

C O N T E N T S

ACKNOWLEDGEMENTS	11
SAMENVATTING	13
1. INTRODUCTION	21
1.1 Problem definition	21
1.2 Research objectives	21
1.3 Report structure	23
2. THE CATCHMENT OF THE GEUL	25
2.1 General characteristics	25
2.2 Geology and geomorphology	26
2.3 Soils	27
2.4 Hydrology	28
2.5 Mining activities	29
2.6 Landuse	31
3. ANALYTICAL PROCEDURES	33
3.1 Introduction	33
3.2 Sample collection and preparation	33
3.3 Extracting heavy metals from soil samples	34
3.3.1 Total extractions by nitric acid and hydrofluoric acid	34
3.3.2 The sequential extraction scheme	34
3.4 Measurement of heavy metals in solution	35
3.4.1 Methods	35
3.4.2 Sensitivity, detection limit and analytical range of the analytical equipment	35
3.5 Errors associated with the analysis of heavy metals	37
3.6 Measurement of ¹³⁷ Cs activity in soil	42
4. HEAVY METALS IN SEDIMENTS AND SOILS	43
4.1 Introduction	43
4.2 Toxicity	44
4.3 Metal associations in aquatic sediments	45
4.4 Factors affecting the geochemical mobility	48
4.5 Background levels	50
4.6 Quality criteria	52

5.	THE DISPERSAL OF METAL-RICH MINING WASTES	55
5.1	Introduction	55
5.2	Point source activity	56
5.3	Dissolved and solid transport	56
5.4	Storage	58
5.5	Remobilization	59
6.	THE THEORY OF REGIONALIZED VARIABLES	61
6.1	Introduction	61
6.2	Basic concepts	61
6.3	The semi-variogram	62
6.3.1	Calculation of the experimental semi-variogram	62
6.3.2	Theoretical semi-variogram models	63
6.3.3	Fitting a theoretical model to the experimental semivariogram	65
6.4	Spatial interpolation by kriging	66
6.5	Spatial interpolation by co-kriging	68
7.	THE TRANSPORT OF HEAVY METALS	71
7.1	Introduction	71
7.2	Experimental procedures	72
7.3	Flood effects	72
7.4	The transport of sediment and sediment-associated heavy metals	77
7.5	The transport of dissolved heavy metals	79
7.6	Sediment sources	80
7.7	Mass transport	82
7.8	Conclusions	84
7.9	Summary	86
8.	VARIABILITY OF THE HEAVY METAL CONTENT OF FLOOD DEPOSITS	87
8.1	Introduction	87
8.2	Experimental procedures	88
8.3	Characteristics of the Meuse basin	89
8.4	Pollution levels	89
8.5	The effects of grain size and organic matter content	89
8.6	Downstream changes of total metal concentrations	94
8.7	Chemical partitioning of heavy metals	99
8.8	Downstream changes of partitioned metal concentrations	103
8.9	Evaluating the downstream patterns	104
8.10	Conclusions	106
8.11	Summary	106

9.	LAND USE CHANGE AND ITS IMPACT ON THE DISPERSAL MECHANISM	107
9.1	Introduction	107
9.2	Experimental procedures	107
9.3	Land use changes	108
9.4	Discharge regime changes	109
9.5	River channel migrations	111
9.6	The deposition of contaminated sediments during floods	114
9.7	Conclusions	114
9.8	Summary	115
10.	FLOOD HAZARD MAPPING USING A DIGITAL ELEVATION MODEL	117
10.1	Introduction	117
10.2	Experimental procedures	117
10.3	Interpolation and testing	118
10.4	Modelling flood water levels	121
10.5	The relation between floodplain characteristics and soil pollution	124
10.6	Conclusions	126
10.7	Summary	126
11.	COMPARISON OF SPATIAL PREDICTION METHODS FOR MAPPING FLOODPLAIN SOIL POLLUTION	127
11.1	Introduction	127
11.2	Experimental procedures	127
11.3	Spatial prediction methods	129
11.4	Estimating the variograms for kriging and co-kriging	131
11.5	Goodness-of-fit of the modelled zinc surfaces	132
11.6	The spatial distribution of prediction errors	136
11.7	Discussion	136
11.8	Conclusions	137
11.9	Summary	138
12.	MAPPING HEAVY METAL POLLUTION ON FLOODPLAINS BY CO-KRIGING FROM ELEVATION DATA	139
12.1	Introduction	139
12.2	Experimental procedures	139
12.3	Methods used for mapping	142
12.4	Anisotropy effects	146
12.5	Comparing the three methods	147
12.6	Conclusions	149
12.7	Summary	149

13. DEPOSITION AND STORAGE OF HEAVY METALS IN RIVER FLOODPLAINS	151
13.1 Introduction	151
13.2 Experimental procedures	153
13.3 Estimating sediment deposition rates by using ¹³⁷ Cs	153
13.4 Variations of metal concentrations in the soil profile	157
13.5 Spatial patterns of soil metal concentrations	159
13.6 Mass storage calculations	165
13.7 Conclusions	167
13.8 Summary	167
 14. SYNTHESIS	 169
14.1 Introduction	169
14.2 Multiscale spatial models of metal pollution	169
14.3 The compilation of budgets of sediment and heavy metals	174
14.3.1 The sediment budget	174
14.3.2 The metal budgets	177
14.3.3 The significance of the Geul as a source of heavy metals	181
14.4 Health risk assessment	182
14.4.1 Pollution maps for planning	182
14.4.2 Health aspects	184
 REFERENCES	 189
 APPENDICES	 199
1. Publications and contributions to scientific meetings	
2. Map of sample locations	
3. Map of zinc concentrations in the top soil	
4. Map of lead concentrations in the top soil	
5. Map of cadmium concentrations in the top soil	
 CURRICULUM VITAE	