DATA DRIVEN LANDSLIDE HAZARD ASSESSMENT USING GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

OF

THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

MEHMET LÜTFİ SÜZEN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

THE DEPARTMENT OF GEOLOGICAL ENGINEERING

JANUARY 2002

Approval of the Graduate School of (Name of the Graduate School)

_____

Prof. Dr. Tayfur Öztürk
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Doctor of Philosophy.

_____

Prof. Dr. Nurkan Karahanoğlu
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

_____

Prof. Dr. Vedat Doyuran
Supervisor

Examining Committee Members

Prof. Dr. Nurkan Karahanoğlu _____

Prof. Dr. Vedat Doyuran _____

Prof. Dr. Reşat Ulusay _____

Assoc. Prof. Dr. Vedat Toprak _____

Assist. Prof. Dr. Candan Gökçeoğlu _____

ABSTRACT

DATA DRIVEN LANDSLIDE HAZARD ASSESSMENT
USING GEOGRAPHICAL INFORMATION SYSTEMS
AND REMOTE SENSING

Süzen, Mehmet Lütfi

Ph.D., Department of Geological Engineering

Supervisor: Prof. Dr. Vedat Doyuran

January 2002, 196 pages

The purpose of this thesis is to generate and evaluate a concise system of data driven landslide hazard assessment procedure. The Asarsuyu catchment area and Bolu Mountain highway pass are selected for this purpose

In this study, three data domains, which are remote sensing products, geological maps and topographical maps are used. The landslides of four different historical periods are interpreted using aerial photographs. Land cover is extracted from satellite images. Thirteen sets of parameter maps are produced from geological and topographical maps and from remote sensing products. In order to store the information of these parameter maps in a concise thematic database a 25x25 meter grid is overlaid to the area. Two different sets of points are defined. First one representing the properties of slided masses and the other set representing the conditions contributing to the sliding phenomena. The information falling on these points are stored in five separate thematic landslide attribute databases, as two main databases are Seed Cells and Slided Mass Databases, with accessory three other as, Polystats, Fuzzystats and photo-characteristics databases. Following the creation of the databases, the

information stored are evaluated and preliminary landslide generating decision rules are extracted.

In conjunction with these preliminary results a hazard assessment procedure, starting from the least detailed and simple ranging up to most complex statistical analyses are initiated. Finally a relative accuracy assessment procedure is carried out using the hazard maps produced. It is found that the most accurate, reliable and realistic results concerning the landslide hazard assessment of Asarsuyu catchment are obtained through logistic regression analyses.

The results of landslide hazard assessment of Asarsuyu catchment shows that: the northern slopes of the Asarsuyu catchment is classified as very low hazard due to the presence of low population, undisturbed dense forest land cover, being very distant to E-5 highway and to the major active fault and the favorable lithological conditions. The southeastern slopes especially the Bolu Mountain Highway pass are definitely on very high hazard class due to the removal of lateral supports by E-5 highway cut slopes, close location to active faults, high disturbance of the land cover, high traffic activity along the highway resulting in extra vibration, and the presence of flyschoidal units

Keywords: Asarsuyu Catchment, Bolu Mountain, Geographical Information Systems, Landslide Hazard Assessment, Logical regression, Remote Sensing

ÖZ

COĞRAFİ BİLGİ SİSTEMLERİ VE UZAKTAN ALGILAMA
TEKNİKLERİ KULLANILARAK
VERİ KAYNAKLI HEYELAN AFETİ TAYİNİ

Süzen, Mehmet Lütfi

Doktora, Jeoloji Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. Vedat Doyuran

Ocak 2002, 196 sayfa

Bu çalışmanın amacı, kısa ve öz veri kaynaklı bir heyelan afeti tayin yöntemi geliştirmek ve değerlendirmektir. Bu amaçla uygulama arazisi olarak Asarsuyu su toplama havzası ve Bolu Dağı otoyol geçişi seçilmiştir.

Bu çalışmada, uzaktan algılama ürünleri, jeolojik haritalar ve topografik haritalar, olmak üzere üç veri alanı kullanılmıştır. Hava fotoğrafları kullanılarak dört ayrı dönemin heyelan envanteri çıkarılmıştır. Arazi kullanım haritası için ise, uydu görüntülerinden yararlanılmıştır. Jeolojik ve topoğrafik haritalardan ve uzaktan algılama ürünleri kullanılarak 13 ayrı parametre haritası üretilmiştir. Bu parametre bilgilerini bir veri tabanına aktarabilmek için, 25x25 metrelik bir ağ arazi üzerine oturtulmuştur. İki ayrı takım nokta belirlenmiştir. Bunlardan ilki kayan kütlelerin özelliklerini, diğeri ise kaymaya neden olan koşulları içermektedir. Bu noktalarda saklanan bilgiler, beş ayrı veri tabanına aktarılmıştır. Bunlardan kayan kütle ve kök hücre veri tabanları iki ana veri tabanını oluşturmaktadır. Diğer üç yardımcı veri tabanı ise, alansal (polystats), şekilsel (fuzzystats) ve foto-karakteristik veri tabanlarıdır. Veri tabanlarının üretilmesinden sonra heyelanlar hakkında ilk karar verme kuralları elde edilmiştir.

İlk sonuçlar ışığında en basit ve ayrıntısız analizlerden başlayarak, en karmaşık istatistiksel yöntemlere kadar uzanan bir heyelan afeti tayin yöntemi izlenmiştir. En son olarak ise, göreceli hata tayin yöntemi kullanılmıştır. Bunların ışığında en makul ve gerçeğe en uygun yötemin mantıksal regresyon olduğu sonucuna varılmıştır.

Heyelan afeti tayininin sonuçlarına gore, düşük nüfus yoğunluğu, bozulmamış arazi örtüsü, E-5 otoyoluna ile aktif fay hatlarına uzaklığı ve sağlam kaya birimleri ile Asarsuyu su toplama havzasının kuzey yamaçları çok düşük riskli afet alanı olarak belirlenmiştir. Güneybatı yamaçları, özellikle Bolu Dağı geçişi ise, E-5 yolunun yarmaları nedeniyle yok olan yanal destekler, aktif faylara olan yakınlığı, E-5 otoyolundaki yüksek trafik yoğunluğu ve fliş litolojisinin varlığı nedenyle çok yüksek riskli afet alanı olarak belirlenmiştir.

Anahtar Kelimeler: Asarsuyu Havzası, Bolu Dağı, Coğrafi Bilgi Sistemleri, Heyelan Afeti Tayini, Mantıksal Regresyon, Uzaktan Algılama

To my Family

ACKNOWLEDGMENTS

I would like to express my special thanks to my supervisor Prof. Dr. Vedat Doyuran, especially for his guidance, patience and motivation. I am sincerely in debt to him for outrageous guiding and for his continuous support at every stage throughout this study. To him I am also in great debt for the tedious job of critically reviewing and editing of the manuscript even in zipped form. You know you are much more than a supervisor for me.

I would like to thank to Prof. Dr. Nurkan Karahanoğlu for his valuable contributions and showing the way out of the dungeons of statistical world.

I would also like to thank to Assoc. Prof. Dr. Vedat Toprak for his patience, continuous support and unlimited thrust through every stage of this work.

I would like to thank to Prof. Dr. Reşat Ulusay for his valuable contributions through the progress report discussions.

I would like to thank to Assist. Prof. Dr. Candan Gökçeoğlu for his valuable contributions through the manuscript.

I would like to thank to Assoc.Prof.Dr. Bora Rojay especially for his continuous help in the field studies and his valuable ideas.

I would also like to thank to Middle East Technical University and Department of Geological Engineering as being my employer, for giving the opportunity to do the research, and as all stages of this study is carried out with their facilities and financial support.

I would also like to thank to Assist. Prof.Dr. Nuretdin Kaymakçı especially for his supports in the Netherlands days.

Dr. Arda Arcasoy, Ertan Yeşilnacar, Onur Demir and Gürkan Benekşe are thanked for their support and fighting on my side against murphy at our “lab”. Very special thanks go to these guys for the emission of my stress during this study.

Finally, I would express my special thanks to my family for their unbelievable support, continuous motivation, ultra-patience, and endless trust. Among them I would like to show my sincere gratitudes to my Beyaz as most of the earth shaking ideas come to mind in the morning and evening walks with him. I would like to show my very special thanks and appreciation to my Seda as being the best friend I have ever had even suffered from my often irritating moods and always more believed to me than I do. You know, you deserve this title more than I do.

TABLE OF CONTENTS

ABSTRACT iii
ÖZ v
DEDICATION vii
ACKNOWLEDGMENTS. viii
LIST OF TABLES xiv
LIST OF FIGURES xvi
CHAPTERS
1. INTRODUCTION 1
1.1. Purpose and Scope 1
1.2. Geographical Setting 3
2. BACKGROUND INFORMATION ON LANDSLIDE HAZARD AND USE OF REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS IN LANDSLIDE HAZARD ASSESSMENT 5
2.1. Definition of Landslide Hazard and Terminology 5
2.1.1. Scale Factor in Analysis 7
2.1.1.1. National Scale (<1/1.000.000) 8
2.1.1.2. Regional/Synoptic Scale (< 100.000). 8
2.1.1.3. Medium Scale (1/25.000 - 1/50.000) 8
2.1.1.4. Large Scale (> 1/10.000) 9
2.1.2. Knowledge Type Used 10
2.2. Use of Remote Sensing in Landslide Hazard Assessment 11
2.3. Geographical Information Systems and Landslide Hazard Assessment 14
2.3.1. Phases of Natural Hazard Analysis in GIS. 17
2.3.2. GIS Based Landslide Hazard Zoning Techniques 18
2.3.2.1. Trends in Landslide Hazard Zonation 19
2.3.2.2 Direct Mapping in Landslide Hazard Analysis 20
2.3.2.2.1 Landslide Distribution Analysis 20
2.3.2.2.2 Heuristic Approach (Geomorphic Analysis) 21
2.3.2.3. Indirect Mapping in Landslide Hazard Analysis 21

2.3.2.3.1. Statistical Methods in Landslide Hazard Analysis . . 21
2.3.2.3.1.1. Bivariate Statistical Methods in Landslide Hazard Analysis 22
2.3.2.3.1.1.1. Landslide Susceptibility Analysis 24
2.3.2.3.1.1.1.1. Production of the Susceptibility Map . 25
2.3.2.3.1.1.2. Information Value Method 25
2.3.2.3.1.1.3. Weights of Evidence Modelling. 27
2.3.2.3.1.2. Multivariate Statistical Methods in Landslide Hazard Analysis 31
2.3.2.3.1.2.1. Multiple Regression 33
2.3.2.3.1.2.2. Discriminant Analyses 34
2.3.2.3.2. Knowledge Driven Methods in Landslide Hazard Analysis 35
2.3.2.3.2.1. Qualitative Map Combination 35
2.3.2.3.2.2. Favourability Functions. 35
2.3.2.3.3. Deterministic Modeling in Landslide Hazard Analysis . 36
2.3.2.3.4 Landslide Frequency Analysis 37
2.3.2.4. Accuracy and Objectivity 37
2.3.2.5. Evaluation of Methods via Scale Factor 38
3. GEOLOGY OF THE ASARSUYU CATCHMENT 40
3.1. Geology 40
3.1.1. Regional Geology and Previous Works 40
3.1.2. Stratigraphy 43
3.1.2.1. Yedigöller Formation 44
3.1.2.2. Kocadere Formation 47
3.1.2.3. Aksudere Formation 47
3.1.2.4. Buldandere Formation 48
3.1.2.4.1. Fındıklıdere Member 48
3.1.2.4.2. Çaycuma Formation 49
3.1.2.5. Asarsuyu Formation 49
3.1.2.6. Quaternary Deposits 49
3.2. Tectonism of the Asarsuyu Catchment 50
3.3. Seismicity of the Asarsuyu Catchment and Environs 51
4. INPUT DATA AND DATA PRODUCTION 57
4.1. Geology 57
4.1.1. Data entry 57
4.1.2. Input map generation 60
4.2. Elevation 62

4.2.1. Data entry 62
4.2.2. Input map generation 61
4.3. Infrastructure 68
4.3.1. Data entry 68
4.3.2. Input data production 68
4.4. Land cover 71
4.4.1. Data entry 71
4.4.2. Input map generation 72
4.4.2.1 Georeferencing 73
4.4.2.2 Data Processing 74
4.4.2.2.1. Principal Component Analysis (PCA) 74
4.4.2.2.2. Decorrelation Stretching 75
4.4.2.2.3. Vegetation Indices 77
4.4.2.2.3.1. The Tasseled Cap 78
4.4.2.2.3.2. The Gram-Schmidt 78
4.4.2.2.3.2. Global Vegetation Index (GVI) 79
4.4.2.2.3.3. Infrared Percentage Vegetation Index (IPVI) . . 79
4.4.2.2.3.4. Modified Normalized Difference Index (MNDI) . . 79
4.4.2.2.3.5. Transformed Vegetation (TVI) 80
4.4.2.4. Normalization 80
4.4.2.5. PCA for Vegetation 80
4.4.3. Maximum Likelihood Classification 82
4.4.3.1. Accuracy Assessment 82
4.4.4 Integration of RS, GIS at Database Level 83
4.5. Landslide Inventory 85
4.5.1. Input Data 85
4.5.2. Data Production 86
5. LANDSLIDE DATABASES 90
5.1. Topological, Morphometrical database 90
5.1.1. Polystats Database 91
5.1.1.1. 1952 Period 91
5.1.1.2. 1972 Period 95
5.1.1.3. 1984 Period 98
5.1.1.4. 1994 Period 100
5.1.1.5. The Comparison of Four Periods 102
5.1.2. The Fuzzystats Database 105
5.1.2.1. Form Ratio 105
5.1.2.2. Grain Shape Index 107

5.1.2.3. Compactness 108
5.1.2.4. Circularity 1 109
5.1.2.5. Circularity 2 110
5.1.2.6. Elongation 111
5.1.2.7. The significant changes and evaluation of fuzzy parameters with relation to Polystats database 112
5.2. Photo-characteristics Database 114
5.2.1. Massinfo 114
5.2.2. Type 115
5.2.3. Style 116
5.2.4. Depth 116
5.2.5. Distribution of Activity 117
5.2.6. Land cover 118
5.3. Landslide Attribute Databases 119
5.3.1. Lithomap 120
5.3.2. Distfault and Faultdens 121
5.3.3. Elevmap 123
5.3.4. Distance to drainage 123
5.3.5. Drainage Density 125
5.3.6. Distridge 125
5.3.7. Aspect 126
5.3.8. Slope 127
5.3.9. Distsettlement 128
5.3.10.Distpower & Dist_Roadnetwork 128
5.3.11 Dist E-5 Highway 129
5.3.12. Land Cover. 130
6. HAZARD ASSESSMENT 132
6.1. Thematic Landslide Attribute spatial distribution analysis (TLASDA) . 132
6.2. Landslide activity analysis (LACTA) 135
6.3. Landslide Isopleth analysis (LIA) 138
6.4. Statistical analyses 140
6.4.1. Bi-variate analyses 147
6.4.2. Multivariate analyses 151
6.4.2.1. Factor analysis 152
6.4.2.2. Logical Regression 157
6.4.3. Comparison of two produced hazard maps 163
6.4.3.1. The comparison of methods via their areas and corresponding landslide seed cells 163

6.4.3.2. The comparison of two methods in the spatial domain . . 164
7. DISCUSSION 170
7.1. Data production 170
7.2. Data evaluation 173
7.3. Hazard Analysis 176
7.4. Hazard Map Comparison. 179
8. CONCLUSIONS 182
REFERENCES 184
VITA 196

LIST OF TABLES

TABLE

2.1. The number of GRC needed to identify and interpret object of varying contrast in relation to its background 13

2.2. Minimum object size needed for landslide Identification or Interpretation 14

2.3. Time schedule comparison of phases of landslide hazard assessment of conventional methods and GIS based methods based on scale 18

2.4. The trends in landslide hazard zonation 19

2.5. The possible combinations after map crossing 28

2.6. The possible combinations after crossing of two binary maps 29

2.7. Classification of Methods based on scale factor 39

3.1. Studies performed in the study area and its near vicinity 41

4.1. RMSE of Ground Control Points 74

4.2. Covariance, Correlation and Transformation Matrices for PCA 76

4.3. Eigenvalues and Associated Percentages 76

4.4. Parameters used in the Gram-Schmidt Transformation 79

4.5. Covariance, Correlation and Transformation Matrices of PCA for Vegetation 81

4.6. Eigenvalues and Associated Percentages 81

4.7. Error Matrix of the classification 83

5.1. The names and definitions of variables used from Polystats database 90

5.2. The names, Definitions and formulas of Fuzzy Properties 92

5.3 The descriptive statistics of Polystats 1952 93

5.4. Correlations of Polystats variables 1952 94

5.5. The descriptive statistics of Polystats 1972 96

5.6. Correlations of Polystats variables 1972 97

5.7. The descriptive statistics of Polystats 1984 98

5.8. Correlations of Polystats variables 1984 99

5.9. The descriptive statistics of Polystats 1994 101

5.10. Correlations of Polystats variables 1994 102

5.11. The results of Paired Samples T test 103

5.12. The ANOVA table of Polystats variable 105
5.13. The Descriptive Statistics of Fuzzystats database cumulative periods . . 106
5.14. The Result of One-Sample Komogorov-Smirnov Test for Fuzzystats . . 106
5.15. The changes through time in Polystats database 113
5.16. The re-grouping of distribution of activity variable in the photo database . 117
5.17. The nature and ranges of transferred attribute database 119
5.18. The correlation state of DISTFAULT and FAULTDENS variables 122
5.19 The comparison of whole data and landslide data 122
5.20. The descriptive statistics of the ELEVMAP 123
5.21. The descriptive stats of distance to drainage variable group 124
5.22. The descriptive statistics of the DRAINAGE DENSITY 125
5.23. The descriptive stats of distridge 126
5.24. The descriptive stats of aspect 126
5.25. The descriptive stats of Slope. 127
5.26. The descriptive stats of Distsettlement 128
5.27. The descriptive stats of Distpower, Dist road & Distroad+Distpower . . . 129
5.28. The descriptive stats of Dist_E-5 Road 130
5.29. The % change of Landcover units 131
6.1. The two dimensional matrix of LACTA 136
6.2. Two-dimensional matrix of 1952 and 1972 periods. 137
6.3. Two-dimensional matrix of 1972 and 1984 periods 137
6.4. Two-dimensional matrix of 1984 and 1994 periods 137
6.5. The percentiles of seed cells within each variable 143
6.6. Methodological snapshot of used two methods. 147
6.7. Weight values of the all available parameter classes 150
6.8. KMO and Bartlett's test with initial 13 variables 152
6.9. The Anti-Image matrices of initial 13 variables 153
6.10. The amount of total variance explained via factors 154
6.11. The rotated factor matrix and the variable loadings 155
6.12. KMO and Bartlett's test after removal of two variables 156
6.13. The amount of total variance explained via factors, after removal of two variables 156
6.14. The rotated factor matrix and the variable loadings, after removal of two variables 157
6.15. The initial assumption of the variables 160
6.16. The final classification of logistic regression 160
6.17. The variables and their loadings after logistic regression 161
6.18 The densities of landslides among hazard classes of both methods . . . 164
6.19. The available combinations of re-coding process and their meanings . . 165

LIST OF FIGURES

FIGURES

1.1. The geographic setting of the study area. 4
1.2. The outline of Asarsuyu catchment with important reference locations. . . . 4
2.1. Graphical representation of hazard, vulnerability and risk. 6
2.2. An overview of zonation activities 7
2.3. The scales of analysis and minor details 9
2.4. GIS and its related software systems as components of GIS 15
2.5. The phases of a GIS 15
2.6. The questions of a well-built GIS should answer 16
3.1. Regional geological map of the study area and its environs 40
3.2. The generalized columnar section of the study area 45
3.3. The Geological map the study area 46
3.4. Lineament map of the Asarsuyu catchment 50
3.5. Epicenter locations of Turkey greater than 5 in magnitude. 52
3.6. Epicenter locations of mid-west NAFZ greater than 3.5 in magnitude 53
3.7. Earthquakes occurred in the nearby of the study area. 54
3.8. Surface ruptures of the 12 November 1999 Düzce earthquake 55
3.9. Some examples of landslides occurred after 12 Nov.1999 Düzce earthquake. . 56
4.1. LITHOMAP and the attached topological table of the study area. 58
4.2. The area distributions of LITHOMAP 58
4.3. The FAULTMAP of Asarsuyu catchment 59
4.4. The rose diagram of FAULTMAP; a. Weighted, b Non-weighted 60
4.5. The distance calculations in distance raster map production. 60
4.6. Distance raster image (DISTFAULT) produced from FAULTMAP. 61
4.7. Fault density (FAULTDENS) of Asarsuyu Catchment. 61
4.8. The color-coded CONTOURMAP 62
4.9. Color coded DEM of Asarsuyu catchment. 63
4.10. Color draped relief model of Asarsuyu catchment. 63
4.11. The drainage system of Asarsuyu Catchment 64

4.12. The distance raster of every pixel to the nearest drainage-line (DISTDRAINMAP) 65
4.13. The drainage density of Asarsuyu catchment 65
4.14. The distance raster of every pixel to the nearest ridge-line (DISTRIDGEMAP) 66
4.15. Aspect map of the Asarsuyu catchment 67
4.16. SLOPE map of Asarsuyu catchment 67
4.17. Historical infrastructure databases of Asarsuyu catchment 69
4.18. Distance rasters and frequency distributions of 1994 period 70
4.19. a) True color composite of Landsat TM 5 (R=3, G=2, B=1), b) False color composite of Landsat TM 5 (R=5, G=4, B=1) 72
4.20. The methodological snapshot of land cover extraction scheme 73
4.21. Decorrelation stretching results (R: decor_4, G: decor_3:B: decor_1) . . . 77
4.22. Near Infra Red versus Red band Raster Correlation Graph 79
4.23. Product of Maximum Likelihood Classification 82
4.24.a) Land-cover map of the study area, b) areal distributions of land cover . . 85
4.25. The landslide attribute database 87
4.26. Landslide inventories of the four time periods. 88
4.27. Polygon grid midpoints and transferred attributes 89
5.1. The distribution plots of area of 1952 93
5.2. Histograms of Polystats database 94
5.3. Scatter plots of highly correlated variable pairs of Polystats database (1952). . 95
5.4. The frequency distributions of variables of 1972 Polystats database 96
5.5. Scatter plots of highly correlated variable pairs of Polystats database (1972). . 97
5.6. The frequency distributions of variables of 1972 Polystats database 99
5.7. Scatter plots of highly correlated variable pairs of Polystats database (1984). .100
5.8. The frequency distributions of variables of 1994 Polystats database . . . 101
5.9. Scatter plots of highly correlated variable pairs of Polystats database (1994). 102
5.10. The distributions of Polystats variables in 4 periods 104
5.11. The Frequency distribution of cumulative “Form ratio” 106
5.12. The frequency distributions of “form ratio” in all periods 107
5.13. The Frequency distribution of cumulative “Grain Shape Index” 107
5.14. The frequency distributions of “form ratio” in all periods 108
5.15. The frequency distribution of cumulative “Compactness” 108
5.16. The frequency distributions of “compactness” in all periods. 109
5.17. The frequency distribution of cumulative “Circularity 1” 109
5.18. The frequency distributions of “Circularity 1” in all periods 110
5.19. The frequency distribution of cumulative “Circularity 2” 110
5.20. The frequency distributions of “Circularity 2” in all periods 111

5.21. The Frequency distribution of cumulative “Elongation” 111
5.22. The frequency distributions of “Elongation” in all periods 112
5.23. The Frequencies of the mass info variable through time and data table . . 115
5.24. The Frequencies of the type variable through time and data table 115
5.25. The Frequencies of the style variable through time and data table 116
5.26. The Frequencies of the depth variable through time and data table . . . 117
5.27. The Frequencies of the distribution of activity variable through time and data table 118
5.28. The Frequencies of the Land cover variable through time and data table . 119
5.29. The preferred lithologies and their percentages 121
5.30. The frequency Distributions of DISTFAULT and FAULTDENS 123
5.31. The frequency distributions of ELEVMAP 124
5.32. The frequency distributions of Distance to Stream map 124
5.33. The frequency distributions of Drainage Density 125
5.34. The frequency distributions of Distridge. 126
5.35. The frequency distributions of Aspect 127
5.36. The frequency distributions of Slope 127
5.37. The frequency distributions of Distsettlement 128
5.38. The frequency distributions of Dist_ power+road 129
5.39. The frequency distributions of Distance to E-5 Highway. 129
5.40. The percentage distribution of Landcover units 131
6.1. The Thematic Landslide Attribute spatial distribution of massinfo attribute of 1994 photo characteristics database 133
6.2. The Thematic Landslide Attribute spatial distribution of type attribute of 1994 photo characteristics database 133
6.3. The Thematic Landslide Attribute spatial distribution of style attribute of 1994 photo characteristics database 134
6.4. The Thematic Landslide Attribute spatial distribution of depth attribute of 1994 photo characteristics database 134
6.5. The Thematic Landslide Attribute spatial distribution of activity attribute of 1994 photo characteristics database 135
6.6 The mechanism of the isopleth analysis 139
6.7. The isopleth map of the Asarsuyu catchment 140
6.8. The snapshot of methodology of percentile method and reclassified parameter map production 142
6.9. The percentile maps of morphology of Asarsuyu catchment with frequency and cumulative histograms 144
6.10. The percentile maps of lineament and density patterns of Asarsuyu catchment, with frequency and cumulative histograms 145

6.11. The percentile maps of infrastructure and distance to ridge of Asarsuyu catchment, with frequency and cumulative histograms 146
6.12 The steps through landslide susceptibility analysis 149
6.13. The hazard map and the amounts of landslides in each class as a result of bivariate analysis 151
6.14. Eigenvalues of the factors. 154
6.15. The positions of selected 4430 random landslide free nodes 159
6.16. Observed Groups and Predicted Probabilities 161
6.17. The hazard map and the amounts of landslides in each class as a result of multivariate analysis 163
6.18. The areal distributions of classified pixels 165
6.19. The locations of the misclassified pixels 166
6.20. The locations of the correctly classified pixels. 166
6.21. The locations of the acceptable pixels 167
6.22. The locations of the not acceptable pixels 168
6.23. The locations of the correctly classified and the acceptable pixels united . 168
6.24. The final hazard map and the infrastructure of Asarsuyu catchment . . . 169
7.1. The elements of data production stage 171
7.2. Snapshot methodology for information transformation 174
7.3. Components of data Evaluation stage 175
7.4. Components of Hazard Analysis 176
7.5. Components of Statistical analyses 177
7.6. Components of Hazard Map Comparison 180