the aid of a contour layout within a farmer's individual holding (Douglas, 1988, p 217)	Agro-pastoralism	Flexible and aims at a bottom-up adoption and dissemination. Allows farmers to investigate demonstrated land-use and farm-management options that are economically, ecologically, and socially appropriate (Douglas, 1988, p 217)

[14] A practice of deliberately growing or retaining trees or shrubs within an agricultural or pastoral land-use system, either under the same form of spatial arrangement or in temporal sequence (MAFE, 1995, p 8).

[15] Alley cropping is both a soil-conservation and yield-improvement technology involving the planting of hedges of suitable tree species such as *Leucaena leucocephela* and *Senna spectabilis* for pruning and the addition of cut biomass as green manure to the grain crops grown in the alleys (Leach, 1996, p 3).

Another example of GoM's efforts to combat soil erosion was the creation, in 1968, of a Land Husbandry Branch (now changed to Land Resources Conservation Department) in the MoA. Its mandate is to provide services in land-use capability assessment, land-use planning, design and construction of physical conservation works, and advisory services (Mlia, 1978, p 10). Furthermore, recent publication of official documents, such as the NEAP in 1994, and the State of the Environment Report in 1998, is also an indication of the importance that the GoM continues to attach to conservation issues.

According to Table 2.2, it is apparent that the approaches used by the colonial government have been retained, with the exception of coercion and compulsion. To illustrate further the point made in the preceding sentence, two examples are given. Between 1968 and 1977, before reviewing its policy, the MoA undertook a mechanical works construction programme in the Lilongwe Land Development Programme (10,712 km^2 in size). An integral network of 357 km of crest roads, 7, 325 km of bunds, and 933 km of artificial waterways were constructed using heavy earthmoving machines at a total cost of approximately US$ 5.0 million (Douglas, 1988, p 216). As an attempt to stop soil erosion in one of the most productive parts of Malawi, it was an expensive failure. The programme sought to prevent soil erosion by intercepting and controlling runoff from farmers' fields. However, it failed to tackle the primary cause of soil erosion in Malawi, namely raindrop splash caused by rainfall and poor ground cover (Douglas, 1988, p 216).

The other reason this project failed was the use of the very same top-bottom approach. Possibly, this approach was a legacy of the colonial government. The conservation programme was designed and implemented by outside experts without directly involving the farmers on whose land the structures were constructed. Douglas (1988, p 216) claimed that the farmers were unimpressed by the alleged long-term benefits and were not prepared to commit their scarce labour to maintain something they did not construct or ask for. Commenting on the state of the structures, Kasomekera and Mwendera (1988) stated that lack of maintenance, partly because of the high maintenance costs, and unwillingness on the part of farmers has led to a state of disrepair and malfunction. The structures silted up and overtopping is common. The net result has been an aggravation of previous soil-erosion problems.

Overall, however, there has been a deviation from the approaches used by the Nyasaland Government. Another example of this deviation has been the emphasis on agronomic and agroforestry practices. As soil-conservation technologies have evolved, agroforestry has emerged, and the GoM is actively advocating it. To implement the agroforestry methods listed in Table 2.5, different rural development projects have been undertaken. Notable agroforestry projects include the MAFE, Biomass and Maize Yield, and PROSCARP. Enthusiasm amongst farmers has been high (Leach, 1996, p 4; Management Unit (PROSCARP), 1998, p 12). Since there is so much enthusiasm, and farmers have been given the opportunity to investigate demonstrated land-use and farm-management options that are economically, ecologically, and socially appropriate (Douglas, 1988, p 217), then why does excess soil erosion continue to occur? This is the key question being addressed by this dissertation.

2.4 Research Hypothesis and Objectives

The fact that rates of soil loss in the catchment and the ensuing sediment discharges into Lake Malawi are high is evidence that soil erosion continues to occur notwithstanding the variety of soil-conservation options. With such high rates of soil erosion and sediment discharge, the need for study and conservation is as pressing as the severity of the problem. In view of the foregoing situation, this study examines the hypothesis:

> *that although farmers in Malawi do recognize soil erosion as a problem, they do not regard soil-conservation measures to be of sufficiently high priority when viewed against the potency of survival strategies that confront them, hence there continues to be a loss of soil from their farms.*

The principal focus is to illustrate how various socio-economic constraints have forced farmers to adopt survival strategies, which has meant that they can only use limited farm inputs such as labour, and fertilizers with the net result that soil-erosion processes are exacerbated. Since soil erosion is influenced by physical factors (topography, soil type, rainfall, and vegetative cover) and human influences, this study sets the following objectives to verify this hypothesis:

i) to determine the geographical distribution of soil-erosion risk based on the physical factors that cause soil erosion in the Linthipe River Catchment; and

ii) to identify the socio-economic variables that principally contribute to soil erosion in the catchment.

Knowledge of soil-erosion risk is essential for effective land-use planning. An assessment of soil erosion in the Lake Malawi Basin will contribute to land-suitability analyses to determine how particular lands can be used sustainably. Furthermore, assessment of soil erosion enables this dissertation to compare soil losses with previous studies thereby substantiating the assertion that the problem continues to be severe. Knowledge of the socio-economic variables that principally contribute to soil erosion will assist the GoM to determine other means (besides the ones in Chapter 7) of implementing this study's recommendations in order to alleviate the principal socio-economic constraints that have been identified by this study. Alleviation of constraints will, possibly, lead to use of optimal soil-conservation measures, and hence reduction of soil erosion thereby limiting sediment discharges into Lake Malawi, and mitigating one threat to the biodiversity in the Lake.

The Linthipe Drainage Basin (Fig. 1.1), which will also be referred to as the Linthipe Watershed or Linthipe Drainage Basin, is used as a case study because it drains a large area (8,640 km^2) within which there is widespread farming that has resulted in a forest cover of only about 26.3% and surface-runoff rates of $41 m^3 s^{-1}$ (GoM 1994, p 30). Soil loss in the Salima, Kasungu, and Lilongwe ADDs (ADDs), parts of which lie within the Linthipe Watershed (Fig. 1.1), are 16, 20, and 22 t ha^{-1} yr^{-1} respectively (Table 2.4). Loss of soil from the catchments results into a sediment-discharge rate of about 94.4 g $-m^{-2}$ (3.28 t ha^{-1} yr^{-1}) at the river mouth, which is only surpassed by that of Ruhuhu River (143.2 4 g $-m^{-2}$ or 4.97 t ha^{-1} yr^{-1}) on the Tanzanian side (Table 1.2; Fig. 1.1). Therefore, the Linthipe Drainage Basin is an ideal site in which to investigate what happens to a large catchment when it is extensively utilized for agriculture. Proximity to the LMBCP's research station at Senga Bay, Salima (Fig. 1.1) also made the Linthipe Catchment a logistically convenient study area.

2.5 Summary

The purpose of this Chapter was to elaborate how an increasing human population has been exacerbating the soil-erosion potential in the Lake Malawi Basin, the consequence of which are the observed sedimentation and its effects on the Lake's biodiversity. Special attention was given to the effect of human pressure on arable land, and forest resources because these two are important to the livelihood of the people around the African Great Lakes. Furthermore, the Chapter has described the successes and failures of the various soil-conservation methods that have been, and continue to be employed to curb soil loss.

It is apparent from this Chapter that the human-population increase in the Lake Malawi Basin is contributing to environmental degradation. Specifically, the effect of the human population on arable land partly diminishes farmers' capabilities to conserve soil. Consequently, excessive loss of soil occurs, the effects of which are not only a decline in crop yields on severely eroded soils, but also excessive discharge of sediments into Lake Malawi. Losses in crop yields mean reduction of farm income thereby creating economic pressures on farmers, especially smallholders (who are the majority in Malawi). This being the case, this study asserts that the economic consequences of soil erosion have implications for soil erosion because they limit farmers' capability to deal with soil erosion. Lee (1980) reported that farmers with adequate income seem to be able to practice soil conservation better than those with low income.

With regard to historical and current successes and failures of soil-conservation approaches, the Chapter elaborates that while the efforts of the colonial settlers were made in good faith, the approaches that were used to implement policies were, however, ecologically and socio-economically misplaced. Compounded with political pressure from nationalists, the conservation drive by the Nyasaland Government stood little chance of complete success. The Chapter has demonstrated further that although methods that are purported to be economically, ecologically, and socially acceptable are being advocated by the GoM, soil erosion continues unabated. This situation has, therefore, provided a sound basis for hypothesis formulation. Subsequently, research objectives have been set, which are addressed in Chapters 5 and 6. Before addressing these objectives, however, literature that is pertinent to the central theme of this dissertation is reviewed in Chapter 3, while Chapter 4 specifically focuses on describing the vulnerability of the Linthipe Watershed (as the study area) to soil erosion, in the context of the very same major determinants, i.e., physical and anthropogenic influences.

Chapter 3

Processes and Physical Determinants of Soil Erosion, with Reference to the Lake Malawi Basin

3.1 Introduction

Chapter 2 described the nature of the soil-erosion problem thereby further setting the stage for the scientific framework of this dissertation. This Chapter intends to review literature that is pertinent to the central theme of the study, i.e., soil erosion. Various authors have shown that the important agents of soil erosion are universal (Shaxson, 1970; Morgan, 1986, p 40; Troeh *et al.*, 1991, pp 72 - 83; Hudson, 1995, p 28), but its extent and magnitude varies spatially because of differences in the physical factors and human influences. This being the case, the basic mechanics of soil erosion are described in general terms, but emphasis is placed on how the physical factors influence soil-erosion potential in the Lake Malawi Basin. Anthropogenic influences have been adequately covered in the previous Chapter, therefore, they are only mentioned where it is necessary.

Processes of soil erosion are best considered in combination with impacts and conservation measures. The nature of the problem that is being addressed by this dissertation, however, necessitated that these impacts be part of the problem statement in Chapter 2. Furthermore, the successes and failures of conservation efforts were discussed in the previous Chapter. Therefore only the role of physical factors in soil-erosion processes are considered in this Chapter. What follows is an introduction of the basic mechanics of soil erosion. Thereafter, physical factors that are specifically involved in soil erosion processes in the Lake Malawi Basin are examined (section 3.3). The Chapter then ends with a summary of the salient issues and the importance of this literature review relative to the theme of this dissertation.

3.2 Basic Mechanics of Soil Erosion

Authors have defined soil erosion differently. For example, Zachar (1982, p 16-17) defined soil erosion as disruption of the soil mantle (pedosphere) or underlying rock base (lithosphere) by the action of external geomorphic factors that include water, snow, ice, wind, weathered debris, and organisms (plants, animals, and man). Evans (1980, p 109), on the other hand, stated that soil erosion is considered as the removal of soil at rates in excess of soil formation, and is attributable to humans and their activities. In spite of the various definitions, there is a consensus that: i) there are two types of soil erosion; natural or geological (GoM, 1974, p 1-1; Morgan, 1986, p 1; Troeh *et al.*, 1991, p 66; Chappell and Brown, 1993; Hudson, 1995, p 36), and accelerated; ii) soil erosion by water involves soil particle detachment, transport, and deposition; and iii) the major determinants are topography, soil type, rainfall, and vegetative cover.

In natural soil erosion, movement of soil materials takes place over a long period of time, while in accelerated or augmented soil erosion, substantial losses of soil take place over relatively short periods of time. From the foregoing definitions, it is obvious that natural soil erosion is inevitable, and it constitutes the intrinsic potential that is exacerbated by anthropogenic activities. This is why augmented soil erosion is often of more concern to humans than natural soil erosion.

Be it in geologic or augmented soil erosion, raindrop splash causes soil-particle detachment, while surface runoff entrains and transports the detached soil particles as unconcentrated overland flow or in a concentrated mode as rills, gullies, and streams. If the surface runoff is detachment limited, which means that it has the capacity to transport more material than is supplied by detachment (Morgan, 1986, p 12), its scouring force causes channel erosion. When sufficient energy is no longer available to transport the soil particles, the third phase, deposition, occurs.

Not all of the material eroded from upland contributes immediately to downstream sediment problems because deposition occurs in catchments (Glymph, 1957). Sediments that are carried further downstream are deposited in coastal zones, which are the ultimate sinks. Sediment deposition occurs when the flow velocity of the transporting agents falls below its threshold, which is known as *fall velocity* (Hjulström, 1935). The distance which soil particles are transported depends upon their size, shape, density and the energy of runoff. Coarse particles tend to be deposited even when the velocity is high because of their size and mass. As the velocity decreases, deposition of finer particles of sand, silt and clay occurs.

3.2.1 General Review of Influences of Physical Factors on Soil Erosion

When raindrops strike the soil surface, they release energy that does three kinds of work (Troeh *et al.*, 1991, p 75). First, it detaches soil particles by breaking soil aggregates and clods into smaller aggregates and individual particles. Second, it provides a source for sediment transport by moving soil grains to new locations as water splashes back into the air. Third, the raindrops reduce the infiltration rate of the soil through formation of crusts on the soil surface, thereby causing increased surface runoff. Soil erosion is, therefore, a function of rainfall erosivity (the potential of rainfall to cause soil erosion) and soil erodibility. In turn, erosivity is a function of the physical characteristics of rainfall such as amount, intensity, momentum, energy, and duration (Morgan, 1986 p 41; Hudson, 1995, p 73).

Rainsplash erosion begins when individual raindrops strike the soil surface at velocities up to 9 m s^{-1}, creating very intense hydrodynamic forces at the point of impact (Foster and Meyer, 1977 p 3). During a rainstorm, some of the rain falls directly onto the land, either because there is no vegetation or it passes through gaps in the plant canopy, a component known as direct throughfall (Morgan, 1986, p 14). The rain that falls on the plant canopy is intercepted, and it is either returned to the atmosphere through evaporation or finds its way to the ground by leaf drip, and stem flow. Direct throughfall and leaf drip cause rainsplash erosion by detaching soil particles from the soil aggregates within the surface-soil layer because of raindrop impact.

Soil becomes detached and transported by rainfall splash and surface runoff in proportion to its erodibility. This property is related primarily to soil texture and structure, both of which affect the size of soil grains and aggregates exposed to erosive elements. Brady and Weil (1999, p 125) stated that three broad groups of textural classes are recognized: sandy soils, clayey soils, and loamy soils. Sands and loamy sands are dominated by the properties of sand, for the sand separate comprises at least 70% of the material by weight (less than 15% of the material is clay). Characteristics of the clay separate are distinctly dominant of clays, sandy clays, and silty clays.

Evans (1980, pp 116-121) has described how the various soil characteristics influence its erodibility. Overall, sand particles are easy to detach but difficult to transport because of their size and mass. The high infiltration rates of sand and coarse loamy sand, however, enable them to absorb a lot of water. Even if the infiltration rates are exceeded, sand particles of more than 0.3 mm diameter are not easily eroded by flowing water or raindrop impact. Stony soils are less susceptible to soil erosion because stones do not only protect the soil, but infiltration is increased as water flows into the soil around the edges. Clay particles tend to stick together, hence they are difficult to detach, but are easily carried over long distances once separated from the soil mass. Silty soils are frequently well aggregated, but the aggregates break down when wet, and the individual particles are also easily transported.

The term soil structure relates to the arrangement of primary soil particles into groupings called aggregates (Brady and Weil, 1999, p 149). The pattern of pores or aggregates greatly influences soil porosity and water movement. Large, stable aggregates make soils difficult to detach and transport because they are more permeable to water (Troeh *et al.*, 1991, p 82). Different studies confirm the importance of water-stable aggregates, for example Hamilton (1977), Elwell (1986) and Paez and Pla (1987). Factors that influence the size and stability of aggregates include texture, cations on the exchange complex, type of mineral, and organic-matter content (Troeh *et al.*, 1991, p 82).

The other factor influencing soil erodibility is cropping history (Evans, 1980, p 120; Troeh *et al.*, 1991, p 82). In the tropics, erodibility is greatly enhanced not only by the physical and chemical properties of the soil, but also by management factors (Elwell and Stocking, 1973). Soil is disturbed by tillage operations such as ploughing or hoeing (in the case of most smallholders), and by the trampling of people and livestock. The latter activities allow the soil to crust, increase in bulk density[16] or decline in organic matter (Morgan, 1986, p 48; Stocking, 1995). After cultivation, the soil surface is rough. Clayey soils have a rougher surface, especially just after ploughing (Evans, 1980, p 120). Therefore, the amount of water that can be stored on the surface before runoff takes place is large at this time. After ploughing, clay soils have 1.6 - 2.3 times more storage volume than do sandy clay loams, and the mean depth is much greater. Surface runoff is, therefore, reduced.

Topographic factors that influence soil erosion are slope steepness, length, and shape. Soil erosion is greater on steeper, longer, and convex slopes than on gentle, short, and concave hillsides (Zingg, 1940). The effect of length of the slope is similar to that of slope angle; rates of soil erosion increase with an increase in slope length and angle (Zingg, 1940). This relationship exists because there is a bigger build up of volume and velocity of runoff on a long slope (Hudson, 1995, p 98). Such a relationship would not occur on a short slope, or where the effective downhill gradient is reduced to the distance between channel terraces. A uniform slope loses more soil than a concave one, but less than a convex slope because the greatest volume and velocity of the runoff that occurs at the bottom operates on the steepest part of the latter (Hudson, 1995, p 99).

[16] Bulk density is the mass of dry soil per unit of bulk volume, including air space (Brady and Weil, 1999, p 831).

The role of vegetative cover and residue is to intercept raindrops and absorb their kinetic energies harmlessly (Stocking, 1994, p 212). The impact of raindrop splash on the soil surface is, therefore, minimized. Under vegetated conditions, there is less detachment by raindrop impact than on bare land. Furthermore, vegetation increases surface roughness. In this way, it reduces overland-flow velocity, which in turn decreases the hydraulic competence[17] and capacity[18] of the flow to remove soil particles. The presence of cover is the key factor in reducing soil loss (Hudson, 1995, p 267). Therefore, soil erosion is bound to be dominant where the ground cover is poor, which is typical of farmland in Malawi (Douglas, 1988, p 216).

3.3 Influence of Physical Factors on Soil-erosion Processes in the Lake Malawi Basin

The succeeding subsections describe the role of each physical factor in soil-erosion processes in the Lake Malawi Basin specifically. This description is important because it renders credence to the assertion made in Chapter 2 that the vulnerability of the Lake Malawi Basin to soil erosion is on account of its physical factors.

3.3.1 Topography

In the Lake Malawi Basin, like in other parts of the world, topography is a major determinant of soil erosion, as it enhances soil-particle detachment by rainsplash and

[17] The stream's ability to entrain a certain maximum size of bedload, which is the sediment that is transported close to or at the channel bottom by rolling, sliding, or bouncing (Laronne and Carson, 1976).

[18] The ability of a transporting agent to move bed material and its concentration in suspended load (Blatt *et al.*, 1980, pp 82 and 108).

scouring by runoff. In addition, topography is important in sediment transport and deposition by surface runoff, rivers, and streams. This role will become evident in the next subsections, but first of all, it is necessary to present a summary of the salient relief features of the Lake Malawi Basin.

According to the GoM (1983, p 40), five geomorphological zones (Fig. 3.1) have been identified in the catchment of Lake Malawi: the Rift Valley Floor (35-500 m); Rift Valley Scarp (500-600 m); Plains (600-1400 m); Hill Zone (1400-1500); and High Plateau (1500-2400 m). These types of morphology results in steep slopes, particularly in the Hills and Scarp zones (Fig. 3.1). Gradients that are steeper than 12% (the dividing line of arable and non-arable land) are common, except within the Rift Valley Floor occupied by the Lakeshore Plain and the Shire River (GoM, 1983, p 40; Khonje and Machira, 1987, p 2). Other studies (Kettlewell, 1965; Crossley, 1984) have also noted that the steep topography in Lake Malawi's catchment is influential in soil erosion.

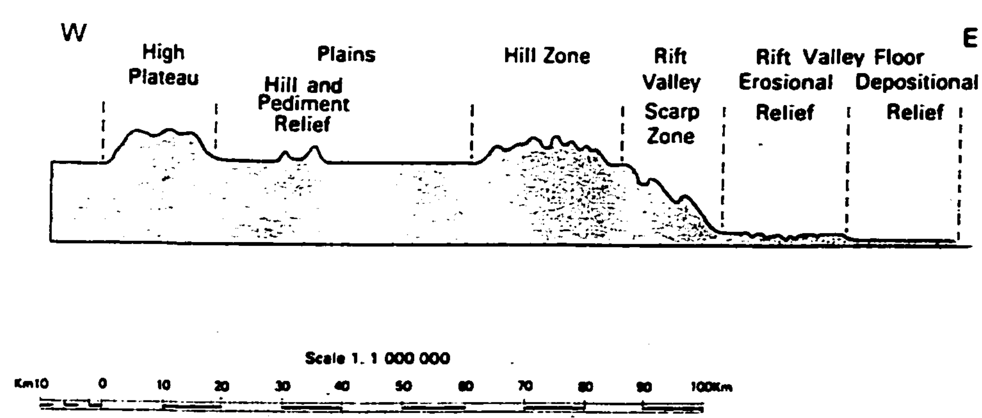

Fig. 3.1: A profile of the geomorphological zones of the Lake Malawi Basin from the Malawi side (GoM, 1983, p 41).

3.3.1.1 Influence of Topography on Rainsplash Erosion, and Sediment Transport by Sheet flow, Rills, and Gullies

On sloping land, the distance travelled by soil particles splashed by raindrops is greater downhill than on the uphill side of the points of impacts (Shaxson, 1970). This results in downslope transfer of soil particles. The steep topography in Malawi (Fig. 1.2) is, therefore, ideal for this type of soil erosion.

It is conventional knowledge that sediment transport is predominantly by river or stream flow, and surface runoff, including sheetflow, rills and gullies, which are mainly a result of scouring by surface runoff that occurs when the soil is unable to take in more water. This is also the case in the Lake Malawi Catchment. However, slope is an important factor in sediment transport because the erosive power of surface runoff is affected by increased gradient (Hudson, 1995, p 98). An increase in steepness of slope rapidly increases the rate at which runoff flows downhill thereby increasing the competence of the flowing water to carry along soil particles.

Table 3.1: Surface runoff and flow data of some major rivers draining into Lake Malawi

Catchment	Rainfall (mm y^{-1})	Runoff (mm)	River flow ($m^3 s^{-1}$)
Linthipe	964	151	36
Bua	1032	103	-
Dwangwa	902	109	21
South Rukuru	873	115	35
North Rukuru	970	252	-
Songwe	1601	327	45

Source GoM (1994, p 19) and Johnson, Wells and Scholz, (1995) Variables that interact with slope gradient are the amount of surface runoff and river-flow rates, which according to Table 3.1 suggest that the runoff has high competence while the rivers have large capacity for transporting sediments. Capacity and competence of the eroding agents, as well as the quantity of material supplied by detachment, influence the effectiveness of the sediment transport processes (Laronne and Carson, 1976). In large rivers, however, capacity is more important in moving sediment than competence (Blatt, Middleton, and Murray, 1980, p 108). The reason is that bed material is generally sufficiently fine grained so that a substantial quantity can be held in suspension in high flows. Given the steep gradient of the catchment, surface runoff, and river flow rates, it is not surprising that increased quantities of sediments are being discharged into Lake Malawi.

3.3.1.2 Influence of Topography on Sediment Deposition

Crossley (1984) stated that rift-valley structures are extremely important in controlling both the distribution of sediments in the Lake Malawi Basin as a whole, and also sedimentation on a local scale. An indication of potential places for sediment deposition within the Lake's catchment can be obtained from its profile (Fig. 3.1). The Rift Valley Floor includes a depositional relief zone consisting of nearly level land formed of alluvium brought down from the hills by rivers that deposit their load where flow velocities are reduced because there is less particle movement on gentler gradients than in steep ones (GoM, 1983, p 40; Laronne and Carson, 1976).

In the Lake, rift structure is also the principal control on whether direct discharge into deep water or delta progradation occurs (Crossley, 1984). Deltaic deposition occurs where the gradient is gentle. For example, most of the sediments carried by the Dwangwa River (Fig. 1.1) are deposited within the delta, in swamps and lagoons separated from the open Lake by fringing beach-ridge systems. On the other hand, sediments are discharged deeply into the Lake where gradient is steep. For instance, the North Rukuru delta (Fig.1.1) is no longer prograding because its margin has reached the edge of a major drop over a submerged fault scarp (Crossley, 1984). Therefore, the river discharges sediment further into the Lake where it deposits its coarse clastics (broken fragments of rock and minerals) and waterlogged vegetative material on the steep fault-controlled slope.

Within the Lake Basin as a whole, the amount of sedimentation associated with rift boundaries comprising tilted fault blocks is variable depending upon the precise nature of the topography (Crossley, 1984). With the exception of the Ruhuhu River in Tanzania (Fig.1.1), the rift cuts across a dominantly west to east drainage system. Therefore, the headwaters of this system flow into the western side of the trough. Consequently, sediment inputs into the rift are asymmetric, with the western side receiving more than the eastern (Crossley, 1984).

3.3.2 Rainfall

The rainfall characteristics that have been measured in Malawi, e.g., amount, intensity, energy, and duration indeed indicate that the Lake Malawi Catchment is vulnerable to soil erosion on account of rainfall erosivity (Table 3.2). Generally, the annual rainfall in

Malawi ranges from about 600 to 3000 mm, but annual rainfalls that are lower than 600 mm also occur in certain areas (Table 3.2). Rainfall distribution is strongly influenced by relief effects (GoM, 1983, p 37). Windward slopes on steep topography facing the prevailing south-east winds may receive twice the rainfall of the low lying areas nearby, but overall rainfall is greatest at higher elevations, and least in the Lower Shire Valley (outside of the Lake Basin), and the Chitipa Plain (Fig. 1). Areas of high annual rainfall, therefore, experience more soil erosion than those of low rainfall because generally more rainfall results in more soil erosion (Hudson, 1995, p 55).

Table 3.2: Some characteristics of rainfall from selected sites in the Lake Malawi Catchment, 1995/96 rainy season

Place	**No. of storms**	**No. of storms with KE > 25[b]**	**Mean duration (min)**	**Total rainfall (mm)**	**Total energy ($Jm^{-2}\ hr^{-1}$)**
Chulu[a]	25	10	54.8	454.3	11,044
Chilindamaji[a]	46	16	74.5	986.7	23,522
Kamundi[a]	43	13	54.6	550.4	13,018
Njolomole[a]	50	18	43.0	650.2	11,916

Source T. Mbale, Professional Officer, Malawi Environmental Monitoring Programme (*personal communication*)

[a] Locations shown in Fig. 1.1

[b] Total kinetic energy of all rainfall falling at more than 25 mm hr^{-1}

Besides its amount, the seasonal distribution of rainfall in Malawi also contributes to soil erosion. The warm/wet season is from November to March in the southern part of the country, but extends until April or May in the North (GoM, 1983, p 37). The heavy rains in the wet season and the desiccation of plant life during the dry season, therefore, both induce soil erosion (Hudson, 1995, p 56). This rainfall pattern also results in seasonality of river discharges and hence in clastic and organic inputs into the Lake (Crossley, 1984). Those rivers with a high proportion of their catchments on the rift shoulder tend to be perennial though still markedly seasonal in discharge. Rivers developed in escarpments show strong "flashy" behaviour and are only effective in sediment transport during storm events.

Hudson (1995, p 79) stated that rainfall intensity of about 25 mm hr^{-1} can be taken as the practical threshold separating erosive from non-erosive events, and an erosivity index of KE > 25 has been found to give an excellent correlation with soil loss. In Malawi, rainstorms are intensive, and intensities of about 20 mm hr^{-1} for several minutes may be exceeded in several parts of the country (GoM, 1974, p 1-6). As the rainfall intensity increases during rainstorms, 40% of which are erosive, so does the energy to detach soil particles (GoM, 1974, p 1-6). According to Fig. 3.2, rainfall events with 1-year return periods are intensive, and rains with longer return periods are even more severe. The minimum intensities for 20 and 50-year return-period rainfalls are 65 mm hr^{-1} and 75 mm hr^{-1} respectively, which are about twice or thrice the practical threshold intensity of 25 mm hr^{-1}. Data from 1995/96 rainy season also show that the erosivity of rainfall in Malawi is high; at least one-third of all the storms had values that exceeded KE > 25 (Table 3.2), indicating that these storms exceeded the soil erosion threshold intensity.

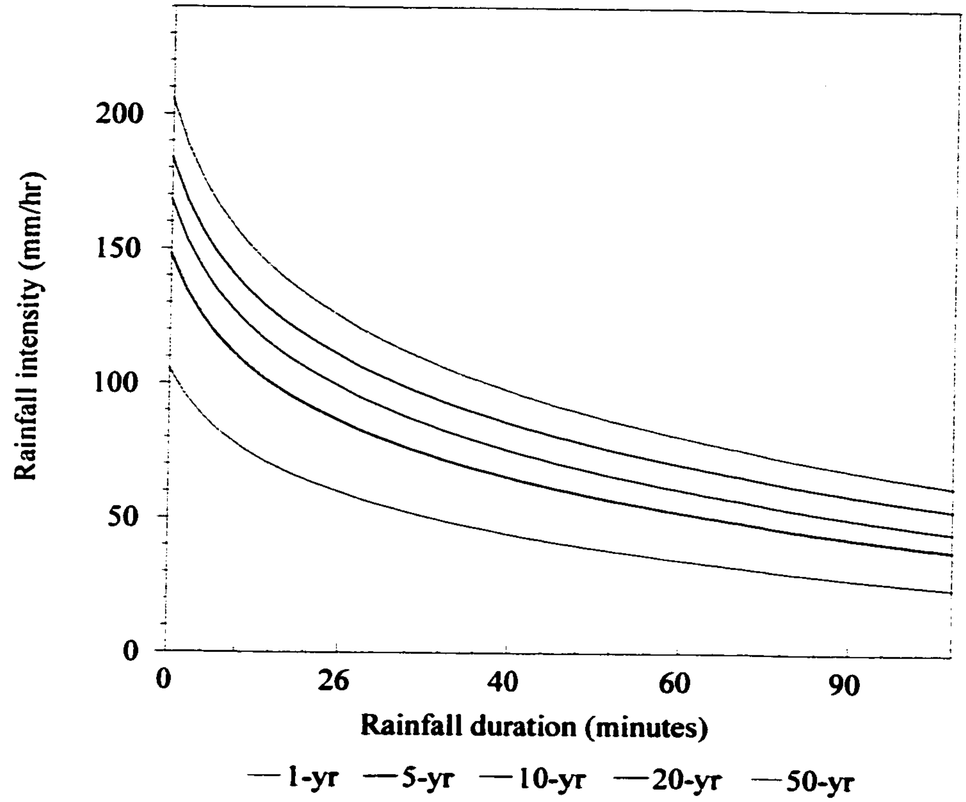

Fig. 3.2: Rainfall intensities and duration for different return periods for the whole of Malawi (after GoM, 1974, p 1-1)

Another factor that contributes to rainfall erosivity in Malawi is the high kinetic energy (Table 3.2). In an examination of the relationship between soil loss on bare land and rainfall energy, Elwell and Stocking (1982) and Stocking, Chakela and Elwell (1988) have shown that the most erosive rainfall has an energy value that is below 15,000 J m^{-2}. This relationship suggests that first, the values in Table 3.2 represent a highly erosive rainfall season. Second, it shows that rainfall would be erosive even when its quantity is low. For example, an annual rainfall of 454 mm, as is the case with the Chulu rains, is erosive (Table 3.2). High kinetic energy values should be expected given that rainfall intensities in Malawi are high, and that rainfall energy is computed from intensity (Morgan, 1986, p 45).

Hudson (1995, p 112) observed that it is common experience that the most severe rainfall lasts only a few hours. The data from Malawi (Fig. 3.2 and Table 3.2) confirm this observation. The rains with shorter duration are higher in intensity than those of longer duration. Therefore, even rains of short duration are erosive.

3.3.3 Soil Erodibility

Malawian soils have been classified and mapped into 13 soil groups following the FAO classification (Table 3.3). The differentiating criteria for the soil groups are characteristics that are most relevant for land suitability evaluation, such as soil depth, drainage, texture, occurrence of flooding and inherent chemical fertility of the top 50 cm of the soil (Lorkeers, 1991, p 29). Vulnerability of these soil groups to soil erosion has been determined according to their basic erodibility and management practices such as contour ridging (Paris, 1989, p 7). Erodibility under traditional crop management (tm) retains the basic erodibility because ridging by smallholders, who primarily employ this system, is poor. On the other hand, under improved traditional management (itm), practiced by estate farmers more typically than smallholders, a correction factor (1 unit) is added for contour ridging because it is generally of good quality. Given that Elwell and Stocking (1982) rated soil erodibility on a scale of 1.0 to 10, low numbers representing high erodibility, it is only the Salic, Mopanic and Vertic soils that are highly erodible (Table 3.3). The majority of soils are moderately (4.5-6.5) or slightly (6.5-7.5) erodible. On account of basic soil erodibility, therefore, a large part of the Lake's basin is moderately susceptible to soil erosion.

Table 3.3: **Erodibility factors of different soil groups in Malawi; low values indicate highly erodible soils**

Soil group	Diagnostic characteristics	Surface texture	Erodibility (tm)	Erodibility (itm)	Area ('000 km²)	% of Total
Arenic	Sandy or loamy sand texture throughout upper 100 cm	Coarse, medium + fine	4.5	5.5	24.32	23.6
Fluvic	Flooding and sedimentation at regular intervals	Coarse, medium + fine				
Paralithic	Weathered rock within 75 cm and > 20% fine earth in upper 75 cm	Coarse, medium + fine				
Salic	High salinity (> 4 mmho/cm) in most of the upper 100 cm	Medium + fine	3.5	4.5		
Calcaric	Calcareous most of upper 100 cm	Coarse, medium + fine	4.5	5.5	8.75	9.2
Dystric-ferralic	Low base saturation (< 50%) in at least part of the upper 50 cm and low CEC clay (< 24 me/100g) in most of the upper 100 cm	Medium + fine	6.5	7.5	3.30	3.5
Dystric-fersialic	Low base saturation (< 50%) in at least part of the upper 50 cm and medium to high CEC clay (> 24 me/100g) in most of upper 100 cm	Coarse, Medium + fine	4.5 6.5	5.5 7.5	22.3	2.3
Eutric-ferralic	High base saturation (> 50%) in at least part of the upper 50 cm and low CEC clay (< 24 me/100g) in most of the upper 100 cm	Coarse, Medium + fine	4.5 6.5	5.5 7.5	2.44	25.8
Eutric-fersialic	High base saturation (> 50%) in at least part of the upper 50 cm and medium to high CEC clay (> 24 me/100g) in most of the upper 100 cm	Coarse, medium + fine	4.5	5.5	25.24	26.7
Gleyic	Seriously impeded drainage, with or without seasonal high groundwater	Coarse, medium + fine, unknown	4.5	5.5	4.09	4.3
Lithic	Effective depth 30-50 cm and < 40% coarse mineral fragments	Coarse, medium + fine	4.5	5.5	0.46	0.5
Mopanic	Within 50 cm from surface a horizon with high bulk density, extremely hard consistence and very low permeability	Medium + fine	3.5	4.5	1.77	1.9
Vertic	Clayey topsoil (> 30% clay) and deep, wide cracks when dry	Medium + fine	1.5	2.5	1.89	2.2
Total					94.56	100

Source Lorkeers (1992, p 30) and Paris (1990, p 5)

3.3.4 Vegetative Cover

Orr *et al.*, (1998, p 28) categorized Malawi's total forest resource into 5 main classes (Table 3.4). Apart from small areas of montane and sub-montane rain forests, most of the indigenous forests are *Miombo* woodlands frequently dominated by associations of leguminous trees of the genera *Brachystegia, Julbernadia, and Isoberlinia* (Abbot and Homewood, 1999). Three-quarters of the woodland is under customary land tenure by local communities, and the Government holds one-quarter in gazetted forest reserves for purposes of protecting river basins and water catchments (WB, 1991, p 32; Orr *et al.*, 1998, p 26).

Table 3.4: Ecological resource distribution in Malawi as of 1991

Class	Land-cover type	Area (km²)	% of Total
Natural Woodland	Evergreen forest	0.8	
	Miombo in flat areas	7.3	
	Miombo in hilly areas	16.9	
	Subtotal	**25.0**	**27**
Plantation	*Eucalyptus*	0.2	
	Leucaena	0.1	
	Logged area	0.0	
	Pine	1.1	
	Rubber	0.0	
	Tung	0.0	
	Subtotal	**1.5**	**2**
Predominantly Grass	Grass	3.1	
	Dambo, often cultivated	4.1	
	Savanna	0.4	
	Subtotal	**7.7**	**8**
Predominantly Agriculture	Agriculture in forest areas	24.3[a]	
	Agriculture in mainly grass areas	2.3[a]	
	Arable land	27.9[a]	
	Coffee/Tea/Macadamia	0.4	
	Rice scheme	0.1	
	Sugar	0.2	
	Tobacco and maize	2.4	
	Subtotal	**57.7**	**61**
Other	Built-up area	0.2	
	Not classified	0.0	
	Bare rock	0.2	
	Marshy area, often partly cultivated	1.8	
	River bed or beach	0.0	
	Subtotal	**2.2**	**2**
Total		**94.0**	**100**

Source Orr *et al.*, (1998, p 29)
[a] Maize and tobacco are also grown in these areas

In Malawi, like anywhere else in the world, vegetative cover (as it relates to soil erosion) has been viewed in terms of its ability to intercept rainfall energy. With respect to this variable, there is a clear division between agricultural crops and natural vegetation, the latter being more effective than the former (Table 3.5). The inefficiency of crops to intercept raindrop energy is one of the reasons for the high soil-loss rates from agricultural land. On the contrary, natural vegetation is perennial, hence it has some form of cover all the time. Even if the vegetation is deciduous, there is always some form of foliage as shrubs or herbs, in addition to residue of dead leaves on the ground. That 61% of the land is classified as predominantly agriculture (Table 3.4), implies that this high proportion is exposed to forces of soil erosion at the beginning of the rainy season.

Table 3.5: Rainfall energy interception factors (*I*) of various cover types in Malawi

Land-cover class	I value	Land-cover class	I value
Broad-leaf forest	100	Dambo/waterlogged area	70
Evergreen forest	100	Marsh vegetation	70
Mixed forest	100	Thicket	65
Riverine forest	100	Grassland	50
Moist hilly woodland	100	Grassland/predominantly agriculture	50
Pine plantation	100	Grassland/soil	50
Eucalyptus plantation	95	Herbaceous vegetation/soil	50
Miombo woodland	95	Predominantly agriculture	40
Tea estate	95	Soil	5
Colophospermum mopane woodland	90	Open Miombo woodland	90
Improved traditional management	45-70[a]	Traditional management	35-50[a]
Scrub	60	Bush/trees	65

Source (Orr *et al.*, 1998, p 65) and Paris (1990, p 6)

[a] Depends on quality of crop cover: poor-cover annuals, good-cover annuals, and perennials (Paris, 1990, p 6)

On cultivated land, interception factors are lower under traditional (tm) than improved traditional management (itm) because the former does not usually involve the use of fertilizers and hybrid seed (Lorkeers, 1992, p 81). Since the important crops in Malawi, maize and tobacco, are annuals, the land that is under these crops is mostly bare at the onset of the rainy season.

3.4 Summary

This Chapter has reviewed literature that is pertinent to soil erosion, which is the main subject of discussion. In this regard, it has described the basic mechanics of soil erosion, and the important factors that generally influence these processes. Emphasis has been on how physical factors influence soil-erosion potential in the Lake Malawi Basin.

The Chapter has stated that irrespective of the type of soil erosion, be it geologic or augmented soil erosion, raindrop splash causes soil-particle detachment, while surface runoff entrains and transports the detached soil particles as overland flow or in rills, gullies, and streams. If the surface runoff is detachment-limited, its scouring force causes channel erosion. When sufficient energy is no longer available to transport the soil particles, the third phase, deposition, occurs. The Chapter has specifically showed that on account of physical factors, the Lake Malawi Basin is highly vulnerable to soil erosion. For instance, the steep topography in the catchment undoubtedly enhances soil-erosion processes, such as soil-particle detachment by rainsplash and scouring, in addition to sediment transport and deposition. Precipitation characteristics, e.g., amount, intensity, energy, and duration, also indicate that the Lake Malawi Catchment is vulnerable to soil erosion on account of rainfall erosivity. In terms of basic soil erodibility, however, the majority of soils are moderately (4.5-6.5) or slightly (6.5-7.5) erodible; in terms of this variable, therefore, the Lake Malawi Basin is not highly vulnerable to soil erosion. By 1991, only about 37% of the land was under natural vegetative cover, which intercepts raindrops better than agricultural crops. Since this cover has been declining at annual rate of about 3.5%, it is inferred that vegetative-cover loss due to human activities is responsible for the excessive rates of soil erosion and sediment discharge.

By providing a literature review of the soil-erosion processes as a function of rainfall, soil, slope, and vegetation, this Chapter has confirmed the assertion in Chapter 2 that the Lake Malawi Basin is potentially vulnerable on account of these physical determinants. Having described the vulnerability of the Lake Malawi Basin as a whole, and considering the local and regional variability in the determinants of soil erosion, it is only appropriate that a similar description of how the physical and anthropogenic factors influence soil erosion in the Linthipe Watershed be given. This is in fact the focus of Chapter 4.

Chapter 4

Description of Physical and Anthropogenic Determinants of Soil Erosion in the Linthipe River Catchment

4.1 Introduction

The preceding Chapters have illustrated the vulnerability of the Lake Malawi Basin to soil erosion in general terms of an array of physical and human factors. A similar description of these factors is specifically given for the Linthipe Drainage Basin in this Chapter. To this end, section 4.2 illustrates how each physical variable (slope, rainfall, soil, and vegetation) renders the Linthipe Catchment vulnerable to soil erosion, which inevitably results in the observed augmented sediment discharges. The likely anthropogenic influences (e.g., population pressure, and cropping practices) on soil erosion in the Linthipe Watershed are described in section 4.3 of the Chapter, while section 4.4 reviews the soil-conservation methods that farmers commonly employ in the study area. To provide a relative comparison of soil-erosion severity based on these factors, the study area is divided into five geographic regions, essentially the geomorphological zones described in Chapter 3. By examining these determinants and their influence on soil erosion in the Linthipe Drainage Basin, a preliminary picture of the factors that create high soil erosion and sediment discharge is developing as a precursor to the quantitative assessment of these variables in subsequent Chapters.

4.2 Physical Factors of the Linthipe Catchment

Since determinants of soil erosion vary regionally or locally, their description at a spatial scale that is finer than the Lake's basin is essential in order to understand why observed soil losses and sediment-discharge rates are high in the Linthipe Watershed. To this end, the succeeding subsections describe the role of these factors in soil-erosion processes in the study area specifically.

4.2.1 Slope

The five geomorphological zones (GoM 1983, p 41) of the overall Lake Malawi Catchment also typify the Linthipe Watershed (Rimmington, 1963) and thus are used stratify the study area into geographical regions (Appendix A). The largest geographic region, the Lilongwe Plain is about 5940 km^2 in size, with an elevation that ranges from 1000 to 1800 m above seal level. The smallest geographic region, the Lakeshore Plain, lies in the Rift Valley Floor at 300 and 600 m above sea level, and occupies an area of about 230.78 km^2. The remaining three regions are as follows: the Dzalanyama Range (315.1 km^2) in the High Plateau zone (1800-2400 m); Dowa Hills (1878.05 km^2) ranging from 600 to 1400 m; and the Rift Valley Scarp (276.07 km^2) lying between 600 and 800 m.

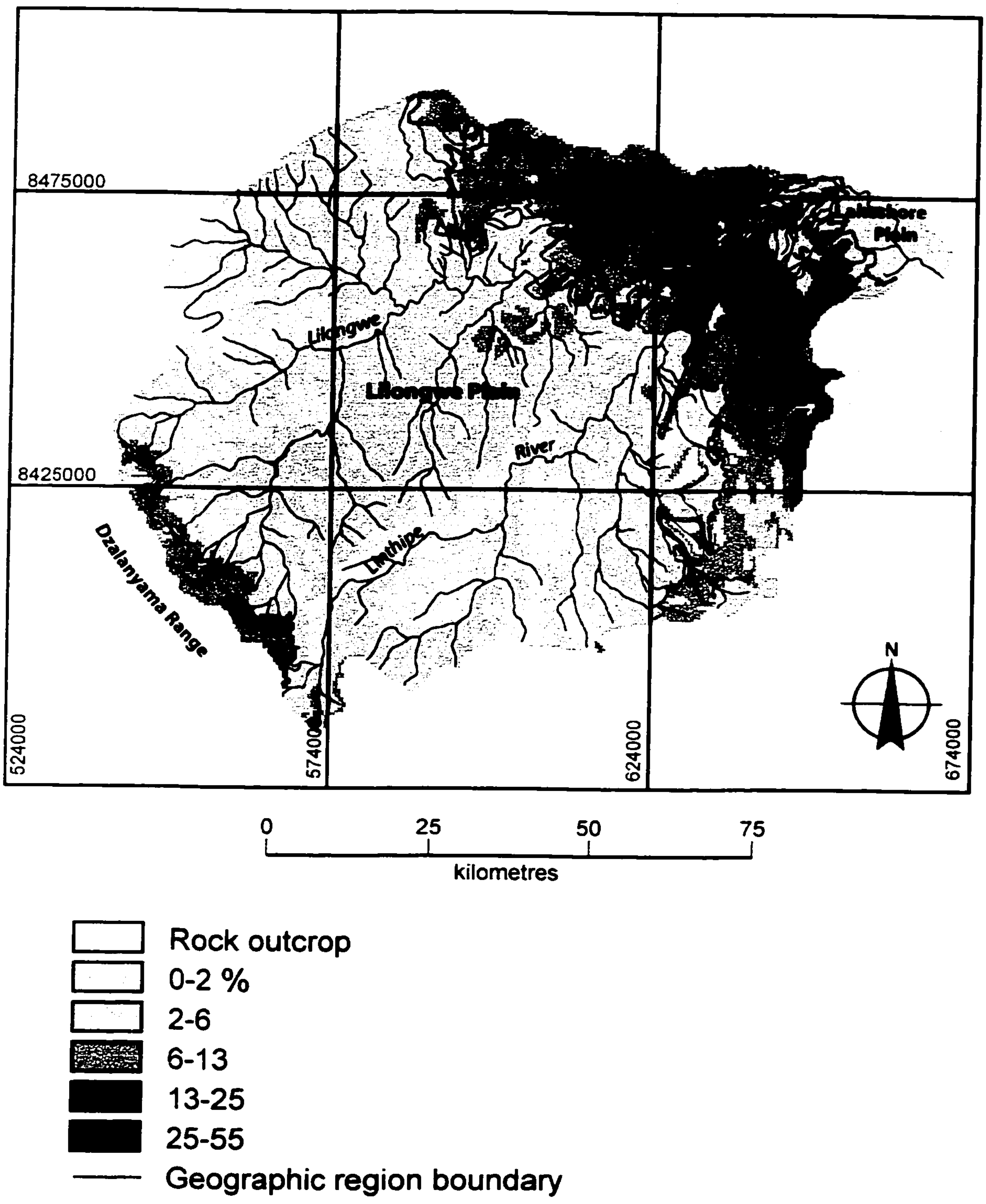

Fig. 4.1 **Slope-gradient categories in the Linthipe River Catchment.** ***Source*** **LREP Maps by Lorkeers and Venema (1991)**

The geomorphological zones give rise to slopes that vary considerably in the Linthipe Drainage Basin. Their gradients fall into the five categories (Fig. 4.1) that have been described by Paris (1990, p 4). About 90% of the Linthipe Watershed comprises slopes that range from level to moderate (0-13 %) in terms of gradient; most of this proportion being accounted for by the Lilongwe and Lakeshore plains (Fig. 4.1). Steep slopes (13-55%), constituting only about 10% of the catchment's area, occur in the Dzalanyama Range, Dowa Hills, and Scarp regions. With regard to topography, therefore, it is only these steep slopes only that can be considered as being highly vulnerable to soil erosion. The occurrence of soil-loss rates that are above the acceptable limit of about 12 t ha^{-1} yr^{-1} on areas of low or moderate gradient, therefore, is a result of high rainfall energy, low vegetative cover, and human factors (sections 4.3 - 4.4).

4.2.2 Rainfall

The rainfall pattern for the period 1988 and 1999 for the Linthipe Catchment (Fig. 4.2) emerges from data obtained from the MEMP, and DoM in Malawi (K.W. Burger[19], and D.R. Kamdonyo[20], *personal communication*). This study collected additional rainfall data during the 1998/99 rainy season. It is evident from the rainfall data that the greater part of the catchment receives an annual rainfall ranging from 800 to 1200 mm. A relationship has been observed between annual precipitation and energy ($\boldsymbol{E}$), which is described by the formula

$$\boldsymbol{E = 18.846\,P}, \qquad [3.1]$$

where $\boldsymbol{P}$ is the annual rainfall (Paris 1990, p 3). When converted into seasonal rainfall

[19] Programme manager for MEMP
[20] Director of the DoM

energy using this formula, values range from 15,076 to 22,615 J m^{-2}. Since energy values that are less than 15,000 J m^{-2} are highly erosive (Elwell and Stocking, 1982), it is inferred that the whole catchment is highly vulnerable to soil erosion.

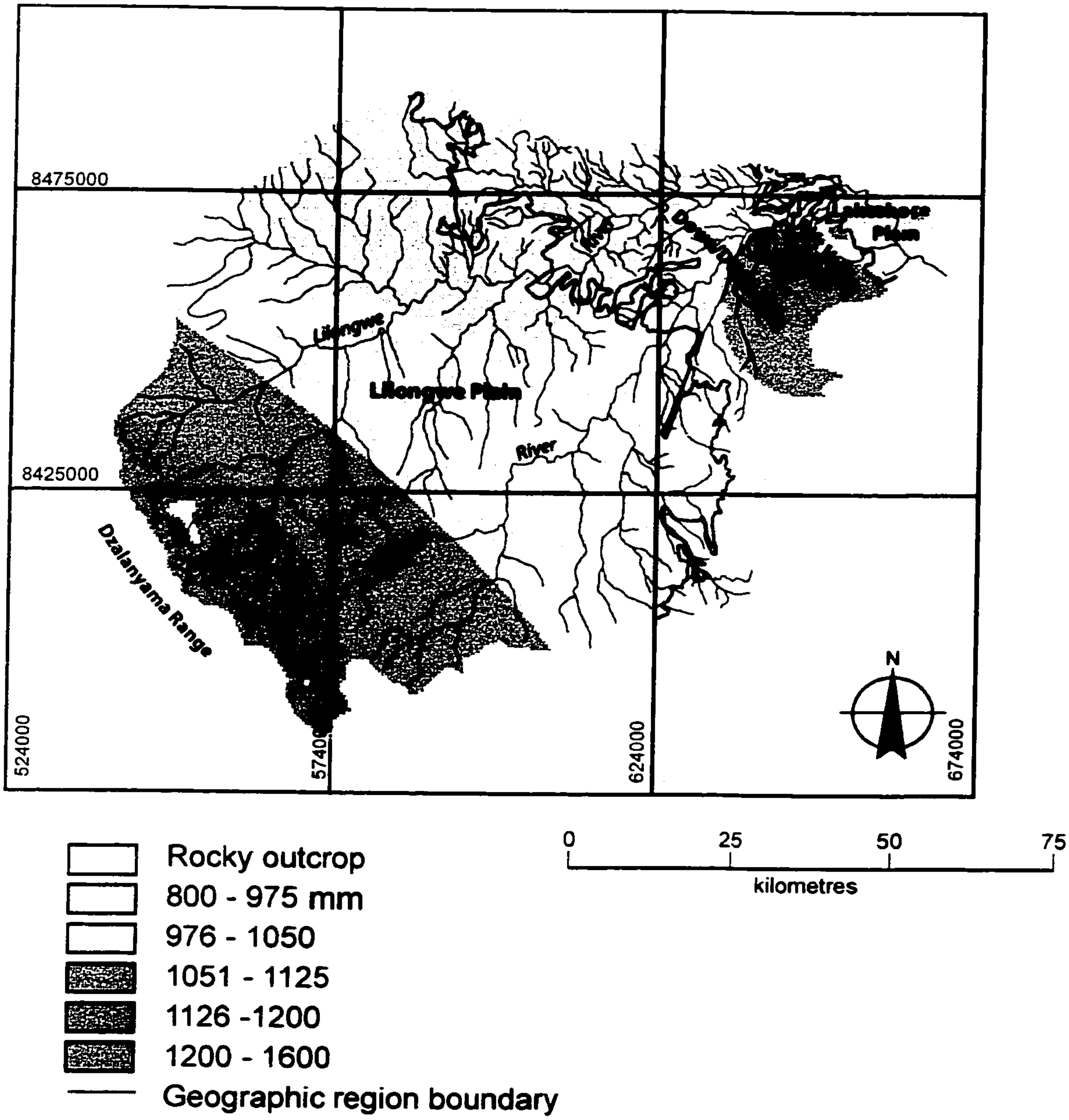

Fig. 4.2: **Mean annual rainfall in the Linthipe River Catchment based on data from 1988 to 1999**

4.2.3 Soils

Seven different soil groups, and two associations of these groups, occur in the Linthipe Drainage Basin (Fig. 4.3). The eutric fersialics (Table 4.1) are the dominant soil group. These occur in each geographic region, especially in the Lilongwe Plain (Fig. 4.3). The Vertic soil group occupies only about 22 km^2 (0.25%), and occur only in the Rift Valley Scarp region. The Dowa Hills consist mostly of paralithic soils and associations of eutric fersialic and paralithic groups. The arenic and eutric fersialic/gleyic associations are confined to the Dzalanyama region.

Based on the basic erodibility factors of the soil groups in the Linthipe Watershed (Table 4.1), it is inferred that about 99.75% of the catchment is considered to be moderately erodible; erodibility factors range from 4.5 to 5.5 when crop management (traditional or improved traditional) is taken into account. It is only the vertic soil group that is highly erodible (Table 4.1). The high soil-erosion rates observed in the Lilongwe, Salima, and Kasungu ADDs (Table 2.4), therefore, can be attributed mostly to factors other than the inherent erodibility of the soils (e.g., the high erosivity of rainfall, poor vegetative cover, and human influences).

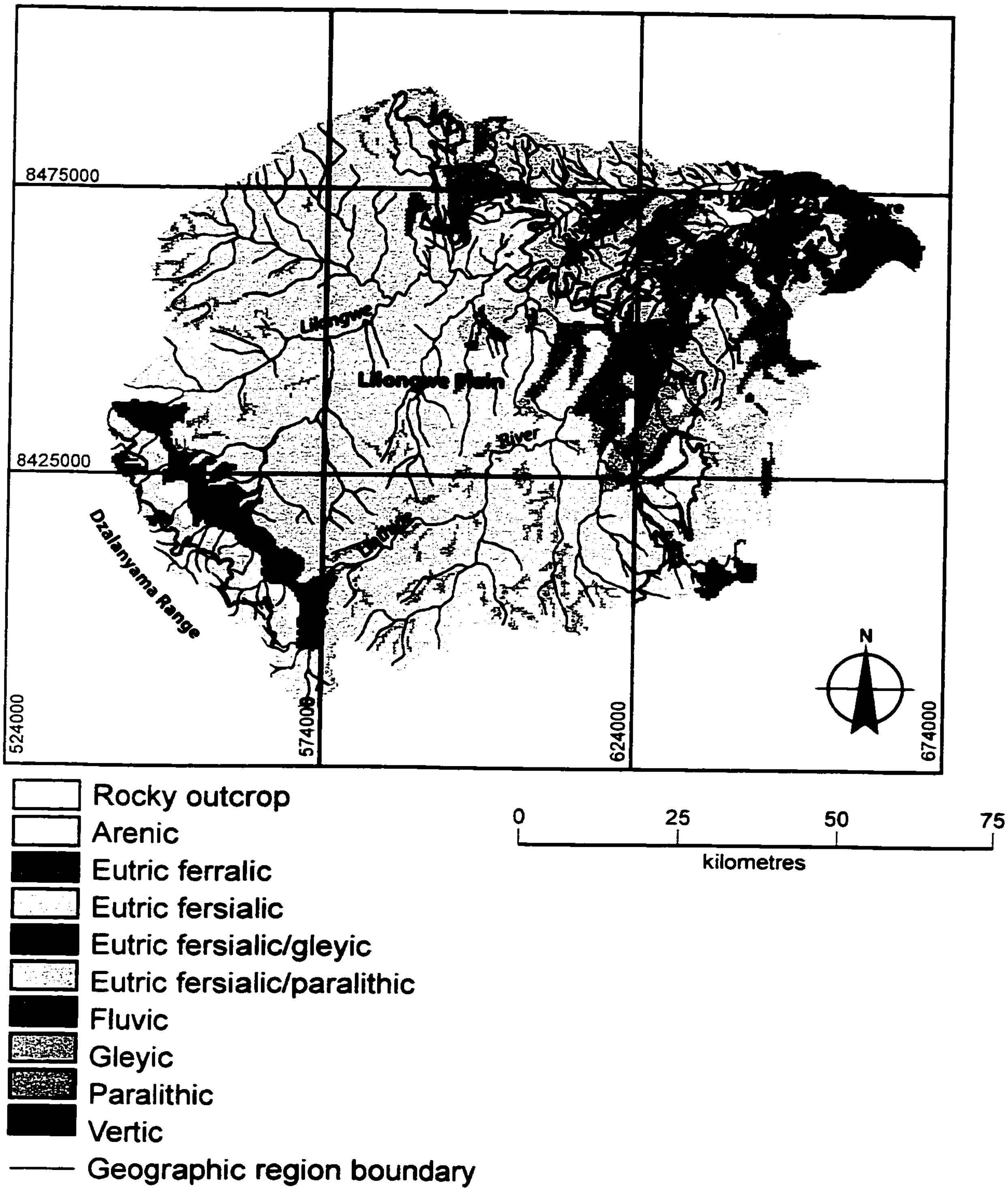

Fig. 4.3: Soil Groups in the Linthipe River Catchment. *Source* LREP Maps by Lorkeers and Venema (1991) and Lorkeers (1992)

Table 4.1: Some characteristics of soil groups in the Linthipe River Catchment, Malawi

Soil Group	Depth (cm)	Drainage	Particle size		pH (0-50 cm)	Colour (Subsoil)	Erodibility factor
			Top soil (0-30 cm)	Subsoil (> 30 cm)			
Arenic	> 150	Well-drained	Coarse	Coarse	5.0-6.5	Yellowish brown/brown	4.5-5.5
Eutric ferralic	> 150	Well-drained	Coarse + medium	Fine to medium	5.0-6.5	Greyish brown to red	4.5-5.5
Eutric fersialic	100-150	Well	Coarse + medium	Medium + fine	5.0-6.5	Brown/reddish brown	4.5-5.5
Fluvic	> 150	Moderate to imperfect	Fine-coarse	Medium + fine	5.0-6.5	Brown/greyish brown	4.5-5.5
Gleyic	> 150	Poor	Variable	Variable	5.5-6.5	Grey	4.5-5.5
Paralithic	50-100	Well drained	Coarse + medium	Medium skeletal	5.0 – 6.5	Yellowish brown /brown	4.5-5.5
Vertic	> 150	Poor	Fine	Fine	7.0-8.0	Black/dark grey	1.5-2.5

Source Legends of LREP maps by Lorkeers and Venema (1991), Lorkeers (1992)

4.2.4 Vegetative Cover

According to a land-cover map by Satellitbild and the DFor in Malawi, the five distinct land-cover classes (Table 3.4) are discernible from 1991 Landsat TM images of the Linthipe Watershed (Fig. 4.4). Land-cover data 1991 are used because it was not possible to obtain satellite data during the field season. A satellite data provider that was requested to capture such data encountered programming difficulties. The use of 1991 data is, however, not entirely out of context because this study is more concerned with spatial distribution of soil erosion in the catchment as opposed to temporal changes in soil-erosion risk.

The available satellite data indicate that *Brachystegia* woodland covers the whole of the Dzalanyama range and the adjacent area east of this region (in the form of Dzalanyama

Forest Reserve). This vegetation type also occurs in Thuma, Dedza and Chongoni Forest Reserves in the Dowa Hills and Scarp regions. In total, it occupies approximately 16% of the catchment. Land that is predominantly grassland (8.9%) generally comprises a wide floristic spectrum including open canopy woodland of fertile areas, such as *Acacia*, *Combretum*, and *Mopane* species (GoM, 1986, p 4-4.3) as well as grass/scrub vegetation dominated by grass of the genera *Hyperrhania*. Forest plantations consisting of *Eucalyptus* spp., *Toona ciliata*, *Pinus* spp., and *Gmelina arborea* cover about 1.4% of the catchment. Built-up land comprises urban areas such as the City of Lilongwe and towns like Salima, and Dedza, as well as numerous villages. This category of land use represents about 3% of the catchment's land area.

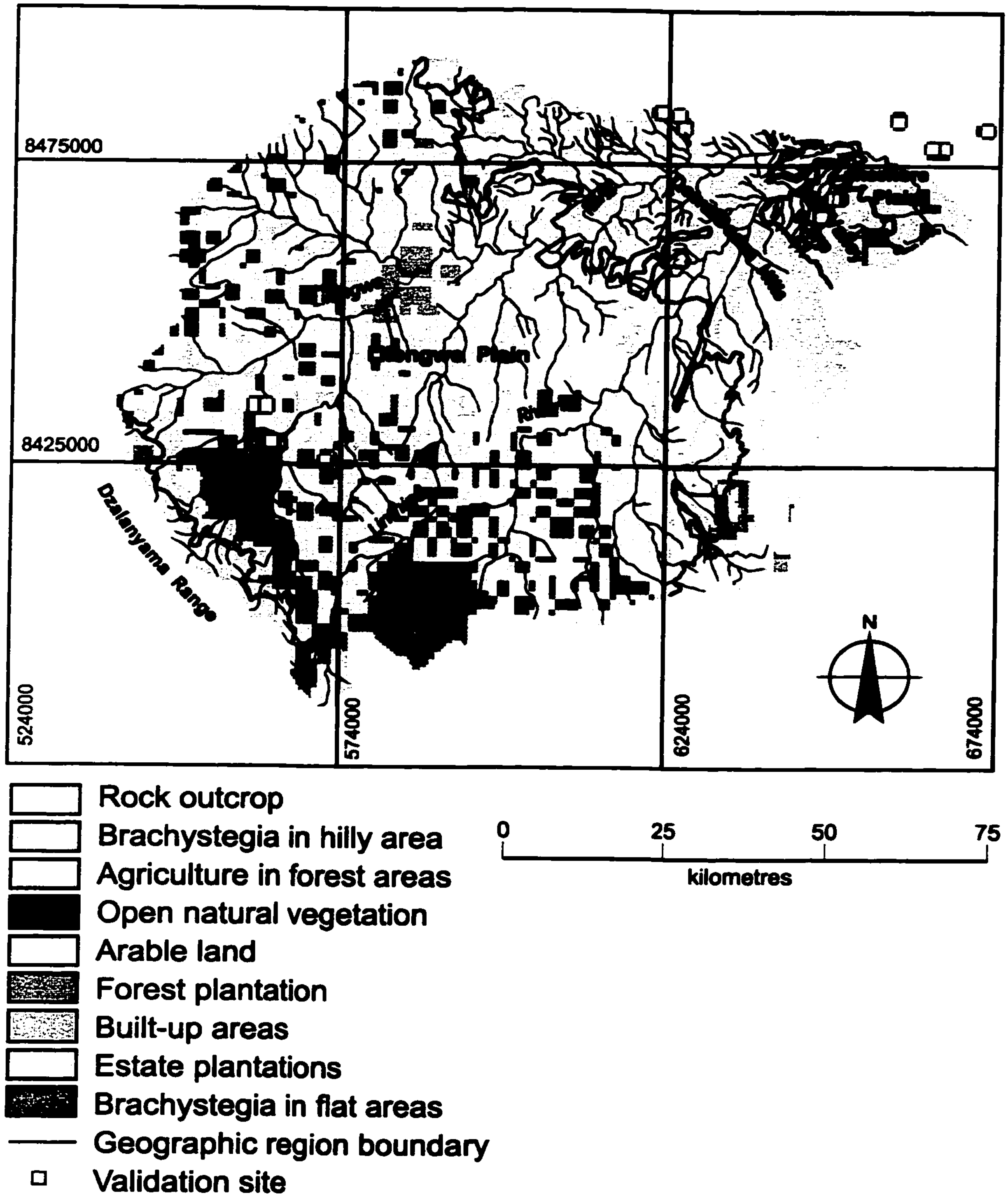

Fig. 4.4: Major land-cover types of the Linthipe River Catchment resampled from 1991 Landsat TM images. *Source* Digital data from Satellitbild and DFor (1993)

The remainder of the Linthipe Catchment (about 72%) is under agriculture mainly on arable land, but also in forest areas (Fig. 4.4). Obviously in terms of land cover and use, the Linthipe Watershed is vulnerable to soil erosion because agricultural crops, which are poor interceptors of raindrop energy (the major cause of soil-particle detachment), occupy a large proportion of the catchment. The Lilongwe Plain is the most intensively utilized region for agriculture because of its low relief and fertile soils (Kettlewell, 1965).

4.3 Some Anthropogenic Activities in the Linthipe Catchment

Given the influence of human activities on soil erosion in the Lake Malawi Basin, and by association the Linthipe Watershed, a mere description of the role of physical factors, as done in the preceding sections of this Chapter, is insufficient in portraying the vulnerability of the study area. The succeeding sub-sections, therefore, add a human dimension to the overall susceptibility of the study area to soil erosion. As a preamble to this section, a description of the human population is provided.

4.3.1 Human Population

According to the 1987 census, the population in the study area was about 1.3 million, thereby giving an arithmetic density of approximately 1.57 persons ha^{-1}, which surpassed the national average of 0.85 persons ha^{-1}, and the mean densities of the three administrative regions (Fig. 1.1). At approximately 0.34, 0.87 and 1.25 persons ha^{-1}, the densities for the Northern, Central and Southern regions (Fig. 1.1) respectively were 5, 2, and 1.3 times lower than in the study area in 1987. Population data for the five administrative districts that cover the catchment (Kasungu, Dowa, Dedza, Salima, and

Lilongwe shown in Fig.1.1) indicate that the natural rates of increase between 1987 and 1998 ranged from 1.5 to 3.6% in Dedza and Kasungu respectively (GoM, 2001), giving an average of 2.54% for the catchment. The extrapolated population for the catchment is about 1.76 million for the year 1998, giving an arithmetic density of approximately 2.04 persons ha^{-1}, which is almost twice the national average of 1.05 persons ha^{-1}, or the mean of 1.14 persons ha^{-1} for the Central Region (GoM, 2001).

Again, arable density is used to illustrate the pressure on land in the Linthipe Drainage Basin. In view of the fact that 12% slope is the dividing line of arable and non-arable land in Malawi (Khonje and Machira, 1987, p 2), the amount of arable land in the Linthipe Watershed is determined to be approximately 763,000 ha. The arable density for 1998 was, therefore, about 2.32 persons ha^{-1} or a holding size 0.43 ha per capita, which was lower than 0.53 ha per capita for the whole of Malawi, or 0.55 ha per capita for the Central Region. The higher arithmetic and arable densities for the Linthipe Catchment can be attributed to what Kalipeni (1992b) describes as the GoM's efforts to redistribute its population since 1964. Examples include the moving of the nation's capital from Zomba in the Southern region to Lilongwe in the 1970s, and shifting of a portion of the industrial and commercial activities in Blantyre to Lilongwe and other areas such as Liwonde and Mzuzu. There has also been considerable investment in infrastructure in the Central region; examples include the Blantyre-Lilongwe-Mchinji highway, and the extension of the railhead from Salima to Mchinji through Lilongwe. These were some of the efforts that the Government made to disperse the population northward.

Historical background to population redistribution efforts is narrated by Kalipeni (1992b) who states that at the time of independence, the leadership was aware of the regional imbalance in the country's development, which had increased land pressure, specifically in the Southern Region. In 1964, the bulk of public- and private-sector infrastructure was concentrated in the Southern Region, where British settlers had opened tobacco and tea estates to take advantage of the region's temperate climate. The Central and Northern regions were neglected during the colonial era; the latter was usually referred to as the "dead north", a phrase that emphasized its economic underdevelopment. The main urban centres of Blantyre, the commercial hub, and Zomba, the seat of the colonial government, were in the Southern region. To reduce the impact of human population pressure in the Southern region, the GoM targeted development efforts towards the Centre and North. The post-independence efforts to redistribute the country's population have meant that the Linthipe Drainage Basin, where the current capital city, Lilongwe, is located, has been the major recipient of internal migrants.

As a consequence of this population increase, there has been an expansion of land under cultivation. This expansion explains why, in the first place, forest areas are under cultivation. Second, it also reveals why only about 25% of the catchment comprised natural woodland and grassland in 1991 (Fig. 4.4). The cultivation of land under forest, especially in Dowa and Scarp regions where gradients are steep, supports the observation that as land suitable for cultivation becomes scarce, people have resorted to cultivating steep slopes, thereby dramatically increasing the potential for soil erosion (Cohen *et al.*, 1993). This point is further augmented by the distribution of the human population in 1998 in the study area (Fig. 4.5). Although high densities were apparent in the geographic regions of steep gradients (e.g., Dowa Hills and Scarp regions) the general pattern is that the areas of low relief (the Lilongwe and Lakeshore plains) had, and will continue to have, higher populations. Most important of all, it is obvious that the mean size of holdings in the Linthipe Watershed is too small to allow the use of optimal soil-conservation practices. Therefore, the population pressure on land in the study area partly explains why soil loss is higher than the acceptable limit, and sediment discharge rates by the Linthipe River are among the highest of all the riverine inflows into Lake Malawi (Table 1.2).

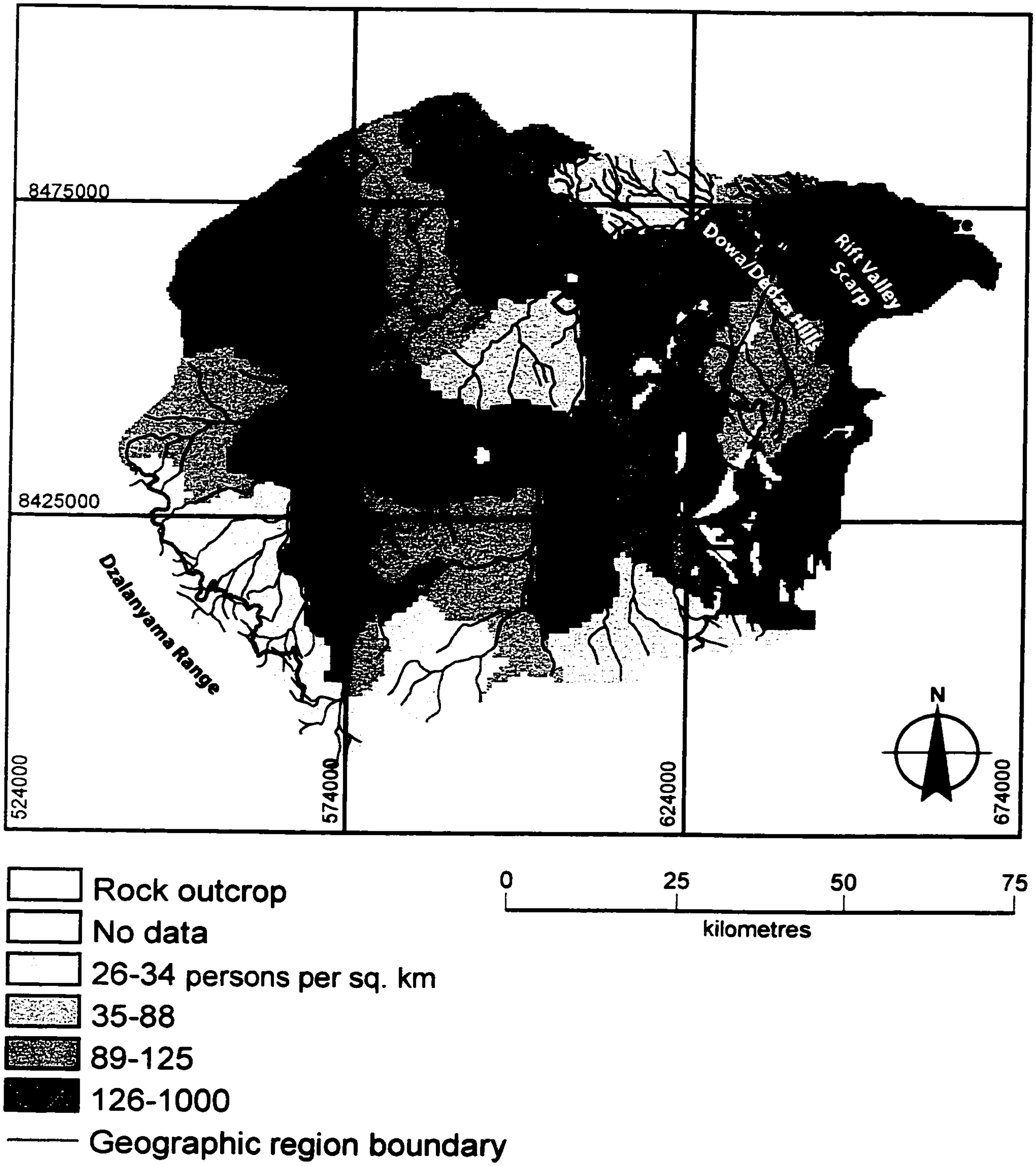

Fig. 4.5 Population density in Linthipe River Catchment in 1998; extrapolated from 1998 population and average annual growth rates of the administrative districts that cover the area

4.3.1.1 Farmer Characteristics

To get an indication of how human activities may be influencing soil erosion in the Linthipe Watershed, it is first of all necessary to show how farmers are spatially distributed between the geographic regions so that possible links between soil-erosion severity and farmer category can be established. The data that are used in the succeeding descriptions are a mere subset of the information on the socio-economic characteristics of the farmers in the Linthipe Catchment. These data were collected using a questionnaire survey (Appendix B) that was conducted in the study area in 1998. A detailed description of the methods used to collect the data is given in Chapter 6, where it is more appropriate than in this Chapter. Initially the number of farmers in each category is presented for each sub-division, e.g., small- to large-scale for estate farmers, but thereafter the farmers are grouped into the two major categories for ease of data interpretation.

4.3.1.2 Type of Farmer by Geographic Region

The higher number of smallholders than estate farmers (Table 4.2) is reflective of the general situation in Malawi, i.e., more smallholders than estate farmers. The occurrence of more small-scale estate farmers than the rest in this sub-sector can be attributed to the fact that the majority of them were originally smallholders who merely converted their land from customary to leasehold tenure. Mkandawire *et al.*, (1990, p 23) stated that smallholders were prompted to register their land as estates in order to obtain a licence and quota[21] to produce burley tobacco, and also as a consequence of perceived or real

[21] Introduced following excess production of burley tobacco in 1981/82. According to A. Bulirani (*personal communication*), the current project manager of the LMBCP, the quota system was abolished in 1998

threat of insecurity in the face of large-scale estates alienating customary land around them. This being the case, some smallholders simply formalised their fragmented holdings as estates.

Table 4.2: Distribution of farmers by region, Linthipe River Catchment, Malawi, 1998

Farmer	No. of farmers by geographic region				Total	% of Total
	Dowa	Lakeshore	Lilongwe	Scarp		
Estate						
Small-scale	11	6	51	42	110	87.3
Medium-scale	7	0	1	2	10	7.9
Large-scale	4	2	0	0	6	4.8
Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholder						
Smallholder1	6	16	2	28	52	22.2
Smallholder2	25	32	22	11	90	38.5
Smallholder3	37	34	12	7	92	39.3
Total	**68**	**82**	**38**	**46**	**234**	**100.0**

Small-scale estate = < 30.0 ha, medium-scale = 30.1-100.0 ha, and large-scale = > 100.0 ha, smallholder 1= < 0.7 ha, smallholder 2 = 0.8 – 1.5 ha, and smallholder 3 = > 1.5 ha

There is no apparent reason for the distinction in the distribution of farmers by region, such as occurrence of more small-scale estate farmers in Lilongwe and the Scarp regions while smallholders are mostly concentrated in the Lakeshore and Dowa. Kalipeni (1992b) reported that in the process of searching for vacant land, Malawi's population has been redistributing itself since independence. Therefore, it is speculated that in view of the increase in population on land, farmers (irrespective of category) have settled wherever they found vacant land. Since small-scale estate farmers and smallholders are usually associated with poor land-management practices, their occupancy of regions with steep topography, e.g., the Scarp and Dowa Hills, is conducive to soil erosion.

4.3.1.3 Cropping Practices

Typical of the farming systems in Malawi, the commonly grown crops in the study area are maize (*Z mays*) and tobacco (*N tabaccum*). Although there is crop diversity, growing of crops such as sweet potato (a snack), which is a good annual-cover crop (Paris, 1990, p 6), is limited due to a restricted market. Its effectiveness as a cover crop is, therefore, only beneficial to the few farmers who cultivate it. Other farmers also grow cotton (*Gossypium hirsutum*) in addition to maize and tobacco, but this is another poor-cover crop (Paris, 1990, p 6), hence it is as inefficient as tobacco in intercepting raindrops. Additional crops grown by smallholders in the Lilongwe, Kasungu, and Salima ADDs include finger millet (*E corocana*), cassava (*Manihot esculenta*), and various grain legumes (Lorkeers and Venema, 1991, p 66; Lorkeers, 1992, p 70; Nanthambwe and Eschweiler, 1992, p 63). These crops, however, occupy only small portions (0.3 - 2.2%) of land in each ADD; hence they are less significant than maize or tobacco in terms of restricting soil erosion. For this reason, the emphasis of this section, and subsequent ones, is on maize and tobacco.

Improved maize varieties such as MH 12 and NSCM 41 are popularly grown by both farmer categories, although small proportions of farmers also grow local maize (Tables 4.3 and 4.4). Hudson (1981, p 52) claimed that economic constraints generally prevent smallholders from taking risks. Consequently, the strategy is geared to safety. This claim seems to be applicable to the situation in the Linthipe Watershed. Adherence to the unimproved (local) maize variety is more out of necessity than reluctance to change. Unimproved varieties are generally more resistant to weather, diseases and pests than hybrids. Farmers would rather use the unimproved maize variety that is low yielding, but produces some yield yearly, than an improved variety that gives high yields most years, but none in a bad year.

Table 4.3: Crops commonly grown by estate farmers; Linthipe River Catchment, Malawi, 1997/98

Crops	No. of farmers by geographic region				Total	% of Total
	Dowa	Lilongwe	Lakeshore	Scarp		
Maize						
Hybrid and local	2	24	1	0	27	21.6
Hybrid	18	14	6	37	75	60.0
Mixed-cropping [a]	1	3	1	0	5	4.0
Local	0	11	0	7	18	14.4
Total	**21**	**52**	**8**	**44**	**125**	**100.0**
Tobacco						
Burley	22	30	8	44	104	82.5
Malawi Western	0	14	0	0	14	11.1
Burley and Malawi Western	0	8	0	0	8	6.4
Total	**22**	**52**	**8**	**44**	**126**	**100.0**
Other crops						
Cotton	0	0	1	2	3	3.7
Groundnuts	15	40	1	16	72	88.8
Sweet potatoes	1	3	2	0	6	7.5
Total	**16**	**43**	**4**	**20**	**81**	**100.0**

[a] Usually local or hybrid maize mix-cropped with beans (*Phaseolus vulgaris*), soya beans (*Glycine max*), pumpkins (Curcubitacea family), and ground beans (*Vigna subterranea*)

Table 4.4: Crops mainly grown by smallholders; Linthipe River Catchment, Malawi, 1997/98

Crops	No. of farmers by geographic region				Total	% of Total
	Dowa	Lilongwe	Lakeshore	Scarp		
Maize						
Hybrid and local	8	16	5	0	29	12.7
Hybrid	22	6	55	40	123	53.9
Mixed cropping [a]	10	2	9	1	22	9.6
Local	28	13	9	4	54	23.8
Total	**68**	**37**	**78**	**45**	**228**	**100.0**
Tobacco						
Burley	18	0	0	13	31	96.9
Malawi Western	0	1	0	0	1	3.1
Total	**18**	**1**	**0**	**13**	**32**	**100.0**
Other crops						
Groundnuts	46	26	13	23	108	75.0
Sweet potatoes	1	3	17	0	21	14.5
Rice	0	0	14	1	15	10.5
Total	**47**	**29**	**44**	**24**	**144**	**100.0**

Some farmers practice mixed cropping in the study area, but the majority of them grow maize in pure stands (Tables 4.3 and 4.4). Mixed cropping, which is the growing of more than one crop on the same piece of land (GoM, 1992, p 10), is popular among smallholders because it is a crop diversification technique intended to reduce the risk of crop failure (GoM, 1992, p 10). Second, it enables farmers to harvest more than one crop on the same piece of land from one season, particularly where land is limited (GoM, 1992, p 10). While these are the primary reasons for mixed cropping, the accompanying benefits of this practice include improved soil fertility where legumes are used, and provision of additional cover that protects the soil from the impact of raindrops. Mixed cropping generally provides a mean ground cover of at least 40%, which is considered as critical for reducing soil loss, whereas many poor unfertilised monocrops do not (Stocking, 1985, p 751). The use of monocropping by the majority of the farmers (Tables 4.3 and 4.4) implies that the mean ground cover must have been poor considering that use of fertilizers by farmers is generally low in Malawi (Chipande, 1988, p 163; WB, 1991, p 10).

In Malawi, monocropping has been enhanced by increased prices in the high value crops such as hybrid maize and tobacco (WB, 1991, p 21). Estate farmers and smallholders who have access to the credit system (specifically the larger smallholders), tend to be relatively price-responsive. This encourages them to move out of the mixed cropping systems into growing pure stands of high value crops. This system, therefore, spurs soil erosion. In view of the large proportion of farmers growing maize in pure stands, especially in the steep regions such as the Scarp (Tables 4.3 and 4.4), the implication is that the likelihood of soil erosion is enhanced on such land. This inference also applies to land under tobacco, which is also grown in pure stands by all estate farmers who own large holdings.

4.4 Soil-Erosion Control Measures

Field observations confirm that farmers in the study area use four main soil-erosion control measures that are advocated by the MoA, namely, soil management, agronomic including agroforestry, mechanical, and land-use planning. The most preferred approach by both categories of farmers is to integrate agronomic, mechanical and soil management practices, followed by the inclusion of land-use planning (Table 4.5). Integration of these methods is the most preferred approach because they include activities that are routinely undertaken as part of farm operations. For example, agronomic practices such as early field preparation, timely planting and correct plant spacing constitute part of the cultivation practices recommended by the MoA, and they have since been adopted by farmers. Similarly, mechanical measures, e.g., contour and box ridging, are part of land preparation.

Table 4.5: Soil-erosion control measures commonly used by farmers; Linthipe River Catchment, Malawi, 1998

Farmer	Measures	No. of farmers by geographic region				Total	% of Total
		Dowa	Lilongwe	Lakeshore	Scarp		
Estate	ag/fp/mm	3	0	1	6	10	7.9
	ag/fp/mm/sm	14	3	4	15	36	28.6
	ag/mm	1	2	1	10	14	11.1
	ag/mm/sm	4	47	2	13	66	52.4
	Total	**22**	**52**	**8**	**44**	**126**	**100**
Smallholders	ag/fp/mm	13	0	6	6	25	10.7
	ag/fp/mm/sm	49	3	28	4	84	35.9
	ag/mm	5	2	24	11	42	17.9
	ag/mm/sm	1	33	24	25	83	35.5
	Total	**68**	**38**	**82**	**46**	**234**	**100**

The codes are as follows: ag = agronomic, fp = land-use planning, sm = soil management, and mm = mechanical

The least-used approach by both farmer groups is the blending of agronomic, land-use planning, and mechanical measures. The lack of popularity of land-use planning techniques (Table 4.5) such as avoidance of watercourses and slopes is indicative of the pressure on land due to the increase in human population pressure. Farmers disregard land-use planning as a conservation tool when they are forced to shift from areas of low relief and occupy/cultivate fragile steep slopes. Cultivation of riverbanks and permanently wet areas, locally known as *dimba* cultivation, is another factor that explains why land-use planning does not feature highly among farmers. *Dimba* cultivation is used as a means of supplementing crop yield during the dry season. In fact the MoA encourages this practice especially in the event of drought. Once these areas are occupied, it is unlikely that farmers abandon them during years of normal rainfall.

Although this type of cultivation does not cover much land (Lorkeers and Venema, 1991, p 73), proximity of this type of cultivation to watercourses is a sign of lack of land-use planning, which may exacerbate bank erosion.

The regional differences in the number of control measures used by farmers indicate that there is some sense of rationality in their use. For instance, both farmer groups used all the available measures in Dowa, while those in Lilongwe and Lakeshore used only 3 and 2 methods respectively. Most likely farmers realize that integrating more methods in regions with steep gradients such as the Dowa and Scarp may afford better protection against soil erosion than using fewer practices. In contrast, only two measures were significantly associated with the Lakeshore Plain where the slope gradient is gentle. Hence the farmers' perspective is that there is no need for employing all the methods in Lilongwe and the Lakeshore regions.

4.5 Summary

This Chapter has provided an introduction and background to the vulnerability of the Linthipe Drainage Basin to soil erosion, from both a physical and anthropogenic context. It has described the influence of slope, rainfall, soil, and vegetation by geographic region. Additionally, it has linked anthropogenic factors such as population growth, farming practices and soil-erosion control measures on the one hand, and potential for accelerated soil erosion on the other.

Given the physical characteristics and human population pressure in the Linthipe Watershed, it can be stated that the study area is principally susceptible to soil erosion because of high rainfall energy and low vegetative cover, but that slope and soil erodibility also play a role. Human factors, such as high arable density and farming practices, have led to vegetation removal thereby accelerating soil-erosion processes. As a consequence of population increase, there has been an expansion of land under cultivation, explaining why forest areas are under cultivation, and hence only 25% of the catchment comprised natural forests in 1991. The cultivation of land under forest, especially in Dowa and Scarp regions where gradients are steep, supports the observation that as land which is suitable for cultivation becomes scarce, people have resorted to cultivating steep slopes, thereby dramatically increasing the potential for soil erosion. Since population growth leads to overexploitation of resources, environmental degradation, and soil erosion, then the high population density in the Linthipe Catchment must be a key reason for the high rates of soil erosion and sediment discharge in this catchment.

While this Chapter endorses the significance of the different variables in terms of their contribution to soil-erosion risk in the catchment, it is contended that a mere description of the existing situation, is however, inadequate. Given this assertion, Chapter 5 provides a quantitative assessment of soil erosion in order to illustrate how the physical and human factors interact to cause soil erosion in the Linthipe Watershed.

Chapter 5

Geographic Distribution of Soil-Erosion Risk in the Linthipe River Catchment

5.1 Introduction

The Linthipe Drainage Basin was qualitatively described as vulnerable to soil erosion on the basis of high rainfall, poor land cover, steep gradient, and moderately erodible soils in the preceding Chapter. To render credence to this claim, this Chapter quantitatively assesses soil-erosion risk in the study area thereby achieving objective (i) of this dissertation. Its principal focus is to determine the spatial distribution of soil-erosion risk in relation to its physical determinants and to develop a quantitative framework within which soil-erosion risk can be assessed. It is important for prevention of soil erosion that quantitative tools be developed. These tools will allow managers to assess the impacts of changing physical and anthropogenic variables as the country (Malawi) changes over the next several decades. The reproducibility of this approach is also necessary to ensure that managers can be confident in the impacts of intervention.

One rationale for assessment of soil-erosion risk is to provide information (Chapter 2) that could be incorporated in the extant land-use policy (GoM, 2000) so that the Government allocates soil-conservation efforts objectively. This being the case, it is necessary to obtain insights into the variability of soil-erosion risk spatially in response to policy-induced changes in land use/cover. The second purpose of this Chapter therefore is to determine how changes in land cover/use will affect the spatial variability in the distribution of soil-erosion risk in the Linthipe Watershed.

5.2 Methods

To assess risk of soil erosion and potential changes in its geographic distribution, the modified Soil Loss Estimation Method for Southern Africa (SLEMSA, refer to sections 5.2.1 and 5.2.2), which is a predictive soil-loss model,[22] was used. The results were validated using values measured in runoff/sediment plots (refer to section 5.2.5). A modelling approach was preferred because the catchment covers a large area (8640 km^2). Under such circumstances, soil-loss models are more efficient means of assessing soil erosion than the use of experimental plots, which are limited in their spatial coverage. The SLEMSA was chosen because it offers advantages of low cost and maximum use of scarce data, while providing important information for design, planning and extension (Elwell and Stocking, 1982). In fact the model is considered to be more applicable to tropical, developing-country conditions than the Universal Soil Loss Equation (USLE, Wischmeier, 1976) or the Revised Universal Soil Loss Equation (RUSLE, Yoder and Lown, 1995), which are commonly used in North America. In Southern Africa, including Malawi, the SLEMSA has been found to be more appropriate than the USLE because there are considerable differences between American and African farming methods and practices. Consequently, it is difficult to apply the American coefficients to local conditions, as factor selection is reduced to the level of guesswork (Elwell, 1978b). What follows is a detailed description of the SLEMSA before illustrating how it was employed to predict soil loss.

[22] A soil-loss model brings together the various factors and processes in erosion in such a way that they most faithfully reproduce what occurs in reality, and soil loss is predicted accurately (Stocking *et al.*, 1988).

5.2.1 Description of the original SLEMSA

The SLEMSA (Fig. 5.1) was designed in Zimbabwe as a framework for developing soil-loss models that could be modified to take into account local environmental conditions in Southern Africa (Elwell, 1978b; Elwell and Stocking, 1982). To predict soil loss, the SLEMSA, like the USLE, considers vegetation, rainfall, soil, and topography. Each factor represents its respective role in the soil-erosion process. For instance, vegetation integrates the protective effect of cover over a wide range of land uses; rainfall expresses the energy transfer and splash from the action of raindrops, and the input to overland flow of water; topography accounts for all the influences of relief and shape of the land; and soil includes its resistance to detachment and transport (Stocking *et al.*, 1988).

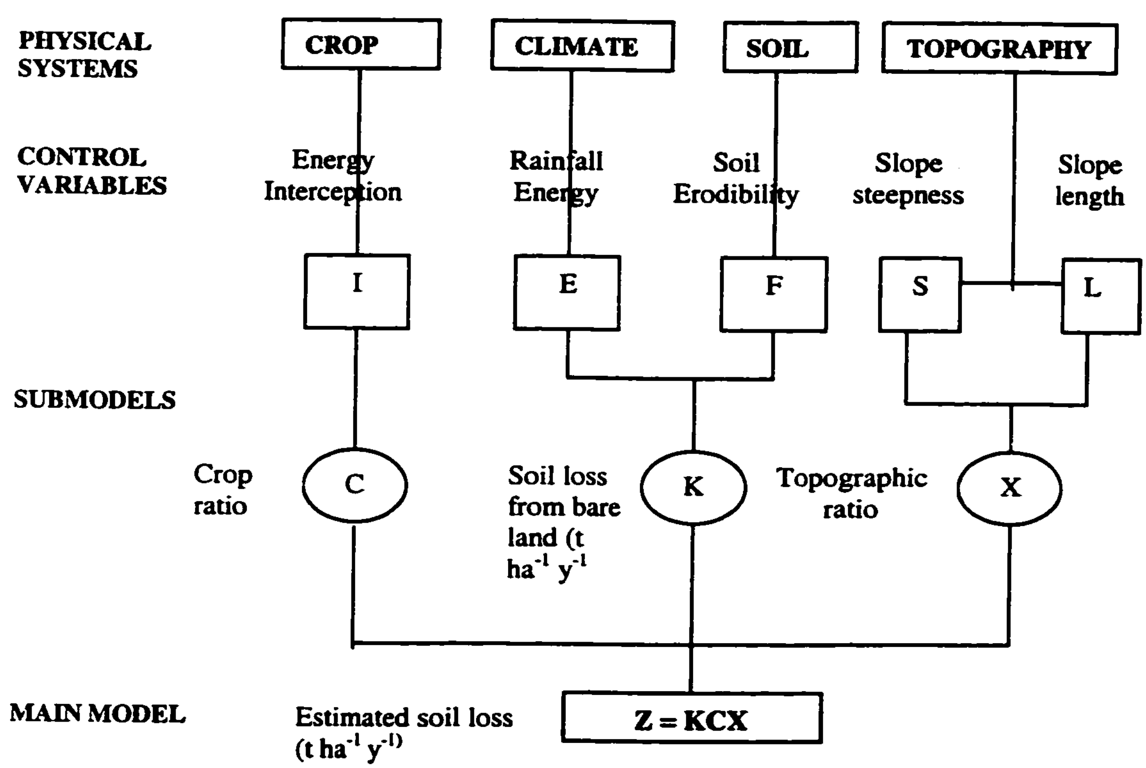

Fig. 5.1 The Soil Loss Estimation Method for Southern Africa framework (after Elwell and Stocking, 1982)

Each physical system is represented in the model by control variables, such as rainfall energy (***E***), rainfall-energy interception (***I***) by the cropping system or vegetation, soil erodibility (***F***), slope gradient (***S***), and slope length (***L***). Each control variable is expected to meet certain criteria (Stocking *et al*, 1988):

(i) it is expressive of the dominant influence of the factor in the region. For example, under high-intensity rainfall conditions the over-riding influence of vegetation is through the interception of raindrops;

(ii) availability from existing records or from easily assembled data for the whole region. For example, soil data usually have descriptions enabling estimates to be made of soil erodibility;

(iii) consistency with the requirements of a soil-loss model, in this case the SLEMSA; and

(iv) it is mappable over the study area, providing results that are sensible and in accordance with experienced observation.

Mathematically, the SLEMSA is expressed as a main model with three submodels as follows:

$$Z = KCX, \text{ where} \qquad [5.1]$$

Z is the main model expressed as soil loss from cropland (t ha^{-1} y^{-1});

K represents the climate and soil submodel for soil loss (t ha^{-1} y^{-1}) from a standard conventionally-tilled field plot of 30 m, for soil of known erodibility ***F***, under weed-free fallow of 4.5% slope (Elwell and Stocking, 1982). The equation used in the submodel is:

$$K = exp. \{(0.4681 + 0.7663\,F)\ ln\,E + 2.884 - 8.1209\,F\}\ \text{t ha}^{-1}\ \text{y}^{-1}, \quad [5.2]$$

where F is soil erodibility, E is rainfall energy calculated from either the regression equation

$$E = 18.846\,P \text{ or}$$

$$E = 17.37\,P \qquad [5.3]$$

for normally aggressive climates and areas prone to drizzles respectively (Stocking *et al.*, 1988);

C stands for the crop-ratio submodel, or the ratio of soil loss from a crop compared to soil loss from bare fallow. According to Elwell (1978a) the equations that are used in this submodel are as follows:

$$C_1 = e^{(-0.06i)} \text{ when } i < 50\%\text{; and } C_2 = (2.3 - 0.01i)/30 \text{ for } i \geq 50\% \quad [5.4, 5.5]$$

where (i) is the percentage of rainfall energy intercepted by the crop or vegetation; and

X represents the topographic submodel, which is a function of percent gradient (S), and slope length (L) in metres: The equation used to describe the submodel is:

$$X = (L)^{0.5}\,(0.76 + 0.53S + 0.076S^2)/25.65 \qquad [5.6]$$

The main criticism about empirical models, such as the SLEMSA, is that they do not separately consider deposition and sediment transport (Foster, 1981, p 278), unlike the physically-based ones, for example the WEPP (Water Erosion Predicted Project) or CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems). The second criticism is that accuracy is lost in the initial simplifying processes (Elwell and Stocking, 1982). However, for purposes of illustrating the spatial distribution of soil-erosion risk in relation to its physical determinants, deposition and transport processes are considered to be of lower priority than the identification of vulnerable areas.

Many countries (Malawi included) face rapid soil degradation on a massive scale, hence they need easily available information as to the geographical extent of the problem so that control measures can be allocated rationally. Simple yet practical models such as the SLEMSA are capable of providing the required information, hence they are considered as indispensable planning tools. In fact, it has been contended by Elwell and Stocking (1982) that a model that gives early answers, even if they are merely 'best estimates', is likely to find ready acceptability, particularly if it has the potential to ultimately achieve an acceptable degree of accuracy. To attempt a high degree of accuracy at the outset is bound to be wasteful of time and scarce resources (Elwell and Stocking, 1982). Moreover, models that simulate runoff, e.g., physically-based ones, are not easily applied to large diverse landscapes or easily used by land managers and planners (Sauchyn, 1989, p 109). In fact despite its caveats, the SLEMSA has been used even in other regions, for example Brazil and Spain (Stocking *et al.*, 1988; Chakela and Stocking, 1988; Montoro and Stocking, 1989). In Malawi, Paris (1990, p 1) observed that there was no model that showed more promise than the SLEMSA. Therefore, when executing the LREP (LREP), Paris (1990, p 1) modified the SLEMSA to suit the ecological conditions in Malawi.

5.2.2 The Modified SLEMSA

While the original model was developed with a view to assessing the amount of sheet erosion on arable land (Elwell and Stocking, 1982), it has been modified for use under rain-fed cropping in Malawi (Paris, 1990, p 16). The other forms of soil erosion, such as rainsplash, rill, and gully also occur under such conditions. Important parameters that have been changed to suit the local farming conditions are as follows:

i) the subdivision into two regression equations ($E = 17.37\ P$ and $E = 18.846\ P$) of the control variable E in the K (Soil and Climate) submodel of the original SLEMSA is omitted because analysis of data from stations with drizzle rainfall revealed that this type of precipitation contributes only a very small amount of the total annual rainfall in Malawi. Therefore, the modified SLEMSA only uses the equation for non-drizzle rainfall, which is $E = 18.846\ P$;

ii) the original SLEMSA offers a long list of soil-management correction factors, most of them consisting of detailed descriptions of cultivation practices that are not applicable to the smallholder situation in Malawi. Therefore, the correction factors are excluded; and

iii) a standard slope length of 20 m is used for the tm (traditional management) and g (grazing) models, while 10 m is assigned to the itm (improved traditional management) model instead of a slope length of 30 m, which is based on spacing of contour bunds on cultivated land (Hudson, 1957). Under smallholder conditions in Malawi, contour bunds are not often used, hence the adoption of 20 and 10 m as standard slope length. Effective slope length is shorter for the itm-model than the tm- and g-models because the quality of ridges is better and crop stands are denser and stronger in the improved traditional management situation.

Other studies, for example by Mkandawire (1996, p 1), and Orr *et al.*, (1998, p 160) have in fact used the modified SLEMSA to assess soil loss in Malawi. In view of its acceptability, and the principal focus of this dissertation, it is contended that the modified SLESMA model suits the purpose. It is worthwhile mentioning that presently, efforts are underway by a WB-funded study to introduce the Agriculture Non-point Source (AGNPS) model (physically-based) in Malawi. The study is part of an attempt to model comprehensively different processes in Lake Malawi and its catchment (Neysmith, Leon, Lam, and Swayne, 2001). However, until the superiority of the AGNPS over the modified SLEMSA has been proved, the latter remains the model of choice.

5.2.3 Rationale for Validation of Predicted Soil Losses

Amounts of soil loss derived by all empirical equations involve potential estimation errors that may result from four major mechanisms in the modelling process (Wischmeier, 1976; Nearing, Lane, and Lopes, 1994, p 134). The first error is in the formulation of the basic equations. Any mathematical representation of a natural process is approximate and will cause the introduction of some error in terms of describing the system. The second source of error is in the solution and coding of the equations. A third source is experimental error and variation in the experimental data. Lastly, there are errors in parameter prediction procedure. Any statistical method developed for predicting parameters for untested situations will have some, and usually a large amount, of error associated with it. Therefore model evaluation is used to assess its validity in order to make changes in the basic equations, model structure, or parameter estimation procedures necessary to development of the validated working model. The underlying assumption is that the observed values are considered to be representative of the actual situation; if there is error, it is very small in comparison with that expected in the predicted value (Morgan, 1986, p 138).

The errors described in the preceding paragraph are inherent deficiencies in the model itself and they occur during model development. The SLEMSA, however, has been tested and found to be able to predict mean annual soil losses to within 1.7, 2.6 and 4.3 t ha^{-1} and 50%, 70%, and 90% of cases, respectively, for the normal range of soil losses from agricultural lands (Elwell, 1978b). Additionally, its modified version is used in Malawi. Model validation in this case was, therefore, not aimed at improving its accuracy. Rather, the purpose was to ascertain if the rainfall-energy interception factor of 48%, which was assigned to arable and agricultural land generically when calibrating the model, instead of using 35% and 70% on land under smallholder and estate agriculture respectively, significantly reduced the model's accuracy. Prior to model calibration, there was a notion that this value would affect the model's accuracy, but the magnitude of error was unknown. Therefore, model validation helps to confirm this notion. In addition validation was useful in determining the margin of error so that future assessments of soil erosion could either avoid similar generalisation, or take into account these errors.

Regrettably, the decision to use a generic value was inevitable given that the classified satellite data used in the analysis did not distinguish between land under estate and smallholder agriculture (refer to section 5.2.4.1.1). Lack of distinction between the two farming systems is quite understandable. Unlike in developed nations, or even other African countries such as Zimbabwe and South Africa, where either hedgerows or stone dykes are used to demarcate farm boundaries, this is usually not the case in Malawi. Most often, boundaries consist of ridges or concrete pegs, which are usually difficult to identify on satellite images. A compounding factor is that in the majority of cases, tobacco estates share common boundaries with customary land in Malawi. Therefore, if images are captured during the dry season (as was the case with the ones used in this analysis) when all agricultural land is dry and bare, distinction of land under the two farming systems is impossible. In view of the foregoing, it was found necessary to test the model's predictions with soil losses measured in the field.

5.2.4 Modelling the Geographic Distribution of Soil-Erosion Risk

The modified SLEMSA was calibrated in a Geographic Information System (GIS) environment using the Idrisi32 software. A GIS approach was preferred to non-automated calculations because the former merges various layers of digitised maps of physical factors in order to determine relative soil-erosion risk. In contrast, a non-automated approach, as done by Khonje and Machira (1987, p 4) and Mwendera (1988, p 2) is tedious, and such efforts often result in limiting the amount and usefulness of data and information included. According to Sheng, Barrett, and Mitchell. (1997), manual methods, even in simple situations, may be difficult or impossible as the number of parameters grows beyond seven. Accuracy of the results is, therefore, affected. Alternatively a GIS copes with many layers of spatial data, thereby providing a mechanism for dealing successfully with a large number of parameters and/or complex analyses. As models become more complex and describe more physical processes, data needs increase. A GIS is, therefore, an excellent tool to link such data with soil-erosion modelling because it offers a quick and effective means of predicting soil erosion under different combinations of soil type, vegetation, rainfall, and topography. Furthermore, a GIS environment can represent spatial features of land surfaces and, in turn, bring a spatial context lacking in the past (Spence, Dalton, and Kite, 1995).

5.2.4.1 Calibration of the Modified SLEMSA

To estimate soil loss, it was necessary to create three GIS data layers that would represent the SLEMSA submodels: Climate and Soil (***K***); Topographic Ratio (***X***); and Crop Ratio (***C***). The model was, therefore, calibrated as these data layers were being created. Calibration of the model followed the methods provided by Clark Laboratories (manufacturer of Idrisi32) at an Environmental Modelling Workshop held from 14 to 19 December, 1998 at Bunda College of Agriculture, University of Malawi (Mathilda Snel[23],

[23] Resource person at the modeling workshop

personal communication). Cartographic modelling capabilities of the Idrisi32 software (Eastman, 1999, p 53) formed the basis of calibration because cartographic models can be easily displayed, and they act as a guide in the use of appropriate modules. Since there are various inputs into the modified SLEMSA, this approach simplifies the prediction of annual soil loss. Detailed procedures, cartographic models, and look-up tables that were used in this process are attached as Appendices B and C; hence the following subsections only describe the important steps that were used to calibrate the model. All digital data that were used to create the images displayed in this Chapter are on CD-ROM at the Centre for Earth Observation Science, Department of Geography, University of Manitoba.

5.2.4.1.1 Calibration of the Crop Ratio (C) Submodel

Crop ratio (Fig. 5.1) was derived from a land-cover image, and rainfall-energy interception factors. Sources of rainfall-energy interception factors included Table 3.5 and vegetative cover, which was assessed in 5 x 5 m plots. These plots were installed during the 1998/99 rainy season (November to April) for purposes of validating predicted soil losses. When validating the predicted soil losses, the intention was to compare predicted and observed values on agricultural land, bare soil, and natural vegetation (Appendix E) in order to objectively illustrate the advantage of natural vegetation over the other types of surfaces. Morgan (1986, p 5) cites several other studies that have made similar comparisons. This being the case, therefore, the type of vegetation in which cover was assessed, depended on fulfilment of this objective principally. This prerequisite notwithstanding, there were also two important considerations that were made when locating a plot at each site: availability of labour to help with data collection, and safety of the monitoring equipment.

Four consequences are associated with the use of the criteria described in the foregoing paragraph. First, not all the land-cover types shown in Fig. 4. 4 were included. As such, some of the interception factor values are derived from Table 3.5. Second, the number of plots varied between the different types of vegetative cover and regions (Tables 5.1 and 5.2). Therefore some treatments were not replicated while others had up to four or more replicates. Third, the standard slope (4.5%) that is used in the Soil and Climate submodel (*K*) of the SLESMA was not met. Fourth, in the Lakeshore plain region, the plots had to be located out of the Linthipe Catchment (Fig. 4.4), but on sites with soil, slope, and rainfall characteristics that were similar to those in the Linthipe Watershed. Amphlett (1986, p 6) addressed a problem of this nature in the same manner.

Table 5.1: Details of runoff/sediment collection plots; Linthipe River Catchment, 1998/99

Plots [b]	Description	Slope (%)	Rainfall energy ('000 J m^{-2})
1-3	Bare fallow on estate land	13, 2, 13	< 15.0, 15.0-22.6[a]
4	Bare fallow on smallholder farm	2	< 15.0
5-8	Brachystegia woodland in forest reserves	6, 6, 2, 2	< 15.0, 15.0-22.6[a]
9-11, 21	Grass/shrub vegetation[c]	6, 13, 6, 13	
12	Maize on smallholder farm, crop residue use very apparent	13	< 15.0
13-14	Maize on smallholder farms, inter-cropped with pumpkins, and contour vegetation of vetiver grass in use	13	< 15.0
15-17, 20, 26	Maize on smallholder farm	6, 6, 2, 2, 13	< 15.0, 15.0-22.6[a]
19	Maize on smallholder farm, inter-cropped with soya bean, contour vegetation of vetiver grass in use	2	15.0-22.6
18	Maize on smallholder farm, contour vegetation of vetiver grass	2	15.0-22.6
22-25	Maize on estate farm	2	15.0-22.6
27-29, 30-33	Burley tobacco on estate farms	13, 2, 13, 6, 2, 2	< 15.0, 15.0-22.6[a]
34	Burley tobacco on an estate farm, contour vegetation of vetiver grass	13	< 15.0

[a] The first and second rainfall-energy values correspond to the first and subsequent slope gradient (respectively) in the row.
[b] Basic soil erodibility factor ranged from 4.5 to 6.5.
[c] The location of plot 10 was burnt by wild fire before the experiment.

Table 5.2: Distribution of sampling plots by geographic region and land cover/use; Linthipe River Catchment, 1998/99

Land cover/use	Geographic region					Total
	Dowa	Dzalanyama	Lakeshore	Lilongwe	Scarp	
Bare fallow	1	0	1[a]	1	1	4
Brachystegia woodland	0	2	2[a]	0	0	4
Burley tobacco	2	0	2[a]	2	2	8
Grass/shrub	2	0	0	0	2	4
Maize smallholders	4	0	1[a]	2	3	10
Maize estate	0	0	2[a]	2	0	4
Total	9	2	8	7	8	34

[a] Located outside of the Linthipe Watershed but on sites with similar characteristics as those in the study area.

Since vegetative cover was assessed in plots that were used to validate soil loss, the standard dimensions (30 m upslope by 3 m wide) given by Stocking (1995, p 229) should have been used. However, the decision to use 5 x 5 m plots was made after consultations with farmers on whose land soil-loss measurements were conducted. Although the farmers willingly offered use of their land, they were, nonetheless, concerned about the dimensions of the standard plot because its boundaries would cross several ridges at spots that would have otherwise been used as planting stations. The chosen plot size was, therefore, reached as a compromise between modifying the standard specifications and not validating the model at all. For purposes of confidentiality, only geographical locations and plot numbers, instead of farmers' names, are used to identify each site.

In natural vegetation, plots were located in *Brachystegia* woodland (Table 5.1) in two government gazetted forest reserves. These plots were relatively protected from human influence when compared with the rest. Four additional plots were established in grass/shrub vegetation.

All farmers involved in this study, irrespective of category, grew hybrid maize (MH 12 and NSCM 41) and burley tobacco. The fields were prepared early, and planted with the first rains. Management practices in the plots located on agricultural land simulated those employed by farmers, which were generally consistent regardless of farmer category, although some variations are evident (Table 5.1). In the Dowa Hills for example, one farmer used more crop residue in addition to fertilizer than the rest. Additionally, although all farmers applied 23:21:0+4S as basal-dressing[24] fertilizer in maize, and CAN as top-dressing, application rates were distinct between the two farmer categories.

[24] Basal dressing is applied either at the time of planting or when the crop has at least three leaves, while top dressing is the second application done after 3-4 weeks (Lorkeers and Venema 1991, p. 58).

Smallholders applied ≤ 30% of the rates of 23:21:0+4S and CAN (200.0 and 290.0 kg ha^{-1} respectively) that the MoA recommends for maize (GoM, 1992, p 45), while estate farmers applied on the average about 50% of the recommended rates in maize. In burley tobacco, however, all estate farmers applied the recommended amounts of Super Mixture and of CAN (450.0 and at least 150.0 kg ha^{-1} respectively; GoM, 1992, pp 87 and 88). Application of more fertilizer in tobacco than maize by estate farmers is obviously based on an economic rationale. If high yields and good quality tobacco are to be realised in order to fetch better prices on the market, the recommended fertilizer-application rates have to be used in its production. If low maize yields were realised as a result of using low fertilizer rates, farmers would simply use the profits from tobacco to buy maize.

Weeding in all the plots (except in natural vegetation) was done at the same frequency (twice) as in farmers' fields. All farmers employed contour and box ridging as mechanical conservation measures. Other practices were also used, but they varied between individuals (Table 5.1). For example, some of the farmers employed contour-vegetation strips planted with Vetiver (*Vetiveria zizanioides*) grass as additional agronomic measures. This was especially so in the case of smallholders in Dowa and Lilongwe, but also by one estate farmer in Dowa.

5.2.4.1.1.1 Measurement of Vegetative Cover and Rainfall-Energy Interception

To determine vegetative cover and its rainfall energy interception (*i*) value, the total vegetative cover method (De Jong, 1994) was used. This approach measures canopy in all the three layers of a vegetation community: trees (> 2.0 m); shrubs (0.3-2.0 m); and herbs or grasses (< 0.03 m). It is clear that this method excludes plant residue, which is always beneath the canopy cover (Stocking, 1994, p 212). Therefore the metre-stick method (Hartwig and Laflen, 1978) was also employed to assess the amount of residue.

Sampling was done monthly in natural vegetation and cropland between October 1998 (before the rainy season), and in April 1999 (end of the season). Within each plot, cover abundance was determined from canopy measurements using the line-intercept[25] and the Crown-Diameter methods (Mueller-Dombois and Ellenberg, 1974, pp 81 and 90). Five 1-metre strips were made within each plot using a metre-tape that was laid out on the ground at 1-metre interval across the plot. The crown diameter of each tree, shrub, herb or grass intercepted by the tape was measured. Where crowns overlapped in layered vegetation, the cover for each height class was measured separately. The measurements were taken from one side of the crown across the centre to the other side of the crown perimeter. This resulted in one crown-diameter reading. Since crowns do not form a perfect circle (Mueller-Dombois and Ellenberg, 1974, p 81), it was necessary to run a second crown-diameter measurement more or less perpendicular to the first one. The crown cover was then obtained from the formula:

$$cc = \left(\frac{D_1 + D_2}{4} \right)^2 \pi \qquad [5.7]$$

where D_1 is the first crown diameter measurement, D_2 is the second crown diameter measurement (Mueller-Dombois and Ellenberg, 1974, p 81). Canopy cover was

[25] The line-intercept method is based on the principle of reducing a belt-transect, which has two dimensions of length and width, to a line with only one dimension (Mueller-Dombois and Ellenberg, 1974, p 90).

expressed in square metres, and the total for all plants was determined. This total was then expressed as a percentage of the plot area (25 m^2).

To assess the proportion of the plot covered by plant residue, a metre-stick was placed on the soil surface in each strip. Beginning at one strip, and ending at an adjacent strip, total length of residue along the edge of the metre-stick was measured. Residue coverage was taken as the total length of residue divided by strip spacing, and it was defined by the formula:

$$CR = l_1 + l_2 + l_n/L, \qquad [5.8]$$

where ***CR*** is the crop residue coverage, ***l*** is the residue length, and ***L*** is the total strip length. The estimated cover for each piece of residue was added for the plot. For each plot, mean percent cover was obtained by dividing the values obtained from the residue and crown area (of trees, shrubs, herbs, and grass) by 4. This proportion was considered as the area in which rainfall energy was intercepted by vegetation.

In cropland, cover abundance of each crop was assessed at the same sampling frequency as in natural vegetation. Cover was estimated from the canopy of crops, weeds, and the amount of residue following the methods described in the preceding subsection. Where farmers practiced mixed cropping, the cover of different crops was measured separately because crown cover varies between crops.

5.2.4.1.1.2 Assigning Cover Values to Land-cover Classes

An image (classified from Landsat TM images) of Malawi's land-cover classes for 1991 was obtained from the Public Lands Utilization Study (PLUS, Orr *et al.*, 1998). A window of the Linthipe Drainage Basin (Fig. 4.4) was demarcated at the following geographic locations: 524000[26] as minimum X; 68700 as maximum X; 8375000 as minimum Y; and 8506000 as maximum Y. The resulting window was converted into an image (Fig. 5.3) of rainfall-energy interception factors (*i*) by assigning appropriate values from Table 5.3 to each land-cover class in Fig. 4.4.

[26] Units are Malawi36 reference system coordinates

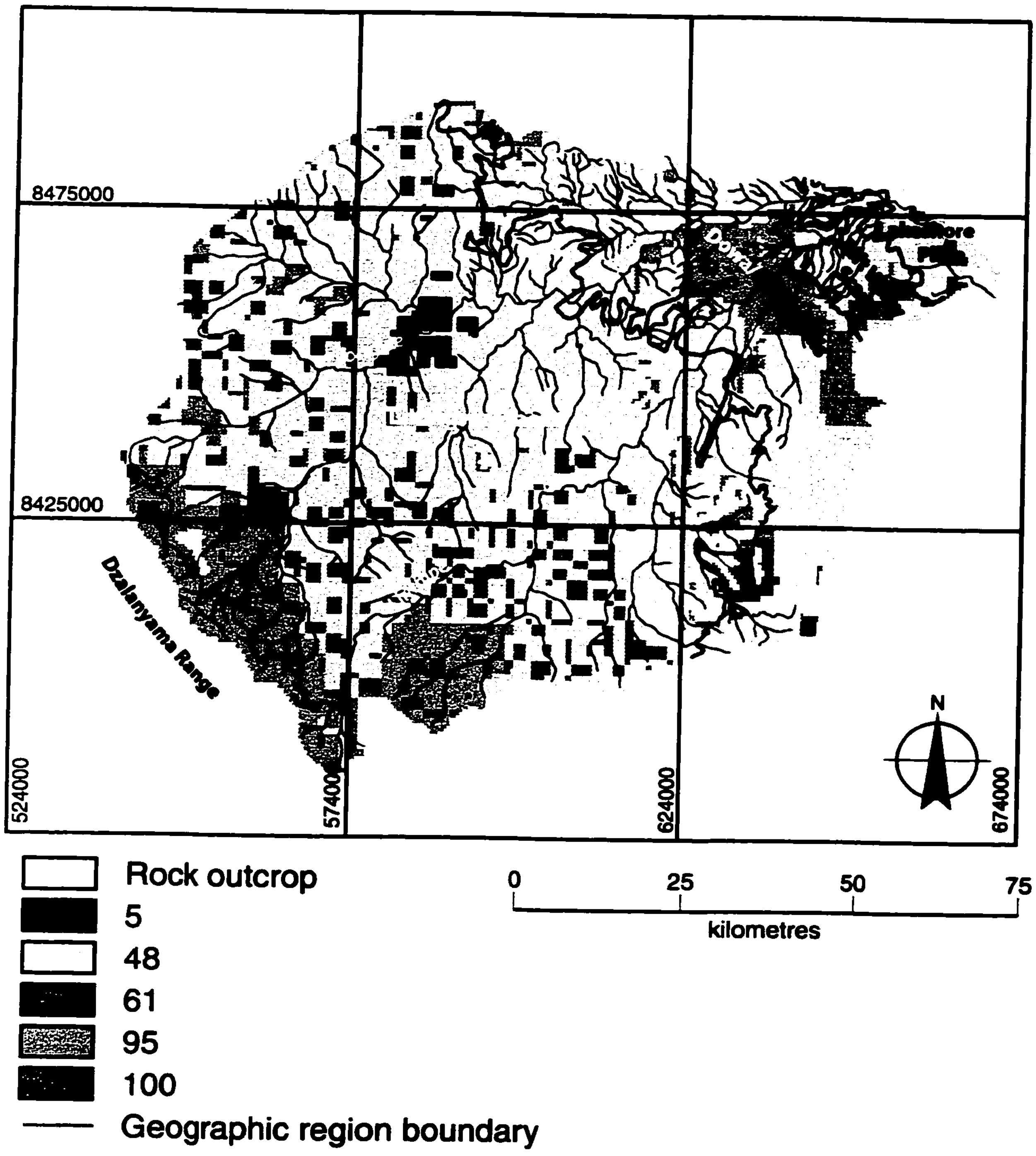

Fig. 5.2: Rainfall-interception factors (i) based on the 1991 land-cover data of the Linthipe Watershed

Table 5.3: **Rainfall-energy interception-factors assigned to the major land-cover classes (1991) of the Linthipe River Catchment**

Land cover	Interception factors
Brachystegia in hilly areas	95
Agriculture in forest areas	48
Open natural vegetation	61
Arable land	48
Forest plantation	100
Built-up areas	5
Estate plantations	95
Brachystegia in flat areas	95

Table 5.4: Comparison of observed vegetative-cover values (%) with those in the SLEMSA look-up tables

Cover type	Observed		SLEMSA value[a]	Difference
	Range	Mean		
Brachystegia woodland	58.09-88.44	77.68	95	18
Maize (Smallholder)	19.75-69.35	43.24	50	6.76
Maize (Estate)	13.75-80.28	56.23	70	13.77
Tobacco (Estate)	14.59-71.25	44.35	45	0.65
Shrub/grass	38.15-73.55	61.30	60	-1.3

[a] Obtained from look-up tables of the modified SLEMSA.

Given the differences in vegetative cover between the measured and SLEMSA values (Table 5.4), where possible, the former were employed in the model because they represented the situation on ground at the time of the field research. Actually, some explanation is warranted for the differences in Table 5.4. In case of maize under small-holder farming, it is common knowledge that crop cover is poor because of low fertilizer-application rates. These low rates must have declined even further as a result of rising costs of fertilizers, which have been precipitated partly by removal of government subsidies (Douglas 1988, p 222; Sahn and Arulpragasam 1991). This study adds further that the consistent decline in the value of the local currency (Malawi Kwacha)[27] has also contributed to the low fertilizer use because the devaluation has inevitably caused costs

[27] According to the Central Intelligence Agency (2000), the exchange rate was Malawi Kwacha (MK) 46.35 per US$ 1.00 by December 1999, while in 1995 the rate was MK 15.28 to US$ 1.00.

of importing fertilizers to rise. Data from ADMARC, a statutory company that is a major market for farm inputs and output, show that in 1996/97 growing season, the cost of 23:21:0+4S fertilizer was approximately MK 300.00 per 50-kg bag. During the growing season of 2000/2001, this same type of fertilizer was selling at MK 1,600.00. Such a situation must certainly have made it more difficult for farmers to procure this crucial input; hence crop cover continues to decline. The foregoing explanation, that the observed cover in maize was lower (than the value in SLEMSA) is due to low fertilizer-application rates, also applies to the cover on maize fields belonging to estate farmers (Table 5.4). That the observed crop cover in tobacco, where the recommended fertilizer rates were applied, is close to the SLEMSA values (Table 5.4) renders weight to the preceding speculation.

The lower cover measured in *Brachystegia* woodland (than the value given by the modified SLEMSA) is attributed to the fact that sampling was limited to forest reserves that have old trees and hence understorey vegetation, in the form of herbaceous layer, was low because of shading by the tall trees. For example, there was no herbaceous layer from October to December in the plots located in the Dzalanyama Forest Reserve. Hence it may have affected the estimated total cover (Fig. 5.4). In an examination of diversity in fire-protected and unprotected sites in Miombo (*Brachystegia*) woodland, Chidumayo (1988) found that the former had fewer species, largely because of the loss of understorey species. Therefore, if the sites where the SLEMSA cover values were measured had herbaceous layers, then they are bound to produce higher values than the sites used by this study.

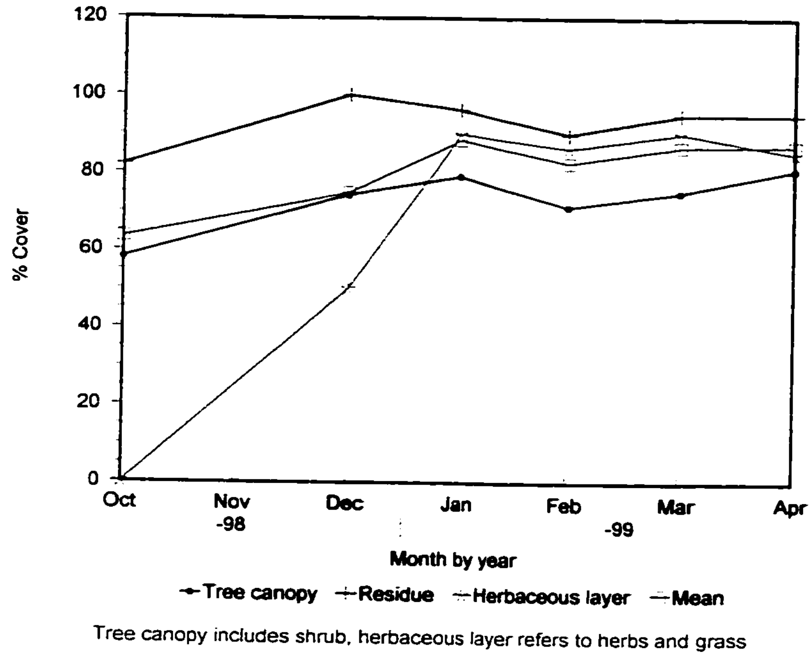

Fig. 5.3: Average vegetative-cover trend in two plots of *Brachystegia* woodland in the 1998/99 rainy season; Linthipe River Catchment

While all land-cover types were assigned their corresponding values, agricultural land, on the other hand, was given an interception value of 48%, which is the average of the three values from tobacco and maize (Table 5.4). Since uncultivated arable land is subject to cultivation, the same value was applied to this land-cover class. Having assigned the appropriate values to the land-cover data layer, the IMAGE CALCULATOR[28] was used to generate two crop-ratio layers by evaluating the vegetative cover models (***C_1* = *exp [-0.06i*]** with ***i*** < 50%, and ***C_2* = *[2.3 – 0.00i]/30*** with ***i*** ≥ 50%. The resulting layers were added to come up with the final crop-ratio image (Fig. 5.4).

[28] All capitalized terms in this section and the subsequent ones are names of Idrisi32 modules

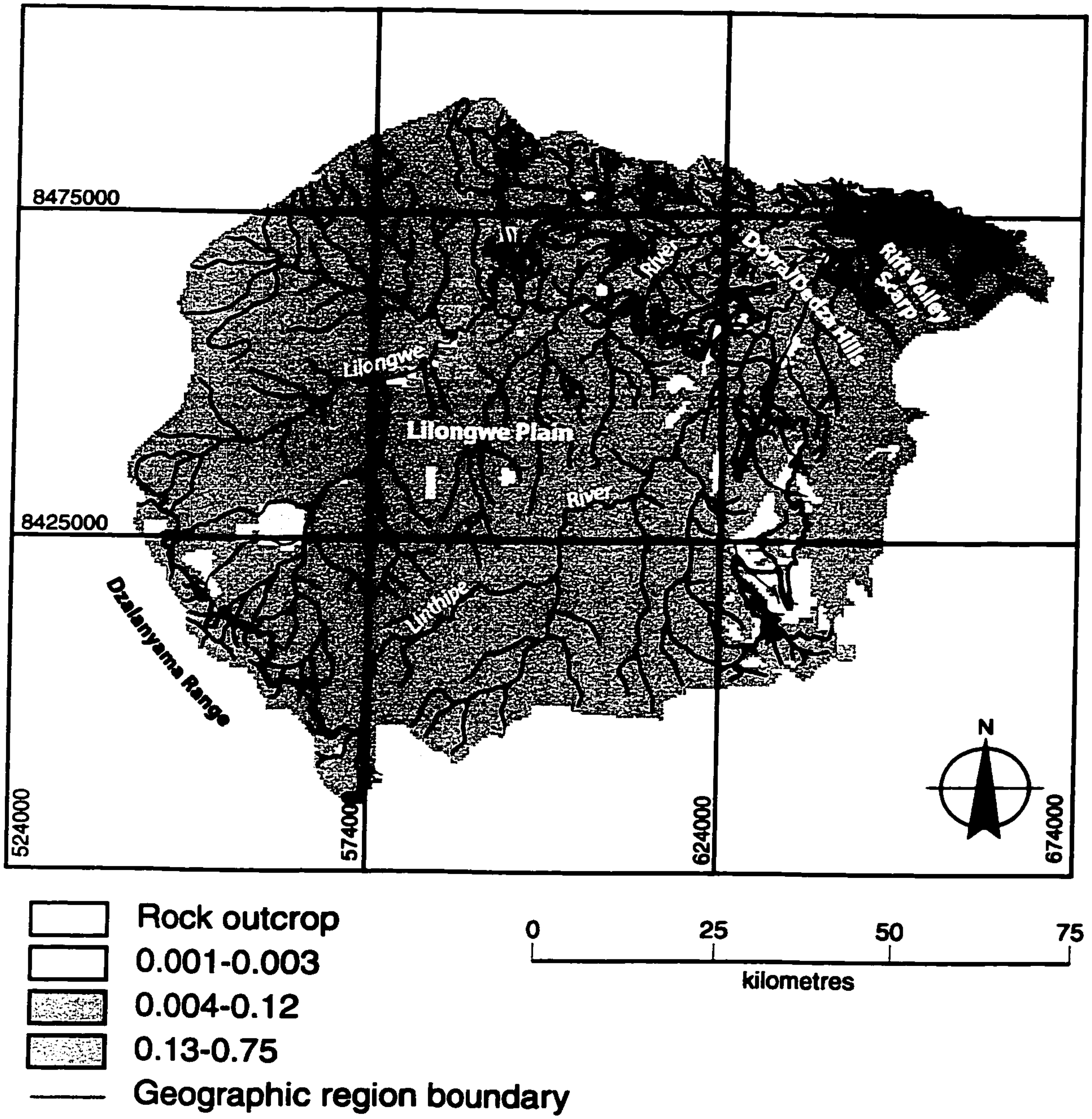

Fig. 5.4 Crop-ratio based on field data and values from the modified SLEMSA look-up tables (high values represent poor interception); Linthipe River Catchment

5.2.4.1.2 Calibration of the Climate and Soil (K) Submodel

To calibrate the ***K*** submodel (Fig. 5.1), creation of data layers that represented rainfall energy (***E***) and soil erodibility (***F***) was necessary. Seasonal rainfall energy was generated from two data sets. The first consisted of *in situ* rainfall measurements, from Truchek standard rain gauges, collected during the 1998/99 rainy season (Appendix D, Table D1). In all cases, except on bare fallow, rain gauges were located in an open space approximately 10 m away from the plot in order to avoid interception of rainfall by vegetation or crops. On bare fallow the gauges were located within the plot. The second set comprised 1988-98 rainfall data for the whole of Malawi (Appendix D, Table D2), which was obtained from the MEMP and the DoM in Malawi (K.W. Burger and D.R. Kamdonyo *personal communication*).

Coordinates of each rain gauge were noted to enable comparison of interpolated and observed soil loss from the same geographic locations. The coordinates were determined using a global positioning system (GPS, Fig. 5.5) connected to a TDC1 Asset Surveyor data logger. Positions were collected using two receivers: a Trimble Pro XR 8 channel GPS (reference); and TDC1 data logger (roving) that were coupled (using differential GPS) with a 12 channel Pathfinder Community Base Station (PFCBS). According to Hurn (1993, p 12) differential GPS works by cancelling out most of the natural and humanly-induced (selective availability) errors that creep into non-corrected GPS measurements. The reference receiver continuously monitors the errors and transmits or records corrections. The roving receiver can apply the transmitted corrections to its measurements either as it makes the errors or use the recorded corrections some time later. In this study, differential data were post processed using Trimble Pathfinder Office software (v. 1.0).

Fig. 5.5: Determining coordinates of a validation plot using differential GPS

Each rainfall data set was used to create an x, y, and z (geographic location and rainfall value) vector (point in this case) file. The values in both files were interpolated into a rainfall surface (Fig. 4.2) using the POINTRAS module in the REFORMAT/RASTER/VECTOR CONVERSION menu. To obtain the rainfall image of the Linthipe Catchment (Fig. 4.2) from the Malawi data layer, a window covering the geographic locations specified in section 5.2.4.1.1.2 was used to demarcate the Linthipe Watershed within the rainfall data layer of Malawi. To change the projection from the 'latlong' georeference system (Appendix D, Table D2) to 'Malawi 36' (the reference system used in the rest of the data layers), the PROJECT module was used. The interpolated mean rainfall values for 1988-1998 were transformed because a test for normality using the Shapiro-Wilk W[29] test (Sall and Lehman, 1996, p 446) revealed that the data were not normally distributed ($W = 0.87$, $p < 0.0007$). On the contrary, the distribution of the 1998/99 data was normal ($W = 0.98$, $p = 0.88$), hence it was not transformed. After transformation, the T-test (Sall and Lehman, 1996, p 133) was used to compare if the rainfall values from the two data sets (Table 5.5) were statistically different. Since the test showed that there was no significant difference (t-ratio = -0.06, p = 0.47) between the data sets, the 1998/99 image was converted into a seasonal rainfall-energy data layer (Fig. 5.6) by using the IMAGE CALCULATOR to evaluate the equation $\boldsymbol{E = 18.846P}$.

Table 5.5: Comparison of interpolated (1988-98) and *in situ* rainfall data; Linthipe River Catchment(t-ratio = - 0.06, p = 0.47)

Source		**Rainfall (mm)**			**Region**
		Dowa	Lakeshore	Lilongwe	Scarp
Interpolation[a]	Range	942-970	991-1006	874-945	967-983
	Mean	960.22	995.38	908.11	974.63
In situ	Range	650-1167	655.4-1224.3	944.4-1393.05	696.5-1597.1
	Mean	825.41	883.52	1103.00	1030.86

[a] Interpolated from data that were obtained from the MEMP and DoM.

[29] If the p value is less than 0.05, then the distribution is not normal (Sall and Lehman, 1996, p 446)

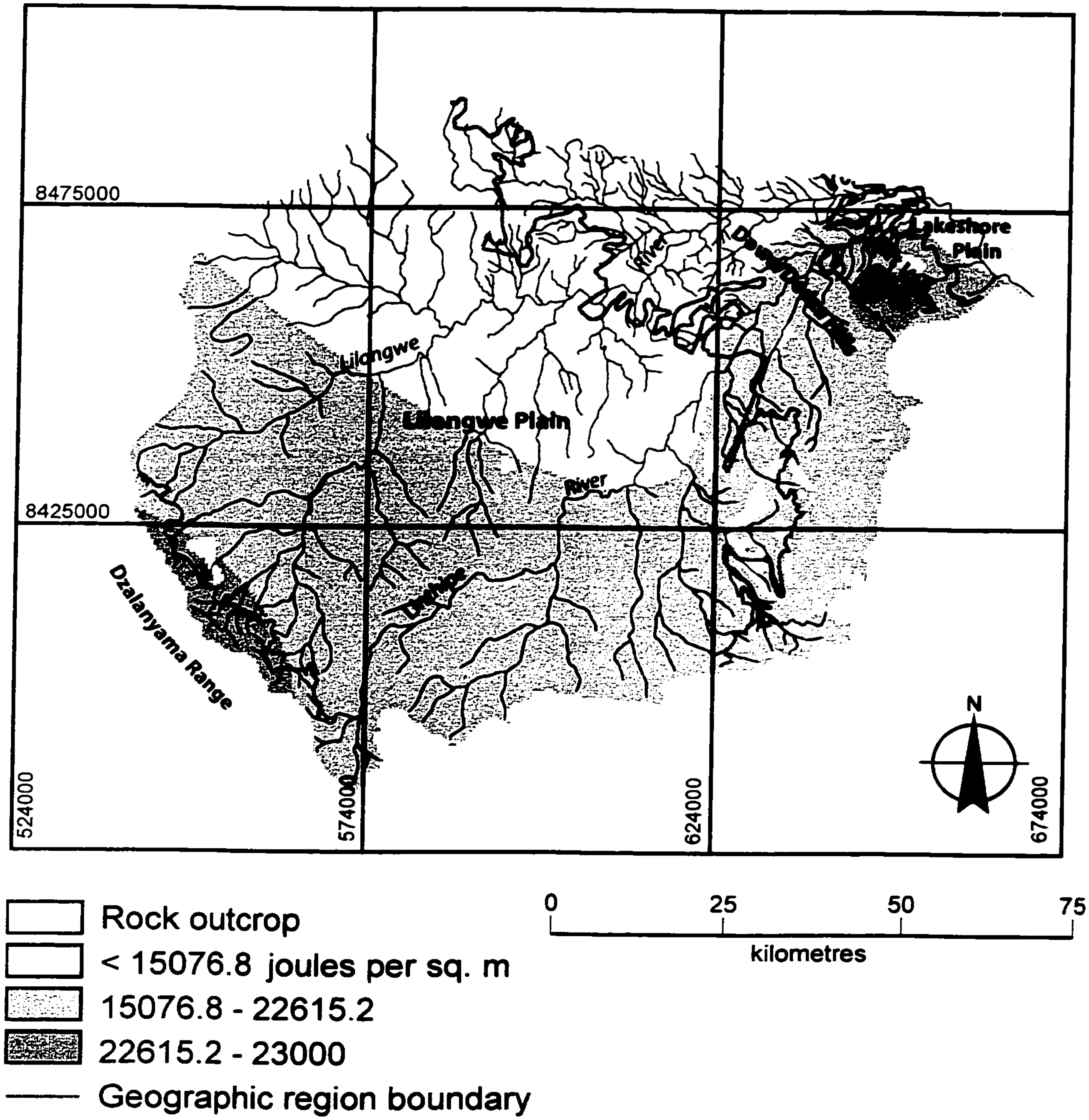

Fig. 5.6: Rainfall energy, 1998/99 rainy season; Linthipe Drainage Basin

While the original SLEMSA depicts linearity between annual rainfall and energy, such a relationship does not exist in Malawi for values lower than 800 mm and above 1200 mm, which the modified SLEMSA considers as cut-off points (Paris, 1990, p 3). To include rainfall amounts of less than 800 and higher than 1200 mm, they were equated to the energy values to those for 800 and 1200 mm respectively. This procedure resulted into energy values that are equivalent to three annual rainfall categories: < 800, 800-1200, and > 1200 mm, as depicted in Fig. 5.6.

Soil erodibility was assessed according to the method used by Elwell (1978a), which takes into account two distinct parameters, the soil itself, and management practices. The soil has a basic erodibility that varies with its physical and chemical properties. A GIS data layer of this erodibility was, therefore, created from vector layers of soil texture and group that were digitised from LREP maps (1:250.000) of the Lilongwe, Kasungu and Salima ADDs (Lorkeers and Venema, 1991; Nanthambwe and Eschweiler, 1992; Lorkeers 1992). Digitising was done manually using Carta Linx software version 1, and a Calcomp digitising table. The following settings were used: root mean error of < 65.5 m; and a snap tolerance of < 31.0 m so that only nodes at essentially the same location would snap (Hagan, Eastman, and Auble, 1998, p 52). The vector layers were imported into Idrisi32 where they were converted into data layers of soil texture and group using the REFOMAT/VECTOR/RASTER CONVERSION/POLYRAS module. To create a data layer of basic erodibility, which is represented by the major soil groups (Fig. 4.3), the soil texture and soil-group layers were cross-tabulated using the CROSSTAB module in the ANALYSIS/DATABASE QUERY menu.

In using the existing soil texture and group maps, it was assumed that the basic soil erodibility had not changed since the LREP study. To confirm that the soil texture of the topsoil, which is vulnerable to soil erosion, had not changed the runoff/sediment plots were used for soil sampling. Brady and Weil (1999, p 119) stated that the texture of various soil horizons is often the first and most important property to determine, for a soil scientist can draw many conclusions from this information. Furthermore, the texture of a soil in the fields is not readily subject to change, so it is considered a basic property. Soil samples were collected following the method prescribed for soil sampling in Malawi (GoM, 1982, p 3). The "W" sampling pattern was used to collect five samples per plot. Depth was measured in each pit, before installation of collection tanks, in order to determine if most of the topsoil had been eroded.

The samples were mixed to form composites, from which 1.0 kg sub-samples were taken for physical analyses to determine soil-particle size in the LMBCP laboratory at Senga Bay (Salima). Components of each sample were separated using a USA Standard Testing sieve (pore sizes ranging from 63 μm to 200 mm) and weighed using a Sartorius Supermicro® Type S4 sensitive balance (± 0.0001 mg) in order to determine the amount of each separate. The sieved particles were described using the United States Department of Agriculture nomenclature as follows:

i) very coarse sand (1.0-2.0 mm);

ii) coarse sand (0.5-1.0 mm);

iii) medium sand (0.25-0.5 mm); and

iv) fine sand (0.10-0.25 mm)

The percentage of each separate in the sample was calculated in order to determine the dominant particle size. This procedure made it possible to conform to the description of surface soil texture used in the LREP maps. Both texture, and range of soil depth were compared with descriptions and values (respectively) of the soil groups that were sampled.

Table 5.6 Comparison of observed soil depth and texture of soil groups with descriptions in LREP reports

Soil group	Depth range (mm)		Dominant surface texture	
	Measured	LREP	Assessed	LREP
Eutric ferralic	10-69	50-150	Very coarse	Coarse
Eutric fersialic	12-185	50-150	Coarse	Coarse
Eutric fersialic/paralithic	15-100	50-150	Very coarse	Coarse
Fluvic	112-185	> 150	Fine	Fine

Overall, the measured soil depth falls within the values obtained from the literature. Similarly, the soil texture is comparable to what was described by Lorkeers and Venema (1991), Nanthambwe and Eschweiler (1992), and Lorkeers (1992) for the soil groups shown in Table 5.6. Therefore, there is no reason to believe that the basic soil erodibility had changed significantly, thereby providing confidence in the use of soil texture and group from LREP maps.

Since the final erodibility takes into account land management practices, for example crop cover, land-use/cover classes such as built-up areas, agricultural and arable land were assigned a value of 0 because it has been shown that raindrop interception is poor.

In contrast, classes such as natural vegetation and plantations were represented by a value of 1 because they provide better protection than agricultural land. In other words, soil on agricultural land retained its basic erodibility factor while that on forested land acquired an additional unit. The result of assigning these values to the land-cover layer was a Boolean data layer (containing 0 and 1), which was added to the soil group image (Fig. 4.3) to generate the final soil-erodibility (***F***) data layer (Fig. 5.7). The two layers of the control variables (***E*** and ***F***) were used to create an image of the ***K*** submodel (Fig. 5.8) in the IMAGE CALCULATOR by evaluating the following equation: $K = exp[(0.4681+0.7663F) lnE+2.884-8.1209F]$.

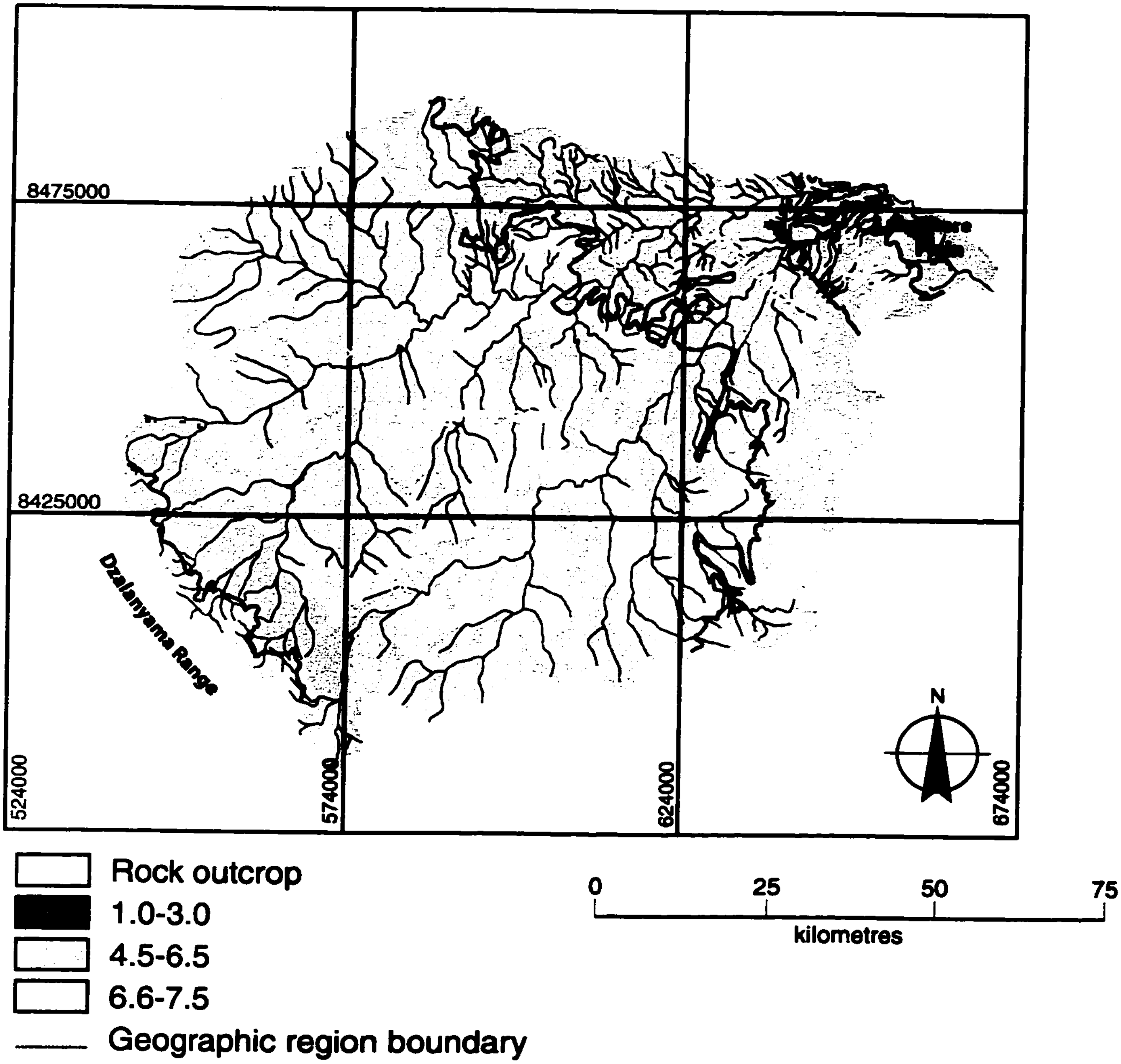

Fig. 5.7 Final soil erodibility (accounting for soil properties and land management); Linthipe River Catchment

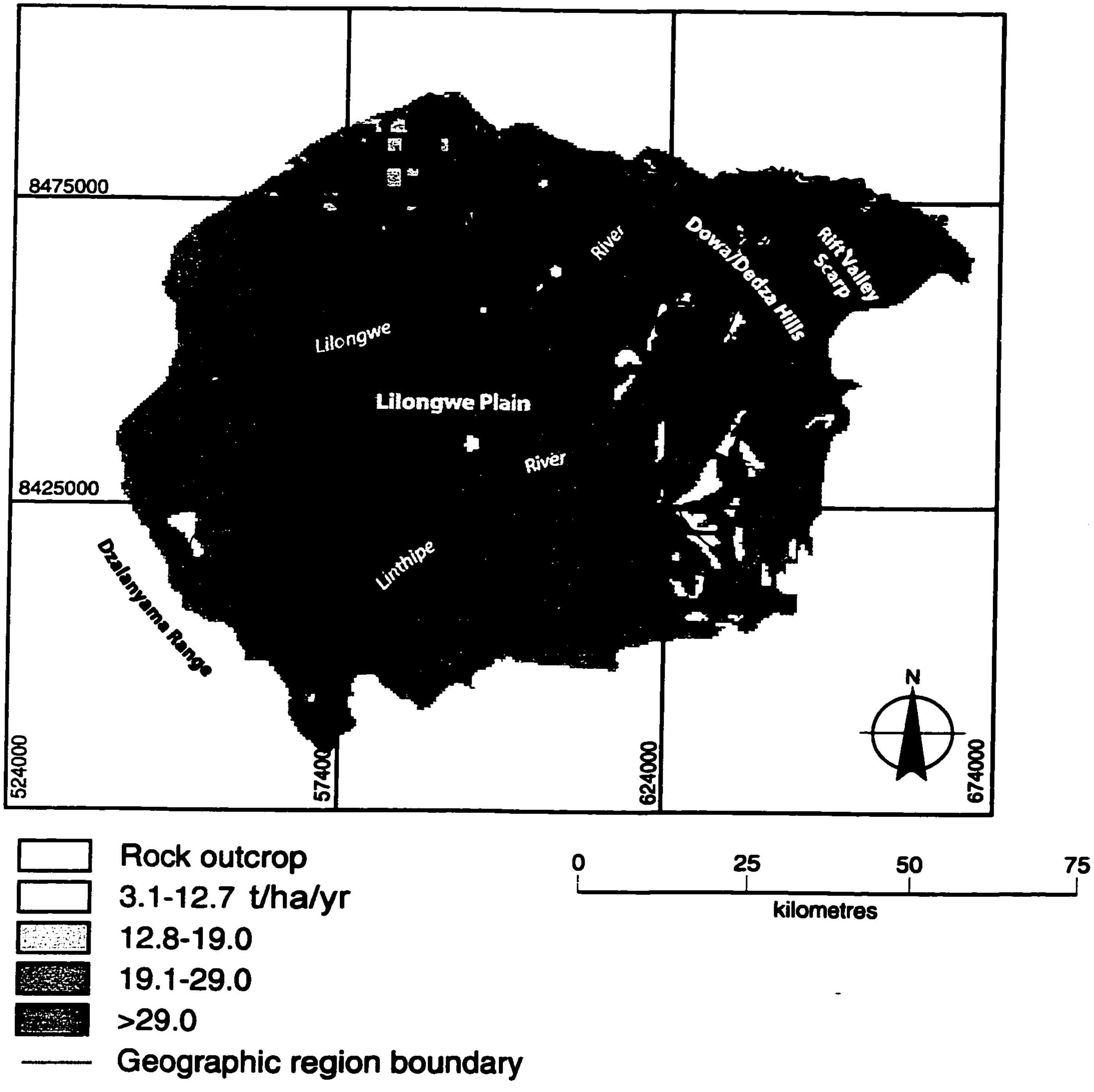

Fig. 5.8: Soil loss (t ha^{-1} yr^{-1}) from bare land, as predicted by the Soil and Climate (*K*) submodel; Linthipe Watershed

5.2.4.1.3 Calibration of the Topographic Ratio (X) Submodel

Topographic ratio (Fig. 5.1) was derived from slope gradient (*S*), and slope length (*L*). According to the modified SLEMSA, the latter is also obtained from vegetation-cover classes. To determine the five slope categories (Fig. 4.1) a vector (line) file of slope gradient was digitised from the LREP maps (1:250,000) and converted into a slope-gradient image using the approach described in section 5.2.4.1.2. In this particular circumstance, however, the POLYRAS module was employed in the same REFORMAT/RASTER/VECTOR CONVERSION menu.

Preliminary results by Brook (2000, p 147) illustrate that with respect to elevation, digital elevation models (DEMs) generated from field data and topographic maps do not generally compare well. For instance, it is only elevation models (1:250,000 and 1:50,000) of a site representing gentle slopes in the Lakeshore region that show a high rate of agreement (Table 5.7). These results, therefore, indicate that the steeper the slope a region has, the greater the chance a small-scale DEM will not produce correct elevations and slope values. Therefore, it was inferred that if left uncorrected, the gradient values for regions with steep slopes (Dowa, Dzalanyama and Scarp regions (Fig. 4.1)), were likely to cause errors in the model. On the other hand, where slope gradient is low, as is the case in parts of the Lakeshore and Lilongwe plains, it is unlikely that any differences between the observed and field soil losses would be due to errors in slope gradient. This being the case, slope values in the Lakeshore and Lilongwe plains were left uncorrected.

Table 5.7: **Summary of initial elevation differences between DEMs generated from topographic maps and validation data using two scales; Linthipe River Catchment**

DEM Scale	**Difference (m)**	**Region**		
		Scarp	Dowa	Lakeshore
1:250,000	Range	-196.52 -13.67	-33.16-48.22	-21.56-5.40
	Mean	-105.00	15.93	-2.57
1:50,000	Range	-29.00-19.45	-11.57-36.06	-18.47-8.24
	Mean	3.88	12.9	-2.57

Adapted from Brook (2000, p 147)

Since there is a tendency for DEMs generated from topographic map to under-represent slope, only the upper limit (2, 6, 13, and 20%) of each gradient range (Fig. 4.1) was used. Of the five slope ranges, only four: 0-2%; 2-6%; 6-13%; and 13-20% were used because the SLEMSA is not valid for slopes that are greater than 20% (Stocking *et al.*, 1988). The slope range of 13-25% was, therefore, changed to 13-20% and the fifth gradient range of 25-55% was considered as 100%.

Slope-length values (Fig. 5.9) were assigned according to the type of land cover (Fig. 4.3); thus 20 m was the standard slope length for agricultural land and settlement, while 10 m was used for forests. The long length (20 m) being used on cropland to account for ridging because it is less effective in controlling soil erosion because of poor quality of ridges. Moreover, crop stands are sparse and weaker than in forested areas, which were assigned a slope length of 10 m. The resulting data layers, (*S*) and (*L*), were used to evaluate the topographic ratio formula: $(X) = (L)^{0.5}(0.76 + 0.53S + 0.076S^2)/25.65$ in the IMAGE CALCULATOR to obtain the topographic ratio image (Fig. 5.10).

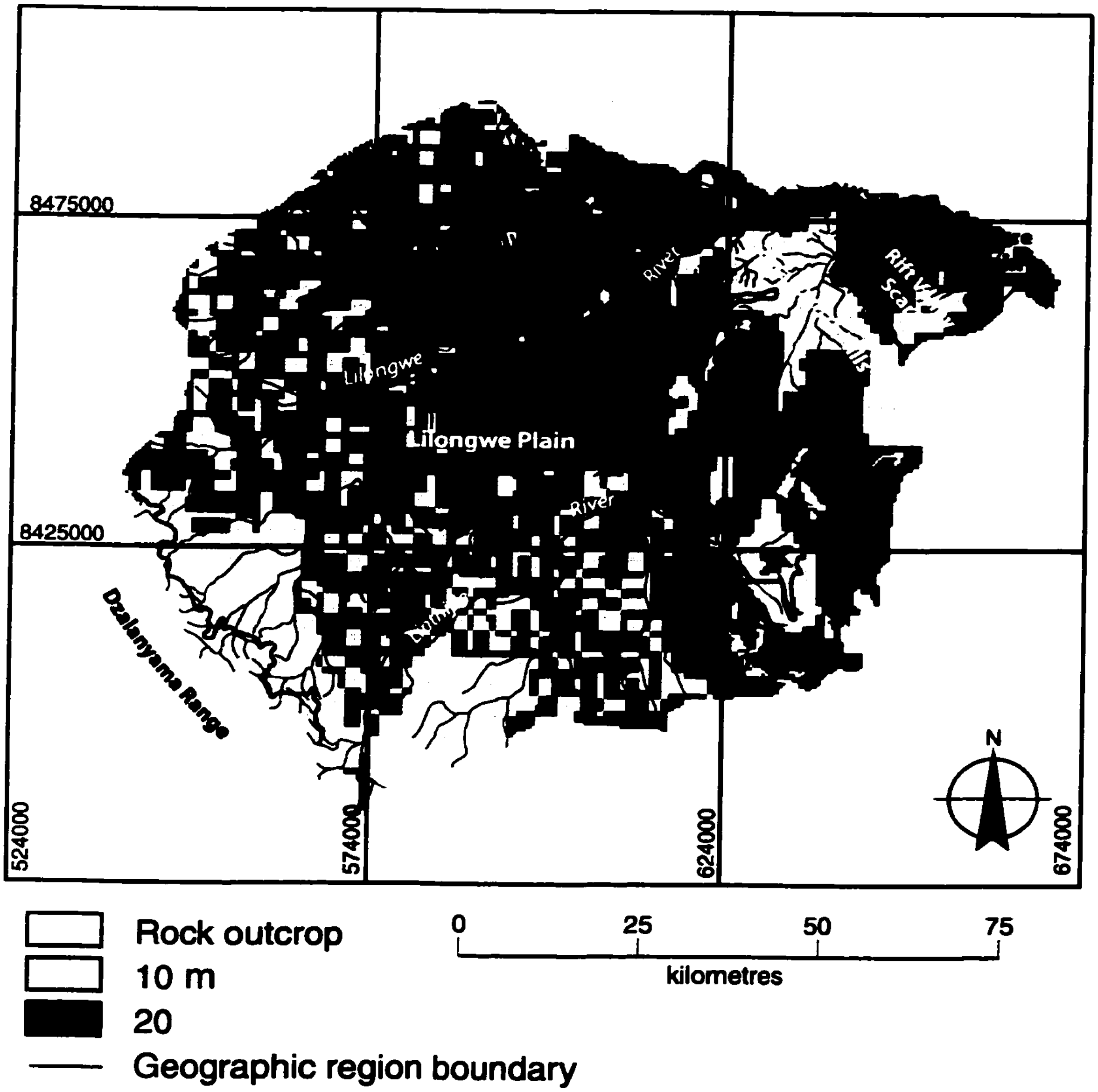

Fig. 5.9: Slope-length determined from 1991 land-cover classes; Linthipe River Catchment

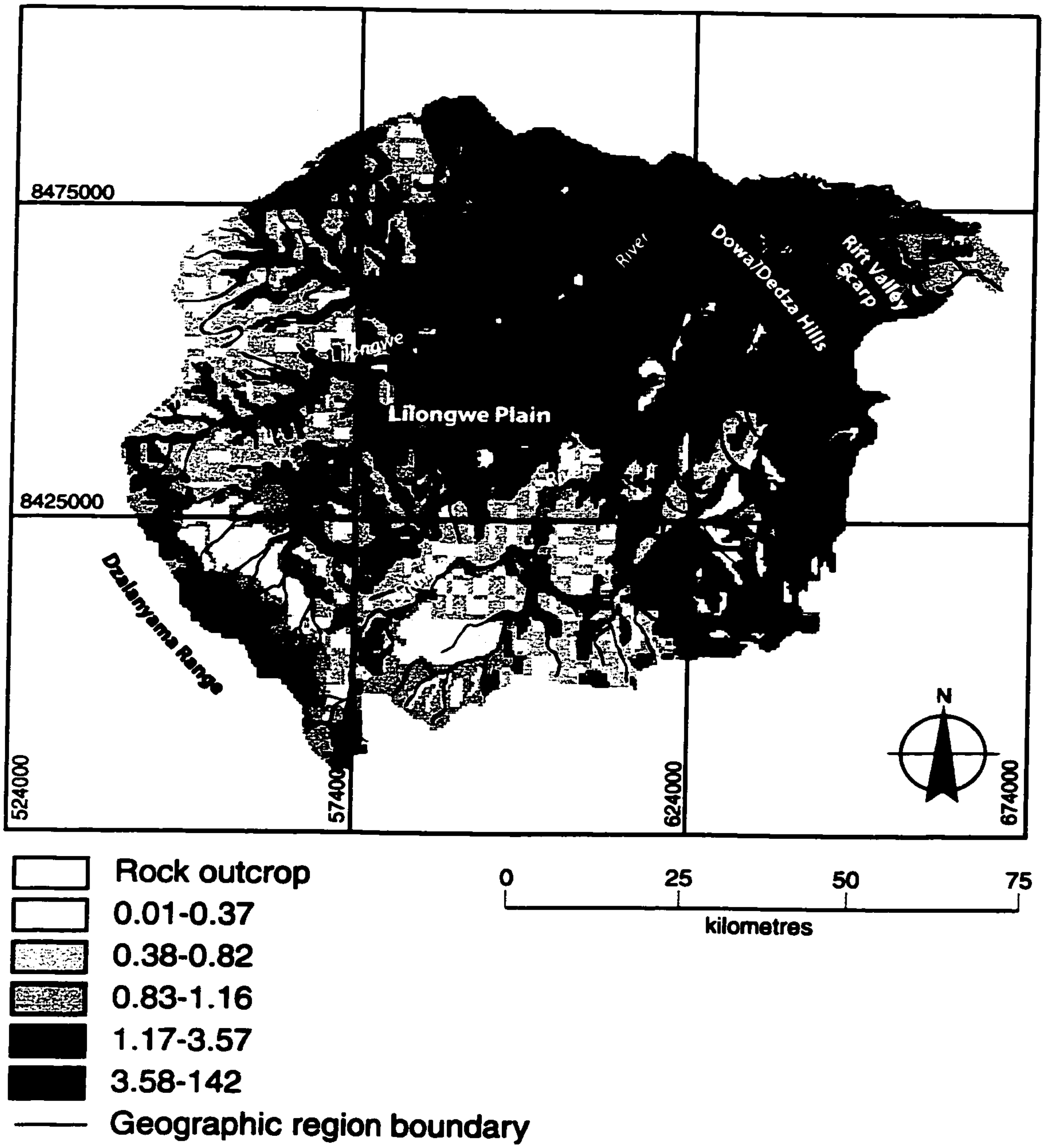

Fig. 5.10: Topographic-ratio; Linthipe River Catchment

5.2.4.1.4 Prediction of Soil Loss

Having created the images that were required to represent each submodel in Fig. 5.1, they were multiplied using the IMAGE CALCULATOR in order to estimate soil loss. The estimated soil loss was categorised into five ranges, the lowest being < 3.0 t ha^{-1} yr^{-1}, and the highest as 29 t ha^{-1} yr^{-1} following the lower permissible limit used in Zimbabwe (Elwell and Stocking, 1982), and the highest rate of soil loss shown in Table 2.4 respectively. The DATABASE/QUERY/RECLASS module was used to divide the soil-loss range into five categories that were ranked using the terms adopted from the SARCCUS (1981, p 3) as follows: < 3.0 = low; 3.1 - 12.7 = moderate; > 12.8 - 19.0 = severe, 19.1 –29.0 = very severe; and > 29.0 = extremely severe.

5.2.4.2 Potential Changes in Distribution of Erosion Risk in Response to Alterations in Land Cover

Three scenarios are employed to evaluate potential changes in the distribution of soil-erosion risk in the study area. They depict the best, medium, and worst cases of land cover, but the same calibration procedures apply. Land cover is the only variable being examined because of its dominance in the model; it is employed in all the submodels, as can be seen from the preceding subsections. This being the case, any change in land cover will be represented in all the submodels in the form of slope length, soil erodibility and energy interception factors. Consequently, these are the values that change from the preceding analyses. Since validated slope-gradient values were used to calibrate the topographic ratio (*X*), these values were held constant.

Rainfall-energy values were also kept constant because firstly, there was no difference in rainfall pattern as evidenced from a comparison of rainfall data for the period 1988-98 with 1998/99 (Table 5.5). It might be contended that in the event of changes in rainfall due to anthropogenically-induced global warming (Parry and Carter, 1998, p 21), there could be a proportionate change in seasonal rainfall energy. However, evidence obtained from climate-change scenarios that have been created from outputs of general circulation models (GCMs) illustrates the contrary (Table 5.8). According to Parry and Carter (1998, p 83) GCMs are three-dimensional numeric models of the global climate.

Table 5.8: Minimum and maximum annual changes in precipitation and energy by 2050 in the Linthipe River Catchment, predicted using outputs of three General Circulation Models

Model	% Δ in precipitation [a]	Δ in annual precipitation (mm)		Δ in Energy J m^{-2}	
		Minimum	Maximum	Minimum	Maximum
UK89 [b]	2.11	816.86	1633.76	15402.71	30806.18
GFDL	17.23	937.84	1737.84	17683.91	32768.71
CCC	-8.28	733.92	1467.84	13838.79	27677.59

[a] After Mkanda (1996, 1999)
[b] UKMO 98 (Mitchell, Senior, and Ingram, 1989)

The low-precipitation scenario, as depicted by the CCC model (Boer, McFarlane, Lazaro, 1992) indicates that the minimum annual precipitation will be about 734 mm. This value is higher than the annual rainfall of 454.3 mm which is equivalent to rainfall energy of about 11, 044 joules m^{-2} that exceeded the threshold erosivity value of KE > 25 (Table 3.2). The impact on soil-particle detachment and transport even under a predicted low annual-precipitation scenario therefore will not be lower than present. Under a predicted high-precipitation scenario, as illustrated by the GFDL (Manabe and Wetherald, 1987), rainfall will be higher than present, but its erosivity will not be more excessive because the most erosive rainfall energy is below 15000 J m^{-2} (Elwell and Stocking, 1982;

Stocking *et al.*, 1988). Since the energy values in the study area already high (Fig. 5.6, Table 5.8), it is inferred that potential increase in soil erosivity will be negligible.

5.2.4.2.1 Worst-case Scenario: Traditional Management and Deforestation

This scenario represents traditional management of agricultural land and further deforestation of natural vegetation at the estimated annual rate of 3.5% (Orr *et al.*, 1998, p 28 and 29). The first rationale behind this scenario is that after several years of soil-conservation efforts, soil losses are still high in Malawi. At the same time, there has been an increase in prices of production inputs such as fertilizers. The implication of these increases is that this input is beyond the means of most smallholders and small-scale estate farmers. Consequently, the number of farmers that are being forced to employ substandard farming practices may continuously rise thereby triggering an accompanying increase in the area of land that could be rendered vulnerable to soil-erosion processes. Second, it is supposed that practices will not change on agricultural land because of bureaucracy. Kalipeni (1992a) cites examples where government officials in Africa have used bureaucratic means to frustrate well-intended projects. Therefore, similar bureaucracy could prevent implementation of the recommendations of this study. Third, it has been suggested by Shaxson (1981, p 386) that attempts to introduce changes in land use, for example realigning farm and field boundaries with strict reference to contours of the land, in the interest of better soil-erosion control, may cause considerable disruption of farming activities, and engender much argument. This being the case, it can be anticipated that implementation of recommendations of this study will depend on their acceptance by the public.

The increase in human population justifies the assumption of continued deforestation of natural vegetation. Its consequence, which is a corresponding rise in demand for land to cultivate, and fuelwood has been elaborated in Chapters 1 and 3. One manifestation of this consequence is encroachment and deforestation of protected areas (Mkanda, 1991; GoM, 1998, p 44). In contrast, plantation forests are not subjected to the same pressure because they are conceived as "private property". The scenario, therefore, assumes zero deforestation of *Eucalyptus* and Pine plantations owned by individual estate farmers and government respectively.

Since crop cover is always poor under traditional management, agricultural and arable land was assigned 16% as the rainfall-energy interception factor. This value is the mean of the lowest crop cover measured by this study (Table 5.4). This low cover helps to explain the phenomenon of reduced energy interception in this type of management. Forest cover is assigned the interception values shown in Table 5.9. The two slope-length values that account for ridge quality were retained. Soil erodibility on agricultural land was assumed to be basic because of the poor management practices, while a value of 1 was added to land under forest (natural woodland, predominantly grassland, and plantations) cover.

Table 5.9: **Rainfall-energy-interception factors assigned to the major land-cover classes under different scenarios; Linthipe River Catchment**

Land cover	**Interception factors by scenario**		
	Worst-case	**Best-case**	**Moderate-case**
Brachystegia in hilly areas	16	95	95
Agriculture in forest areas	16	95	100
Open natural vegetation	16	61	61
Arable land	16	70	48
Forest plantation	100	100	100
Built-up areas	5	5	5
Estate plantations	95	95	95
Brachystegia in flat areas	95	95	95

5.2.4.2.2 Best-case Scenario: Improved Traditional Management and Reforestation

This is a best-case scenario depicting improved traditional management of agricultural land, halted deforestation, and reforestation of areas classified as "agriculture in forest areas" (Fig. 4.4). The underlying rationale is that this type of management is beneficial to soil conservation; hence the recommendations in Chapter 6 will be adopted and implemented. Secondly, it is assumed that the GoM will continue to encourage farmers to evolve into a cash economy (Elwell and Stocking, 1982, Bell, 1984, p 310) through removal of the constraints that force them to employ suboptimal farming practices. This being the case, it is assumed that bureaucracy will not frustrate implementation of changes in land use. Acceptance of these recommendations by the public is also assumed because smallholders, who are the majority in Malawi, will see the potential to evolve into a cash economy.

The rationale behind reforestation and halted deforestation is underpinned by initiatives under the Nature Project[30] whereby relocation of people from vulnerable areas to arable land is underway in the Northern Region (Dr. Anthony Seymour[31], *personal communication*). Monetary compensation being the major incentive to relocate, such a scenario is highly feasible in the Linthipe Catchment. Under such a scenario, farmers who presently cultivate in forest areas would have to be relocated to arable land elsewhere in the Central or the Northern regions where population densities are lower than in the Linthipe Watershed. Whether funding will be available for such an exercise in the Linthipe Drainage Basin is not known yet, but the likely consequences are worth exploring.

The assumption behind elimination of deforestation is that once farmers have evolved into a cash economy, they will be able to realise high yields without having to extend the amount of land they cultivate. Secondly, it is postulated that the cash economy will enable farmers to afford use of electricity more than fuelwood.

Considering that crop cover under improved traditional management is better than in traditional management, agricultural land was assigned an interception factor of 70%, which is the highest value for agricultural land (Table 3.5). The high value helps to explain a phenomenon of increased energy interception in improved traditional management; hence less energy penetrates crops under the former than in the latter. Reforested areas are assigned a value of 95%, which is the interception factor of

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[30] The Nature Project provides technical and financial support to the GoM so that the latter can develop and implement nature-conservation policies and legislation.
[31] Consultant to the Nature Project

Eucalyptus, a species that is recommended and used on private plantations. Again, the two slope length values accounted for ridge quality. In this case, the short length was used because the quality of ridges is better, and crop stands are denser and stronger than under traditional management. Therefore it is more effective in controlling soil erosion. Soil erodibility on agricultural land is assumed to have improved, therefore the final erodibility factor acquires a value of 1 over and above the basic factor. Land management is, therefore, considered to be as good as under forested conditions.

5.2.4.2.3 Moderate-case Scenario: Agriculture and Reforestation

This a moderate-case scenario that assumes a *status quo* in farming practices on arable and agricultural land, but reforestation and a halt in deforestation. It assumes that bureaucracy and public outcry will hinder changes on arable land. On the other hand, the assumption that all agricultural land in forest areas is reforested, and discontinued deforestation is based on the premise described for scenario 2. For these reasons, the rainfall-energy interception factor on agricultural land remains at 48%, but reforested areas are assigned the value used in scenario 2.

5.2.5 Validation of Soil Losses Predicted by the SLEMSA

Plots that were located in natural vegetation were used as a control, while those on cultivated and bare land were considered to be treatments. Variability of crops on cultivated land, and the criteria for site selection notwithstanding, sampling was limited to maize and tobacco fields because the importance of these crops in Malawi's economy implies that they occupy a large proportion of the cultivated land in the study area. Therefore these crops are more representative of the situation on the ground than any other crop. While standard plots could have been used on bare land and in natural vegetation, it has been reported by Stocking (1995, p 231) that small, bounded plots give the highest measured soil loss per unit area because each soil particle that is detached and starts to move is caught and weighed. As the area of assessment increases, there is a greater likelihood of storage of sediment within the bounded area (and hence there being no recording of its movement at the downslope end of the plot). For purposes of consistency, therefore, the same plot size (5 x 5 m) was also employed in natural vegetation and bare land. All plots were bounded with wooden planks (about 45 cm high) to keep outside runoff from entering the plots. Metal drums with a capacity of 200 litres were inserted into each pit to act as collection tanks. To this end, the drums were located at the bottom of each plot so that they could catch run-off from the plot.

5.2.5.1 Sediment Sampling

Surface runoff was recorded after every 24-hr rainfall event, following Shakesby, Boakes, Coelho, de Goncalves, and Walsh (1996). All research assistants involved in sampling received clearly-defined sampling procedures, and they were supervised closely. The volume of water collecting in each tank was measured using calibrated vertical rulers in order to determine the volume of run-off from the plot. Sediment content was measured by taking a thoroughly agitated (to ensure suspension of soil particles) sample of water and sludge from each tank, followed by drying and weighing. One-litre water samples were collected by drawing ten sub-samples at different depths in the tank. These sub-samples were mixed to form composite samples that were taken to the LMBCP laboratory for filtering. The tanks were emptied in preparation for the next storm.

In the laboratory, 25 ml sub-samples were taken from the composite samples after stirring. Agitation was done by stirring 10 times in one direction and ten times in the opposite direction as done by Zöbisch, Klingspor, and Oduor, (1996). The sub-samples were filtered using glass fibre Whatman GF/C filters (with a nominal pore size of 1.2 μm), which were coupled to a Gast vacuum pump (model DAA-V174-ED). Prior to filtering, the weight of each filter was obtained by using the Sartorius Supermicro® Type S4 sensitive balance in order to determine its weight in the dry samples. The filtered samples were then dried in desiccators at room temperature until they attained a constant weight. The dry samples were weighed, using the same sensitive balance, in order to determine the amount of sediment in each amount of filtered runoff. This weight was in turn multiplied by the total runoff measured in each tank in order to determine the amount of sediment collected per plot (Appendix E, Table E2), which was subsequently converted to soil loss in tonnes ha^{-1} yr^{-1}. The terminology used to rank soil losses predicted by the model was also used to describe the magnitude of observed soil losses.

5.2.5.2 Comparison of Observed and Predicted Soil Losses

To confirm that indeed the model's accuracy was affected by the use of the generic rainfall energy-interception factor that was assigned to agricultural and arable land, validation data was used to evaluate absolute and relative accuracy of the model, as done by Montoro and Stocking (1989). Therefore this section addresses the following two questions:

i) how close were the predicted values to the observed soil loss?; and

ii) did the model discriminate between areas of high and low soil-erosion potential in a pattern that was similar to the observed data?

To statistically evaluate the model's accuracy, the method used by Montoro and Stocking (1989) was employed. The analysis of variance with the F-test (Sall and Lehman, 1996, p 151) was used to assess absolute accuracy by comparing the predicted values (from 1991 land cover) with observed values. The predicted values were, therefore, extracted from the model output for each geographic location of a validation plot. The Shapiro-Wilk W test showed that the predicted values were not normally distributed ($W = 0.8$, $p < 0.0001$), while the distribution of the observed data was normal ($W = 0.9$, $p = 0.17$). The predicted values were, therefore, transformed using a natural logarithm. To assess the model's relative accuracy, on the other hand, the Spearman's rank correlation coefficient (Sall and Lehman, p 465), a nonparametric measure of the relationship between two sets of ordinal values was used. The null hypothesis was that the rankings of the soil losses (Appendix E, Table E3) were uncorrelated.

5.3 Results and Discussion

This section provides an interpretation of the results arising from the quantitative assessment of the geographical distribution in the Linthipe Watershed. Specifically it describes the extent of the predicted and observed soil losses in the context of the dominant physical factors that influence soil erosion. Furthermore, the section provides explanations for the low level of agreement, in terms of absolute accuracy, between the predicted and observed soil losses. In this regard, recommendations that can improve the degree of agreement between the results that are predicted by modified SLEMSA and field data are given.

5.3.1 Predicted Soil Losses

The model predicts very severe to extremely severe soil losses in regions that have steep slopes, such as the Dowa and Scarp regions (Figs 5.11 a-d). If soil erosion is markedly greater on slopes of 5-10% compared to gentle slopes (Evans 1980, p 122), then it is not surprising that severe losses are predicted for these regions because slope gradient is great than 6% (Fig. 4.1). Where slope gradient is predominantly less than 6%, e.g., in the Lilongwe and Lakeshore plains, soil losses should indeed range from low to moderate, as predicted by the model.

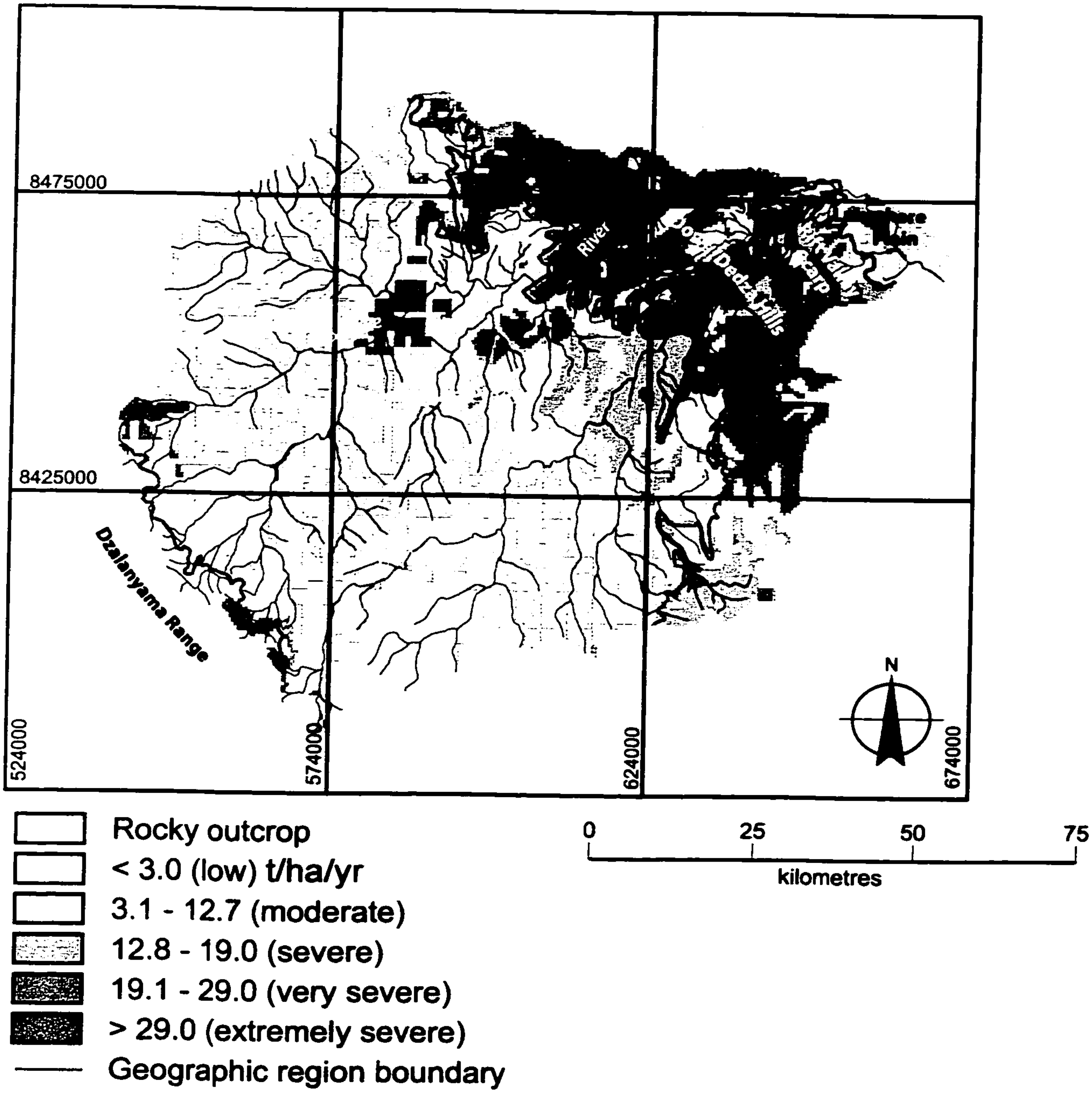

Fig. 5.11 Geographical distribution of soil-erosion risk based on 1991 land cover/use data; Linthipe River Catchment

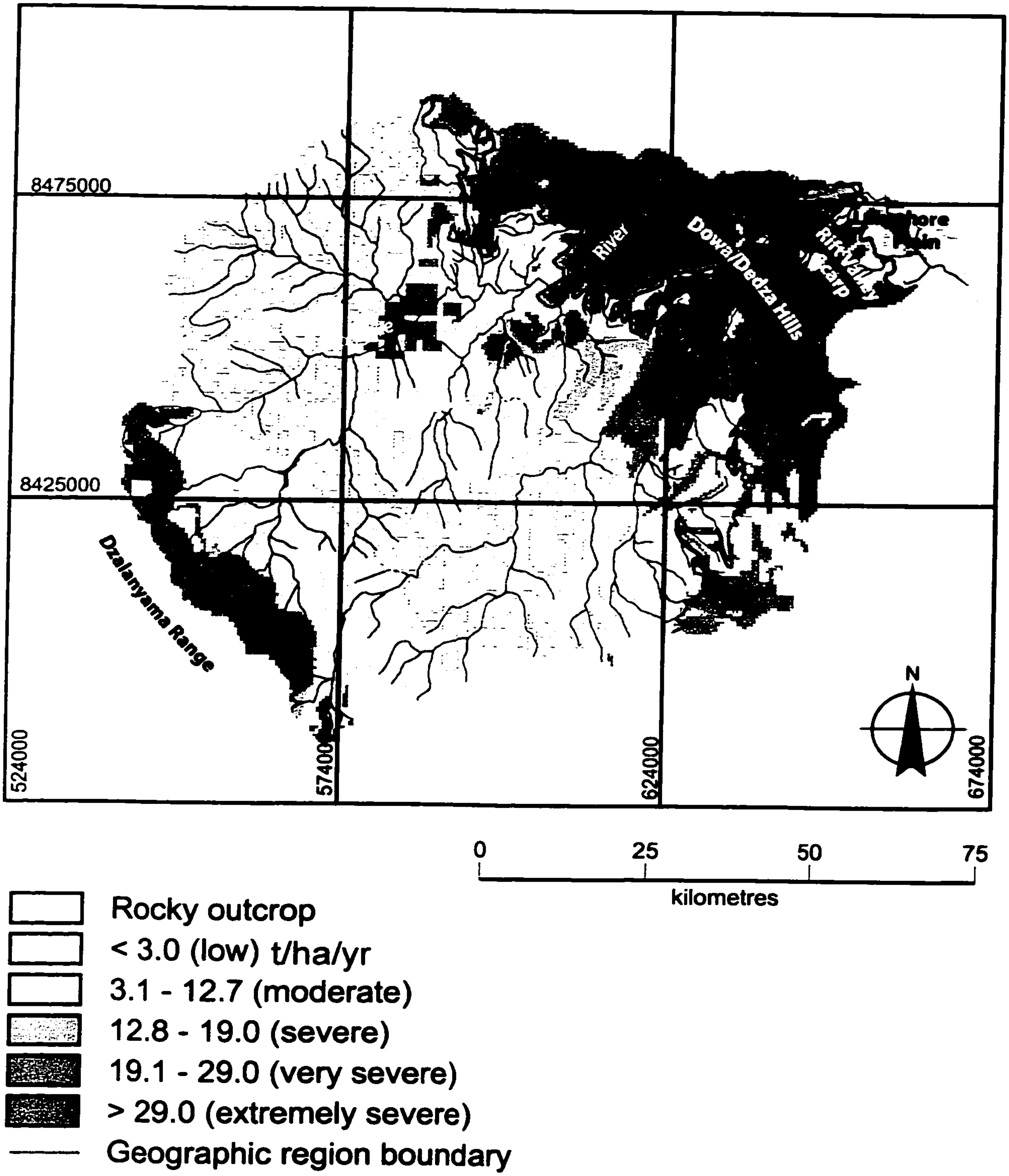

Fig. 5.12 Geographical distribution of soil-erosion risk under the worst-case scenario (traditional management and continued deforestation); Linthipe River Catchment

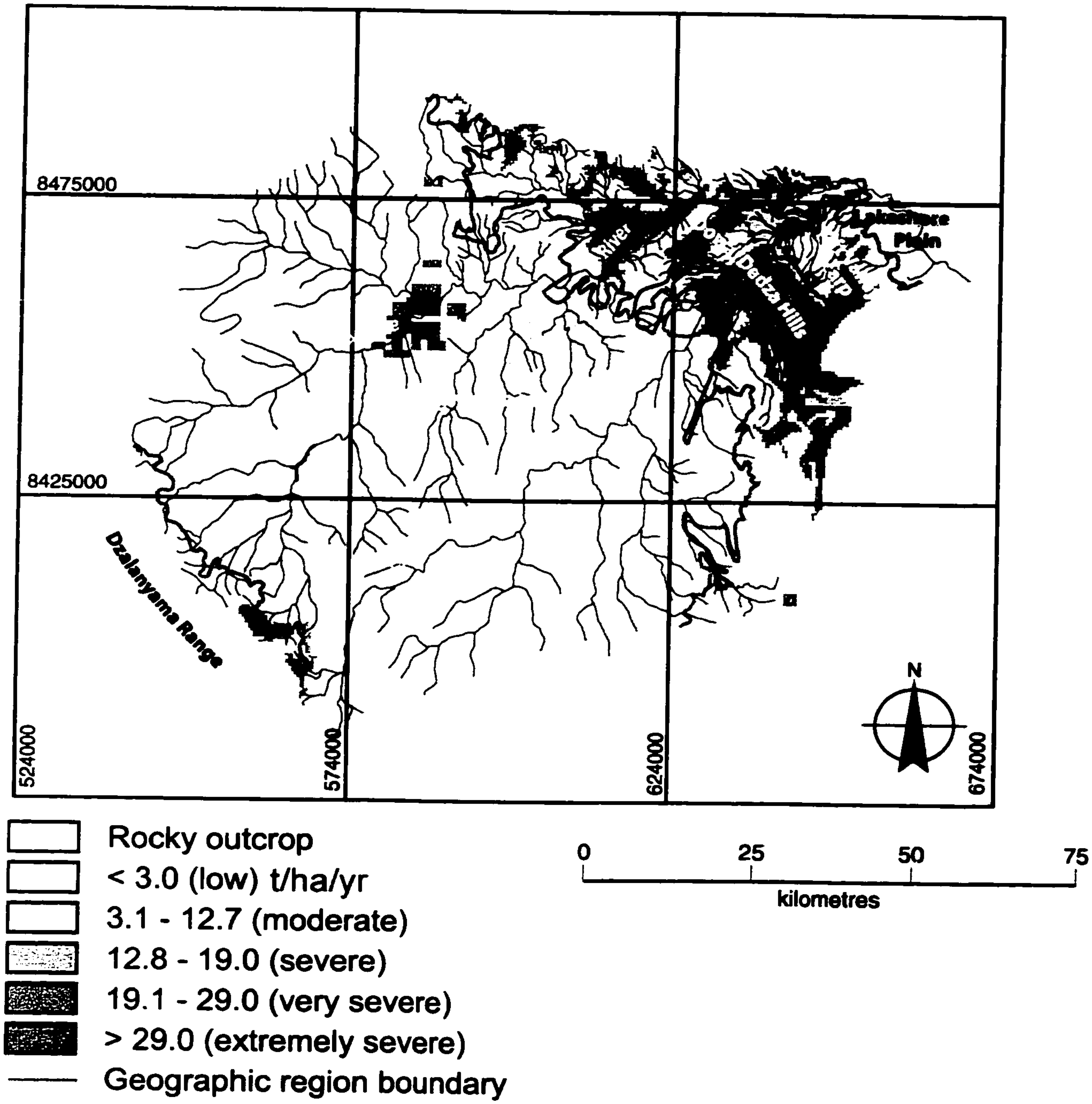

Fig. 5.13. Geographical distribution of soil-erosion risk under the best-case scenario (improved traditional management and reforestation); Linthipe River Catchment

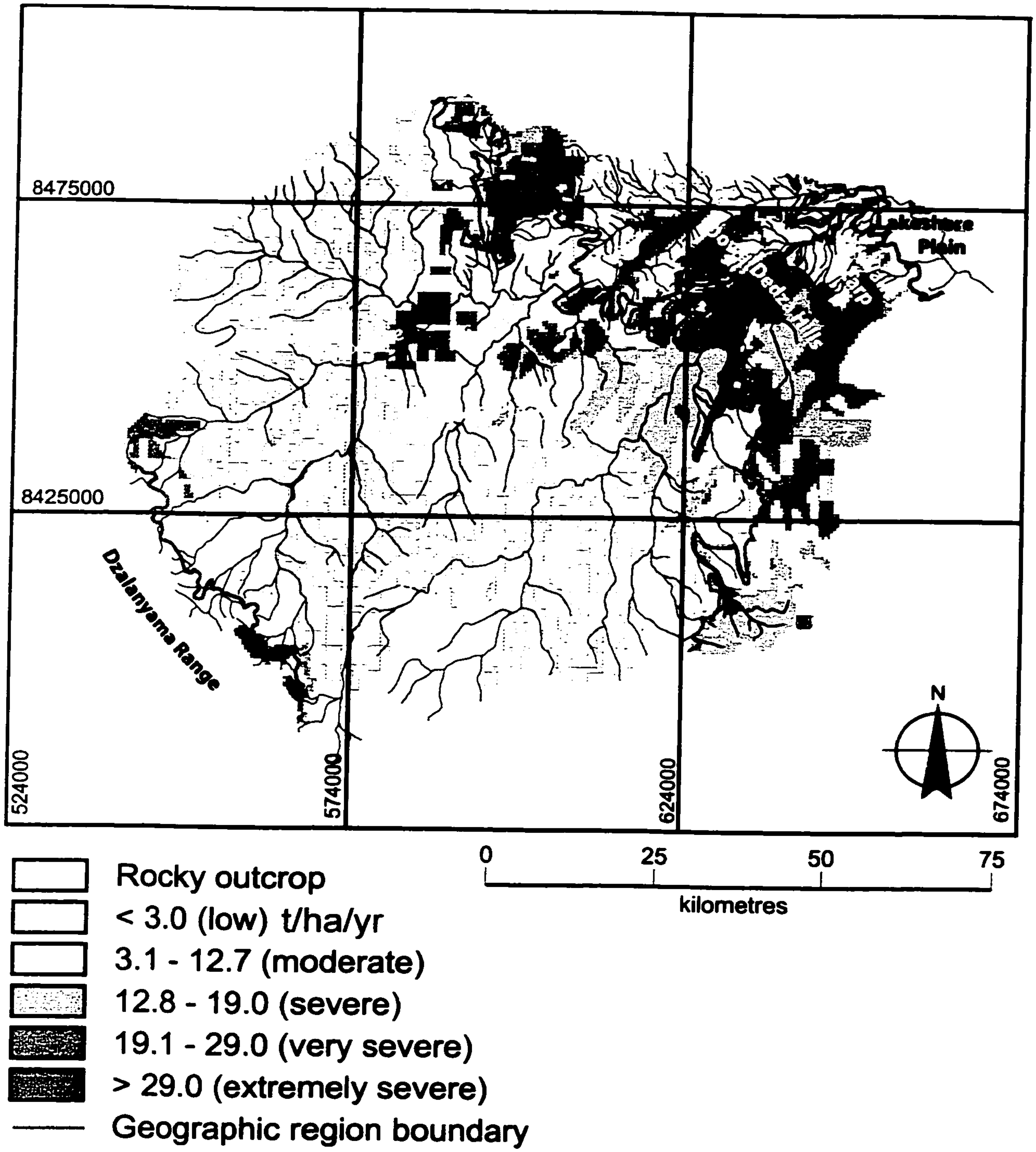

Fig. 5.14. Geographical distribution of soil-erosion risk under the moderate-case scenario (*status quo* on agricultural land, and reforestation); Linthipe River Catchment

Apart from slope gradient, the intensive settlement and cultivation in the Dowa and Scarp regions (Figs. 4.4 and 4.5) also contribute to exacerbated rates of soil loss in these regions. This claim is supported by low soil losses predicted for the Dzalanyama region, which has gradients that are comparable to the slopes in the Dowa Hills and Scarp where predicted soil losses are severe. The whole of the Dzalanyama region is under natural vegetation, while parts of the Scarp and Dowa Hills are cultivated, as evidenced by the encroachment of agriculture in forest areas (Fig. 4.4). Considering that the influence of all other factors, especially rainfall energy, soil erodibility and slope gradient in the Dowa Hills and Scarp are similar to those in the Dzalanyama region, except for settlement and cultivation, then the latter must be accounting for the differences in the severity of the predicted soil losses. Even in areas of comparable slope gradient within the Dowa Hills and Scarp, predicted soil losses differ between cultivated areas and those under natural vegetation (Fig. 5.11 - 5.14).

A comparison of soil losses between agricultural land and natural vegetation confirms that vegetation removal through intensive settlement and cultivation is an important factor in the difference between soil losses predicted not only for the Dzalanyama and the Dowa or Scarp regions, but also the Lilongwe and Lakeshore plains. Obviously, this difference emanates from the fact that agricultural crops have lower cover than natural vegetation. Consequently, their over-riding influence in intercepting raindrops is diminished. These results, therefore, emphasize the important role that natural vegetation plays in intercepting raindrop impact, as is universally recognized.

The importance of vegetation is further emphasized by its inclusion in the determination of the final soil erodibility, where forested land is usually assigned an additional unit, but not agricultural land. Elwell (1978b) reported that a difference of one unit in the value of *F* (soil erodibility) can greatly affect the estimate of soil loss. The addition of one unit to forests, therefore, helps to explain why predicted soil losses on agricultural land range from severe to extremely severe in the Dowa Hills and Scarp (Fig. 5.11).

Considering that the most erosive rainfall energy is < 15000 Jm^{-2}, it can be deduced, firstly, that there is negligible variation between the regions. Since there is also negligible variation in soil erodibility within the catchment, then it is clear why apart from slope, vegetative cover emerges as a very dominant determinant of soil erosion.

In as far as the extent of change in soil-erosion risk distribution is concerned, the worst-case scenario (traditional management and deforestation) shows that the amount of land in the low soil-loss category (< 3.0 t ha^{-1} y^{-1}) is the smallest (Fig 5.11-14 and Table 5.10). Therefore it is no surprise that high proportions of the catchment are predicted to have very severe and extremely severe soil erosion under this scenario. In contrast, the best-case scenario depicts an increase in the proportion of the catchment that would experience low rates of soil loss. Conversely, there is a decrease in the area of the catchment that is predicted to be under severe to extremely severe soil losses (Table 5.10). These scenarios also stress the significance of vegetation not only in soil-erosion processes, but also its omnipresence in the modified SLEMSA. However, it should be noted that even the best-case scenario, parts of the Dowa Hills would still experience severe to very severe rates of soil erosion; hence more the reason to relocate settlements and cultivation.

Table 5.10: Area of land in different soil-loss categories under different vegetative-cover scenarios; Linthipe River Catchment

Soil-loss category	Area (km^2) and proportion of land for each scenario							
	Area[a]	%	Area[b]	%	Area[c]	%	Area[d]	%
Low	3144.36	37.09	1499.78	17.69	6890.30	81.27	3691.80	43.55
Moderate	2938.88	34.66	4049.40	47.76	507.26	5.98	2995.77	35.34
Severe	541.19	6.38	132.99	1.57	47.22	0.56	561.99	6.63
Very severe	311.37	3.67	446.58	5.27	114.98	1.36	281.64	3.32
Extremely severe	1542.31	18.19	2349.36	27.71	918.35	10.83	946.91	11.17
Total	8478.11	100.00	8478.11	100.00	8478.11	100.00	8478.11	100.00

[a] Based on 1991 land cover
[b] Worst-case scenario
[c] Best-case scenario
[d] Moderate-case scenario

That the model depicts lower soil loss under natural than disturbed conditions supports the long-established fact that generally, disturbed conditions are more susceptible to forces of soil erosion than undisturbed surfaces (Amphlett, 1986 p 34; Douglas, 1988 p 216; Stocking, 1994, p 212; Hudson, 1995, p 267). As such, the model distinguishes the circumstances under which high soil loss can be anticipated from those providing good protection. Therefore based on the results of the model, it is evident that any attempt to conserve soil should aim at retaining the present natural vegetation while improving soil-conservation practices on agricultural land. It is evident that the best-case scenario would be the preferred choice of land cover, which can hopefully be attained if the recommendations in Chapter 6 are accepted by both the public and government.

5.3.2 Validated Soil Losses

Considering that some farmers applied soil conservation, one would expect the soil loss rates to be lower than observed (Table 5.11). The fact that severe to extremely severe soil losses were recorded suggests that the conservation measures were ineffective, except in a few cases. For example, use of contour vegetation strips and mixed cropping helped smallholders to keep soil loss at the same level as the estate farmers who must have benefited from the application of more fertilizers (Table 5.11). However, that smallholders in Dowa experienced severe soil loss despite using vetiver strips is attributed to the grass having been only in place for one year, hence it was not fully established. The vetiver strips on smallholders' properties in Lilongwe, on the other hand, were 3 years old, hence their effectiveness in keeping soil loss rates lower.

Table 5.11: Observed soil loss (t ha^{-1} y^{-1}) by cover type and geographic region in the 1998/99 rainy season; Linthipe River Catchment

Cover	Dowa	Dzalanyama	Lakeshore	Lilongwe	Scarp	Mean[c]
Bare fallow	25.12 [a]	-	11.16[a]	28.07[a]	29.27[a]	23.40
Brachystegia	-	1.04[b]	1.37[b]	-	-	1.20
Grass/shrub	13.98[b]	-	-	-	6.00[b]	9.99
Maize (smallholder)	13.9[b]	-	12.05	7.07[b]	16.78[b]	12.44
Maize (estate)	-	-	11.71[b]	7.76[b]	-	9.73
Tobacco	20.36[b]	-	19.27[b]	23.1[b]	24.73[b]	21.86

[a] Data from unreplicated plots
[b] Means of two to four replicates
[c] < 3.0 = low; 3.1 - 12.7 = moderate; > 12.8 - 19.0 = severe, 19.1 –29.0 = very severe; and > 29.0 = extremely severe

The high rates of soil loss among the rest of smallholders can be explained in terms of poor vegetation because they did not use practices that provided good cover (e.g., mixed cropping and vetiver grass). Secondly, fertilizer-application rates were low, a fact that is supported by the mean soil loss in maize fields owned by estate farmers; the latter applied higher rates of fertilizers than smallholders, hence their maize crop had better cover (Table 5.4). Consequently, the mean soil loss was moderate (Table 5.11). In tobacco fields, soil loss was higher than in maize among estate farmers for the obvious reason that it is a poor-cover crop. Furthermore, the fact that six of the farmers did not use additional agronomic measures such as contour vegetation strips, explains why the observed mean rates of soil losses were 'very severe' (Table 5.1).

5.3.3 Observed Versus Predicted Soil Losses

In terms of agreement between observed and predicted, it is clear that the modified-SLEMSA predictions are underestimates at most of the validation sites, except for tobacco (Table 5.12, Fig. 5.15). In fact the difference between the two data sets is highly significant ($F = 175.6$, $p < 0.0001$). Given that calibration of the model involved mostly use of validated data, a high degree of agreement between the predicted and measured amounts of soil losses was expected. That there is a significant difference between these two data sets is a clear indication that there are errors associated with these results.

Table 5.12: Comparison of predicted and observed soil loss based on 1991 land-cover and 1998/99 field data; Linthipe River Catchment

Vegetation	**Predicted ($t\ ha^{-1}\ yr^{-1}$)**		**Observed ($t\ ha^{-1}\ yr^{-1}$)**		**Difference ($t\ ha^{-1}\ yr^{-1}$)[a]**
	Range	Mean	Range	Mean	Mean
Bare fallow	2.22-30.50	22.76	11.16-29.27	23.4	-0.65
Brachystegia woodland	0.08-1.47	0.52	0.86-1.63	1.20	-0.68
Grass/shrub	1.54-2.21	1.98	2.04-9.97	9.99	-8.01
Maize (smallholders)	2.20-16.55	6.44	5.58-18.55	12.45	-6.01
Maize (estate farmers)	1.54-4.22	3.05	4.24-11.72	9.73	-6.68
Tobacco	16.90-29.50	22.33	18.74-25.38	21.86	0.81

[a] Predicted less observed values

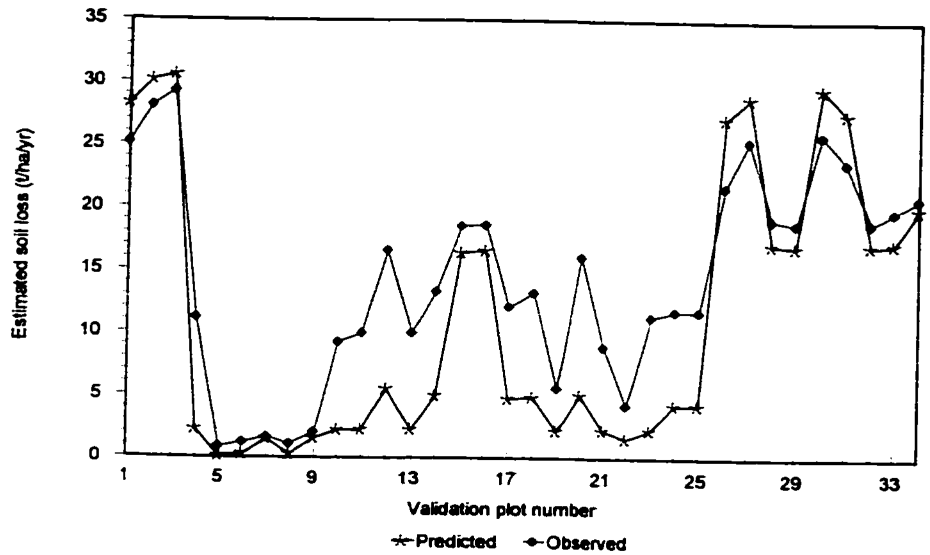

Fig. 5.15: Relationship between predicted and observed soil-loss estimates ($r_s = 0.99$, $p < 0.0001$) for each validation site in the Linthipe River Catchment

Although it is normal to assume that validation data are error-free, this is not usually the case because they are not deterministic. An examination of site characteristics (Table 5.1), actually, suggests that both the model calibration and ground validation data were sources of error. As stated earlier on, calibration of the crop-ratio submodel involved assigning of a generic rainfall-energy interception factor value of 48% to agricultural and arable land. As speculated, this value indeed affected the model's accuracy. For example, the model underestimates at sampling points number 28 and 29, which were burley tobacco estates (Fig. 5.15). According to Paris (1990, p 6) tobacco is a poor-cover annual and its effectiveness in rainfall interception ranges from 35-45%. Given the absence of additional agronomic measures, e.g., vetiver strips on these plots, the appropriate energy interception factor would have been 35%, instead of 48%. Scrutiny of the soil-loss data in tobacco among farmers in Dowa shows that soil loss was higher (21.65 t ha^{-1} yr^{-1}) on the field that did not have vetiver strips when compared to 9.97 t ha^{-1} yr^{-1} that was observed on a farm that used vetiver as a conservation measure. The land-cover classification system used, therefore, dictated that these localised variations in farming practices be ignored when calibrating the model.

By virtue of using the generic value, sampling point number 4 was also assigned 48% as the interception factor, but this site was kept bare as part of the experiment, therefore, the appropriate interception factor should have been 5% factor (Table 3.5). Another example is the assigning of cover values to grass/shrub vegetation. In one of the plots located in this vegetation, cover was about 38% (Table 5.4) because it was burnt prior to installation of the plot (Table 5.1). However, during the calibration process, this site was preliminarily assigned an interception factor value of 61%, which is almost twice as high as the measured cover. By assigning higher values, in these particular instances, the model must indeed under-estimate soil loss (Fig. 5.15).

From the examples in the preceding paragraph, it can be inferred that the model predicted soil loss on agricultural and arable land, as well as burnt natural forests, in a similar manner when calibrated for each land-cover scenario. One way of eliminating errors of this nature would be to use satellite data that are acquired during the same year that field sampling is taking place. Use of analogue data captured by video camera in aerial surveys is the other way. However, analogue data are more appropriate where the area under study is smaller than the Linthipe Catchment. Whether up-to-date satellite data or analogue data are used in land-cover classification, there would be a need to collect coordinates of several estate and smallholder farms and crop data. The coordinates would be used as ground-control points when classifying the satellite data, while crop data would aid in the assigning of appropriate interception factors.

Apart from generalisation of the interception values, there were also errors that were associated with the validation procedure. First, the recommended slope gradient for the soil and climate (*K*) submodel in the SLEMSA is 4.5%, but the plots were located in slopes with varying gradient. For example, 10 plots were located at sites where slope was about 13% instead of 4.5%. Observed soil loss at 7 of these sites (10-13, 17-18, and 20) is higher than the values predicted by the model (Fig. 5.15). The second source of error was the use of plots that were smaller than the standard dimensions. This must have allowed more sediment to be caught and measured than would have been the case if a standard plots were used. Considering the limitations imposed by the criteria used to locate the plots, such errors were, however, inevitable. Use of standard plots located on 4.5% slope would therefore eliminate this error. If sampling is to be done on farmers' fields, the farmers should be compensated monetarily in order to persuade them to allow use of as much land as needed to meet the specifications of the modified SLEMSA. It is also normal practice to use correction factors to eliminate these errors, as done with slope values. The presence of errors in the validation data, however, precluded use of this procedure.

The recommendations made in the preceding paragraphs are aimed at achieving improved precision in the model predictions. For planning purposes, however, mere discrimination between high- and low-risk areas suffices. As a matter of fact, the pattern of the predicted results is consistent with the measured soil loss (Table 5.11, Fig. 5.15). For instance, low amounts of soil loss were recorded from natural vegetation, as opposed to cultivated land, which is also what the model predicts (Figs 5.11 a-d and 5.12). Additionally, rates of soil loss are consistent with steep slopes of the study area. Be it on bare fallow, cultivated land, or in natural vegetation, more soil was lost in the regions of steep gradient such as the Scarp and Dowa Hills than in the Lilongwe and Lakeshore plains (Table 5.11, Figs. 5.11 a-d). In fact there is a very close relationship ($r_s = 0.99$, $p < 0.0001$) between the observed and predicted soil losses. As far as relative precision is concerned, therefore, use of 48% as a generic interception factor for agricultural and arable land did not affect the model's ability to distinguish between areas of high and low soil-erosion potential nor its spatial pattern. Considering that the SLEMSA is more applicable to assessing relative than absolute accuracy, this high correlation is an endorsement of validity of the predicted geographical distribution of soil-erosion risk in the study area. This being the case, therefore, it can be inferred that the changes in soil-erosion risk distribution, are also relatively precise.

5.4 Summary

This Chapter set out to determine the distribution of soil-erosion risk and its potential change in response to potential policy-induced changes in land use/cover in the Linthipe Watershed. A modelling approach was used because it is more efficient in assessing soil loss over large areas than experimental plots, which are limited by their spatial coverage. Specifically, the modified SLEMSA model was employed because it is applicable to the environmental conditions in Malawi. The predicted soil losses were compared with field observations in order to assess the model's accuracy. Additionally, various scenarios were used to assess any potential changes in soil-erosion risk distribution consequent upon changes in land cover.

The results show that the Dowa and Scarp regions are highly vulnerable to soil erosion because of steep slopes, thereby supporting the well-known fact that areas of steep gradient are more susceptible to soil erosion than areas with gentle relief. Additionally, the model illustrates that indeed human activities such as deforestation for fuelwood and agriculture enhance the likelihood of high rates of soil loss, especially in regions that have steep slopes. Various land-cover scenarios provide an insight as to the potential soil-erosion risk in the event of further deforestation for agriculture or fuelwood gathering. Conversely, the scenarios suggest that reforestation and protection of the remaining natural vegetation in the catchment could reduce the extent of soil-erosion risk even in the steepest parts of the catchment. Given the highly erosive rainfall in the catchment, it is no surprise that areas that have steep slopes and are devoid of forest cover are the worst in terms of soil loss. These results are collaborated by field data, which correlates highly with the predicted soil losses thereby validating the geographical distribution of soil-erosion risk based on the model output. The fact that there is a high agreement, in terms of relative accuracy, between the predicted and measured soil losses gives confidence in the predicted potential changes in soil-erosion risk distribution depicted by each land-cover change scenario.

Considering that vegetative cover emerges as the primary determinant of soil erosion in the Linthipe Drainage Basin, it would be practical to promote agricultural practices that would enhance vegetative cover. Promotion of practices that enhance vegetative cover, however, already seems to have been the focus of the GoM, as stated in Chapter 1, and confirmed by the use of agronomic and agroforestry practices by some farmers in the Linthipe Watershed. If these measures are effective in mitigating soil erosion because of the strong control they have over detachment and transport by splash and runoff (Morgan, 1986, p 165), but soil losses are still high, then it is logical to conclude that the measures are suboptimally employed. Therefore, there is indeed a case for determining the primary socio-economic factors that inhibit farmers from practicing soil conservation effectively. This is what Chapter 5 sets out to achieve.

Chapter 6

Principal Socio-economic Factors that Contribute to Soil Erosion in the Linthipe River Catchment

6.1 Introduction

Considering that farmers used to employ traditional methods before the advent of soil-conservation policies (Chapter 2), and they presently employ different soil-conservation practices (Chapter 4), then the moderate to very severe soil losses on cultivated land (Chapter 5) should be clearly evident to them. Additionally, loss of soil nutrients, consequent upon soil erosion, should also be manifested in the form of declining soil fertility and crop yields. This being the case, farmers ought to be employing the measures prescribed by the MoA effectively.

Evidence from the preceding Chapter does show that some farmers employ measures that can be linked to the observed low or moderate rates of soil erosion on their land. For instance, moderate rates of soil loss were observed on some smallholdings that practiced mixed cropping and also used vetiver grass, while severe losses were recorded on holdings that did not have these measures in place. However, although substantial amounts of soil are being lost from their holdings, the majority of farmers merely relied on mechanical measures, apart from the conventional farming practices, such as fertilizer application, early planting, and correct plant spacing. In fact, the observed severe to very severe soil losses seem to suggest that these practices must have been employed suboptimally, hence they were ineffective in preventing soil erosion. The contention that farmers practice soil conservation suboptimally is collaborated by the fact that the rates of soil losses observed in the field fall within the range of the data in Table 2.4.

Shaxson 1985 (p 668) stated that land users manipulate biological systems to ensure subsistence or profit; hence they make decisions about land use and management in response to immediate social and economic pressures. This being the case, their priorities, and hence farming practices, are likely to be different. While these statements may be useful in explaining why some farmers in the Linthipe Catchment are still experiencing severe soil losses despite the abundance of soil-conservation measures, they do not, however, explicitly reveal much information about the farmers in the Linthipe Watershed. For example, are these farmers aware of the magnitude of soil erosion and its effects on their land? Second, are they aware of the effects of such high losses of soil on their land? Third, what are the socio-economic factors that primarily influence farmers to employ inadequate soil-conservation measures in the study area? Lastly, in what manner do these socio-economic factors influence the degree of soil erosion that farmers perceive? The first purpose of this Chapter, therefore, is to confirm that the majority of the farmers in the study area are aware of the degree of soil erosion on their land. Second, it intends to ascertain whether or not these farmers do know the consequences of soil erosion. Third, an attempt is made to identify those principal constraints that inhibit farmers from employing optimal soil-conservation measures. Fourth, the Chapter aims to determine why the identified principal variables influenced the manner in which farmers perceived the magnitude of soil erosion. Information derived from these objectives will not only address objective (ii) of the study, but it is also important in confirming or rejecting the hypothesis.

6.2 Methods

To address the objectives of this Chapter, a questionnaire survey was used to collect the necessary socio-economic data. This method was considered to be more appropriate than other techniques, for example the Rapid Rural Appraisal (RRA)[32] and Participatory Rural Appraisal (PRA, Townsley, 1996, p 23) because it can be administered randomly, thereby taking into account the dualistic nature of the farming systems and the stratification of the study area into geographic regions. The findings are, therefore, more statistically sound than those from PRA and RRA, because the latter are often carried out with the community as a whole thereby obscuring the extant stratification within a community, be it by wealth, social status, gender or ethnic group (Townsley, 1996, p 28). Therefore, information gathered by these methods does not tell researchers very much about general conditions of a study area. Furthermore, PRA raises expectations that cannot be realized since it is common for rural communities involved in the study to have expectations that their wishes will be met. However, it often happens that such wishes may be in conflict with institutional or political situations that may frustrate fulfilment of those expectations (Townsley, 1996, p 64).

Other workers who have used survey questionnaires, in fact, value them highly. Harcourt, Pennington, and Webster (1986), for instance, argued that while questionnaires are

[32] In RRA, researchers work in a structured but flexible way with rural communities; they use a set of tools such as workshops, diagrams, and graphics to aid communication and interaction with the subjects. While similar to RRA in terms of the participatory approach, PRA, on the other hand, focuses on the stimulation of participation by the local people (Townsley, 1996, p 23).

subjective, they do at least result in data that may be used to compare with similar studies in different regions under different conditions. Parfitt (1997, p 76), in fact confidently recommends the use of questionnaire survey in human geography because they are indispensable when primary data are required about people, their behaviour, attitudes and opinions, and their awareness of specific issues.

6.2.1 Questionnaire Design

Questionnaire design considered content, wording, and format, as recommended by Parfitt (1997, p 86). To this end, a structured and open-ended questionnaire (Appendix E) was formulated. The structured questions were employed on issues where a specific range of known responses was expected. Such questions allow easier interpretation and analysis than open-ended questions. On the other hand, the open-ended questions were included so as to allow interviewees to construct their own accounts of experiences because the explanatory power of structured questions is limited (Valentine, 1997, p 111). The questionnaire employed here included reliability questions in order to identify invalid or false responses (Infield, 1988). It comprised 52 variables that fell under five major sections that were considered as encompassing in as far as the general farming and soil-erosion situation in the study area is concerned. The sections are as follows:

1. Awareness of soil erosion and attitudes toward the problem;
2. Knowledge of the effects of soil erosion;
3. Farming practices;
4. General farm characteristics; and

5. Personal background of the respondents.

Questions in Section 1 of the questionnaire aimed to assess farmers' awareness of the degree of soil erosion and level of importance that they attach to this problem in relation to other problems that they face when cultivating their land. This section was, therefore, crucial to verification of the research hypothesis. Section 2 collected data that would help determine if awareness of the impacts of soil erosion influenced any land-use and soil-conservation decisions that farmers made. Section 3 intended to assess the commonly employed farming practices, as it has been indicated that considerations such as crop husbandry (e.g., crop rotation, early field preparation, early planting, and several others) help to diminish the amount of bare ground exposed to rainfall impact (Douglas, 1988, p 220). The purpose of questions in Section 4 was to collect information that would provide insight into the layout of farms in relation to slope, which can be viewed as an indication of whether or not farmers used land-use planning. The questions in Section 5 were designed to gather background data (e.g., age, farming experience, and education level) since these variables are known to influence farmers' attitudes and practice around the African Great Lakes (Cohen *et al.*, 1996, p 579).

6.2.2. Data Collection

Prior to the survey, a pilot study of 20 farmers was undertaken as suggested by Parfitt (1997, p 102). Its purpose was to check a number of questionnaire design aspects, such as clarity, appropriateness of the questions, and farmers' willingness to answer the questions. Farmers that were interviewed during the pilot study were excluded from the main survey to avoid any bias in responses. As a result of the pilot survey, the scale for rating the perceived degree of soil erosion was modified. In the original questionnaire, the degree of soil erosion was rated from 1 (not at all) to 8 (very high or extremely severe). This scale was instead modified to range from 1 to four (severe). Categories such as 'very severe' and 'extremely severe' were grouped under 'severe erosion' because of lack of equivalent superlatives in the local language, in as far as describing the magnitude of soil erosion is concerned.

In order to reflect the dualism in Malawi's farming system (WB 1991, p 10), a stratified random sampling method was employed so as to give each farmer category an equal probability of being sampled (Fowler and Cohen 1992, p 5; Mead, Curnow, and Hasted, 1993, p 393). Only four (Dowa, Lilongwe, Scarp, and Lakeshore) of the five geographic regions were used to stratify the study area because the Dzalanyama region consists of gazetted forest reserves. Ninety questionnaires were assigned to each region, and each set was randomised using a random-number table following the method described by Little and Hills (1978). More specifically, the approach that was followed requires writing down numbers in the order of their appearance beginning at a random point on the table in each row. For numbers ≥ 10, pairs of rows were used, while those that either appeared before in the series or those > 90 were disregarded. The selected random numbers were allocated to a 0.5 x 0.5 km grids that were drawn on tracing paper and then superimposed on 1:50,000 map sheets of the study area. Farmers whose homesteads or farms fell in these grids were chosen for the interviews. Where more than one homestead or farms were in a grid, only one was chosen. Due to the irregular shape of the catchment, some grids did not exactly fit in the study area. Consequently, the total number of grids in some geographic regions did not reach the required sample size. To ensure that each region had the necessary number of grids, the homesteads or farms that had not been previously allocated a random number were assigned to those grids falling outside of the catchment.

Before commencing each interview, the overall research concept was explained to the subjects so as to obtain their informed consent. Interviews were conducted in *Chichewa*, the *lingua franca* of the study area, and they were carried out simultaneously in each geographic region with the assistance of three students (from Bunda College of Agriculture) who had previous experience in conducting socio-economic surveys. Each student was assigned to one of the four regions (Lilongwe, Dowa, and Scarp), while the author conducted interviews in the Lakeshore Plain. To ensure that the enumerators understood the questions, they were required to rehearse the interviews, using each other as proxy respondents. The author conducted weekly supervisory trips to ascertain that the questionnaires were being administered properly and that appropriate data were being collected. Responses were generally consistent. However, in cases where closely related issues or ideas seemed contradictory, discussions after the interviews were completed helped to resolve such contradictions.

6.2.3 Data Analysis

6.2.3.1 Perceived Degree of Soil Erosion and Awareness of Effects of Soil Loss

Perceived degree of soil erosion was ranked according to the method that was used to categorise soil losses in Chapter 5 (Table 6.1). The number of farmers in each category was determined for each class of perceived degree of soil erosion, and region.

Table 6.1 Ranks assigned to perceived degree of soil erosion and effects of soil loss; Linthipe River Catchment

Variable	Rank
Degree of soil erosion	None= 1
	Low = 2
	Moderate = 3
	Severe = 4
On-site effects	Not at all = 1
	Other [a]= 2
	Soil-fertility reduction = 3
	Crop-yield reduction = 4

[a] refers to wastage of farm inputs such as seed and labour

On-site effects of soil erosion were also ranked from 1 to 4 on the basis of the ultimate consequence that a particular response represented (Table 6.1). Since there were multiple responses under this variable, the frequency of each response, as opposed to total number of farmers per response, was calculated as a percentage of the total number of times all responses were recorded. As done in the case of degree of soil erosion, the frequency of each response was grouped by region and farmer category, and the results were plotted as bar charts.

Relevant statistical tests were applied in order to determine if differences in response probabilities were statistically different between the farmer categories, and regions. To this end, the Pearson's Chi-square test (Sall and Lehman, 1996, p 205) was used to determine if the number of farmers in each category of perceived degree of soil erosion differed significantly between the farmer groups. The same test was also used to determine if the response probability of each effect of soil erosion varied significantly between the farmer groups. The Correspondence Analysis[33] was then used to examine if responses under each category of perceived degree of soil erosion were statistically different between the geographic regions within each farmer category. These tests were conducted in the JMP IN Start Statistics software version 3.2.1 (Sall and Lehman, 1996). For purposes of statistical comparison between these two major farmer groups, the large-, medium-, and small-scale estate farmers were grouped together as 'estate farmers'. Similarly, the three categories of smallholders were also grouped together under one category. This decision was made in view of the small sample sizes in certain regions, and lack of representation by one farmer group in others (Table 4.2). For instance, there were only 8 large-scale estate farmers in the Lakeshore plain, while none was represented in the Rift Valley Scarp region.

6.2.3.2 Identification of Principal Socio-Economic Factors

To identify factors that primarily contribute to soil erosion, a principal factor analysis was used to reduce the amount of data by objectively isolating the variability in an item that it has in common with the other variables (Comrey, 1973, p 8). According to Stat Soft Inc., (1997), this method is similar to the principal component analysis, but it is often preferred when the goal of the analysis is to detect structure of the data, which in this case, was a conversion of different independent variables in the questionnaire into distinct principal categories such as background variables, farm characteristics, farm inputs, and farm output. The approach recommended by Comrey (1973, p 4), which involves, computation

[33] Similar to the Chi-square, but more useful for data with many levels (Sall and Lehman, 1996, p 222); in this case 4 geographic regions, 4 levels of perceived degree of erosion, and 2 different farmer categories.

of correlations, extraction of principal factors, rotation of the factors, and multiple regression analyses, was employed.

In order to standardize the values used in the correlation analyses, all responses of the remaining 51 variables (excluding degree of soil erosion) were ranked depending on the control they have on soil-erosion processes (Table 6.2). The ranks ranged from 1 to 4, where 1 = very strong, 2 = strong, 3 = moderate, and 4 = weak. When only two responses were obtained, 1 and 2 were ranked as strong and weak respectively. These variables were subjected to the Pearson's correlation tests in the JMP IN statistics software (Sall and Lehman, 1996, p 465) in order to eliminate collinearity between variables[34] because they mirror each other. One of each of the collinear variables, i.e., the one that was deemed to be more representative, was retained.

[34] Collinearity is the closeness of two or more regressors in a linear relationship (Sall and Lehman, 1996, p 249),

Table 6.2: Ranking of socio-economic variables that significantly contribute to soil erosion in the Linthipe River Catchment; an example of the manner in which all responses employed in the factor analyses were ranked

Category	Variable	Ranks
Background	Source of farming knowledge	1 = personal experience, 2 = school, 3 = extension
Farm characteristics	Cultivated farm size (ha)	1 = > 100, 2 = 30-100, 3 = < 30,
	Shape of cultivated land	1 = flat, 2 = concave, 3 = convex
Farm inputs	Basal fertilizer (kg ha^{-1}), maize [a]	1 = 81-200, 2 = 21-80, 3 = 1-20, 4 = 0
	Top fertilizer (kg ha^{-1}), maize [a]	1 = 131-290, 2 = 81-130, 3 = 1-80, 4 = 0
	Basal fertilizer (kg ha^{-1}), tobacco [b]	1 = 451-600, 2 = 1-450, 3 = 0
	Top fertilizer (kg ha^{-1}), tobacco [b]	1 = 150 –400, 2 = 1-150, 3 = 0
	Farm equipment	1 = mechanized, 2 = non-mechanized
	Amount of labour	1 = sufficient, 2 = deficient
Farm output	Tobacco yield (t ha^{-1}) [b]	1 = 3.1-4.0, 2 = 2.1-3.0, 3 = ≤ 2.0
	Maize yield (t ha^{-1}) [a]	1 = 6.1-8.0, 2 = 3.1-6.0, 3 = < 3.0
	Farm income (MK)	1 = sufficient, 2 = deficient
Soil conservation	Methods	1 = planning, 2 = agronomic, 3 = soil management, 4 = mechanical

[a] Average rates of both local and improved varieties
[b] Average rates for burley, and Malawi western tobacco

Upon removing variables that were highly collinear (r ≥ 0.80), again following Comrey (1973, p 232), the number in the data set of each farmer category was reduced to 30 and 27 for estate farmers and smallholders respectively. These variables were, therefore, subjected to the principal factor analyses, from which the numbers of factors to retain was extracted objectively using a scree plot (Keen, 1997, p 81) of percent variance and the resulting total number of factors. This plot helps to find the point where the smooth decrease in variance of the factors appear to level off to the right of the graph (Fig. 6.1).

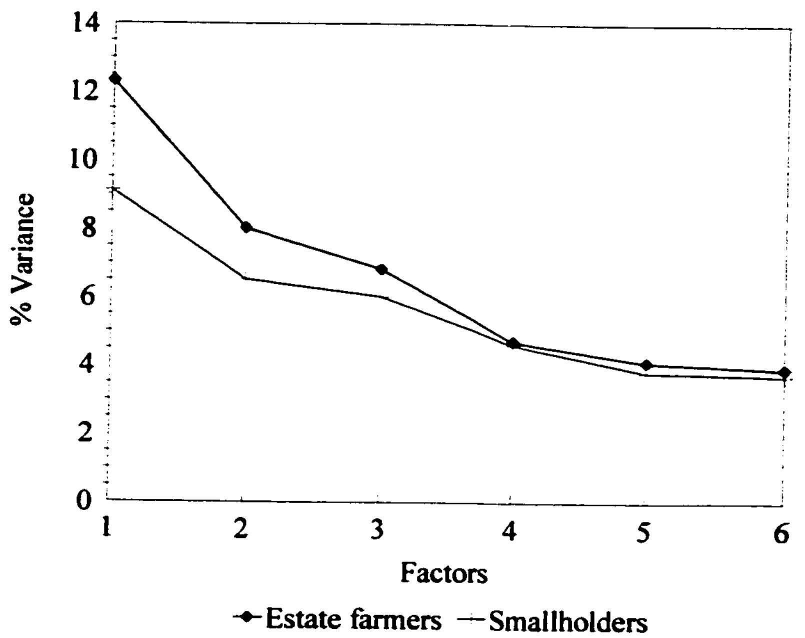

Fig. 6.1 Scree plot used to determine the number of factors to retain from the principal factor analysis of socio-economic variables that influence soil erosion in the Linthipe River Catchment

It is evident that the second factor is the point where the straight line curves to the right (Fig. 6.1). The retained factors were rotated in order to obtain loadings (values) that were greater than 0.3 irrespective of their polarity, and communalities[35] which ranged from 1 and 0 (Tables 6.3 and 5.4). Comrey (1973 pp 8 and 225) considers these values as cut off levels. The Varimax Normalized Loadings technique was employed to rotate the factors because it provides optimal interpretable results (StatSoft, Inc. 1997). After rotation of the factors, 18 and 15 variables were retained for estate farmers and smallholders respectively (Tables 6.3 and 5.4).

[35] Communalities give confidence in the results because they represent the extent of overlap between the variables and factors, in this case the categories.

Table: 6.3 Retained factors and loadings of variables related to perceived degree of soil erosion among estate farmers; Linthipe River Catchment, 1998

Category	Variable	Loadings of retained factors		Communalities
		1	2	
Background	Farming knowledge source	0.36	0.09	0.19
	Farming experience (years)	-0.03	-0.64	0.41
	Education level	0.55	0.48	0.54
	Age	-0.07	-0.53	0.12
	Interest in soil-erosion assessment	0.01	0.35	0.24
	Knowledge of soil-erosion effects	-0.58	0.14	0.42
	Attitude to questioning	0.01	0.38	0.19
Farm characteristics	Cultivated farm size	0.75	-0.29	0.68
	Soil-erosion control measures	0.41	0.18	0.21
	Other crops	0.08	-0.40	0.17
	Crop pests and diseases	0.38	0.16	0.18
	Shape of cultivated land	0.16	0.38	0.17
Farm inputs	Soil-erosion control costs	0.68	0.27	0.54
	Amount of labour	-0.52	0.11	0.28
	Farm equipment	0.37	-0.02	0.47
	Fertilizer rates	0.32	0.25	0.17
Farm output	Farm income	0.54	0.22	0.59
	Maize yield	0.22	0.30	0.14
	Tobacco yield	0.51	-0.01	0.26

Table 6.4: Retained factors and loadings of variables related to perceived degree of soil erosion among smallholders; Linthipe River Catchment, 1998

Category	Variable	Loadings of retained factors		Communalities
		1	2	
Background	Farming knowledge source	0.52	-0.06	0.28
	Education level	0.52	0.01	0.27
	Age	0.12	-0.36	0.14
	Interest in soil-erosion assessment	0.15	0.45	0.22
	Knowledge of soil-erosion effects	-0.41	-0.13	0.19
	Gender	0.45	-0.19	0.24
Farm characteristics	Cultivated farm size	0.56	0.02	0.31
	Shape of cultivated land	0.14	0.35	0.14
Farm inputs	Soil-erosion control cost	0.65	-0.19	0.46
	Amount of labour	0.12	0.48	0.24
	Other farming limitations	0.04	-0.44	0.19
	Fertilizer rates	0.02	0.42	0.18
Farm output	Farm income	0.46	-0.22	0.26
	Maize yield	0.32	-0.03	0.10
	Tobacco yield	0.59	0.05	0.35

6.2.3.2.1 Multiple Regression Analyses

Variables that were retained after rotation were subjected to regression analyses in order to pick a subset that significantly contributes to the perceived degree of soil erosion. To identify such variables, the General Multiple Linear Regression Model (Sall and Lehman, 1996, p 274) was used in JMP IN software following the steps recommended by Keen (1997, p 101). Distributions of the variables were tested for normality using box plots. Where necessary, the data were transformed and outliers were removed. These variables were then used as predictors (independent variables) in the model, while soil-erosion degree, according to farmers' perception, was used as the dependent variable. Variables with probability levels of ≤ 0.05 were accepted to be contributing to the model significantly because this level is customarily treated as a "border-line acceptable" error level in many areas of research (StatSoft Inc., 1997). Any variable that did not contribute significantly to the multiple regression models ($p > 0.05$) was ignored, as done by Brierley (1978).

6.2.3.3 Determination of Reasons the Principal Variables Contributed to the Degree of Soil Erosion as Perceived by Farmers

To explain statistically why the principal variables contributed either positively or negatively to the degree of perceived soil erosion, and hence farmers' perception, each variable was subjected to further analysis. All the data were grouped by farmer category and geographic region. With the exception of farm equipment, all variables were subjected to appropriate statistical tests in order to determine if at all any observed differences were statistically significant. Statistical testing was not done on the farm equipment data because the differences between the two farmer categories, and regional variations within each group of farmers were self-evident. What follows is a description of the specific analytical steps that were followed.

6.2.3.3.1 Farmers' Background

6.2.3.3.1.1 Sources of Farming Knowledge

Different sources of farming knowledge listed by farmers were classified as follows: i) 'personal experience' where farmers claimed to have acquired their knowledge from friends, neighbours, parents, or grandparents; ii) 'school', if training in agriculture occurred during formal education at primary, secondary, and tertiary levels; and iii) 'extension' if a farmer was visited by agricultural extension workers from the MoA, participated in agricultural seminars, or attended field days. The number of responses in each farmer category was added for each source of farming knowledge. Since there was an apparent association between responses and farmer category, the Pearson's Chi-square (Sall and Lehman, 1996, p 205) was applied to determine if this relationship was statistically significant. The Correspondence Analysis (Sall and Lehman, 1996, p 222) was applied to determine if there was association between any geographic region and sources of farming knowledge.

6.2.3.3.2 Farm Characteristics

Farm characteristics that are described in the succeeding sections are farm size and shape of cultivated land, i.e., flat, if it was not on a slope, or concave, uniform, and convex if slopes were involved, following Hudson (1995, p 99). Farm size is examined in terms of its constituent elements, e.g., cultivated and uncultivated land, and fragments. Focus is given to land under cultivation because it is more vulnerable to soil erosion than uncultivated land. Fragmentation is considered because it limits use of appropriate land-use practices. Kettlewell (1965) partly attributed the failure of the Master Farmer scheme to the difficulty of consolidating fragmented plots.

6.2.3.3.2.1 Sizes of Cultivated Farmland

Mean farm size, including cultivated and uncultivated land as well as fragments, was calculated. The Kruskal-Wallis, a nonparametric test (Sall and Lehman 1996, p 12), was used to compare if, for each farmer category, any significant differences in farm size were evident between the geographic regions. This test was chosen because the number of estate farmers (126) and smallholders (234) were unmatched. Statistical comparisons between the farmer categories were not done because farm size is a known criterion for distinguishing between the two farmer categories.

6.2.3.3.2.2 Shapes of Cultivated Land

The numbers of farmers that claimed to have cultivated land with a particular shape were added in each category by geographic region. The Chi-square test was applied to statistically determine if there were any significant number of farmers in either category that cultivated land with a particular shape. At the same time the Correspondence Analysis was used to determine if there were any regional variations in the shapes of land cultivated by each farmer group.

6.2.3.3.3 Farm Inputs

6.2.3.3.3.1 Fertilizers

Application rates of fertilizers (kg ha^{-1}) were estimated from the number of bags of known weight that farmers claimed to have applied in their tobacco and maize fields. Quantities of fertilizers applied to local and hybrid maize were averaged because of the small number of farmers that grew the former (Tables 4.3 and 4.4). A similar approach was used for tobacco because the number of farmers growing the Malawi Western variety was also small. Fertilizer rates recommended by the MoA (Table 6.5) for these crops were also averaged. The number of farmers that claimed to have used different types of fertilizers, e.g., basal- and top -dressing was calculated in order to determine their percentage by category.

Table 6.5: Recommended blanket application rates (kg ha^{-1}) of fertilizers applied to maize and tobacco varieties in Malawi. Figures in parenthesis are averages for tobacco (burley and Malawi western), and maize (local and hybrid maize), as calculated by the author

Variety by crop	Basal-dressing fertilizer	Rate	Top dressing fertilizer	Rate
Hybrid maize	DAP	80.0	CAN	290.0
	23:21:0+4S	200.0	CAN	200.0
Local maize	DAP	20.0 (50.0)	CAN	130.0 (210.0)
	23:21:0+4S	50.0 (125.0)	CAN	110.0 (155.0)
Burley tobacco	Super C and Super D Mixtures	450.0	CAN	150.0-400.0
	Ordinary Mixtures B, C and D	600.0		
Malawi western	Super C	150.0-200.0 (416.7)	CAN	200.0
			Urea	125.0 (241.7)

Source GoM (1992, pp 45, 87, 88)

Since it is also known that estate farmers generally use more fertilizers than smallholders, a statistical comparison was deemed unnecessary. However, the Kruskal-Wallis test was used to compare rates between geographic regions within each farmer category. The Lakeshore region was excluded in the test because it was represented by a small number of estate farmers in the sample (Table 4.2). Similarly, the small number of smallholders that grew tobacco meant that any statistical result would not be meaningful. To determine the proportion of farmers that claimed to have applied fertilizers their proportions were calculated by type of fertilizer.

6.2.3.3.3.2 Farm Labour

Farm labour was calculated from the number of days and hours that a farm worker was engaged in farm work, and it was expressed in terms of person-hours ha^{-1} yr^{-1}. The amount of family and hired labour, including visiting tenants, were added and averaged for each farmer category. To distinguish between labour-deficiency and -sufficiency, family and hired labour was aggregated, with 888 person-hours ha^{-1} yr^{-1} being considered the dividing line. This decision rule was based on the amount of labour derived from a study of variable costs required to produce maize under alley cropping by Leach (1996, p 42) who reported that among smallholders almost 111 person-days were used on farms ranging from 0.5 to 1.5 ha. Labour use during peak and slack periods as determined from the questionnaire survey showed that a person-day is about 8 hours on the average. Therefore 111 person-days convert to 888 person-hours ha^{-1} yr^{-1}. According to Leach (1996, p 42), out of this amount, about 688 person-hours ha^{-1} yr^{-1} was spent on farm operations as follows: ridging (30%); planting (6%); weeding (12%); banking (17%); fertilizing (12%); and harvesting (23%). Alley cropping alone took up about 200 person-hrs ha^{-1} yr^{-1} or 23% of the 888 person-hrs ha^{-1} yr^{-1}. Using these calculations, therefore, any farmer whose amount of labour was either below or above 888 person-hours ha^{-1} yr^{-1} was considered as labour deficient or sufficient respectively. The Kruskal-Wallis test was used to compare if in each farmer category there were any differences in farm labour between the regions. To find out the proportion of farmers that were either labour-sufficient or deficient, the number of farmers in these two classes of labour was calculated.

The use of 888 person-hrs ha^{-1} yr^{-1} as a decision rule could be considered a caveat in this analysis because it excludes labour requirements for operations specifically undertaken in tobacco production, e.g., nursery management, transplanting, and desuckering. However, all the farmers that claimed to be growing tobacco did not use alley cropping, which is also demanding in terms of labour because it involves management of the nurseries initially, transplanting, pruning and spreading of the biomass equally over the whole garden (Leach, 1996). It is, therefore, contended that the labour that farmers used in tobacco production accounts for what could have been used for alley cropping.

6.2.3.3.3.4 Farm Equipment

Farm equipment was categorized as mechanized or non-mechanized, the former referring to implements such as ploughs, ox-carts, and tractors while the latter include hoes, axes, and *pangas* (wide-bladed knives). As done with other data containing few samples, statistical comparison was not made because only very little mechanized equipment was in the sample, for example 4 tractors, 31 ploughs, and 28 ox-carts belonged to estate farmers, while smallholders only had 8 ploughs and 6 ox-carts.

6.2.3.3.4 Farm Outputs

6.2.3.3.4.1 Crop Yields

Yields of maize and tobacco were estimated taking into account factors such as area of cultivated farmland, potential yield, fertilizer type, and the fertilizer-application rates recommended by the GoM (Table 6.5). The results were expressed as t ha^{-1}. Mkanda (1992) used this approach to assess the amount of crop damage by wildlife in communities neighbouring Kasungu National Park (Malawi), and found that estimated yields of tobacco and maize were close to the actual yields realized by farmers. Yields of different varieties of maize or tobacco were aggregated as was done with the fertilizer data. Proclaimed yields of these crops (Table 6.6) were also averaged for the crop varieties that farmers grow in the Linthipe Drainage Basin. Any farmer with a yield that was lower or higher than the average of the proclaimed yields was considered as either having sufficient or insufficient yield respectively. The number of farmers in these two categories of yields was determined in order to facilitate comparison between the two farmer categories.

Table 6.6 Proclaimed maize and tobacco yields in Malawi

Crop	Variety	Yield t ha^{-1} y^{-1}	[a]Average t ha^{-1} y^{-1}
Maize	Hybrid Maize	8.0	5.5
	Local Maize	3.0	
Tobacco	Burley	4.0	3.0
	Malawi Western	2.0	

Source GoM (1992, pp 41 and 75)
[a] Calculated by the author

The Kruskal-Wallis test was used to determine if there were any statistically significant differences in crop yields between geographic regions in each farmer category. Again, because of the small number of estate farmers in the Lakeshore region, this area was excluded from the statistical test. Also, the fact that it has also been established that crop yields are generally lower among smallholders, a statistical comparison between farmer categories was not done.

6.2.3.3.4.2 Farm Income

Farm income was derived from the gross profits that farmers indicated they had earned over the previous (1997/98) farming season. Although the field data showed that some farmers engaged in other types of employment, e.g., vending, weaving, and carving, the questionnaire did not specifically require that respondents divulge their earnings from these activities. Therefore, these income sources were excluded. Chipande (1988, p 167) states that non-farm sources of income are limited because of the few employment opportunities in the rural areas. This being the case, it is contented that the contribution by other sources of income to farmers' total earnings would have been negligible. The Kruskal-Wallis test was used to find out if these variables varied between the regions within each farmer category.

According to the World Fact Book (Central Intelligence Agency, 2000) the estimated GDP *per capita* income in Malawi was US$ 940.00 or MK 42,300.00 using the 1998 exchange rate[36]. This *per capita* income was, therefore, considered as the borderline between low- and high-income farmers, and the number of income-deficient and -sufficient farmers was determined for each category using this decision rule. It is common knowledge that rural incomes are generally lower than those in urban areas. The use of GDP *per capita* income, may not be considered an appropriate decision rule, but in the absence of data that are disaggregated by location (rural and urban), its use helps to establish a common economic parameter for determining income sufficiency or deficiency.

6.3 Results and Discussion

This section interprets and discusses the results, from the analysis of the socio-economic data on soil erosion and conservation in the Linthipe Watershed, in the context of the study hypothesis and objective (ii) of the study. Specifically it discusses the results in

[36] US$ 1.00 was approximately Malawi Kwacha (MK) 45.00 in 1998

relation to farmers' awareness of the magnitude of perceived soil erosion and the effects of soil loss on their holdings. Furthermore, the section explains why each principal socio-economic factor that has been identified as important in soil conservation is contributing significantly to soil erosion. Lastly, it gives an explanation as to how these variables force farmers to develop strategies for survival in light of difficult conditions under which they operate.

6.3.1 Perceived Degree of Soil Erosion and Awareness of Soil-Loss Effects

Farmers' perception of degree of soil erosion confirms that they are indeed aware of the magnitude of the problem and the effects of soil loss on their holdings (Table 6.7; Fig. 6.2 a and b). The proportions of estate farmers and smallholders in each category of perceived soil erosion illustrate that both farmer categories had similar perceptions of magnitude of soil erosion on their properties (Table 6.7), the dichotomy of the farming systems notwithstanding. This similarity is confirmed by the lack of any significant association in the Chi-square results ($X^2 = 5.9$, $p = 0.11$) between soil-erosion degree and farmer type. Since there is consistency between farmers' perceptions of the magnitude of soil erosion on their holdings (Table 6.7) and the observed soil-loss data (Table 5.11), it is concluded that the occurrence of severe soil erosion is not due to ignorance on the part of the farmers. Furthermore, as observed soil losses are linked to slope gradient (Chapter 5) as one of the major determinants of soil erosion, then the perceived degree of soil erosion is also a manifestation of the influence of slope. In fact the Correspondence Analysis test (Figs. 6.3 a and b) reveals that the association between perceived degree of soil erosion and geographic region is highly significant for estate farmers and smallholders ($X^2 = 50.71$, $p < 0.0001$); $X^2 = 67.94$, $p < 0.0001$ respectively). This being the case, these results seem to support the earlier assertion that the soil-conservation measures farmers had in place were not effective. Had they been so, then the influence of slope on perceived degrees of soil erosion would not have been so apparent. Lack of effectiveness is in itself an indication that soil-erosion control did not receive high priority. The fact that gullying, which is highly visible on eroded properties (Fig. 2.2), was not mentioned as one of on-site effects of soil erosion implies that in comparison to low-crop yields and decline in soil fertility, soil loss is of less concern to both farmer categories. Under such circumstances, therefore, it is unlikely that soil conservation would take precedence over survival needs; hence the perceived/observed severe soil losses.

Table 6.7: Degree of soil erosion as perceived by farmers in 1998; Linthipe River Catchment

Farmer	**Soil erosion degree**	**No. of farmers by region**					**% of Total**
		Dowa	Lilongwe	Lakeshore	Scarp	Total	
Estate	None	1	15	2	5	23	18.3
	Low	-	3	2	6	11	8.7
	Moderate	2	20	0	29	51	40.5
	Severe	19	14	4	4	41	32.5
	Total	**22**	**52**	**8**	**44**	**126**	**100**
Smallholder	None	8	11	30	9	58	24.8
	Low	-	5	13	7	25	10.7
	Moderate	16	15	10	25	66	28.2
	Severe	44	7	29	5	85	36.3
	Total	**68**	**38**	**82**	**46**	**234**	**100**

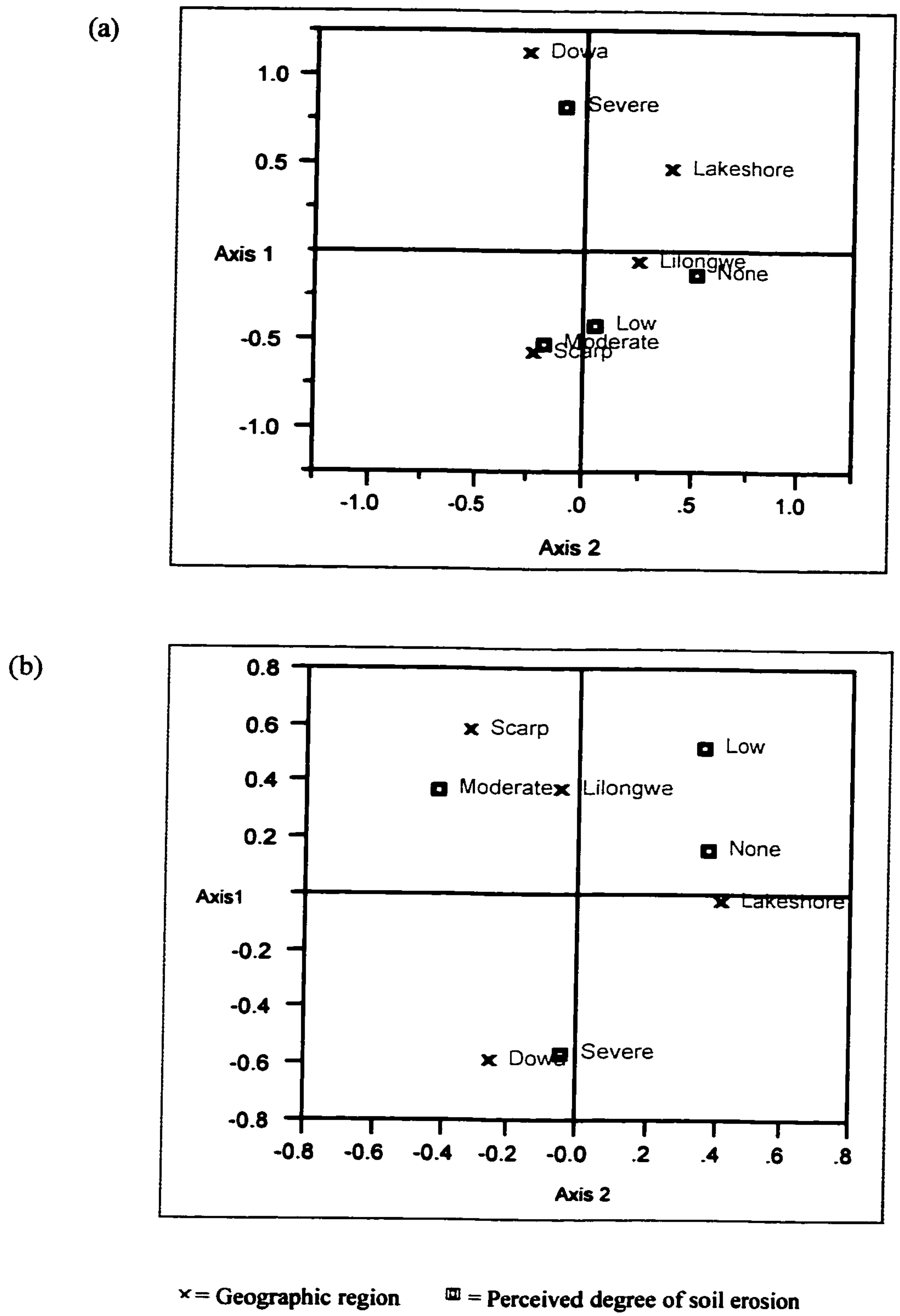

Fig. 6.2 Correspondence Analysis of perceived degree of soil erosion by geographic region: (a) estate farmers; and (b) smallholders; Linthipe River Catchment. Clusters of soil-erosion degree and region indicate close association between these variables.

This high degree of awareness is not surprising because of three factors. First, if farmers used indigenous methods of conserving soil, then they must have known the consequences of soil erosion on agricultural land long before the introduction of land-use policies by the colonial government. Indigenous knowledge, therefore, must have contributed to the high degree of awareness.

Second, the history of soil conservation in Malawi reveals that public-awareness campaigns began during the colonial era (Kettlewell, 1965). Agricultural extension was, and continues to be one of the methods used to impart natural-resource conservation knowledge to the public in Malawi. Furthermore, the process of formulating conservation plans, such as the NEAP, involved elaborate consultations with members of the public. This process was highly publicized through the national radio and print media. These actions therefore must have acted as reminders that soil erosion is still a problem.

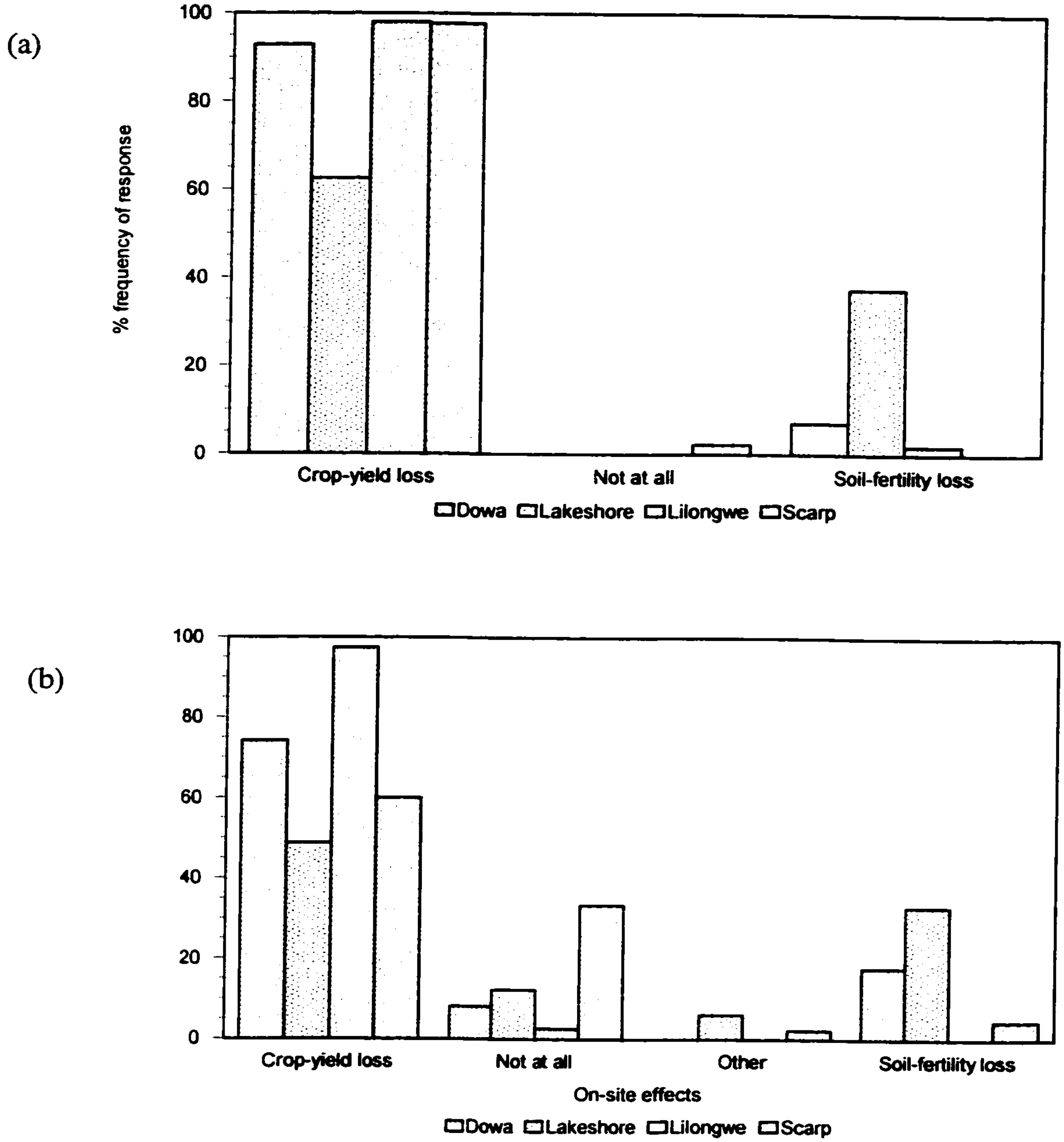

Fig. 6.3 Response frequencies of on-site effects of soil erosion in 1998: (a) among estate farmers; and (b) smallholders, Linthipe River Catchment

The third reason can be attributed to agricultural education. This method also began during the colonial period. Since about 75% and 59% of estate farmers and smallholders respectively had formal education in the study area (section 6.3.2.1.1), it is inferred that agricultural education has most certainly played a role in farmers' awareness of the degree of soil erosion and its impacts.

The significantly higher frequency of reference to crop-yield loss by estate farmers than smallholders ($X^2 = 27.64$, $p < 0.001$) is surprising because estate farmers' fertilizer application rates were generally higher than smallholders', and their crop yields were correspondingly better. This being the case, then this frequency should have been higher among smallholders. That it is high among estate farmers can only be explained in terms of differences in aspirations between these farmer groups. Estate farmers focus more on tobacco than maize for economic reasons, while risk minimisation and subsistence constitute a fundamental purpose for farming among smallholders (Hudson, 1995, p 368). The attitudes, opinions, and beliefs (which in turn influence the nature of responses by these two groups), are therefore also bound to be different. Parfitt (1997, p 90) states that an individual's attitude, opinion, and belief can be referred to as some measure of an individual's underlying state of mind. Since estate farmers are motivated mostly by profit in addition to subsistence, they are likely to express their feelings more easily than the majority of smallholders. In other words, since the former lose twice as much as the latter, i.e., maize and tobacco yields (as opposed to only maize for the latter), they seize any opportunity to vent their frustrations (refer to section 6.3.2.3.2). Moreover, smallholders compensate this loss by offering their labour in exchange for food.

6.3.2 Contribution to Soil Erosion by the Principal Variables

What follows is an explanation of how variables that significantly contribute to the perceived degree of soil erosion force farmers to adopt different survival strategies, and in turn lead to suboptimal farming practices, the results of which are severe to extremely severe soil erosion. Before doing so, however, an interpretation of the results from the regression models is necessary. First, it is important to note that variables with negative regression coefficients (Table 6.8) imply that the help minimise soil erosion and *vice versa*. Second, the coefficients of determination[37] (R^2) in Table 6.8 account for only 54% and 52% of the regression model of estate farmers and smallholders respectively. It follows, therefore, that other factors, for example erodibility, slope, and rainfall contribute 46% and 48% to each respective model.

Table 6.8 Principal socio-economic variables that contribute to the degree of soil erosion perceived by farmers in 1998 (estate farmers' $R^2 = 0.54$, $p < 0.0001$, smallholders' $R^2 = 0.52$, $p < 0.0001$); Linthipe River Catchment

Category	Variable	Estate		Smallholder	
		r[a]	p[b]	r[a]	p[b]
Background	Farming knowledge source	0.18	0.005	-0.19	0.006
Farm characteristics	Cultivated farmland	0.91	0.0001	0.35	0.0001
	Shape of cultivated land	-0.25	0.04	0.23	0.0001
Farm inputs	Fertilizer amount	0.19	0.005	0.22	0.01
	Farm equipment	-0.27	0.01	0.38	0.001
	Labour	-0.37	0.04	0.26	0.01
Farm output	Farm income	-0.29	0.03	0.26	0.01
	Tobacco yield	0.29	0.01	0.29	0.0006
	Maize yield	0.22	0.01	0.33	0.02

[a] r is the regression coefficient
[b] p is the probability level

[37] A measure of the proportion of the variability in one variable that is accounted for by variability in another (Fowler and Cohen, 1990, p 140).

6.3.2.1 Background Factors

6.3.2.1.1 Sources of Farming Knowledge

The field data indicate that personal experience and schooling are the important sources of farming knowledge for the two farmer categories in the Linthipe Catchment. However, there is an apparent distinction between the two farmer categories in as far as these main sources of farming knowledge are concerned. For instance, estate farmers claimed that school is a more important source of farming knowledge than personal experience (Table 6.9). In contrast, smallholders claimed that personal experience was a more important source of farming knowledge than school. This distinction is statistically confirmed by the Chi-square test, which shows that overall differences in response probabilities between these two farmer categories are highly significant ($X^2 = 35.7$, $p < 0.0001$). Therefore, it explains why this variable contributes negatively to the regression model (i.e., degree of perceived soil erosion) of smallholders, but positively to that of estate farmers (Table 6.8). A comparison of the data between the geographic regions reveals that a significant association ($X^2 = 42.6$, $p <0.0001$, and $X^2 = 35.7$, $p < 0.0001$ for estate farmers and smallholders respectively) exists between geographic regions and source of farming knowledge.

Table 6.9: Sources of farming knowledge among smallholders and estate farmers; Linthipe River Catchment, 1998

Farmer	Source	Number of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	Experience	1	3	7	2	13	10.3
	Experience/extension	1	0	16	0	17	13.5
	Extension	1	1	0	0	2	1.6
	School	19	4	29	42	92	74.6
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholder	Experience	30	31	27	43	131	56.0
	Experience/extension	5	3	3	0	11	4.7
	Extension	3	9	0	0	12	5.1
	School	30	39	8	3	80	34.2
	Total	**68**	**82**	**38**	**46**	**234**	**100**

Sources of farming knowledge are not survival strategies, but they contribute to soil erosion by influencing farmers to adopt either modern technology or conform to traditional farming practices. Cohen *et al.*, (1996, p 579) have observed that around the African Great Lakes, young and literate farmers have been easily swayed to abandon traditional technologies, e.g., mulching and mixed cropping, which help to conserve soil. All other variables in soil-erosion processes notwithstanding, there appears to be a relationship between education (as a source of farming knowledge), and level of cultivation methods (traditional or modern) in the study area. For example, mixed cropping, especially of maize with groundnuts, soya beans, ground beans or pumpkins is popular among smallholders because they tend to adhere to traditional methods of farming, unlike estate farmers who mostly grow high value crops in pure stands. About 82% of estate farmers grew maize as a monocrop, when compared to approximately 67% of smallholders (Tables 4.3 and 4.4).

Since there is an association between sources of farming knowledge and farmer type, and there is also regional variation in source of farming knowledge within each farmer category, two conclusions are made. First, in the Linthipe Watershed, more estate farmers than smallholders have a higher propensity for adopting modern technology such as monocropping. Second, that the Dowa and Scarp regions have proportionally more estate farmers and smallholders that had formal education than the other regions means that these two regions are not only vulnerable to soil erosion because of steep topography, but also to the abandonment of traditional farming methods. These farmers' propensity for monocropping (Tables 4.3 and 4.4) is inducing soil erosion on holdings of both farmer groups, but more especially estates. The net results are excessive loss of soil and increased sediment input into the Lake.

6.3.2.2 Farm Characteristics

6.3.2.2.1 Sizes of Cultivated Farmland

As is the case in Malawi, estate farmers in the Linthipe Drainage Basin own and cultivate larger holdings than smallholders (Table 6.10). The Kruskal-Wallis test indicates there are regional variations in farm size within each farmer category. For example, estate farmers in Dowa owned, cultivated, and left areas of uncultivated land that were significantly larger than in the other regions ($X^2 = 47.6$, $p < 0.001$). Among smallholders, there are also significant differences in the same land-use variables. Those in the Scarp and Lilongwe plain owned, cultivated, and left pieces of land uncultivated that were significantly smaller than those in Dowa and Lakeshore ($X^2 = 50.4$, $p < 0.001$). The general pattern in land use, therefore, is that in the Scarp and Dowa regions, both farmer groups owned, cultivated, and kept more land uncultivated than in the Lakeshore and Lilongwe plains (Table 6.10).

Table 6.10 Farm size, cultivated and uncultivated land, and number of fragments by farmer category; Linthipe River Catchment, 1997/98

Farmer	Variable	Farm size by geographic region				Mean
		Dowa	Lilongwe	Lakeshore	Scarp	
Estate	Farm size (range)[b]	7-150.0	0.6-73.1	0.4-1245.0	0.4-67.2	
	Farm size (ha)[a]	47.7	4.4	308.8	7.3	92.0
	Cultivated (ha)[a]	9.8	2.8	40.2	3.5	14.0
	Uncultivated (ha)[a]	37.9	1.6	268.6	3.8	78.0
	Fragments (range)[c]	1.0-27.0	1.0-7.0	1.0-4.0	1.0-7.0	
	Fragments (No.)[a]	5.9	2.1	2.1	2.6	3.2
Smallholder	Farm size (range)[b]	0.2-54.4	0.4-2.8	0.21-14.0	0.4-42.4	
	Farm size (ha)[a]	3.5	1.3	1.5	0.9	1.8
	Cultivated (ha)[a]	1.8	1.1	1.0	0.6	1.1
	Uncultivated (ha)[a]	1.7	0.2	0.5	0.3	0.7
	Fragments (range)[c]	1-3	1-3	1-5	1-1	
	Fragments (No.)[a]	1.4	1.5	1.9	2.1	1.7

[a] Means. The high mean farm size in the Lakeshore region is due to the occurrence, in the sample, of two large-scale estate farmers owning over 1000.00 ha.
[b] Ha
[c] No. of fragments

These results suggest that the lower population densities in the Scarp and Dowa regions may have enabled some farmers to own larger holdings than in the Lilongwe and Lakeshore plains where relief is gentle, but population is higher. The larger holdings in the Dowa Hills and Scarp must have been a response to land alienation by the large-scale estates when customary land was being converted into leasehold land in the 1970s. This response in essence can be viewed to be a survival strategy meant to circumvent possible landlessness, but the cultivation of large areas in these regions by estate farmers contributes to soil erosion because such steep areas are rendered vulnerable to erosive rains at the beginning of the rainy season.

It was mentioned earlier that a farmer owning a small holding would rather commit all the land to crop production instead of either keeping part of it under fallow or installing mechanical structures such as storm drains and artificial waterways. The small proportion of smallholders that left their land uncultivated (Table 6.10), therefore, suggests that this is the case in the Linthipe Watershed. Therefore, cultivation of all the land by most of the smallholders is considered a survival strategy aimed to boost their production levels in view of their limited use of fertilizers. In doing so, however, these farmers contribute to soil erosion. In terms of geographic regions, the cultivation of small areas of land by smallholders in the Scarp and Dowa Hills (Table 6.10), regions of steep gradient, enhances the soil-erosion potential more than in the other regions.

Concomitant to cultivating large areas of land that expose the soil to raindrops, there is also fragmentation of holdings. While it was originally a predominant feature of smallholder farming (Rimmington, 1963; Kettlewell, 1965), it is now common even among estate farmers in the study area (Table 6.10), especially the case among the small-scale estate owners because these farmers merely converted their customary land into leasehold estates. This practice, in a way, can be considered an insurance against crop failure because the availability of different parcels of land that have soils of different quality enables crop diversification. Farmers are, therefore, assured of some yields even if crops fail on some of their land parcels due to poor soil quality. Second, tobacco farmers have used fragmentation as a tool for ensuring profit optimisation. That some estate farmers registered different parcels of land as estates so that they could obtain additional tobacco quota, while in reality they cultivated only one piece of land, confirms that this practice can be used to the advantage of farmers.

Fragmentation, however, creates problems in soil conservation in different ways. In Chapter 2, it was stated that Kettlewell (1965) observed that fragmentation inhibited land-use planning when implementing the Master Farmer Scheme during the colonial period. Other workers, for example (Douglas, 1988, p 218) and (Shaxson, 1981, p 386) have also expressed similar concerns. These authors stated that from a technical point of view, planning conservation in the framework of a catchment consisting of consolidated holdings might seem tempting. However, attempts to realign farm and field boundaries with strict reference to contours of the land, in the interest of better soil-erosion control, may cause considerable disruption of farming activities, and engender much argument. Individual catchments are likely to contain many farmers with separate holdings and marked differences in farming skills, education, interests, and needs (Douglas, 1988, p 218). A situation like this makes it difficult for farmers to work together and conserve resources because conserving a catchment is not solely an individual farmer's responsibility. Second, it renders different patches of land vulnerable to soil erosion due to cultivation. Third, it limits implementation of soil-conservation measures because of the inherently small sizes of the fragments. Fourth, fragmentation places additional demand on labour (Edwards 1961, p 114), which is an essential input in soil conservation (Stocking 1992, p 213). The implication, therefore, is that the available labour is divided between different fragments thereby reducing the ability of such labour to implement soil-conservation measures effectively. If these are the consequences of fragmentation, then in the study area, they must be mostly manifested in the Dowa Hills and Scarp where estate farmers own more fragmented holdings than in the other regions (Table 6.10).

Since estate farmers leave land uncultivated, they could argue that soil is being conserved on their properties (Table 6.10). While this argument may be valid in terms of individual holdings, the overall benefit at a catchment scale, however, is diminished by the fact that smallholders, who are the majority, either cultivate all their land or leave very little land uncultivated (Table 6.10). Three reasons are advanced to explain why estate farmers leave parts of their land uncultivated.

First, there have been concerted efforts on the part of the GoM to promote estate agriculture. Kydd and Christiansen (1982) stated that land has been preferentially allocated to estate agriculture because of its importance in terms of export earnings. Individuals and corporations were accorded the opportunity to lease large tracts of land at very little cost, land tax was not imposed, and land rents were set at nominal levels, but frequently went unpaid (Mkandawire *et al.* 1990, p 18). These low lease charges have meant that farmers can afford to keep their land undeveloped without incurring any losses from taxation on idle land. In certain cases, leaseholders have acquired leases in other locations, not intending to develop the land, but merely wishing to obtain an additional tobacco quota whose level is met by production from the already existing estate (Mkandawire *et al.* 1990, p 23). Third, for estate farmers who realize high tobacco yields, the quota system proved to be a binding constraint in utilizing their land; therefore, they did not see the value in cultivating all their land. Among smallholders, production constraints, particularly labour availability, limits full utilization of land (Chipande, 1988, p 166).

6.3.2.2.2 Shapes of Cultivated Land

Fifty-six percent of the smallholders cultivated land that predominantly had convex slopes, compared to only 36.5% of the estate farmers (Table 6.11). Conversely, 40.5% of estate farmers cultivated concave slopes compared to only 23.1% of smallholders. The same number of farmers, more or less, in either category, cultivated flat land. The significant differences ($X^2 = 14.9$, $p = 0.0006$) between the percentage of estate farmers and smallholders cultivating different shapes of slopes are certainly due to the selective allocation of land to estate farmers by Government. Whether through indigenous knowledge of soil hazards or with the help of planners, estate farmers leased better land, which is less susceptible to soil erosion than the convex slopes cultivated by the majority of smallholders. The significant association between the geometry of cultivated slopes and farmer category explains why shape of cultivated land is contributing positively and negatively to the regression models of smallholders and estate farmers respectively (Table 6.8).

Table 6.11: **Number of farmers cultivating land of different shapes in 1998; Linthipe River Catchment**

Farmer	Nature	No. of farmers by region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	Flat	3	4	12	10	29	23.0
	Concave	8	1	32	10	51	40.5
	Convex	11	3	8	24	46	36.5
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholder	Flat	0	43	6	0	49	20.9
	Concave	6	15	26	7	54	23.1
	Convex	62	24	6	39	131	56.0
	Total	**68**	**82**	**38**	**46**	**234**	**100**

The Correspondence Analysis confirms that the association between shape of cultivated land and geographic region is statistically significant ($X^2 = 25.5$, $p = 0.0003$, $X^2 = 148.3$, $p < 0.0001$ estate and smallholders respectively, Fig. 6.4). This finding suggests that for both farmer categories pressure on land has been increasing to the point that even some estate farmers have had no choice but to cultivate land of marginal quality. The occupancy of land of marginal quality by farmers, especially smallholders is a survival strategy. As pressure on arable land has been increasing, smallholders have had no choice but to occupy and cultivate whatever land is available irrespective of slope geometry. Again, on account of the geometry of cultivated land, the Dowa Hills and Scarp are worse-off in terms of their contribution to soil erosion in the catchment because both farmer groups in these regions significantly cultivate slopes that are most vulnerable to erosive forces.

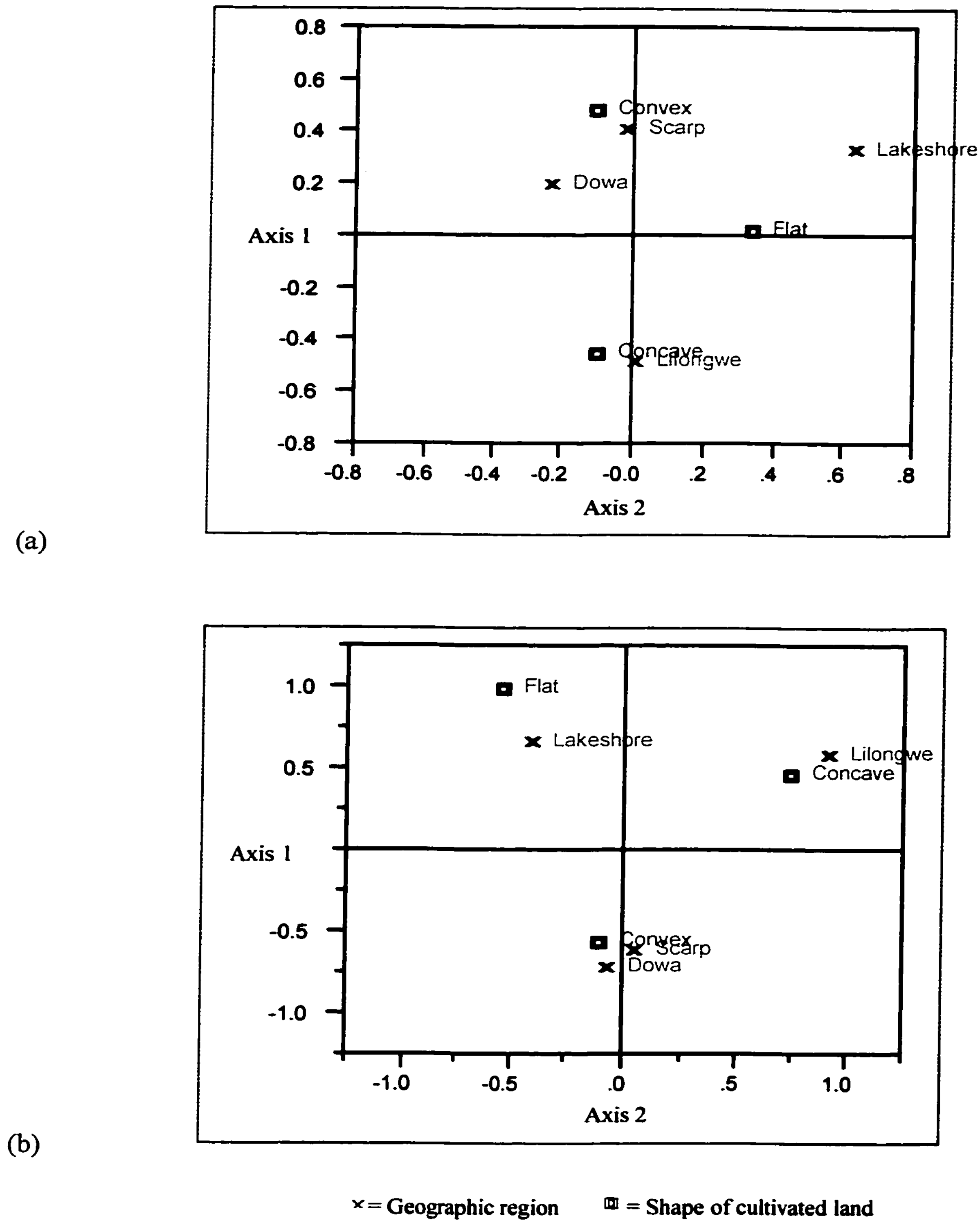

Fig. 6.4 Correspondence Analysis of shape of cultivated land by region in 1998: (a) estate farmers, and (b) smallholders, Linthipe River Catchment

6.3.2.3 Farm Inputs

6.3.2.3.1 Fertilizer Applications for Maize

Previous studies have indicated that fertilizer use is lower than the recommended rates (Table 6.5) in Malawi, especially among smallholders (Douglas, 1988, p 216; WB 1991, p 10). This is also the case in the Linthipe Catchment (Tables 6.12 - 6.14). Although estate farmers applied more fertilizers than smallholders (Table 6.12), the mean quantities used by both farmer categories were generally lower than those recommended by the MoA (Table 6.5). For instance the total mean rates of 23:21:0+S were approximately 33 and 21% of the recommended 200 kg ha^{-1} for estate farmers and smallholders respectively (Tables 6.5 and 6.12). The number of farmers that claimed to have applied basal- and top-dressing fertilizers provides further evidence as to the inadequacy of fertilizer use in the catchment (Tables 6.13 and 6.14). About 54% and 68% of estate farmers and smallholders respectively did not use any basal fertilizer. In addition, about 20% and 42.3% of these respective farmer groups did not apply top-dressing fertilizer. These low rates of fertilizers applied to maize explain why this variable contributes positively to the multiple regression models of both farmer groups (Table 6.8).

Table 6.12: Mean fertilizer-application rates (kg ha^{-1}) of basal and top-dressing fertilizers used by farmers in maize; Linthipe River Catchment, 1997/98

Farmer	Fertilizer	Mean rate (kg ha^{-1}) by region				Total mean
		Dowa	Lilongwe	Lakeshore	Scarp	
Estate	23:21:0+S[a]	81.5	64.9	78.1	58.6	66.6
	CAN	102.6	44.4	181.3	170.9	107.4
Smallholder	23:21:0+S[a]	33.9	36.4	19.4	99.6	42.2
	CAN	37.9	36.0	56.0	165.2	68.9

[a] Averages for local and hybrid maize

Table 6.13: Number of farmers that applied different types of basal-dressing fertilizers in maize; Linthipe River Catchment, 1997/8

Farmer	Fertilizer	No. of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	None	8	4	26	30	68	53.9
	23:21:0+4S	14	3	25	14	56	44.5
	DAP	0	1	1	0	2	1.6
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholders	None	46	65	22	26	159	67.9
	23:21:0+4S	21	12	16	19	68	29.2
	DAP	1	6	0	0	7	2.9
	Total	**68**	**83**	**38**	**45**	**234**	**100**

Table 6.14: Number of farmers that applied different types of top-dressing fertilizer in maize; Linthipe River Catchment, 1997/98

Farmer	Fertilizer	No. of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	None	3	1	14	7	25	19.8
	CAN	19	7	9	36	71	56.3
	Urea	0	0	29	1	3	23.9
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholders	None	40	40	14	5	99	42.3
	CAN	26	33	12	40	111	47.4
	Urea	2	10	12	0	24	10.3
	Total	**68**	**83**	**38**	**45**	**234**	**100**

Comparisons of fertilizer application rates between the regions within each farmer category shows that there are no significant regional differences in the application rates of basal-dressing fertilizers that were used by estate farmers ($X^2 = 3.02$, p 0.38), but the differences are significant in the amount of top-dressing fertilizers ($X^2 = 31.33$, $p < 0.0001$); the Lilongwe farmers applied a lower amount than their counterparts in the other regions. This pattern seems to be consistent with farm earnings by this farmer group (refer to section 6.3.2.5.3), i.e., farmers with higher income used more fertilizers than those that faced financial difficulties.

Among smallholders, basal-fertilizer rates were significantly lower in Dowa and Lakeshore than in the Scarp and Lilongwe regions ($X^2 = 9.84$, $p = 0.01$). Scarp farmers also used more top-dressing fertilizer than the other smallholders ($X^2 = 50.46$, $p < 0.0001$). This pattern is not consistent with income levels at all, suggesting that the regional variation may be an artefact of differences in access to credit facilities. Most smallholders do not have access to farm inputs offered on credit by lending institutions such as the Malawi Rural Finance Company and other similar agencies because eligibility is based on 'ability-to-repay' (Chipande, 1988, p 169). The implication of this criterion was that only those smallholders who produced surpluses, irrespective of geographic region, were able to sell their crops in order to qualify for credit.

The application of smaller quantities of fertilizers by smallholders is obviously influenced by competing demands for cash, e.g., children's school fees, clothing, and so on (Chipande, 1988, p 170). Since the level of income is generally low, farmers are unable to procure sufficient farm inputs although they are aware that hybrid maize does not grow well without fertilizers. In view of the competing demands, farmers would rather apply less fertilizer so they can realise some yield than apply none at all and yield nothing. The use of low quantities of fertilizers by estate farmers can be also attributed to the competing demands. At the same time, it could be that indeed the increases in prices of farm inputs (refer to Chapter 5) have diminished the capabilities of the majority of this group to procure adequate fertilizers.

The use of low rates of fertilizers in order to spare cash for competing demands exemplifies adaptive strategies on the part of farmers. Since fertilizers improve soil fertility, plant nutrition, and hence plant cover, it can be concluded that soil fertility was unquestionably low irrespective of region. Use of manure, which is another means of improving plant nutrition, is limited. In the sample from the Linthipe Watershed, there were only 12 estate farmers and 9 smallholders who indicated they used manure. Consequently, crop cover must have been low on cultivated land belonging to both farmer groups thereby exposing the soil to impacts of raindrop during the whole growing season.

6.3.2.3.2 Fertilizer Applications for Tobacco

The total statistical means of basal-dressing fertilizer were lower than the recommended rates (Tables, 6.8, 6.15 - 6.17); for example that of basal-dressing fertilizer (Table 6.16) are approximately 41 and 30% of the recommended rate of Super and Ordinary Mixture respectively among estate farmers. At 18.9 kg ha^{-1}, the mean amount of Super Mixture used by the smallholders was even lower (only 4.2%) of the recommended rate. Again, additional evidence for the low use of fertilizers is discernible from the number of farmers that claimed to have applied basal- and top-dressing fertilizers in tobacco (Tables 6.16 and 6.17). About 29 and 34% of the estate farmers and smallholders respectively did not apply any basal-dressing fertilizers (Table 6.16). About 35 and 49% of the estate farmers and smallholders did not apply top-dressing fertilizers.

Table 6.15: Estimated mean rates of basal and top-dressing fertilizer (kg ha^{-1}) used in tobacco by farmers in the 1997/98 season; Linthipe River Catchment

Farmer	Fertilizer	Mean rate (kg ha^{-1}) by geographic region				Total
		Dowa	Lakeshore	Lilongwe	Scarp	
Estate	Super Mixtures[b]	207.8	151.9	126.5	249.2	185.2
	Ordinary Mixtures[b]	168.8	187.5	174.8	-	177.0
	CAN[b]	205.8	155.8	91.7	209.7	156.9
Smallholder	Super Mixtures[b]	46.0	0	13.2	17.7	18.9
	Ordinary Mixtures[b]	223.1	-	500.0	-	361.6
	CAN[b]	54.1	-	13.2	17.7	21.3

[b] Averaged rates for burley and Malawi western tobacco

Table 6.16: Number of farmers that claimed to have applied basal-dressing fertilizers in tobacco in the 1997/98 season; Linthipe River Catchment

Farmer	Fertilizer	No. of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	None	3	3	23	8	37	29.3
	Ordinary Mixture	12	2	19	0	33	26.2
	Super Mixture	7	3	10	36	56	44.5
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholders	None	4	0	0	8	12	34.3
	Ordinary Mixture	10	0	0	1	11	31.4
	Super Mixture	4	2	2	4	12	34.3
	Total	**18**	**2**	**2**	**13**	**35**	**100**

Table 6.17: Number of farmers that claimed to have applied top-dressing fertilizers in tobacco; Linthipe River Catchment, 1997/98

Farmer	**Fertilizer**	**No. of farmers by geographic region**				**Total**	**% of Total**
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	None	3	3	27	11	44	34.9
	CAN	19	5	25	33	82	65.1
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholders	None	5	2	1	9	17	48.6
	CAN	13	0	1	4	18	51.4
	Total	**18**	**2**	**2**	**13**	**35**	**100**

These low rates are also due to the fact that farmers face economic pressures, hence they have to use adaptive strategies. A recent press report posted on the Nyasanet[38] renders support to the financial hardships that farmers face. It reads (edited by the author):

> *Many farmers in Malawi have given up growing tobacco, Malawi's chief foreign exchange earner, due to lack of fertilizer and the low prices fetched by the crop. Most smallholder farmers were unable to buy fertilizers this season because they used their little income to repay last year's loans for farm inputs. Rabison Mwase, a medium-scale farmer in the tobacco heartland of the central district of Kasungu, told PANA (Pan African News Agency) he got a loan of about MK 64,000.00 for fertilizer and an additional MK 40,000.00 for other farm inputs. "My income from tobacco was hardly sufficient to enable me repay the loan, let alone pay wages to my tenants," he said. Mwase claimed that he had to sell off some less-valuable items to raise money and pay off some of the creditors lest they impound his property. He vowed not to grow tobacco in the coming season. The Public Relations Officer for the Tobacco Association of*

[38] A discussion list of things Malawian, accessed 23 January 2001.

Malawi (TAMA), Chipiliro Kalebe, confirmed that many tobacco farmers lack fertilizers, a development that is likely to result into low quality and quantity of tobacco.

On a regional basis, the fertilizer rates used by estate owners are significantly higher in Dowa Hills and Scarp regions than in Lilongwe ($X^2 = 15.49$, $p = 0.001$, and $X^2 = 15.68$, $p = 0.001$) for basal- and top-dressing fertilizers respectively. These variations in the rates of fertilizers applied are also reflective of the levels of affordability in these regions. Farmers in the Dowa and Scarp regions earned higher incomes from their farming activities than those in Lilongwe, hence their purchasing power was correspondingly higher (refer to section 6.3.2.5.3). The regional variation, however, is of little consequence because it is inferred that the low amounts of fertilizers used did not cause any considerable variation in crop cover between the regions. Given that tobacco is a poor-cover annual crop, these low application rates and lack of use of fertilizers by some farmers (Tables 6.16 and 6.17) meant that the soil surface was rendered vulnerable to soil-erosion processes.

6.3.2.3.3 Farm Labour

The mean labour for smallholders was nearly half that of estate farmers; a fact evident from Tables 6.18 and 6.19. That approximately 69%, and 71% of estate farmers and smallholders respectively were labour-sufficient and -deficient explains why this variable contributes differently to the respective regression models (Tables 6.19 and 6.8).

Table 6.18: Total farm labour (hired and family) among estate farmers and smallholders; Linthipe River Catchment, 1997/98

Farmer	Variable	Amount ('000 person-hours ha-1 yr-1)				Mean
		Dowa	Lilongwe	Lakeshore	Scarp	
Estate	Range	0.16-4.75	0.34-33.15	0-6.69	0.18-10.63	0-33.1
	Mean	0.95	0.87	0.95	0.87	0.92
Smallholder	Range	0-4.96	0-4.10	0-3.63	0.10-0.93	0-4.1
	Mean	0.37	0.67	0.55	0.40	0.49

Table 6.19: Number of labour sufficient or deficient farmers; Linthipe River Catchment, 1997/98

Farmer	Labour availability	No. of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	Sufficient	16	6	33	32	87	69.0
	Deficient	6	2	19	12	39	31.0
	Total	**22**	**8**	**52**	**44**	**126**	**100**
Smallholders	Sufficient	11	34	18	4	67	28.6
	Deficient	57	48	20	42	167	71.4
	Total	**68**	**82**	**38**	**46**	**234**	**100**

It is paradoxical that in a country where the population is largely rural and dependent on agriculture, labour is deficient among smallholders and some estate farmers. This deficiency, however, is a result of labour dynamics caused by survival mechanisms in the farming communities, e.g., the hiring out of family members. Second, there is competition for labour not only between soil conservation and crop production, but also between different types of crops, e.g., maize, groundnuts, beans, and tobacco. The period of field preparation and planting of the latter crops coincides with the critical time for weeding of maize, which is generally the first crop to be planted with the onset of the rainy season (Weil, 1982). This competition by different crops, therefore, reduces the amount of labour that can be allocated to production of each crop. Since according to farmers, weeding is of more immediate benefit than soil conservation, they would rather allocate more labour to the former than the latter. While application of herbicides could be used to reduce weed-crop competition, it has been found that they are inappropriate uneconomic, ineffective and/or dangerous when used by untrained villagers (Parker, 1972, Brown and Beaty, 1970). Therefore weeding, which is often followed by banking of ridges, is done using hand hoes. The problem with hoe weeding is that it is one of the most labour-demanding phases in crop production (Weil, 1982); therefore it is given priority in terms of labour use. As a result, soil erosion occurs with less than optimal conservation measures in place.

Third, the lack of commitment to soil-conservation by visiting tenants, who were employed by all the estate farmers in the study area, is also a survival strategy. This group would rather incur loss of soil than commit their resources to controlling soil erosion since the costs incurred would reduce the anticipated financial gains.

Fourth, high labour turnover rates on estates are the cause of labour deficiency because hired labourers and sharecroppers frequently change jobs in light of wages and difficult working conditions (WB, 1991, p 12). This factor also contributes to suboptimal land-use practices. The other reason for the high soil loss observed on tobacco estates sampled by this study is that they all used the visiting-tenant system.

Regional comparisons using the Kruskal-Wallis test show that estate farmers used more or less the same amount of labour in each region according ($X^2 = 0.50$, $p = 0.91$). On the other hand, there are significant variations within smallholders ($X^2 = 17.0$, $p = 0.007$). For example the smallholders in Dowa and Lakeshore used significantly less labour than in the Scarp and Lilongwe regions. Smallholders with significantly lower amount of labour, e.g., in the Dowa Hills may possibly have hired out their family members as labourers in order to generate extra income. However, the fact that these farmers heavily depend on family labour may also suggest that those in the Dowa Hills had fewer family members working on the farm than in the other regions. In terms of controlling soil erosion, though, the regional variation is of little significance because labour is generally deficient (Table 6.19). Estate farmers and smallholders who are labour deficient (Table 6.19) in the study area are unlikely to adopt all the soil-conservation measures that are advocated by the Government.

6.3.2.3.4 Farm Equipment

The negative and positive contributions by farm equipment to the models of estate farmers and smallholders respectively can be attributed to the overall difference in the number of all hand implements (hoes, axes, and pangas) used in land preparation (Tables 6.8 and 6.20). Although estate farmers owned more hand tools such as hoes, and pangas, the use of mechanised equipment by both farmer groups was generally low (Table 6.20). Insufficient use of ox-drawn implements by estate farmers is due to the inadequate supply of draught animals, but for smallholders, the small sizes of the land they cultivate impede their use.

Table 6.20: Mechanized and non-mechanized equipment used commonly by farmers; Linthipe River Catchment, Malawi, 1998

Farmer	Equipment	No. of equipment by region				Total
		Dowa	Lakeshore	Lilongwe	Scarp	
Estate	*Non-mechanized*					
	Hoes	203	770	257	895	2125
	Shovels	6	31	12	5	54
	Pangas	93	389	55	141	678
	Axes	87	368	44	122	621
	Mechanized					
	Tractors	1	2	1	0	4
	Ploughs	1	7	23	0	31
	Ox-carts	4	6	18	0	28
Smallholder	*Non-mechanized*					
	Hoes	195	27	122	266	610
	Shovels	6	2	2	0	10
	Pangas	57	6	15	87	165
	Axes	74	8	16	65	163
	Mechanized					
	Ploughs	0	7	1	0	8
	Ox-carts	0	2	2	2	6

The regional variation in farm-equipment ownership, especially hand tools is consistent with farm size; those farmers working bigger holdings tending to own more than those cultivating small ones. For instance in the Lakeshore region, where there were only 8 estate farmers sampled, but two of the estates occupy more than 1000.0 ha, the number of hand tools is the highest (Tables 6.20 and 6.10). Similarly, it was noted earlier on that both farmer groups owned bigger holdings in the Scarp and Dowa Hills. These are also the regions with higher numbers of farm equipment than in the Lilongwe region. Again the regional variation in hand tools is of little benefit in view of the lack of mechanization.

Greater use of hand tools rather than mechanised implements is not a survival strategy *per se*, but the allocation of more labour to farm operations other than soil conservation, is a survival strategy in that it is induced by the lack of mechanisation. In view of the inadequate use of mechanised equipment, it is logical to conclude that generally there is drudgery in farm operations of both farmer groups irrespective of geographic region. This inadequacy implies that most farm operations, such as weeding, banking, pest control, and others have to be done manually using the inadequate labour thereby diminishing the farmers' capability to cope with problems of soil erosion. Under such circumstances, farmers would rather strive to achieve high crop yields by using the available labour to reducing weed-crop competition, for instance, instead of controlling soil erosion. Consequently severe soil losses are being perceived and recorded.

6.3.2.5 Farm Output

6.3.2.5.1 Maize Yields

The estimated mean yield for estate farmers' was about 1.46 t ha^{-1}, which was 26.54% of the potential aggregated yield of hybrid and local varieties (5.5 t ha^{-1}), while smallholders realized only 1.08 t ha^{-1} or 19.6%. This difference between estate farmers and smallholders notwithstanding, the yields realized by both farmer categories are lower than the potential yields as proclaimed by the MoA (Tables 6.6 and 6.21). These low yields are not surprising considering that both farmer categories applied low quantities of fertilizers. This result explains the positive regression coefficients of maize yield in both models (Table 6.8).

Table 6.21: Estimated maize yields among smallholders and estate farmers categories; Linthipe River Catchment, 1997/98

Farmer	Variable	Yield (t ha^{-1} yr^{-1} by geographic region				Total
		Dowa	Lakeshore	Lilongwe	Scarp	
Estate	Range	0.31-3.91	0.31-3.12	0.24-6.01	0.39-0.80	0.24-8.0
	Mean	1.29	1.55	1.41	1.60	1.46
Smallholder	Range	0.07-7.5	0.09-4.68	0.16-6.87	0.35-8.0	0.07-8.00
	Mean	0.94	0.78	0.11	1.79	1.08

Table 6.22: Number of farmers insufficient or sufficient in maize; Linthipe River Catchment, 1997/98

Farmer	Yield class	No. of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	Insufficient	21	8	50	43	122	97.6
	Sufficient	0	0	2	1	3	2.4
	Total	**21**	**8**	**52**	**44**	**125**	**100**
Smallholder	Insufficient	66	78	36	43	223	97.8
	Sufficient	2	0	1	2	5	2.2
	Total	**68**	**78**	**37**	**45**	**228**	**100**

The Kruskal-Wallis test shows that between the regions, estate farmers in Lilongwe had significantly lower yields than the rest (X^2 = 18.73, p = 0.0003). On the other hand, smallholders in the Scarp achieved significantly higher yields than in the other regions (X^2 = 45.49, p < 0.0001). The significant regional variations in yields seem to be consistent with mean sizes of cultivated land and mean quantities of fertilizers applied in the regions (Tables 6.10, 6.12, and 6.21), suggesting that farmers can only realize higher yields by extending the areas that cultivate. Chipande (1988, p 166), also made a similar observation.

Crop yield has been related to ground cover, as illustrated by data from Zimbabwe. Elwell (1978a, p c4), and Elwell and Stocking, 1982) reported that 'on average' good cover is associated with high yield, and poor cover with low yields for all crops. The implication of this relationship is that crop cover must have been generally low on maize fields belonging to the majority of estate farmers as well as smallholders that applied inadequate quantities of fertilizers. Besides enhancing the likelihood of soil erosion due to poor cover, the other implication of low yields of this staple food crop is low labour availability on holdings of farmers because they must have been forced to hire out family members. Again, since labour is an important socio-economic variable that influences the adoption or rejection of soil-conservation practices, it is improbable that farmers (irrespective of geographic region and category) who are deficient both in maize yields (Table 6.22) and labour could effectively control soil erosion on their holdings.

6.3.2.5.2 Tobacco Yields

The estimated mean tobacco yield (Table 6.23) among estate farmers was about only 1.18 t ha^{-1} or 39.3 % of the average yield of the proclaimed levels, whereas that for smallholders was considerably lower than that realised by estate farmers (Tables 6.6 and 6.23). Further examination of the data reveals that over 90% of tobacco growers realised yield levels that were lower than the average of the proclaimed potentials (Table 6.24). Again, the difference in estimated yield levels between these farmer groups is attributed to the differences in the amounts of fertilizers used (Table 6.15). These low yields also explain the positive manner in which this variable contributes to the regression model (Table 6.8).

Table 6.23: Estimated yield of tobacco among smallholders and estate farmers; Linthipe River Catchment, 1997/98

Farmer	Variable	Yield ($t\ ha^{-1}\ yr^{-1}$) by geographic region				Total
		Dowa	Lakeshore	Lilongwe	Scarp	
Estate	Range	0.32-7.50	0.69-3.14	0.19-3.67	0.55-3.53	0.19-7.50
	Mean	1.46	1.09	0.71	1.62	1.18
Smallholder	Range	0.07–4.0	-	2.35	0.88-1.76	0.07-4.0
	Mean	0.35	-	-	0.06	0.14

Table 6.24: Number of farmers that were deficient or sufficient in tobacco yield; Linthipe River Catchment, 1997/98

Farmer	Yield class	Number of farmers by geographic region				Total	% of Total
		Dowa	Lakeshore	Lilongwe	Scarp		
Estate	Deficient	18	6	51	40	115	92.0
	Sufficient	3	2	1	4	10	8.0
	Total	**21**	**8**	**52**	**44**	**125**	**100**
Smallholders	Deficient	18	0	0	13	31	96.9
	Sufficient	0	0	1	0	1	3.1
	Total	**18**	**0**	**1**	**13**	**32**	**100**

A comparison between the regions using the Kruskal-Wallis test indicates that Lilongwe estate farmers had significantly lower yields than those in Dowa and Scarp ($X^2 = 18.52$, $p = 0.0003$). The significant regional differences in tobacco yields are also a function of size of cultivated land and quantities of fertilizers applied by farmers (Tables 6.8 and 6.14). However, these regional differences are of little consequence in as far as regional variation in controlling soil erosion is concerned because the yield was low overall.

Low returns from tobacco mean that farmers cannot, first, afford to pay attractive wages to their visiting tenants, who also depend on farming for survival. Second, they cannot offer alternative incentives to retain the labour force. Therefore, as visiting tenants move, in search of better working conditions, tobacco growers lose a resource that is already deficient. Under such situations, it is inevitable that soil-conservation suffers because it is likely that most of all the labour is allocated to operations that are perceived to be directly relevant to improving crop yields, as opposed to soil-erosion control.

6.3.2.5.3 Farm Income

As elsewhere in Malawi, estate farmers earned approximately 5 times more farm income than smallholders (Table 6.25). That about 71% of estate farmers were income-sufficient while 75% of the smallholders were deficient in earnings also explains the differences in the way this variable contributes to the perceived (in essence observed) degree of soil erosion (Tables 6.26 and 6.8).

Table 6.25: Ranges and means of farm income by farmer category; Linthipe Drainage Basin, 1997/98

Farmer	**Variable**	**Amount by geographic region (MK '000)**				**Total**
		Dowa	Lakeshore	Lilongwe	Scarp	
Estate	Range	0-200	0-1000	0-50	0-400	0-1000
	Mean	61.4	262.5	23.1	82.9	65.9
Smallholder	Range	0-100	0-50	0-50	0-50	0-100
	Mean	23.5	11.6	3.9	6.5	12.8

Table 6.26: Number of farm-income deficient and sufficient farmers; Linthipe River Catchment, 1997/98

Farmer	**Income class**	**Number of farmers by region**				**Total**	**% of Total**
		Dowa	Lilongwe	Lakeshore	Scarp		
Estate	Deficient	4	4	28	1	37	29.4
	Sufficient	18	4	24	43	89	70.6
	Total	22	8	52	44	126	100
Smallholders	Deficient	38	63	35	40	176	75.2
	Sufficient	30	19	3	6	58	24.8
	Total	68	82	38	46	234	100

According to the Kruskal-Wallis test, there are highly significant differences ($X^2 = 23.05$, $p < 0.0001$) in income levels between estate farmers in the Lilongwe Plain and the other regions (Scarp and Dowa). There is also considerable variation in income across the regions among smallholders; farmers in the Lilongwe Plain earning the least income while those in the Dowa had the highest ($X^2 = 22.86$, $p < 0.0001$). As suggested earlier, these regional variations in income appear to be consistent with other variables, such as, farm size, fertilizer-application rates, and crop yields.

Farm income has been associated with farmers' ability to practice soil conservation (Lee, 1980). The significant regional variations in income would have, therefore, meant correspondingly better soil conservation, hence low soil erosion (perceived or observed) in the regions where farmers earned sufficient income, e.g., the Dowa Hills and Scarp for estate farmers, then the Dowa Hills and Lakeshore regions for the smallholders. This is, however, not the case in the Linthipe Watershed. The data show that labour, fertilizers, and crop yields, are generally insufficient mainly because the farm income is low and there are competing demands for cash. Farmers are, therefore, forced to use limited farm inputs, and hence farm outputs are low. In turn, the low outputs force farmers to adopt survival strategies, which constrain their ability to effectively implement soil-conservation practices, hence the continued loss of soil from cultivated land.

6.4 Summary

This Chapter set out to ascertain if farmers were aware of the magnitude of soil erosion, and its effects on their holdings. Additionally, it aimed to identify the principal socio-economic variables that inhibit farmers from practicing soil conservation optimally. This information is valuable in verifying the research hypothesis and addressing its objectives.

Socio-economic data collected from the Linthipe Catchment ascertains farmers' awareness of the degree of soil erosion and soil-loss effects on their land. Their perception of the degree of soil erosion is consistent with the observed soil-loss data. Second, their mention of loss of crop yield as the dominant effect is also supported by the low crop yields, although the low use of fertilizers also contributes to this problem. These results are indicative of indigenous knowledge apart from the conservation campaigns that have been going on for years. Additionally, these data confirm that constraints do prevent farmers from implementing soil-erosion control measures effectively. Therefore, these results verify the hypothesis of this dissertation. Principal variables that force farmers to adopt survival strategies, thereby contributing to soil erosion among estate farmers are sources of farming knowledge, farm size, low-fertilizer application rates, and low crop yields. On smallholders' holdings, similar factors contribute to soil erosion in addition to shape of cultivated land, equipment, and labour; the exception is source of farming knowledge, which seems to be advantageous to farmers in this category. The difference in contribution of principal variables to soil erosion on holdings of smallholders and estate farmers is largely due to the differences in the socio-economic status of these farmer groups.

If these are the principal factors that contribute to soil erosion, then it is logical to infer that their amelioration would be helpful in reducing the observed and perceived soil losses. To this end, the next Chapter provides a set of various recommendations that might help to mitigate the socio-economic constraints.

Chapter 7

Conclusions and Recommendations

7.1 Introduction

This dissertation has attempted to provide an understanding of why soil loss in the Lake Malawi Basin, specifically in the Linthipe Watershed, is high notwithstanding the availability of various soil-conservation practices. In this regard, Chapter 1 established the scientific rationale of this study, which is the threat that increased sediment discharges from the Lake's basin are posing to the ecological integrity and socio-economic importance of aquatic biodiversity. This being the case, the same Chapter iterates that the rich and diverse ichtyofauna of Lake Malawi (Hecky, 1993) needs conserving for the benefit of the riparian states and the scientific community of the world.

Chapter 2 describes the nature of the soil-erosion problem, including successes and failures of the various methods that have been, and continue to be, used to control loss of soil. In view of the continued soil erosion, the need for study was as pressing as the severity of the problem and the necessity for conservation. To provide the necessary understanding, the dissertation, in Chapter 2, formulated objectives that are relevant to verification of the following hypothesis:

> *that although farmers in Malawi do recognize soil erosion as a problem, they do not regard soil-conservation measures to be of sufficiently high priority when*

viewed against the potency of survival strategies that confront them, hence there continues to be a loss of soil from their farms.

As a prerequisite to verifying the hypothesis, the dissertation presented the scientific justification for this work (Chapter 1) followed by a review of the problem and pertinent literature (Chapters 2 and 3) necessary to understand the context for development of the objectives of the study. Chapter 4 described the Linthipe Drainage Basin in relation to the physical and anthropogenic determinants of soil erosion. Chapters 5 and 6 presented methods necessary to address each of the stated objectives and reviewed the analytical approaches that were used to produce statistical tests of the data. Furthermore, these Chapters described the specific results of each objective. This concluding Chapter restates the salient results of this study; presents results in relation to the pertinent scientific literature; and then examines the management implications of the results within the context of the ongoing requirement for biodiversity management within the Lake and its catchments.

7.2 Conclusions

A review of the literature suggests that Malawi is generally susceptible to soil erosion on account of high amounts of rainfall energy, steep slopes, erodible soils, and declining vegetation. This vulnerability is however, exacerbated by human activities due to an increase in population. An examination of the human population trend confirms that population growth is an important factor, as it contributes to environmental degradation in general (Kalipeni, 1992a), and soil erosion more specifically. For example, Chapter 2 showed that population growth created an increased demand for arable land. Consequently, the nation's arable or nutritional density has increased, an indication that food sufficiency is on the decline.

Another consequence of declining nutritional density is shrinkage in the size of holdings particularly among smallholders. This shrinkage implies that sound soil-erosion control practices that minimise soil erosion, for example crop rotation, and artificial waterways or storm drains that prevent gully formation, cannot be implemented effectively because they require large areas of land. Furthermore, small size of holdings means that subsequent generations will inherit even smaller holdings with even more limited opportunities for subsistence and soil conservation. Apart from increasing the demand for arable land, rapid population growth has created a momentum that results in greater demand for trees for fuelwood and construction. Consequently, there is deforestation that further results in soil erosion. Combined with the ecological consequences, socio-economic stress, for example unemployment, poverty, and diseases ensue (Kalipeni, 1992a; House and Zimalirana, 1992).

The general situation described for Malawi in Chapters 2 and 3, also applies to the Linthipe Watershed, which is the second most important catchment in terms of sediment discharge into Lake Malawi. Physical characteristics, such as steep slopes, high rainfall energy, and poor vegetation, combined with a human-population density that exceeds the national average, renders the Linthipe Catchment highly vulnerable to soil erosion. This fact is confirmed in Chapter 5, which illustrates that according to soil losses predicted by the modified SLEMSA, the whole catchment is generally vulnerable to soil erosion on account of steep slopes, intense rainfall, and poor vegetation. Regions of the highest soil-erosion risk are the Dowa Hills and Scarp, specifically because of steep slopes, and removal of natural vegetation for agriculture and settlement. In contrast, the Lilongwe and Lakeshore Plains are less susceptible to erosion than the Dowa Hills and Scarp because of low relief. Since validation data also indicate that rates of soil loss are higher on arable land, especially cultivated farmland than in areas of natural vegetation, it is inferred that vegetative cover removal is the single most important variable determining soil-erosion risk distribution in the study area. Consequently, predicted soil losses indicate that approximately 63% of the Linthipe Watershed has soil-erosion risk that is moderate to severe. The importance of vegetation is further highlighted by the land-cover change scenarios, which suggest that the proportion of the catchment with low soil-erosion risk could increase up to about 81% if crop cover improves and reforestation is undertaken. The high level of agreement, in terms of relative accuracy, between predicted and observed soil losses gives confidence to this conclusion.

Results from analysis of socio-economic data (Chapter 6) confirm that farmers are aware of soil-erosion problems and the effects of soil loss on their land. Therefore, the occurrence of high rates of soil erosion is not due to ignorance, a fact that is clearly supported by farmers' use of different soil-conservation methods in the study area. The second socio-economic issue of significance was an explanation as to why, in light of the use of conservation measures, farmers are losing large quantities of soil. Chapter 6 showed that the principal variables that contribute to soil erosion among estate farmers are farming knowledge source, farm size, low-fertilizer application rates, and low crop yields. Similar factors contribute to soil erosion on smallholders' holdings, in addition to shape of cultivated land, equipment, and labour; the exception is source of farming knowledge, which is the only variable that helps to reduce soil loss under this type of farming. These variables contribute differently to soil erosion on holdings of estate farmers and smallholders thereby underscoring the differences in the socio-economic status of these two major farmer categories. It is deduced that deficiencies in inputs such as labour, and fertilizers, and low returns in the form of crop yields and farm income, force these farmers to adopt survival strategies that lead to ineffective implementation of the recommended soil-conservation practices. Consequently, excessive soil erosion occurs in the catchment so that high rates of sediment are discharged into Lake Malawi, where they have detrimental ramifications for biodiversity conservation. Based on these results, it is speculated that unless these socio-economic constraints are ameliorated, the observed soil erosion and sedimentation discharge will continue unabated. As sediments keep on accumulating in the Lake, they will not just be a mere threat to the fish communities, but they might cause extinction of fish species, thereby diminishing both the ecological integrity and socio-economic significance of the Lake.

7.3 Recommendations

There is compelling evidence that poor vegetation is the most important determinant of soil erosion in the study area, especially on agricultural land. It is also abundantly clear that the poor crop cover is due to socio-economic constraints that prevent farmers from implementing soil-conservation measures effectively. Therefore, to sustain agricultural productivity in the Lake Malawi Basin, specifically the Linthipe Drainage Basin, it would be prudent if the GoM aimed at retaining the present cover under natural vegetation, improving cover on agricultural land, and restoring cover on cultivated land of marginal quality. Implementation of these recommendations will hopefully reduce loss of soil and fertility as well as help to conserve the biodiversity of Lake Malawi sustainably. Means of implementing these recommendations are elaborated in the succeeding subsections.

7.3.1 Retaining Natural Vegetative Cover

Chapter 4 showed that encroachment into protected areas was due to the increase in demand for land for cultivation and harvesting of fuelwood. In addition to these reasons negative public attitudes also contribute to encroachment. Vandalisation of park property (e.g., fences) is another way by which the public manifests its negative attitudes (Munthali and Mkanda, *in press*). There are two reasons for these negative attitudes. First, the benefits of keeping land under natural vegetation in the form of protected areas have not been fully demonstrated to the general public. Rationale for protected areas in Malawi are summarised by Orr *et al.*, (1998, p 28) as follows:

i) catchment and steep-slope protection;

ii) conservation of wildlife and forest resources through managed utilization, including consumptive utilization (harvesting of fuelwood, timber and non-forest products) and non-consumptive utilization (primarily tourism);

iii) conservation of biological biodiversity, and the preservation of examples of wildlland types as scientific and educational assets; and

iv) preservation of wildlands for their aesthetic and amenity values.

It has been previously argued that values of protected areas have for a long time appeared to be nebulous (Mkanda, 1991), as consumptive utilization of resources in national parks and wildlife reserves, for example, did not start until 1985. Mkanda and Munthali (1994) contend that use of wildlife resources in protected areas by rural communities is not a new idea. Examples of resource harvesting in protected areas include collection of firewood, medicinal plants, thatch grass and reeds *Phragmites australis* and bee keeping and Saturniidae caterpillar utilization in Kasungu National Park (Munthali and Mughogho, 1992). Prior to 1985, however, the Government did not do much to provide tangible benefits to rural communities (Mkanda, 1995).

Aesthetic and amenity values, as a rationale for setting aside protected areas, are not good enough for garnering public support because access to these areas is by motor vehicles, and few if any small farmers own cars. Even those with cars do not visit these areas for recreation because of what Lusigi (1981) termed the "structure of the Kenyan society", which is also the case in Malawi. For instance, the extended family system encourages sharing of resources and material wealth; hence people who have the resources and means of visiting protected areas would rather spend their time and extra money with relatives and friends. Consequently, it is only few Malawians, for example students and teachers on educational visits, some government officials, and individuals belonging to nature conservation clubs that visit these areas at no cost, and in the process they get to appreciate their recreational, amenity and educational values. The majority of Malawians have viewed protected areas as a domain of a privileged few. Therefore, the predominant perceptions are negative, because protected areas are seen to be locking up resources that would otherwise have been readily available for exploitation.

Negative attitudes are also augmented by the adversarial nature of the early approaches to conservation by the colonialists, and perpetuated by the GoM in the early days of independence. Different studies that have examined socio-economic issues in natural resource conservation in Malawi point out that early conservation methods were confrontational, be it in agriculture, forestry, or wildlife management (Kettlewell, 1965; Bell, 1984; Mkanda, 1991; Munthali and Mughogho, 1992; Mkanda and Munthali, 1994). These studies show that there was total disregard for indigenous conservation methods such as shifting cultivation in agriculture or use of beliefs such as totemism[39], to conserve wildlife.

In its effort to win the support of local communities in natural resource conservation, the GoM, through the DNPW has since 1985 allowed local communities to collect, on a sustainable basis, some resources (for example thatch-grass, mushrooms, termites and Saturniidae caterpillars) and to practice bee-keeping, in and around the protected areas. The main objective of these micro-enterprises is to diversify the rural people's economic base and, consequently, encourage them to adopt natural resource management as an adjunct to subsistence agriculture.

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[39] It was a taboo for a family whose totem was, for example an elephant, to hunt that animal.

In an examination of potential resources that the public could utilize from protected areas, Mkanda and Munthali (1994) found that bee-keeping, firewood-gathering, and tree-caterpillar collection were some of the activities that 90% of respondents to questionnaire interviews believed were beneficial as a source of food and income. This high percentage is a reflection of a potential for positively changing public attitudes towards protected areas, as households are highly unlikely to abuse a resource from which they derive benefits. Infield (1988) showed that benefitted households are more likely to support conservation than non-benefitted ones. This result is, therefore, enough justification for encouraging these activities. Furthermore, these micro-enterprises have proved to be economically superior to subsistence crops, as they generate extra income by more than 100% (Munthali and Mughogho, 1992). Bell (1984, p 310) asserted that extra income from natural resources could be used to purchase farm inputs to improve crop production. This would catalyse a gradual transition from mere subsistence to a cash-crop economy.

However, in spite of these positive indications, the micro-enterprises have not been actively promoted. Munthali and Mkanda (in press) contend that the major reason these activities are not widespread yet is the *adhoc* manner in which the Government has been promoting them. In most cases there has been inadequate information on their economic viability and efficiency. Consequently, interested rural communities feel that there is an element of risk associated with these activities. This being the case, they are unable to participate because they do not want to take risks. In view of the potential that micro-enterprises have in reducing encroachment into protected areas, there is a need to actively promote them so that rural communities can improve their income thereby positively changing their attitudes.

Methodical implementation of the micro-enterprises will require that the Government entrust these activities in the hands of the private sector that could work jointly with the rural communities to establish grass-roots institutions. Government's role would be to provide administrative support and technical guidance.

7.3.1.1 Promote Ecotourism

Promotion of ecotourism[40] could also be useful in generating income that communities can use as capital for propelling smallholder farming into a cash economy. Secondly, it could change people's attitudes positively towards protected areas, thereby reducing further encroachment. Elsewhere in southern Africa, community-based ecotourism has been developed as a means of diversifying the local communities' income base. Notable examples include the community ecotourism initiative in Ndumo Game Reserve, where the Kwazulu/Natal Nature Conservation Service in South Africa involves local communities in providing an overnight facility at the entrance to the reserve (Munthali and Mkanda, in press). Similarly, in Namibia, besides campsite development by local communities and the provision of local tourism guides, and bed and breakfast in traditional homes, there are numerous examples of joint ventures between the private sector and local communities in the development of ecotourism. Community members control the income that is earned from these ventures and they use it to boost local development and conservation (Munthali and Mkanda, in press).

[40] Ecotourism is tourism to ecologically and culturally sensitive areas; it reflects the integrity of national and socio-cultural environments, contributes to environmental conservation, provides enlightening and meaningful experiences for tourists, and brings long-term benefits to the tourism industry and the local economy (Mannion, 1997, p 285).

Ecotourism could, in fact, be a foundation for viable and sustainable CBNRM programmes in Malawi. The guiding principle under the CBNRM is one of sustainable rural development that enables communities to benefit directly from natural resources, and support their management programmes. It provides local communities with incentives to conserve natural resources such as soil, water, woodlands, arable land and grazing land (Patel, 1998). In southern Africa this philosophy is being promulgated through three major projects, namely the CAMPFIRE in Zimbabwe, the ADMADE in Zambia, and LIFE in Namibia. Besides these examples, several prototype models are being replicated in many southern African countries, hence there is opportunity for Malawi to learn from the diverse experiences within the SADC. However, unlike other southern African countries, where local communities engage in CBNRM activities in buffer zones and communal areas, in Malawi, where protected areas are "islands" surrounded by human settlements, communities have to be allowed to undertake CBNRM activities inside these areas.

Development of community-based ecotourism around and within Malawi's protected areas would be consistent with the Government's goal of alleviating poverty in the rural areas, and would be seen as one of the ways by which communities could emancipate themselves from the web of subsistence livelihoods. Rural communities would undoubtedly be willing to participate, as they do not necessarily want to remain backwards and wedded to a largely subsistence livelihood (Munthali and Mkanda, in press). However, any investment promoted for the local communities neighbouring protected areas should be preceded by a community's needs assessment and socio-economic evaluation. This would help in promoting activities that are acceptable, economically viable, and sustainable.

7.3.1.2 Strengthen Law Enforcement in Protected Areas

Irrespective of availability of incentives to local communities, for example revenues from ecotourism, there will always be individuals who will continue encroaching into protected areas. Therefore, enhancement of law enforcement should always be a priority. This study suggests strengthening the statutes and capacity of all the government agencies responsible for public land such as forest reserves, wildlife reserves, and national parks to curb the current rate of encroachment. Presently, penalties are far too lenient to act as deterrents to poaching or human encroachment into protected areas (also refer to Mkanda, 1993). Part of the revenues earned from ecotourism can be re-invested in strengthening the law enforcement capacity. It has been reported that increasing an overall law enforcement budget led to increased law enforcement capabilities, e.g., improved investigation techniques, which concomitantly enhanced wildlife conservation in the Luangwa Valley, Zambia (Jachmann and Billiouw, 1997). Government institutions that are responsible for management of protected areas, for example DNPW and the DFor would, therefore, benefit by learning from these experiences. Concomitant to strengthening statutes and increasing penalties, the monitoring and surveillance capabilities of these departments will require improvements. For instance, encroachment can be minimised by using satellite imagery to annually monitor changes in vegetation. Once it has been detected, timely remedial measures can be taken to prevent its escalation.

7.3.2 Improving Cover on Arable Land

Farm inputs such as fertilizers and labour have been identified as some of the constraints that limit effective control of soil erosion on cultivated land because of poor crop cover.

Two ways could be used to reverse this situation. First, better use of agronomic practices, agroforestry, and soil-management techniques. As stated earlier on, all these methods are not new to Malawi, it is only that socio-economic constraints force farmers to employ them suboptimally. Therefore, it seems that the long-term solution lies in the removal of the socio-economic constraints that inhibit farmers from using optimal soil-conservation measures. Ecotourism and CBNRM initiatives appear to be viable options for generating income, but provision of favourable credit terms for farm inputs is also an approach that seems feasible. Second, it would be pertinent to reduce the need for farmers to open up land that they are presently keeping uncultivated.

7.3.2.1 Removal of Socio-Economic Constraints

Agricultural intensification has to increase by means of providing a social and economic environment that will enable farmers to use high-yielding crop varieties, and more fertilizers. An improved socio-economic environment would help eradicate, or at least minimise, the need on the part of farmers to extend farmland and cultivate steep slopes as a means of improving productivity. To alleviate the problem of input availability, the GoM's structural adjustment policies of the 1980s focused on stimulating smallholder agriculture (Sahn and Arulpragasam 1991). Hence the Government either facilitated or provided farm inputs such as fertilizers and improved seed on credit in order to improve agricultural productivity (Chipande 1988, p 165; Sahn and Arulpragasam 1991). Farmers who have access to credit (based on their ability-to-pay) and, hence, can afford to use innovations, such as fertilizers and improved seed, have improved their farm productivity

(Chipande 1988, p 168 and 169). Therefore, the pressure for such farmers to cultivate more land in order to increase farm output is diminished.

Among those farmers who are unable to acquire inputs on credit, farm output has, however, stagnated (Sahn and Arulpragasam, 1991). Stagnation has specifically occurred among the majority of smallholders because they are disadvantaged by 'the ability-to-pay' credit criterion, which implies that farmers must first of all produce surpluses and sell them in order to qualify for credit. As smallholders are the ones who often face food deficits (Chipande, 1988, p 170), they do not warrant consideration for loans. Consequently, they have little alternative but to bring more land into cultivation.

In view of the limited access to credit by smallholders, it would be appropriate for the MoA to explore means of providing favourable terms of credit to the disadvantaged farmers. Since the problem at hand is primarily that of survival, involving the need for sustainable agriculture and to conserve the biodiversity of Lake Malawi, a multi-faceted approach is advocated. Involvement of all relevant government agencies and other institutions would, therefore, be appropriate. This approach befits a problem of this magnitude, which transcends the official jurisdiction and mandate of a single government institution. In this regard, it is suggested that both the MoA and DFis, besides other stakeholders, and credit institutions, be involved in formulation of credit criteria that are favourable to the socio-economic situations of farmers', especially smallholders.

While increased use of fertilizers may aid soil conservation by improving plant health and cover, which is essential in minimising raindrop impact, consequences of increased nutrient input on farmland, and subsequent discharges into the Lake, however, would need investigating. Bootsma and Hecky (1999, p 2) have shown that the quality of water in Lake Malawi may be changing as a result of nutrient input from the catchment. Therefore creation of another problem in the course of resolving the current one must be avoided.

7.3.2.1.1 Alleviation of Labour Constraints

Considering the small sizes of holdings that limit mechanisation, this study advocates use of technologies that simultaneously alleviate farm-labour deficiencies and the vulnerability of soil to impacts of raindrops. One such technology involves leaving plots unweeded so as to supplement ground cover in maize crops. The experiment at the Bunda College Farm in Lilongwe has shown that unweeded plots lose about 4.5 t ha^{-1} yr^{-1} of soil compared to 12.1 t ha^{-1} yr^{-1} on weeded plots (Weil, 1982). Therefore it could be advocated as a means of reducing soil loss on agricultural land. Although the loss of soil from weeded plots is within the tolerable limit of about 12.7 t ha^{-1} yr^{-1}, this study argues that reducing the soil-loss rates further is preferable for sustainable agricultural productivity and aquatic biodiversity. The study at Bunda College also demonstrated that excellent yields of maize can be produced without weeding, for example 12.12 t ha^{-1} yr^{-1} when compared to 13.66 t ha^{-1} yr^{-1} on weed-free plots with similar fertilizer application rates and planting densities. Although there is a reduction in maize yield on unweeded plots, the benefits of the unweeded maize system in terms of labour demands and soil conservation are considerable. The annual savings of about 8 t ha^{-1} yr^{-1} of soil would seem to be potentially great enough benefit to offset yield reductions in the long run (Weil, 1982).

In making this recommendation, the study is fully aware of potential resistance that the advocated technologies may engender. However, the long-term benefits (sustainable agriculture and aquatic biodiversity) outweigh the short-term considerations by farmers. The main challenge with use of technologies such as unweeded plots and mulching as a conservation tillage practice is their acceptability by farmers. In Malawi, weeding is undertaken twice (Lorkeers, 1992, p 72), and one of the reasons for doing it is insect-pest reduction (GoM, 1992, p 8); aesthetically, a weeded plot looks more appealing than an unweeded one. Therefore to ask farmers to keep their plots unweeded might bring about disagreement.

Resistance to innovations, however, is not new among farmers in Malawi. When the colonial government introduced contour and box ridging in the 1940s, lots of farmers resented them because they were viewed as alien and hence in conflict with normal tillage practices that involved planting on the flat or mounds (Kettlewell, 1965). After years of using different techniques that included persuasion, propaganda, and coercion, the great majority of the farmers complied. Contour ridging and box ridging were adopted into the traditional farming system (Mlia, 1987, p 11). This study does not advocate re-introduction of coercion and punishments, as employed during the colonial rule. Rather, it wishes to recommend an investigation into the acceptability of different labour-saving technologies and soil-conserving practices by farmers so that appropriate extension and rural sociology techniques are used to encourage their adoption.

Conservation tillage or planting without ploughing is the other practice that needs promoting to circumvent labour deficiency. This technology sprung from the recognition that mechanical ploughing contributes to land degradation on a massive scale (FAO, 2000). In the system of conservation tillage, farmers reduce the number of tillage operations, and maintain crop residues as mulches in the fields instead of removing or burning them. Often it is accompanied by use of cover crops underneath the main crop or between two different crops in order to protect the soil. The benefits of this system are numerous, and they include soil nutrient enrichment, reduction in labour and farm power, as well as less soil erosion (FAO, 2000). In Ghana, soil loss under this practice was observed to be less (0.02 kg m^{-2}) than in traditional tillage using hoes where the soil-erosion rate was 0.09 kg m^{-2} (Baffoe-Bonnie and Quansah, 1975). It also caused the least soil compaction, conserved the most soil moisture, and reduced losses of organic matter, nitrogen, phosphorous, and potassium (Quansah and Baffoe-Bonnie, 1981). The current initiatives to promote this type of farming in Malawi (FAO, 2000) are, therefore, highly commended and should be further encouraged in the Linthipe Watershed.

Other labour-saving technologies include use of old ridges and modified ridges (Kumwenda, 2000). In the former, a crop such as maize is planted on the same planting station as previously occupied by tobacco. Its advantages include decreased soil erosion because it is only planting stations that are disturbed, use of the residual fertilizer that was not utilized by the previous crop, increased water conservation, and enhancement of planting with the first rains thereby avoiding loss of crop yield. Research conducted in Malawi has shown that there is no significant difference in yields of maize grown on new ridges and the yield of maize grown on old ridges (Kumwenda, 2000). Based on these findings, it is suggested that this technology be also advocated in the Linthipe Catchment.

In modified ridging, farmers dig some soil from the old ridge into the furrow where there is more moisture and make a new planting station. During weeding, the farmer constructs a complete ridge along the furrow. This practice therefore reduces labour as it combines ridging and weeding both of which require 30% and 60% of the labour used (respectively) in maize production (Leach, 1996, p 42). Combining these two operations would definitely reduce the total labour, any surplus would therefore be added to the labour that is specifically used in soil conservation.

7.3.2.2 Reducing the Need to Open Up Uncultivated Arable Land

While the recommendations given in the preceding subsections may lead to improved agricultural practices, it is likely that there will be some laggards that may not adopt the recommendations immediately. Such individuals would most likely be tempted to bring any part of their uncultivated land into production in order to improve crop yield. To circumvent the occurrence of high rates of soil erosion on holdings of these late adapters, it would be prudent for the GoM to provide incentives for keeping this land uncultivated. Provision of free or subsidised farm inputs to farmers as compensation for keeping land uncultivated is one means of implementing this recommendation. Exemption of these farmers from payment of annual lease fees is the other way. In Chapter 1, it was stated that as part of promoting estate farming, annual fees were kept low and largely went unpaid. If the proposed approach were to work, then the current fee, which according to one estate farmer was only MK 50.00 per ha by 1998, would not be incentive enough for farmers to continue keeping their land uncultivated. Therefore increasing the annual fee to a level where it would be deemed more conducive to keeping land uncultivated than present is the only way of ensuring that such a practice is indeed beneficial to the farmer. It may be argued in certain Government quarters, for example the Treasury Department, that exemption of annual fees would imply loss of revenue. The long-term sustainability of two socio-economically important sectors (agriculture and fisheries) should, however, be reason enough to forego short-term revenue earnings. After all, revenue has been lost all along from unpaid fees.

7.3.2.3 Research into Possible Mixed-cropping of Tobacco

The GoM recognises the importance of mixed cropping in improving crop yield and optimisation of land and labour where their availability is limited. This study has demonstrated that the only socio-economic variable that currently helps smallholders to minimise soil loss is mixed cropping. However, tobacco, which is a poor-cover annual, is grown in pure stand. In view of this, and the role of this practice in reducing soil erosion, as shown in Chapters 4 and 5, it is suggested that mixed cropping should be extended to tobacco production. Prior to its introduction, there is a need for research in different agronomic aspects such as identification of the most suitable cover crops, and the impact of intercropping on tobacco yield, for example.

7.3.3 Restoration of Cover on Cultivated Land of Marginal Quality

Considering the severity of the problem in the Linthipe Watershed, and the benefits of reforestation as demonstrated by scenario 2 in Chapter 4, it is recommended that the present efforts that involve relocation of people from vulnerable areas to arable land should be extended to the study area, and all vulnerable areas vacated by the relocated farmers should be reforested.

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Appendix A

Geographic Regions of the Linthipe River Catchment

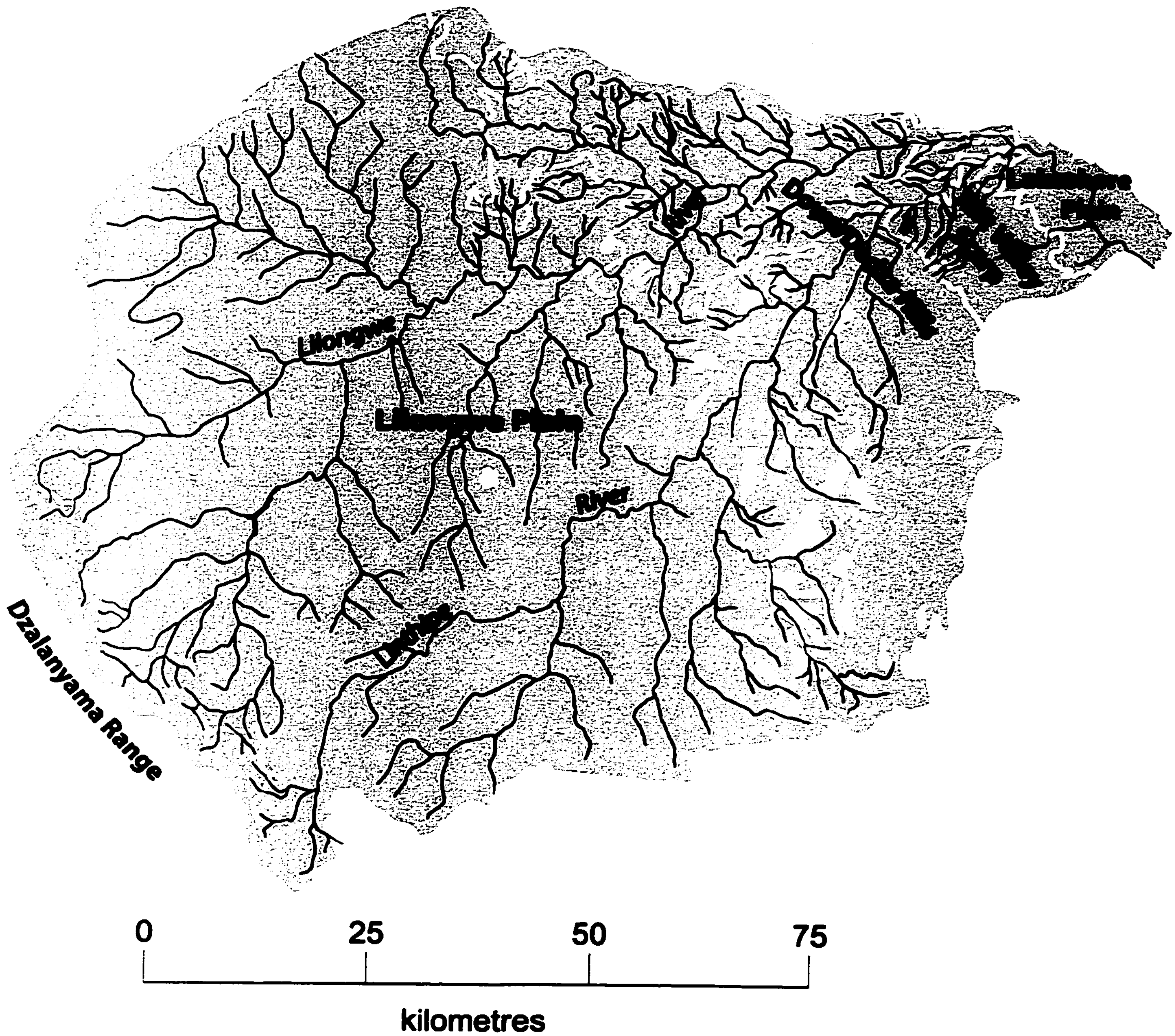

Fig. 1A: Geographic regions of the Linthipe based on geomorphological zones of the Lake Malawi Basin; white lines are approximate geographic region boundaries

Appendix B

Questionnaire for a Socio-economic Survey on Soil Conservation Practices in the Linthipe Watershed, Malawi, 1998/99 Farming Season

Date: ------------------ Sample number: ☐☐☐
EPA-----------------

SECTION 1: ATTITUDE, AWARENESS, AND PERCEPTION OF SOIL EROSION

1. Could you tell me what problems you faced in farming this piece of land last year?

   Low soil fertility-------------- ☐
   Lack of fertilizer-------------- ☐
   Lack of chemicals ----------- ☐
   Inadequate capital------------ ☐
   Inadequate labour------------ ☐
   Insect pests------------------ ☐
   Wildlife pests---------------- ☐
   Rodent pests----------------- ☐
   Diseases--------------------- ☐
   Damage by livestock--------- ☐
   Theft------------------------ ☐
   Low yield-------------------- ☐
   Low prices for produce------- ☐
   Lack of transport------------ ☐
   Soil erosion------------------ ☐
   Other (specify)--------------- ☐

If soil erosion is not identified as one of the problems, then go to question 2, otherwise go to 3.

2. I noticed that you have not mentioned soil erosion, does this mean that it is not a problem?

   No------0, Yes-----1 ☐

   If no, then go to question 7. If yes, then go to question 3.

3. To what degree do you consider soil erosion to be a problem on this piece of land?

   Not at all-----------1
   Very low-----------2
   Low----------------3
   Below average-----4
   Average------------5
   Above average-----6
   High----------------7
   Very high----------8 ☐

If not all, go to question 7, otherwise go to question 4.

Would you like to know the estimated soil loss on this piece of land?

   No------0, Yes--------1 ☐

5. If no, can you explain why?

   Not interested----------- ☐
   Not necessary----------- ☐
   Other (specify----------- ☐
   ----

6. If soil erosion is a problem, how have you dealt with it?

   Farm planning------------- ☐
   Crop husbandry ---------- ☐
   Conservation structures --- ☐
   Agro-pastoral systems ---- ☐
   Agroforestry---------------- ☐
   Not at all------------------ ☐

If the respondent's answer is 'not at all', or the respondent does not mention any one of the above measures, then go to question 7, otherwise go to question 8.

7. Which one(s) of the following terms sound(s) familiar to you:

Farm planning-------------- ☐
Crop husbandry ------------ ☐
Conservation structures ---- ☐
Agro-pastoral systems ---- ☐
Agroforestry----------------- ☐

8. In the cultivation of your crops, from field preparation to harvesting, can you please list some of the considerations you take into account?

Early field preparation ------- ☐
Timely planting -------------- ☐
Use of crop residue------------ ☐
Correct plant spacing---------- ☐
Appropriate inter-cropping--- ☐
Relay cropping---------------- ☐
Crop rotation------------------ ☐
Minimum tillage--------------- ☐
Zero tillage-------------------- ☐
Slope--------------------------- ☐
Planting fallow grass --------- ☐
Avoid tilling watercourses--- ☐
Other (specify)---------------- ☐

Ask question 9 only if conservation measures are taken.

9. Can you give me some idea of how many hours per week you spend on soil conservation on this piece of land during

Land clearing----------- ☐☐
Ridging----------------- ☐☐
Planting----------------- ☐☐
Weeding----------------- ☐☐
Banking----------------- ☐☐

10. How many hours per week do you work on this land during

Peak period ---------- ☐☐
Slack period---------- ☐☐

11. Could you give me an idea of when you maintain the soil conservation structures

At the beginning of the rains--1
During the rainy season--------2
At the end of the rains---------3
Whenever necessary-----------4 ☐

12. Approximately how much would these soil conservation measures have cost to either install or maintain last year?

None at all-----------------0
< MK 5000.00[41]------------1 ☐
MK 5001.00-10,000.00--2
> MK 10,000.00 ----------3
Don't know----------------4

SECTION 2: KNOWLEDGE OF SOIL EROSION EFFECTS

1. When soil is washed away, where do you think it ends up?

On this piece of land --------- ☐
On river banks---------------- ☐
In the streams/rivers---------- ☐
In the Lake--------------------- ☐
Other (specify)---------------- ☐
--------------------------------- ☐

[41] US$ 1.00 was approximately MK 25.00 in May 1998

In what way(s) do you think soil erosion affects your farming?

Not at all---------------------- ☐
Crop yield reduction--------- ☐
Nutrient loss------------------ ☐
Nutrient gain------------------ ☐
Other (specify)---------------- ☐
----

2. Do you have any idea how soil particles might affect rivers and lakes?

No------0 Yes---------1 ☐

If yes, in what ways?

Eutrophication------------------ ☐
Turbidity----------------------- ☐
Fish yield reduction----------- ☐
Fish species reduction--------- ☐
Lake depth reduction---------- ☐
Stream depth reduction------- ☐
Changes in river courses----- ☐
Other (specify)---------------- ☐

SECTION 3: FARMING PRACTICES

1. Would you kindly tell me the number of years you have been farming this piece of land?

☐☐

2. With respect to working and managing this piece of land, who makes the decisions?

Respondent----------1
Family elder---------2
Head person---------3
Owner----------------4
Operator------------ -5
Owner/operator-----6 ☐

3. Can you tell me what your tenure rights are to this piece of land?

Share cropper---------1
Communal------------2
Leasehold-------------3
Freehold---------------4 ☐

4. What crops did you grow on this piece of land?

Maize------------------- ☐
Tobacco---------------- ☐
Cotton------------------ ☐
Groundnuts------------- ☐
Other (specify)--------- ☐
----

5. What was the area in hectares under the following crops?

Maize--------------- ☐☐☐☐☐
Tobacco------------ ☐☐☐☐☐

6. What crop(s) will you grow on this piece of land next season?

Maize--------------- ☐
Tobacco------------- ☐
Cotton--------------- ☐
Groundnuts--------- ☐
Others (specify)---- ☐

Would you tell me the variety of each crop you grow?

Code[42]

Maize-------------------
Tobacco----------------
Don't know------------

7. In this field, what fertilizer type do you use for the basal dressing of?

Code[43]

Maize------------------
Tobacco----------------
Don't know------------1
None at all--------------2

9. What fertilizer type did you use for top dressing of?

Code[44]

Maize----------------
Tobacco--------------
Don't know---------1
Not applicable------2

10. In this field, how much fertilizer in kilograms per hectare did you apply last year for the basal dressing of:

Maize--------------
Tobacco------------
Don't know--------1
Not applicable-----2

11. How much fertilizer in kilograms did you apply last year per hectare for top dressing of:

Maize--------------
Tobacco------------
Don't know--------1
Not applicable-----2

12. Do you use fire to clear this piece of land every year?

No—0, Yes----1

13. If yes, then what benefits do you think you get from it?

Pest/disease control------------
Labour-saving------------------
Nutrient enrichment------------
Other (specify)------------------
----

14. Which of the following tools or equipment do you use on this piece of land, and how many?

Cutlass----------------------
Hoe--------------------------
Shovel/Spade---------------
Tractor----------------------
Plough----------------------
Ox cart----------------------
Panga-----------------------
Axe--------------------------

[42] LM = local maize, HM = hybrid maize, ND = Northern Division Dark Fire Cured Tobacco, SD = Southern Division Dark Fire Cured Tobacco, SC = Sun/air cured tobacco, FC = Flue-cured Virginia tobacco, OT = Oriental tobacco, Bu = Burley

[43] DCO = D Compound, SMI = S mixture

[44] CAN = Calcium Ammonium Nitrate,

What types of activity do you personally undertake?

- Land clearing-------- ☐
- Ridging--------------- ☐
- Planting--------------- ☐
- Weeding-------------- ☐
- Banking--------------- ☐
- Fertilising------------- ☐
- Pest/disease control-- ☐
- Harvesting------------ ☐
- Processing------------ ☐
- Marketing------------ ☐
- Other (specify)-------- ☐

15. Are there other people assisting you?

No---0, Yes------1 ☐

i) If yes, then who are they and how many?

- Family members--------- ☐☐
- Hired hands--------------- ☐☐
- Community members--- ☐☐
- Share croppers---------- ☐☐

ii) In what kind of activity do they help you?

- Land clearing--------- ☐
- Ridging--------------- ☐
- Planting--------------- ☐
- Weeding-------------- ☐
- Banking--------------- ☐
- Fertilising------------- ☐
- Pest/disease control-- ☐
- Harvesting------------ ☐
- Processing------------ ☐
- Marketing------------ ☐
- Other (specify)-------- ☐

SECTION 4: GENERAL FARM CHARACTERISTICS

1.What is the overall farm size in hectares?

☐☐☐☐

2. How many fragments are you working?

☐☐

3. On how many do you consider erosion to be a problem?

☐☐

4. Can you please provide me with a breakdown of your land area by tenure?

- Held communally------- ☐☐☐☐
- Leased------------------ ☐☐☐☐
- Owned------------------ ☐☐☐☐
- Share-cropped---------- ☐☐☐☐

5. How much of the total land was cultivated in the 1997/98 growing season?

☐☐☐

If not all land worked, then

6. It would appear that in past growing season you cultivated less land than you have, can you say why this was so?

- Illness----------------- ☐
- Lack of labour-------- ☐
- Lack of interest------- ☐
- Poor accessibility---- ☐
- Poor soil quality------ ☐
- Inadequate returns---- ☐
- Rotational fallow----- ☐
- Low yield------------- ☐
- Other (specify)-------- ☐

7. How many years have you been working the total land?

SECTION 5: RESPONDENT'S PERSONAL BACKGROUND

1. What is the highest level of education you attained?

None at all-----------------0
Junior primary school-----1
Senior primary school-----2
Junior secondary school---3
Senior secondary school--4
College---------------------5
University-----------------6

2. Did you ever receive specific training in agriculture?

No------0, Yes-----1

If no, proceed to question 3, otherwise go to question 4. If yes, then please specify

Primary school-------1
Secondary school----2
Certificate -----------3
Diploma--------------4
Degree----------------5
Other (specify)-------6
----

3. How did you acquire your farming knowledge?

Personal experience------
Friends/neighbours-------
Extension officers--------
Training centres----------
Parents/grandparents-----
Others (specify)----------

4. Would you please give me an indication of your age?

5. Do you undertake any other work besides working your land?

No-----0 Yes----------1

If yes, then what type?

Unskilled labourer---------
Skilled labourer------------
Fisher-person--------------
Service industry-----------
Junior civil servant--------
Middle-level civil servant-
Senior civil servant--------
Professional---------------
Micro-enterprises---------
Other (specify)------------
----

6. Which profit category best describes last season's farm income (in Malawi Kwacha)?

None at all--------------0
< 5,000------------------1
5,000-10,000------------2
10,000-15,000----------3
15,000-20,000----------4
20,000-30,000----------5
30,000-40,0000---------6
40,000-50,000----------7
> 50,000-----------------8

7. In the past growing season, did you suffer any major illness?

No----0, Yes-------1 ☐

i) If so, then what was it?

Code[45] ☐☐

ii) Did it prevent you from working your holding?

No----0, Yes-------1 ☐

iii) If yes, then for how many days? ☐☐

SECTION 6: OBSERVATIONS BY INTERVIEWER

1. Type of farming

Subsistence-------------1
Small-scale estate------2
Large-scale estate------3 ☐

2. Sex of respondent?

Female-------1
Male----------2 ☐

3. Slope type of the field

None----------0
Concave------1
Convex -------2 ☐

3. Slope aspect

Not applicable------0
North-----------------1
East------------------2
South-----------------3
West-----------------4 ☐

5. Soil type

Clay/Sand----------1
Loam----------------2
Clay-----------------3
Other (specify)-----4 ☐

6. Attitude of respondent to questioning

Suspicious-------------1
Reluctant---------------2
Obliging----------------3
Co-operative-----------4 ☐

Field sketch of ----------------------------- farm, Village----------------, T/A-----------
----

[45] Ma = Malaria, Tb = Tuberculosis, Dy = Dysentery, Rh = rheumatism, Ar = Arithritis

Appendix C

Cartographic Models and Calibration Procedures of the Modified SLEMSA using Idrisi32

The following procedures assume a basic knowledge of GIS, especially using Idrisi32 software. A total of 40 images and vector layers were used to produce the images required to calibrate the model using the 1991 land cover/use and vegetation change scenarios. These will not be displayed because they do not add anything substantative to the dissertation. As stated earlier, these files are in the Linthipe SLEMSA folder on a CD-ROM that is available from the Centre of Earth Observation Science through the Director, Dr. David G. Barber, in the Geography Department (email: dbarber@Ms.UManitoba.CA). The following steps suffice for those interested in following the calibration procedures. For ease of execution, the procedures follow the tutorial format in the Idrisi32 manual.

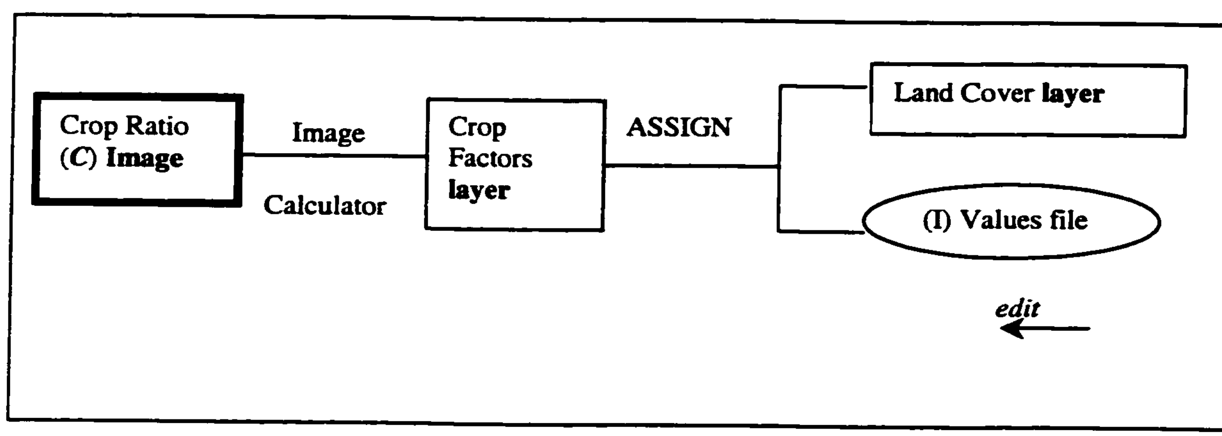

Fig. C1: Cartographic Model for the Crop Ratio Submodel (*C*)

Idrisi32 Application for the Crop Ratio (*C*)

1. Display the land use/cover image {Linthipe Land Cover} with the land cover palette
2. Determine land use practice from legend

3. Open a Boolean image {Agriculture} containing a value of 1 for built-up areas, agriculture and arable land, and 0 for the rest of the land use/cover classes
4. Open the second Boolean image {Forest} that was assigned a value of 1 to natural vegetation and plantation forests, and 0 to the rest
5. Open the attribute value files {Agriculture} and {Forest} in the [DATA ENTRY/EDIT] module. The first columns of each file represent land cover type from the legend of the {Linthipe Land Cover} image, while the second columns contain interception factors from Table 3.5 which were assigned to {Agriculture} and {Forest} Boolean images as shown in Table C1 below.

Table C1: Interception factors used to generate the Crop Ratio image

Land cover code	Agriculture	Forest
1	0	95
2	40	0
3	0	100
4	40	0
5	0	100
6	5	0
7	0	95
8	0	95

6. Use the [ASSIGN] module in the [DATA ENTRY/ASSIGN] menu to assign each attribute value file to {Agriculture} and {Forest} Boolean images respectively and obtain two respective layers of I (crop) factors
7. Using the [IMAGE CALCULATOR], derive two crop ratio layers by evaluating these formulae $C_1 = exp^{(-0.06i)}$ for {Agriculture} and $C_2 = (2.3-0.01i)/30$ for {Forest}
8. Using the IMAGE CALCULATOR again, produce the final {Crop Ratio} image by adding the {Agriculture} and {Forest} crop-ratio layers

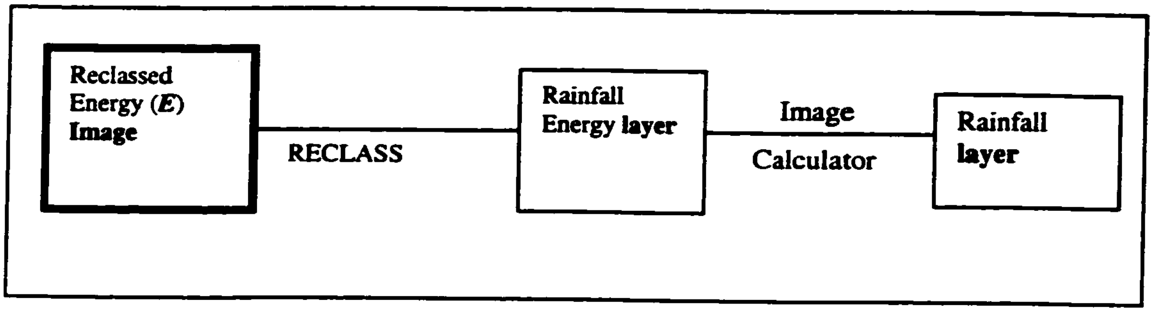

Fig. C2: Cartographic Model for the Rainfall Energy (E) Control Variable

Idrisi32 application for Rainfall Energy (*E*)

1. Launch the rainfall layer called {Linthipe Rainfall}
2. Use [IMAGE CALCULATOR] to multiply the rainfall layer by 18.846 thereby converting it to {Linthipe Rainfall Energy} layer, i.e., {Linthipe Rainfall Energy} = {Linthipe Rainfall Final}* 18.846.
3. Use the [RECLASS] module to reclass the {Linthipe Rainfall Energy} image into three rainfall energy levels that equate to the following rainfall values < 800 mm, 801-1200, and > 1200

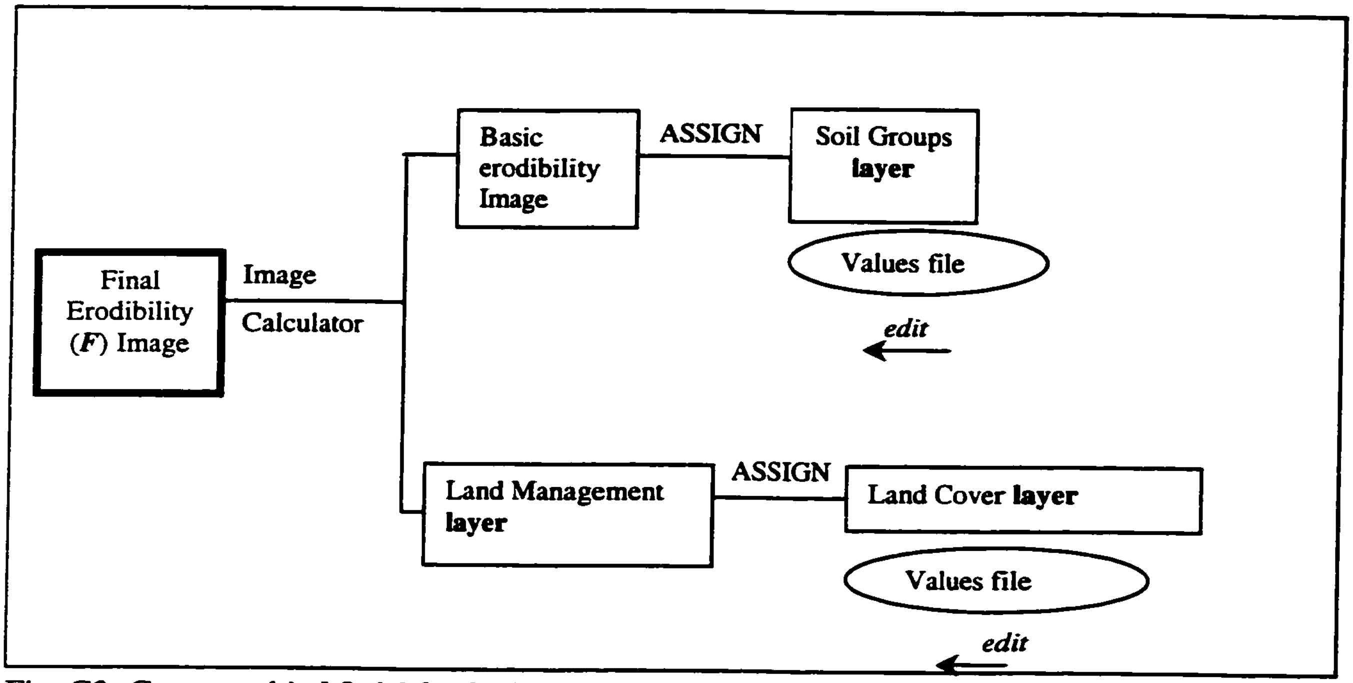

Fig. C3: Cartographic Model for Soil Erodibility (***F***)

Idrisi32 application for Land Management

1. Open land use/cover {Linthipe Land Cover} layer and check the legend again
2. Also open the attribute value file called {Soil Management} which contains land-cover classes in the first column, and land management values in the second one; 1 being assigned to forests, plantations and natural vegetation while 0 was assigned to built-up areas, agricultural and arable land.
3. Assign the {Soil Management} value file to the land-use file and make an output file called {Land Management.

Idrisi32 application for Soils Erodibility (*F*)

1. Display the soils file named {Linthipe Soil Group}.

2. Open the values file named {Linthipe Soil Erodibility} that contains soil group and erodibility factors in the first and second columns respectively. The erodibility factors came from Table 2.3 in the main text of the dissertation.

3. Assign the values file to {Linthipe Soil Group} and name the resulting image as {Basic Erodibility}.

4. Invoke the [IMAGE CALCULATOR] to add the two images {Land Management} and {Basic Erodibility} to create a new image called {Final Erodibility}.

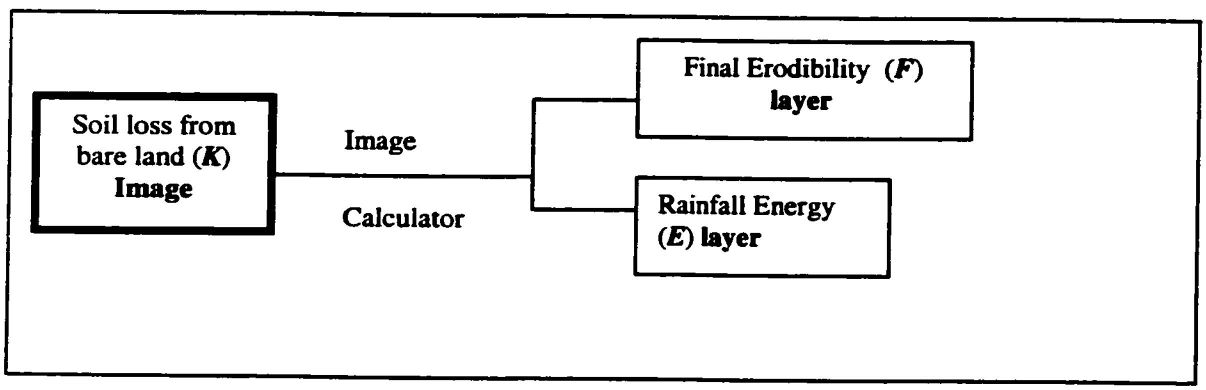

Fig. C4: Cartographic Model for the Soil and Climate Submodel (*K*)

Idrisi32 Application for (*K*)

1. Use the [IMAGE CALCULATOR] to evaluate the formula for the Soil and Climate submodel which is $(K) = \exp[(0.4681+0.7663\,F)\ln E + 2.884-8.1209\,F]$

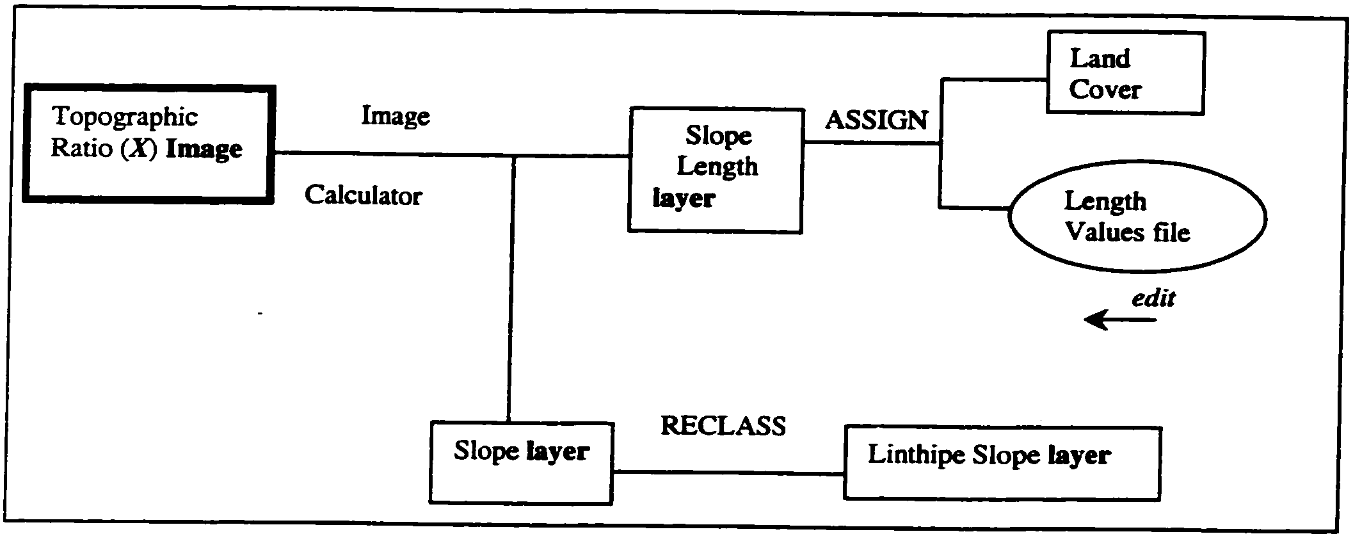

Fig. C5: Cartographic Model for Topographic Ratio (*X*)

Idrisi32 Application for the Topographic Ratio (*X*)

1. Open the {Linthipe Land Cover} file again and check the legend.
2. Open the values files named {Slope Length} that contains, in the first column, land cover/use code, and slope length values in the second column. A short slope-length value (10 m) was assigned to natural vegetation and plantation forests while built-up areas, agricultural and arable land was assigned a long slope-length value (20 m).
3. Assign the {Slope Length} to the {Linthipe Land Cover} image to obtain a {Slope Length} layer.
4. Open the {Linthipe Slope} layer and [RECLASS] it using the upper gradient values that are valid for the modified SLEMSA and call the reclassed file {Upper Slope Values}.
5. Use the [IMAGE CALCULATOR] to compute the topographic ratio using the following formula $X = L^{0.5}(0.76+0.53S+0.07S^2)/25.65$

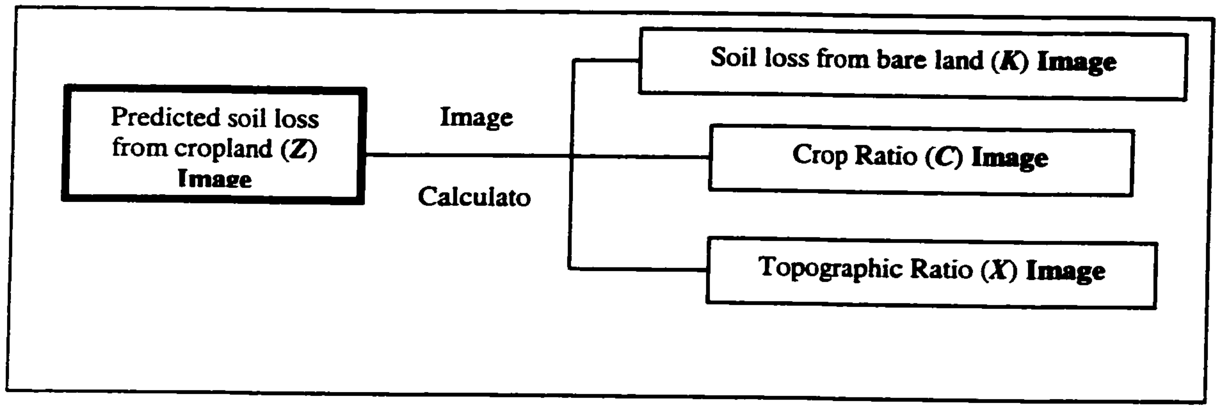

Fig. C6: Cartographic Model for the Main Model (*Z*)

Idrisi32 application for (*Z*)

Use the [IMAGE CALCULATOR] to multiply the three submodels, that is (*Z*) = {Crop Ratio}* {Soil loss from bare land}* {Topographic Ratio}

Appendix D

Rainfall Data used in Generating Data Layers for Calibration of the Soil and Climate (K) Submodel of the Modified SLEMSA

Table D1: Malawi36 co-ordinate points of rain gauges, interpolated rainfall, and runoff/sediment plots, Linthipe River Catchment, 1998/99

Plot No.	Region	Eastings	Northings	% Slope	98/99 Rainfall (mm)	Altitude (msl)	Interpolated 88-98 mean rainfall (mm)
1	Dowa	622831.57	8483387.3	13	838	931.62	969
2	Lilongwe	571976.18	8425905.4	2	988.7	1175.38	944
3	Scarp	648117.92	8466829.9	13	1173.3	616.72	974
4	Lakeshore	665840.91	8477375.1	2	1224.3	519.85	991
5	Dzalanyama	563632.82	8429434.7	6	944.4	1135.51	903
6	Dzalanyama	563581.11	8429325.4	6	1393.05	1137.57	903
7	Lakeshore	672255.75	8480594.8	2	827	1175.38	977
8	Lakeshore	672121.26	8480537.6	2	655.4	520.37	977
9	Scarp	647933.52	8466879.7	6	1051.2	619.1	973
10	Dowa	626431.87	8480714.8	13	806.5	930.42	970
11	Scarp	649754.07	8469634.3	6	696.5	562.27	983
12	Dowa	626362.71	8480781.0	13	650	935.77	970
13	Dowa	613754.22	8478601.4	13	1000.2	1160.86	942
14	Dowa	613632.26	8478379.7	13	735.2	1157.05	942
15	Scarp	649824.32	8469567.8	6	870.9	564.79	983
16	Scarp	647600.87	8466212.9	6	740.58	620.85	971
17	Lakeshore	664186.63	8477337.9	2	962.5	493.27	996
18	Lilongwe	645931.87	8464391.0	2	1597.1	629.84	967
19	Lilongwe	566760.44	8432581.0	6	2082.4	1134.45	906
20	Dowa	613690.53	8478770.5	13	1052.77	1163	942
21	Dowa	562667.82	8435113.3	2	1145.5	1170.9	880
22	Lilongwe	572298.61	8426364.0	2	1020.4	1167.86	945
23	Lilongwe	560872.36	8435096.8	2	1265.5	1164.3	874
24	Lakeshore	658929.17	8482228.7	2	864	506.21	1005
25	Lakeshore	658978.47	8482221.5	2	864	499.15	1006
26	Scarp	622689.02	8483296.8	13	703.1	941.26	969
27	Lilongwe	571880.51	8426194.7	2	978.2	1173.48	944
28	Dowa	625738.16	8482915.9	13	1167	870.22	969
29	Dowa	625744.11	8482911.4	13	476	870.73	969
30	Scarp	647900.47	8466824.6	6	1093.8	621.17	973
31	Scarp	647950.05	8466863.9	6	1023.5	619.72	973
32	Lakeshore	658913.86	8481954.2	2	835.5	503.98	1005
33	Lakeshore	658935.18	8481954.8	2	835.5	505.72	1006
34	Lilongwe	560778.81	8435048.4	2	1108.9	1167.02	874

Table D2: Mean annual rainfall measured at different meteorological stations in Malawi; 1988-98

Station	Longitude	Latitude	Rainfall (mm)	Station	Longitude	Latitude	Rainfall (mm)
Baka	33.92	-9.93	799.83	Mangochi	35.25	-14.47	677.48
Bolero Met.	33.78	-11.02	707.87	Mchinji	32.87	-13.82	850.04
Bunda	33.77	-14.02	391.80	Mimosa	35.62	-16.07	1561.47
Bvumbwe	35.07	-15.92	1119.21	Mkanda	32.95	-13.52	878.13
Chancellor	35.35	-15.38	1137.33	Mlangeni	34.53	-14.68	840.87
Chichiri	35.03	-15.78	1137.72	Mombezi	35.12	-15.73	779.33
Chikwawa	34.78	-16.03	727.50	Monkey Bay	34.92	-14.08	864.88
Chikweo	35.67	-14.75	1000.84	Mponela	33.75	-13.53	854.20
Chileka	34.97	-15.67	874.32	Mpyupyu	35.45	-15.37	1225.25
Nyika Plat.	33.82	-10.58	1133.24	Mwanza	34.52	-15.62	968.84
Chintheche	34.17	-11.83	1444.35	Mzimba	33.60	-11.90	835.06
Chitedze	33.63	-13.97	810.90	Mzuzu	34.02	-11.43	1134.74
Chitipa	33.27	-9.70	959.82	Naminjiwa	35.62	-15.77	916.56
Dedza	34.25	-14.32	980.82	Namwera	35.50	-14.37	1247.65
Domasi	35.48	-15.22	881.46	Neno Agric	34.67	-15.38	764.70
Dowa Agric.	33.93	-13.65	794.39	Ngabu Met.	34.95	-16.50	756.71
Dzalanyama	33.70	-14.47	970.60	Nkhata Bay	34.30	-11.60	1605.48
Dzonzi	34.68	-14.98	901.85	Nkhotakota	34.28	-12.92	1349.93
Fort Lister	35.70	-15.83	1351.28	Nsanje	35.27	-16.95	889.13
Jali Market	35.48	-15.49	899.18	Ntaja Agric.	35.53	-14.87	838.80
Karonga	33.89	-9.96	768.56	Ntcheu -	34.58	-14.78	1041.40
Kasungu	33.45	-13.03	766.34	Ntchisi	34.20	-13.30	1584.45
L.I.A Met.	33.78	-13.78	814.10	Salima Met.	34.58	-13.75	1099.49
Lisungwi	34.77	-15.43	641.14	Thiwi	34.12	-14.32	1009.60
Liwonde	35.22	-15.05	674.88	Thyolo	35.13	-16.13	1170.21
Makhanga	35.15	-16.52	599.03	Toleza	35.00	-14.93	842.80
Makoka	35.18	-15.53	921.32				

Appendix E

Location and Characteristics of Validation Plots, Linthipe River Catchment, 1998/99

Table E1: Validation plot number, location, and land use by geographic region in the Linthipe River Catchment

Land use	Plot No	Eastings	Northings	Region	Farming system
Bare fallow	1	622831.57	8483387.3	Dowa	Estate
Bare fallow	2	571976.18	8425905.4	Lilongwe	Estate
Bare fallow	3	648117.92	8466829.9	Scarp	Estate
Bare fallow	4	665840.91	8477375.1	Lakeshore	Smallholder
Brachystegia	5	563632.82	8429434.7	Dzalanyama	Not applicable
Brachystegia	6	563581.11	8429325.4	Dzalanyama	Not applicable
Brachystegia	7	672255.75	8480594.8	Lakeshore	Not applicable
Brachystegia	8	672121.26	8480537.6	Lakeshore	Not applicable
Grass/shrub	9	647933.52	8466879.7	Scarp	Not applicable
Grass/shrub	10	626431.87	8480714.8	Dowa	Not applicable
Grass/shrub	11	649754.07	8469634.3	Scarp	Not applicable
Maize	12	626362.71	8480781.0	Dowa	Smallholder
Maize	13	613754.22	8478601.4	Dowa	Smallholder
Maize	14	613632.26	8478379.7	Dowa	Smallholder
Maize	15	649824.32	8469567.8	Scarp	Smallholder
Maize	16	647600.87	8466212.9	Scarp	Smallholder
Maize	17	664186.63	8477337.9	Lakeshore	Smallholder
Maize	18	645931.87	8464391.0	Lilongwe	Smallholder
Maize	19	566760.44	8432581.0	Lilongwe	Smallholder
Maize	20	613690.53	8478770.5	Dowa	Smallholder
Grass/shrub	21	562667.82	8435113.3	Dowa	Not applicable
Maize	22	572298.61	8426364.0	Lilongwe	Estate
Maize	23	560872.36	8435096.8	Lilongwe	Estate
Maize	24	658929.17	8482228.7	Lakeshore	Estate
Maize	25	658978.47	8482221.5	Lakeshore	Estate
Maize	26	622689.02	8483296.8	Scarp	Smallholder
Burley tobacco	27	571880.51	8426194.7	Lilongwe	Estate
Burley tobacco	28	625738.16	8482915.9	Dowa	Estate
Burley tobacco	29	625744.11	8482911.4	Dowa	Estate
Burley tobacco	30	647900.47	8466824.6	Scarp	Estate
Burley tobacco	31	647950.05	8466863.9	Scarp	Estate
Burley tobacco	32	658913.86	8481954.2	Lakeshore	Estate
Burley tobacco	33	658935.18	8481954.8	Lakeshore	Estate
Burley tobacco	34	560778.81	8435048.4	Lilongwe	Estate

Table E2: **Runoff, sediment concentration, and soil loss sampled in validation plots (25 m^2), Linthipe River Catchment, 1998/99**

Plot No.	Region	Plot runoff (l)	Soil loss ($t\ ha^{-1}\ y^{-1}$)	Sediment concentration ($g\ l^{-1}$)
1	Dowa	4648.81	25.12	101.03
2	Lilongwe	1832.53	28.07	284.00
3	Scarp	4023.99	29.27	12.67
4	Lakeshore	4448.89	11.16	65.85
5	Dzalanyama	4104.62	0.86	116.19
6	Dzalanyama	3478.22	1.22	71.67
7	Lakeshore	4303.99	1.63	137.37
8	Lakeshore	2010.77	1.11	269.16
9	Scarp	3794.80	2.04	167.22
10	Dowa	5367.86	9.23	1.97
11	Scarp	3982.88	9.97	157.66
12	Dowa	4314.48	16.59	76.38
13	Dowa	3109.44	9.97	22.57
14	Dowa	2355.26	13.29	94.02
15	Scarp	4239.64	18.55	65.78
16	Scarp	2922.11	18.61	113.67
17	Lakeshore	1625.50	12.05	25.11
18	Lilongwe	2977.01	13.18	155.78
19	Lilongwe	3121.61	5.58	149.04
20	Dowa	3529.67	16.06	79.86
21	Dowa	1224.23	8.86	22.60
22	Lilongwe	746.16	4.24	28.77
23	Lilongwe	2722.83	11.28	107.44
24	Lakeshore	1406.77	11.72	21.69
25	Lakeshore	3343.31	11.70	90.14
26	Scarp	3714.80	21.65	67.08
27	Lilongwe	1558.54	25.38	300.58
28	Dowa	2166.35	19.08	191.48
29	Dowa	1320.73	18.74	105.53
30	Scarp	1224.23	25.82	527.23
31	Scarp	3230.08	23.65	71.42
32	Lakeshore	5203.13	18.79	94.89
33	Lakeshore	1848.29	19.75	217.23
34	Lilongwe	3698.30	20.82	197.86

Table E3: Ranking of predicted and observed soil losses, Linthipe River Catchment

Plot No.	Region	% Slope	Predicted (t ha^{-1} y^{-1})	Observed (t ha^{-1} y^{-1})	Difference
1	Dowa	13	28.20 (5)	25.12 (5)	3.08
2	Lilongwe	2	30.10 (2)	28.07 (2)	2.03
3	Scarp	13	30.50 (1)	29.27 (1)	1.23
4	Lakeshore	2	2.22 (21)	11.16 (22)	-8.94
5	Dzalanyama	6	0.08 (28)	0.86 (34)	-0.78
6	Dzalanyama	6	0.27 (27)	1.22 (32)	-0.95
7	Lakeshore	2	1.47 (26)	1.63 (31)	-0.16
8	Lakeshore	2	0.27 (27)	1.11 (33)	-0.84
9	Scarp	6	1.54 (25)	2.04 (29)	-0.50
10	Dowa	13	2.20 (23)	9.23 (26)	-7.03
11	Scarp	6	2.21 (22)	9.97 (24)	-7.76
12	Dowa	13	5.49 (15)	16.59 (15)	-11.10
13	Dowa	13	2.21 (22)	9.97 (25)	-7.76
14	Dowa	13	4.95 (17)	13.29 (17)	-8.34
15	Scarp	6	16.36 (14)	18.55 (14)	-2.19
16	Scarp	6	16.55 (13)	18.61 (13)	-2.06
17	Lakeshore	2	4.71 (19)	12.05 (19)	-7.34
18	Lilongwe	2	4.81 (18)	13.18 (18)	-8.37
19	Lilongwe	6	2.13 (24)	5.58 (28)	-3.45
20	Dowa	13	4.99 (16)	16.06 (16)	-11.07
21	Dowa	2	2.20 (23)	8.86 (27)	-6.66
22	Lilongwe	2	1.54 (25)	4.24 (30)	-2.70
23	Lilongwe	2	2.22 (21)	11.28 (23)	-9.06
24	Lakeshore	2	4.22 (20)	11.72 (20)	-7.50
25	Lakeshore	2	4.22 (20)	11.70 (21)	-7.48
26	Scarp	13	27.10 (7)	21.65 (7)	5.45
27	Lilongwe	2	28.75 (4)	25.38 (4)	3.37
28	Dowa	13	17.08 (10)	19.08 (10)	-2.00
29	Dowa	13	16.90 (12)	18.74 (12)	-1.84
30	Scarp	6	29.50 (3)	25.82 (3)	3.68
31	Scarp	6	27.50 (6)	23.65 (6)	3.85
32	Lakeshore	2	16.99 (11)	18.79 (11)	-1.80
33	Lakeshore	2	17.17 (9)	19.75 (9)	-2.58
34	Lilongwe	2	19.96 (8)	20.82 (8)	-0.86