Contents

Summary vii

Samenvatting ix

Resumen xi

Acknowledgements xv

Contents xvii

List of Figures xxi

List of Tables xxv

1 Introduction 1
- 1.1 Background . . . 1
- 1.2 Scope of the thesis . . . 4
- 1.3 Outline of the thesis . . . 7

2 Regional debris flow susceptibility analysis in mountainous peri-urban areas through morphometric and land cover indicators 9
- 2.1 Introduction . . . 9
- 2.2 Methods and Data . . . 11
  - 2.2.1 Study Area . . . 11
  - 2.2.2 Methodology . . . 14
    - 2.2.2.1 Development of the morphometric indicator . . . 16
    - 2.2.2.2 Development of the land cover indicator . . . 21
    - 2.2.2.3 Development of a composite susceptibility index . . . 22
- 2.3 Results . . . 22
  - 2.3.1 Estimation of the morphometric indicator for the study area . . . 23
    - 2.3.1.1 Morphometric indicator model . . . 23
    - 2.3.1.2 Assessment of appropriateness of the morphometric indicator . . . 25
  - 2.3.2 Land cover indicator . . . 30
  - 2.3.3 Combination of indicators to obtain a final susceptibility index . . . 31

2.4 Discussion . . . 32
2.4.1 Morphometric indicator . . . 32
2.4.2 Debris flow propagation . . . 37
2.4.3 Land cover indicator, composite susceptibility index and comparison of results . . . 38
2.5 Conclusions . . . 39

3 Regional prioritisation of flood risk in mountainous areas 41
3.1 Introduction . . . 41
3.2 Conceptualization of Vulnerability . . . 44
3.3 Methods and Data . . . 46
3.3.1 Study Area . . . 46
3.3.2 Methodology . . . 48
3.3.2.1 Delineation of exposure areas . . . 49
3.3.2.2 Choice of indicators and principal component analysis for vulnerability assessment . . . 50
3.3.2.3 Sensitivity of the vulnerability indicator . . . 53
3.3.2.4 Categories of recorded damage in the study area . . . 54
3.3.2.5 Prioritization of watersheds . . . 55
3.4 Results . . . 56
3.4.1 Exposure Areas . . . 56
3.4.2 Socio-economic fragility indicators . . . 58
3.4.3 Lack of Resilience and coping capacity indicators . . . 59
3.4.4 Physical exposure indicators . . . 61
3.4.5 Vulnerability indicator . . . 62
3.4.6 Prioritization of watersheds according to the qualitative risk indicator and comparison with damage records . . . 63
3.4.7 Sensitivity analysis of the vulnerability indicator . . . 64
3.5 Discussion . . . 65
3.5.1 Exposure areas . . . 65
3.5.2 Representativeness and relative importance of indicators . . . 67
3.5.3 Sensitivity of the vulnerability indicator . . . 68
3.5.4 Usefulness of the prioritization indicator . . . 69
3.6 Conclusions . . . 70

4 Spatial interpolation for real-time rainfall field estimation in areas with complex topography 71
4.1 Introduction . . . 71
4.2 Methods and Data . . . 73
4.2.1 Study Area . . . 73
4.2.2 Precipitation data . . . 75
4.2.3 Geostatistical interpolation procedure . . . 76
4.2.3.1 Interpolation techniques . . . 77
4.2.3.2 Topographic parameters as secondary variables . . . 79
4.2.3.3 Cross validation and statistical criteria of comparison . . . 80

4.2.3.4 Conditional Simulations 81
4.3 Results 81
4.3.1 Exploratory data analysis 81
4.3.2 Classification of daily datasets 82
4.3.3 Variogram analysis 82
4.3.4 Analysis of performance of the interpolators for the individual storms . . 84
4.3.5 Analysis of performance of the interpolators using the climatological variograms and applicability of the climatological variograms for individual event rainfall field generation 87
4.3.6 Analysis of secondary variables 92
4.3.7 Analysis of uncertainty in estimates of storm volumes 93
4.4 Discussion 94
4.4.1 Characteristics of the rainfall fields 94
4.4.2 Performance of the climatological variograms and applicability to the generation of individual event rainfall fields 96
4.4.3 Choice between KED and OK 97
4.4.4 Volumetric comparison 99
4.5 Conclusions 100

5 Hydrological model assessment for flood early warning in a tropical high mountain basin 102
5.1 Introduction 102
5.2 Study Area 104
5.3 Methods 106
5.3.1 Modelling set up and calibration 108
5.3.1.1 Description of the models 108
5.3.1.2 Hydrometeorological forcing 110
5.3.1.3 Model Configuration and Calibration 111
5.3.2 Performance analysis and diagnostics 115
5.3.3 Analysis of precipitation input uncertainty and comparison of models . . 117
5.4 Results 118
5.4.1 Model calibration 118
5.4.1.1 KGE for HECHMSSMA, TOPMODEL and TETIS 118
5.4.2 Comparison of water balance fluxes 118
5.4.3 Signature measures from the flow duration curve (FDC) 121
5.4.4 Rainfall ensemble analysis, input precipitation uncertainty 121
5.4.5 Comparison of model ensembles 123
5.5 Discussion 124
5.5.1 Model calibration and performance 124
5.5.1.1 Water balance fluxes and hydrometeorological forcing 124
5.5.1.2 Pixel size and flux variation for the TOPMODEL and TETIS . 126
5.5.1.3 HECHMSSMA calibration results and fluxes 129
5.5.1.4 Flow duration curve and signatures 130
5.5.2 Comparison of discharge ensembles 131

5.6 Conclusions . . . 131

6 Streamflow forecasts from WRF precipitation for flood early warning in tropical mountain areas 134

6.1 Introduction . . . 134
6.2 Methods and data . . . 136
6.2.1 Study Area . . . 136
6.2.2 WRF model data and observed rainfall fields . . . 138
6.2.3 Methodology . . . 138
6.2.3.1 Generation of Precipitation Forecasts . . . 139
6.2.3.2 Verification of forecasts . . . 142
6.3 Results . . . 144
6.3.1 Bias correction of precipitation forecasts through DBS . . . 144
6.3.2 Quantile regression model . . . 144
6.3.3 Verification of precipitation forecasts . . . 145
6.3.4 Verification of deterministic precipitation forecasts and ensemble mean . 145
6.3.5 Verification of deterministic discharge forecasts and ensemble mean . . . 149
6.3.6 Verification of probabilistic forecasts . . . 149
6.3.7 Discussion . . . 151
6.3.7.1 Evaluating precipitation forecasts from the WRF model . . . 151
6.3.7.2 Evaluating discharge forecast . . . 157
6.4 Conclusions . . . 158

7 Conclusions and Recommendations 160

7.1 Conclusions . . . 160
7.1.1 Regional Flood risk analysis . . . 161
7.1.2 Hydrometeorological inputs . . . 164
7.1.3 Hydrological models for flood early warning . . . 165
7.2 Added value of the numerical weather prediction model WRF in the flood forecasting system . . . 167
7.3 Recommendations . . . 169

Bibliography 171

Curriculum Vitae 197