Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (22): 3342-3355, 2007
ISSN 1812-5654

Mapping Susceptibility Landslide by Using the Weight-of-evidence Model: A Case Study in Merek Valley, Iran

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Abstract: The study area is located in the southwest part of Bisetoon Mountain, south of Kermanshah City in western Iran. Slide is the most common natural phenomenon in the area, which usually is triggered by heavy rainfall and seismic activities. Although there are few active slides in the area, but they are serious threats to population the infrastructures. The aim of this study is to indicate the main factors influencing the slope instabilities. The weights -of- evidence have been applied to evaluate the slide susceptibility using GIS. The relations between slide distributions with the physical parameters such as lithology, elevation, slope gradient, lineaments and distance from streams, vegetation and land use were analyzed by Bayesian statistical model. The weights of evidence were applied to calculate each factor's weight for the Merek region in west Iran, with numerous slides. Factors (data layers) used for the preparation of the slide susceptibility map were obtained from different sources such as topographic maps, geological maps and satellite images. The results of the analysis of mapping were validated using previous and recent slide location. We found that six parameters namely, distance from stream, slope, land use, profile curvature, plan curvature and lithology show better correlation with slide susceptibility. In the study area of the present work, the methodology was tested by the means of consistent slides found in hillslopes of Nesar Kooh valley. Since most of the information related to slides susceptibility map is geo-spatial, GIS is capable to store, update, display, process, analyze and integrate the different geo-spatial data. Based on this study, six appropriate factors were selected for slides potential hazard mapping in the Merek area. Results of six selected factors are in a good accordance with recently occurred slides.

Key words: Slide, WofE, susceptibility, modeling, hillslopes, Kerman Shah

INTRODUCTION

There have been many studies on slide hazard evaluation using GIS. Guzzetti *et al.* (1999) summarized many slide hazard evaluation studies. Recently, there have been studies on slide hazard evaluation using GIS (Burton and Bathurst, 1998; Larsen *et al.*, 1998; Turrini and Visintainer, 1998; Gokceoglu and Aksoy, 1996; Baeaz and Corominas, 2001; Lee and Min, 2001; Lee, 2003; Lee and Choi, 2004; Mandy *et al.*, 2001; Clerici *et al.*, 2002). According to Batty (2000) and Franca-Rocha *et al.* (2003), there are about twenty applications of cellular automation (CA) models to cities. Some of these applications are diffusion or migration of population (Portugali *et al.*, 1997), competitive location of economic activities (Benati, 1997), joint expansion of urban surface and traffic network (Batty and Xie, 1994), generic urban growth (Clarke *et al.*, 1997) and urban land-use dynamics (Deadman *et al.*, 1993; Phipps and Langlois, 1997; White and Engelen, 1997; White *et al.*, 1998). Risk assessment and modeling floods by GIS, (Shanker *et al.*, 2003) has become a key topic of interest for geoscientists, engineers and end-users in the last decade. Spatial relationships between natural seismicity and faults using weights of evidence (Daneshfar and Benn, 2002). In the last decade, statistical modeling of slide susceptibility by GIS has become a major topic of research. Despite some advancement, particularly by implementation of the Bayesian approach based on the concept of weight of evidence, some unsolved questions may be raised: (I) what is the influence of the input data on the quality of the simulations. In addition (ii) how we can resolve the effect of violating the conditional independence assumption.

Previous modeling with Geographic Information Systems (GIS) to date has invoked simple Boolean overlay of evidence and addition of evidence layers, with or without an additional expert weighting

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(Pan and Harris, 2000; Pike *et al*., 2003). These methods, although overly simplicity, are intuitive and allow a consensus in the decision making process. These methods do not consider the essential concepts of prior and posterior probability at the heart of Bayesian methodology.

Binary weights-of-evidence (WofE) offers a more rigorous and objective statistical approach that has found many applications in modeling real world situations (Agterberg, 1989; Bonham-Carter, 1994; Knox-Robinson, 2000). A major benefit of WofE is the unbiased, statistically derived weight it provides for individual layers of data. However, WofE is perceived by many users as both an oversimplification because of its typically binary input and yet overly complex in mathematics. Multi-class WofE offers better representation of data distributions, but statistical noise can sometimes limit the effective use of multi-class weights.

The study area: The study area (Fig. 1) is located in the southwest part of the Bisetoon Mountain, south of Kermanshah, west Iran It covers an area of approximately 1489 km^2. Slide is the most common natural phenomenon in the area and it is usually triggered by heavy rainfall and seismic activities. Although there are few active slides, they have represented a serious threat to human activity and the numerous infrastructures. The region lies within the Zagros Mountains. The studied area is part of the Zagros mountain chain of Iran. Berberian (1995) subdivided the Zagros Ranges into several morphotectonic units with different degrees of thrusting, folding, uplift, erosion and sedimentation. There is a general agreement between the morphotectonic units and the geomorphometric mapping implemented, while a further subdivision of Simple Fold Belt defined by Berberian (1995) to two sub-regions with different geomorphometry was proposed. The geological structure of the area, which is characterized by clastic sedimentary rocks, has influenced the morphological evolution of the slopes since Pleistocene. Numerous paleo-landsides and debris flows can be observed on slopes and hillslopes. Sedimentary rocks deposited during Middle Cretaceous to Late Eocene. Rapid uplift of the nearby mountains supplied a large volume of clastic fragments which can be found at southern part of the Merek's valley. As a result, the sedimentary basin gradually became a shallow sea and then the sea retrogressed due to epirogenic events. Different unconsolidated materials have been observed as

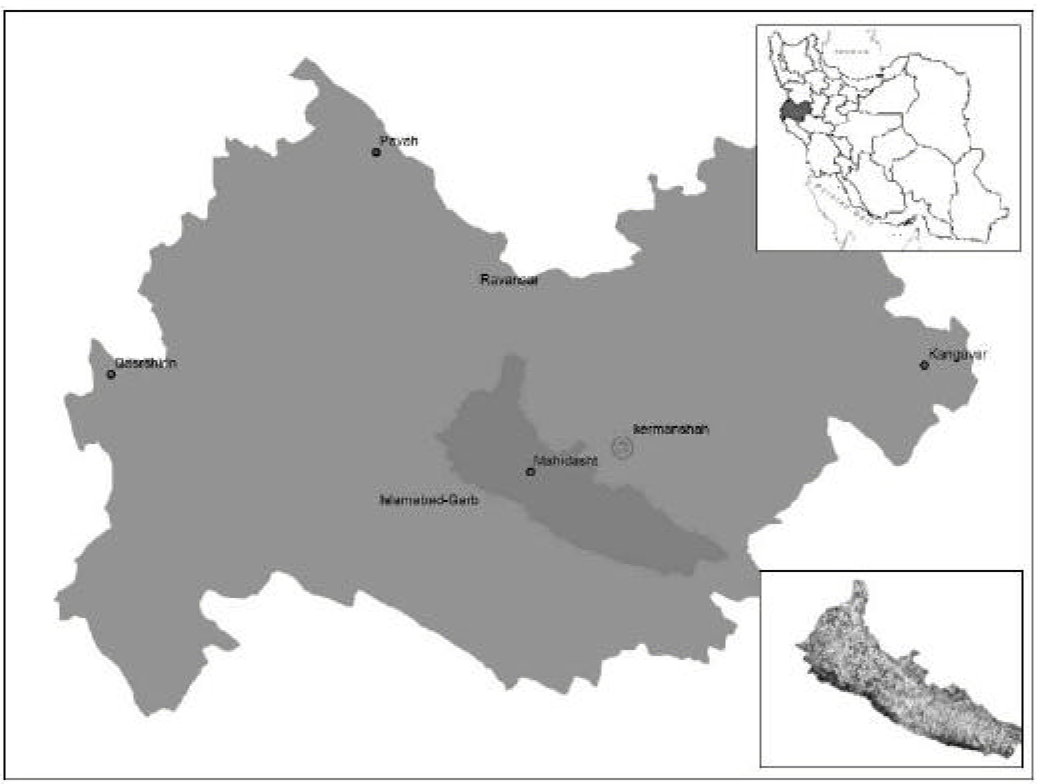

Fig. 1: Study area location in Iran and Kermanshah province

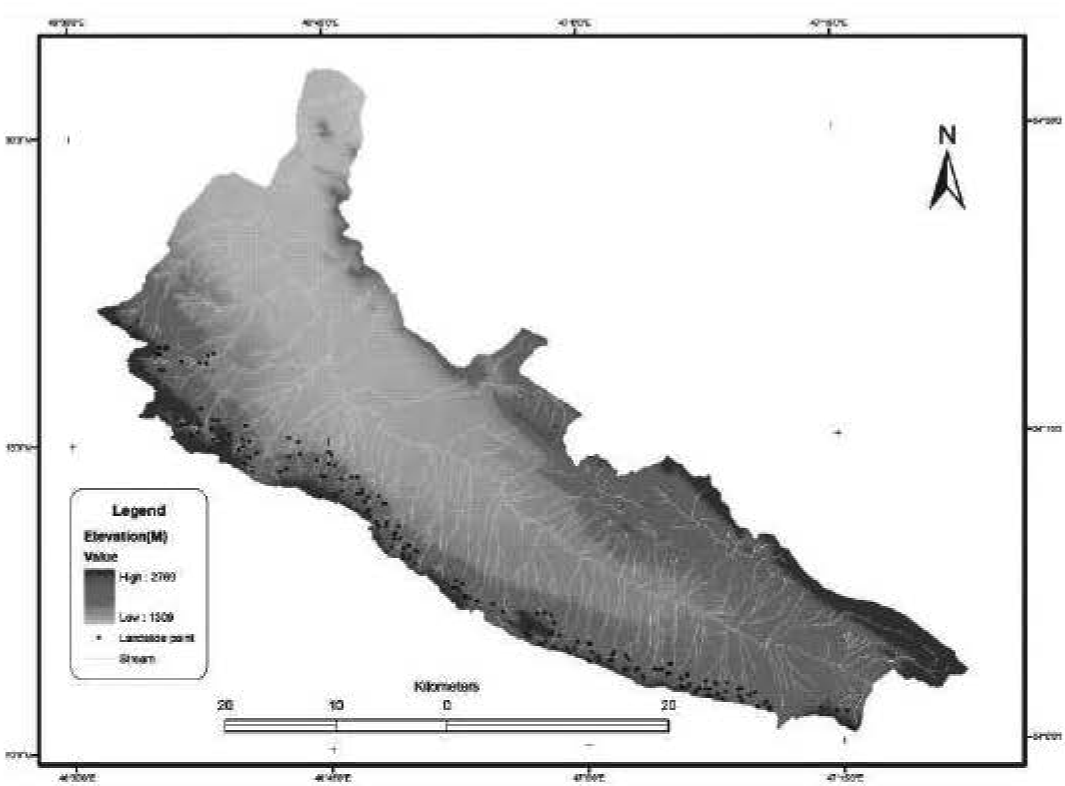

Fig. 2: Distribution of slides points over the southern slopes of Merek Basin

weak conglomerates. These conglomerates include fragments of chert, radiolarians chert, ophiolithic rocks and ultra basic rocks. Almost all instabilities in this area occurred in the conglomerate, sandstone and red marls units. The area is characterized by intense erosion and gully development, mainly on sedimentary rocks. Most of the slides are happened in the Miocene units including Amiran's Flysh and Kashkan formation.

The environmental costs owing to slides include the loss of soil and vegetation, changes in stream morphometry and sedimentation. Slides, which obviously displace rock, soil and vegetation, further disrupt the pedogenesis of soils and damage the habitats of both below ground and aboveground inhabitants. However, the erosive nature of a slide has comparable benefits as well (Fig. 2).

Slide hazard mapping is essential for land-use activities and management decision-making in mountainous areas. This research gives a view of slide characteristics on natural terrain of Merek area, Kermanshah, Iran and developing a Geographical Information Systems (GIS) approach to modeling slope instability. The relations between slide distributions with the physical parameters such as lithology, elevation, slope gradient, slope aspect, lineament, drainage, vegetation and land use were analyzed by Bayesian statistical model. A susceptibility map is modeled by incorporating these parameters in a weight of evidence model using Bayesian approach. The first essential step in this study is to establish spatial database for slides in GIS, including slides inventory data and the effecting factors (Bruce *et al.*, 2004).

The annual mean temperature in the study area is about 12.5°C and the annual mean precipitation is about 550 mm.

MATERIALS AND METHODS

Geographical Information Systems (GIS), defined as a set of tools for collecting, storing, retrieving, transforming and displaying spatial data, have become a valuable tool for planners across a wide range of disciplines. Everything on the surface of the earth has a spatial position. The ability of GIS to perform spatial analyses has great applications in other fields such as hydrology and community planning. Over the past few decades, the field of natural hazards has found particular use for GIS in order to place the constraints on spatial distribution of the hazards. This multidisciplinary approach highlights the ability of GIS as a tool that complements other disciplines such as slide hazard zonation. Arcview GIS is a popular platform to visualize, explore, query and analysis data, geographically. It can access and handle data in various file formats. Arcview version 3.2 was used in this study. Its capabilities can be greatly enhanced by so-called extentions. The following extention was used: (i) Spatial analyst 1.1. This extention from ESRI is necessary to handle files in raster format, (ii) Grid analyst 1.1. which offers a great variability of possibilities to manipulate or extract data from Arcview grid files including statistics calculation and (iii) ArcWofE, weight of evidence extention, which combines various data to analyze weight of each data layer. Four main steps are necessary to build a weight of evidence model and run an analysis:

- Building a spatial database.
- Extracting predictive evidence.
- Calculating weights for each evidential theme.
- Combining the evidential themes to predict the slide susceptibility map.

Factors (data layers), which have been used for the preparation of the slide susceptibility map were obtained from different sources such as topographic maps, geological maps and satellite images. The factors used for the preparation of slide susceptibility map were obtained from topographic sheets of Iranian military geographical service, geological maps of Kermanshah (Geological Survey of Iran) and satellite imagery (landsat ETM^{+}) was used for classification of landuse, also IRS pan imagery was used to delineate liniments, possible faults and to extract terrains properties related to slides. All the above data layers were converted to raster format in GIS (Nurla, 2003; Fernande *et al*., 2003) and each representing an independent variable of constructed spatial database. Computerization of the database would be necessary to make such analysis possible within an acceptable period. Data preparation is the first fundamental and essential step for slide susceptibility analysis. The spatial database is mainly composed of two parts: slide inventory and slide affecting factors. Its compilation follows several procedures: stereoscopic interpretation of multi-temporal vertical aerial photographs, recognition of topographic features indicative of slide landforms on aerial photographs, IRS pan image and topographic maps, which can be finished by its combining with slide data from previous investigations and information, field verification of landside data and compilation of the slide inventory map and digitization of data into GIS.

The slide inventory of this area contains about one hundred slides. Figure 2 shows the slide inventory map in the Merek watershed (valley). The slides localities were detected by interpretation of aerial photographs and limited field surveys. A map of inventory slides was prepared from 1:20 000 scale aerial photographs. This map was used to evaluate the frequency and distribution of slides in the region. Topography, geology, land cover and lineament databases were constructed for further studies.

Maps relevant to slide occurrence were constructed from a vector type spatial database using ARC GIS software. These included 1:50000 topographic maps and 1:100 000 geological maps. A digital elevation model (DEM) was created using the topographic database. The released SRTM DEMs for the study region are at 90 m resolution. As they are very recent, no publications were encountered on the use of SRTM DEMs in slide hazard assessment. It is expected that SRTM DEMs will be used extensively in the near future in regional scale slide hazard assessment projects in developing countries. Although a resolution of 90 m still is not very promising and not suitable for generating slope maps, it would allow characterization of the terrain using morphometrical analysis. Some data layers, which are used here, are extracted from DEM.

Elevations were interpolated to grid cell size 100, 50 and 25 m, using same input data and interpolation algorithm proposed by Hutchinson and Gallant (2000). As part of the slide mapping effort, slide-initiation localities (the upslope end of each mapped slide, i.e., the head scarp) were identified and were digitized (as points) and a 50 m resolution DEM was generated from the 20 m elevation contours on the two topographic maps (Coe *et al*., 2004). Some data, which were used here, have been derived from a DTM, which gives some indication about the terrain morphometry according to the algorithms used. The information derived from the DTM is very useful for statistical model, but they are available only if the DTM has good precision for the scale of work. For example, the National Height Elevation Database (spatial resolution of 50 m) is not adapted, in particular for complex mountainous environments.

Different algorithms were performed and compared (Borgefors distance method, radial basis method, kriging method). Best results were obtained by complex interpolation method as kriging method with specific variogram. In addition, it is essential to have precise and adapted topographic information (metric resolution and elevation precision close to the meter), built either by precise digitization of elevation lines (time-consuming task), or derived from expensive technical image processing (photogrammetry, laser scanning) to obtain good simulation for this scale (Thiery and Sterla Chini, 2004).

Slope, aspect and curvature, which are relevant to the slide analysis, were calculated from the DEM. Lithology was extracted from the geological database. The land-use data were taken from Landsat TM imagery with 30 m resolution. The lineaments were detected from IRS imagery with 5 m resolution, using the expertise of a structural geologist. In addition, distance from lineament was calculated by buffering (Herva *et al*., 2003). Using the detected slide locations and the constructed spatial database, slide analysis methods were applied and validated. The calculated and extracted factors were mapped to a 50×50 m grid in Arcveiw GRID extension. In the next step, by using the weights-of-evidence method, spatial relationships between the slide location and each of the slide-related factors, such as topography, lithology, land cover and distance from lineaments, were analyzed (Brardinoni and Slaymaker, 2002). The spatial relationships were used as each factor rating in the overlay analysis. Subsequently, tests of conditional independence were performed for the selection of the factors to be used in slide susceptibility mapping. Finally, the results of a comparison of 17 different combinations were validated using previous slide locations.

Affecting factors: Some GIS-based slide analysis models, such as statistical models, are based on the assumption that an area where slides occur is now under prone to slide environments (LAN *et al*., 2004). Moreover, such environments have high potential of new slides occurrence. Future slides will occur under circumstances similar to those of past slides. Such slide prone environments are depicted by factors affecting the occurrence of slides, such as rock and slope angles and landuse that are usually digitized as layers in GIS.

In this study, eleven categories of slides effecting factors are defined and selected. They includes: slope degree, aspect of slope, profile curvature, plan curvature, curvature, elevation, lithology, landuse and inventory slides from DEM, air photos and IRS satellite imagery. Arc GIS calculated also distance from streams and faults. Each category is subdivided into different classes by its value or feature (Table 3).

Lithology: Lithology is one of the most important factors, controlling slides. Researchers (Koukis and Ziourkas, 1991) emphasized on the role of lithology in stability of slopes. These statistical analyses together with field observations were used to assess the weightings of different formations towards slide susceptibility. The geological map was transformed into a digital form by simple digitization. The main part of the study area is covered by limestone, Neogene's sediments, mainly marls and clastic materials.

It is expected that lithology would be a major controlling factor for sliding. A new simplified lithology map prepared and digitized, which was modified from the original geological map. Twelve major units are defined in the Merek area, but cataclastic rocks are widely distributed in the south part of the Merek watershed.

Distance to the major Lineaments

Faults: Lineaments are defined as straight linear elements, visible at the earth's surface, which are the representations of geological and/or geomorphological phenomena. In geomorphometric analysis, a linear feature may have geometric origin only and represent a change in terrain elevation, such as a valley or ridgeline, slope-break or inflexed line (Daneshfar and Benn, 2002). In terms of digital modeling, a lineament is a continuous series of pixels having similar terrain values. The most significant faults in this region are the active Nesar and Merek faults. These faults pass through the whole watershed from east to west. These are composed of several fault section. The distance of all pixels to each fault section is calculated and classified into nine categories.

Slope angle, slope aspect and elevation

Slope has multiple influences on the slide susceptibility. It directly effects on shear stress in soils - unconsolidated materials - and indirectly controls surface water velocity (degree of saturation). Gentle slope - low gradients are expected to have lower susceptibility to sliding than steep ones. Slope gradient was modeled by Horn's method (Horn, 1981) using a grid-based DEM. As the first derivative of elevation slope, gradient was derived by calculating the maximum rate of change in elevation from a center cell to its eight neighbors. The method takes into consideration the local variability of terrain and applies weights to each of the neighboring cells according to the distance from the center cell (transverse cells are given higher weights than the diagonal ones).

The slope angle, slope aspect and elevation data are extracted from the Digital Elevation Model of the Merek area. This task has been implemented in Arc Map by means of spatial extension model. The values of slope angle are divided into nine classes (using quantile classification method): 0-5°, 5-10°, 10-15°, 15-20°, 20-25°, 25-30°, 30-35°, 35-40° and 40-45°. The values of slope aspect are divided into nine classes with the 40° intervals.

Slope aspect: The degree of saturation of slope forming material has significant control over the occurrence of slides. Previous studies have shown that slides are usually abundant on N, NNE and SSW orientations a fact that was attributed mainly to climatic factors (Koukis and Ziourkas, 1991).

Distance to streams: Some studies showed that proximity to drainage lines of intensive gully erosion is an important factor controlling the occurrence of slides (Gokceoglu and Aksoy, 1996; Pachauri *et al*., 1998). This can be attributed to the fact that terrain modification caused by gully erosion (undercutting action of streams) may influence the initiation of slide. In addition, maximum infiltration is observed on slopes adjacent to streams where the materials have maximum permeability, i.e., fragmented rock/colluvial deposits. Drainage lines were derived directly from the topographic sheets and distances (in meters) were calculated in the form of buffers around the vector datasets.

Curvature values: Primary topographic attributes are specific geometric properties of the topographic surface calculated directly from the DEM. Primary attributes include slope, aspect, plan and profile curvature, flow-path length and upslope. Most of these topographic attributes are calculated from the directional derivatives of a topographic surface. They can be computed directly with a second-order finite difference scheme or by fitting a bivariate interpolation function, z f (x, y), to the DEM and then calculating the derivatives of the function.

RESULTS AND DISCUSSION

Weights-of-evidence model: Slope instability hazard zonation is defined by mapping of areas with an equal probability of occurrence of slides within a specific period of time (Varnes, 1984), while susceptibility mapping depicts division of land surface into zones of varying degree of stability based on the estimated significance of the causative factors, including instability (Anbalagan, 1992). Thus, susceptibility should be examined as the likelihood that such phenomena occurs under the given terrain conditions regardless of the time

Scale (time-recurrence) within which a particular slide is likely to take place (Atkinson and Massari, 1998). Although knowledge on the causes of slides is essential in decision-making, the occurrence of slope instability is highly correlated with intrinsic variables that contribute to the occurrence of slides, such as geology, land cover, slope gradient etc. The spatial distribution of intrinsic variables within the study area determines the spatial distribution of relative slide susceptibility in the region.

A binary WofE model was constructed using the same training sites and evidence layers used to build the density function model. Arc View 3.2a software was used for modeling computations. Arc SDM is a spatial data-modeling package developed by the Geological Survey of Canada (GSC) and the United States Geological Survey (Kemp *et al.*, 1999). Weights-of-evidence analysis is based on Baye's Theorem, which assumes conditional independence between evidence maps. The application of WofE analysis to mineral deposit modeling has been used previously (Bonham-Carter, 1994; Wright *et al*., 1988). Raines *et al.* (2000) provide a concise description of the application of WofE analysis to mineral deposit exploration using ArcView software.

For each of the eleven evidence layers in the model, a binary map was produced indicating areas favorable and unfavorable for the occurrence of geomorphologic systems. The optimal binary pattern for each map was determined by either maximizing the WofE cumulative contrast statistic (C), or by maximizing the studentized contrast statistic (SC). The contrast is defined as the absolute difference between positive (W^+) and negative (W^-) weights of evidence (Wright *et al*., 1988; Bonham-Carter, 1994):

$$C = | W^+ - W^- | \quad (1)$$

The studentized contrast is a measure of confidence and is defined as the ratio of the contrast divided by its standard deviation (Bonham-Carter, 1994):

$$SC = \frac{C}{S_{contrast}} = \frac{|(W^+ - W^-)|}{\{sqrt\ [S^2(W^+) + S^2(W^-)]\}} \quad (2)$$

For evidence layers with a maximum contrast greater than 2, the maximum contrast was used to determine the binary pattern. For evidence layers where the maximum contrast was less than two, the maximum studentized contrast was used instead, to help insure statistical significance. Positive weights, negative weights, contrast and studentized contrasts for each of the eleven evidence layers are calculate (Table 3).

The posterior logit was chosen for plotting favorability instead of the more customary posterior probability, because the former yielded superior amounts of color-scaled detail on the map and was the only representation of weights that could compete with the detailed color-rankings provided by the density function method discussed below. A possible explanation is provided by the fact that posterior probabilities in this study approximate a log-normal distribution and plotting on a log-scale (such as that afforded by the posterior logit equation) should yield a better spread of rankings.

As slope instability processes are the product of local geomorphic, hydrologic and geologic conditions (Soeters and Van Westen, 1996), several different methods for assessing slide hazard were proposed or implemented by considering physical parameters that may affect probability of slide occurrence. In this study, the relative importance of each terrain parameter as a determining factor of slope instability was quantitatively determined by weights-of-evidence (WofE) method.

Weights-of-evidence is a quantitative data-driven method used to combine datasets (Bonham-Carter, 1994; Carranza, 2003). It uses a log-linear form of the Bayesian probability model to estimate the relative importance of evidences by statistical means. This method was developed at the Canadian Geological Survey (Bonham-Carter, 1994) and was applied to the mapping of mineral potential. In the Bayesian approach, prior and posterior probabilities are amongst the most important concepts (Raghavan *et al*., 2004).

Given an area of study that contains certain number of slides, the prior probability of occurrence of slide per unit area is calculated as the total number of slides over the total area (Bonham-Carter, 1994; Maria, 2005).

$$P\{D\} = N\{D\}/N\{T\} \tag{1}$$

This initial estimate can be later increased or diminished in different areas by the use of other evidence.

All the data layers mentioned above were converted to raster format in the GIS, each representing an independent variable of a constructed spatial database. Each of the data layers was grouped into various classes and each class was assigned a rate. Rating of individual classes denotes the degree of susceptibility they represent. The distribution of values within each data layers was taken into consideration for the differentiation of the classes. Classification values from studies at different areas of the world were found not to be applicable in this specific case. Previous statistical studies though offer complementary information regarding the actual behaviors of various factors. The weights of each factor, after the combination of various factors, are tabulated in (Table 1).

Pair wise test of conditional independence: The conditional independence was tested before the integration of the predictor patterns to map the slide susceptibility. All the pairs of binary predictor patterns were tested. The results (Table 2). The χ^2 values for testing the conditional independence between all pairs of binary patterns for each factor were calculated at the 99% significance confidence level and 1 degree of freedom. If the χ^2 value in the contingency table is below 6.63, the pair of binary predictor patterns is independent. One of the assumptions of WofE is that of CI, where CI between two binary evidential themes, B1 and B2 with respect to a set of deposit points, D, is defined as [B1nB2|D] = P [B1|D].P [B2|D]) (Fernande *et al*., 2003). If we assume CI, the effect of interaction between themes can be ignored and each theme can be evaluated individually and combined together by adding the weights. As each evidential theme relates to the same reference set, it is natural that assumption of CI will be violated to some degree. The question is when CI is serious? One of the effects of CI violation is that even though in some instances the posterior probabilities are too large, often the ranking of areas by probability is essentially unchanged, so the spatial patterns of the response theme are little affected. Carrying out a logistic regression analysis using the same data can also test this. In several studies involving violation of CI in WofE, similar maps (in terms or ranking) were obtained with WofE and logistic regression (Agterberg, 1989; Wright *et al*., 1988).

In order to judge the seriousness of CI, various tests have been suggested, but Chi-square has the best result.

Chi-square test: This method considers all possible pair wise comparisons of evidential themes. A contingency table is set up for each pair, using only reference point locations (slide sites). The number of observed sites in

Table 1: Environmental attributes derived from digital elevation model

Attribute	Definition	Significance
Elevation	Height above see level	Climate, vegetation, potential energy.
Slope	Change in elevation divided by horizontal distance	Overland and subsurface flow velocity and runoff rate. precipitation, vegetation, geomorphology, soil water content, land capability class
Aspect	Slope azimuth	Solar insolation, evapotranspiration, flora and fauna distribution and abundance.
Profile curvature	Slope profile curvature	Flow acceleration, erosion/deposition rate, geomorphology.
Plan curvature	Contour curvature	Converging, diverging flow, soil water content, soil characteristics.
Tangent curvature	Curvature of line formed by intersection of surface with plane normal to flow line	Erosion/deposition.

Table 2: Calculated χ^2 values for testing the conditional independence between all pairs of binary patterns with each factor in the 99% significance level (the grey area is not independent)

Factors	Aspect slope	Tangent curvature	Distance from faults	Hypsometery	Lithology	Plan curvature	Profile curvature	Slope	Distance from streams	Distance from streams with 5-10° gradint
landuse	9.73	1.05	1.11	7.76	35.46	0.79	5.00	1.46	12.41	0.03
Distance from streams with 5-10° gradint	14.00	2.20	0.78	10.57	2.56	1.36	1.44	1.50	78.16	-
Distance from streams (km)	23.24	3.22	6.49	5.99	14.83	0.85	2.08	2.20	-	-
Slope	2.64	2.03	2.00	27.56	23.24	12.65	22.86	-	-	-
Profile curvature	6.75	14.90	3.09	16.91	1.34	27.51	-	-	-	-
Plan curvature	1.25	2.68	2.69	0.65	2.26	-	-	-	-	-
Lithology	28.80	1.82	35.78	26.28	-	-	-	-	-	-
Hypsometery	8.48	2.57	8.21	-	-	-	-	-	-	-
Distance from faults	1.59	0.73	-	-	-	-	-	-	-	-
Tangent curvature	4.21	-	-	-	-	-	-	-	-	-

each cell of the table is compared with the expected value (row total multiplied by column total, divided by overall total). The goodness of fit is then measured with the chi-square test. It can be seen that the pairs of slope and aspect show a conditional independence, because the χ^2 is equal with 2.64 relative to the criterion that the χ^2 value is 6.63 at the 99% significance level. This implies that these binary predictor patterns could be used together to map the slide susceptibility. However, the pairs of slope and lithology show conditional dependence, because the χ^2 value is 14.83 relative to the criterion of χ^2 value of 6.63 at the 99% significance level. This implies that these binary predictor patterns could not be used together to map the slide susceptibility (Table 2).

The present research is aimed to examine the integration of terrain data in slide analyses and to contribute to the recognition of areas of possible environmental degradation. The location chosen for the study was Merek, which repeatedly suffered slides. Our focus was on Merek River basin, the largest drainage basin, in the SE of Kermanshah. The entire area is characterized by complex geology, active tectonics-seismicity and occasional heavy rainfalls. Their influence on natural hazards, including slides (ground mass movements) is significant.

For preventing natural hazards, techniques for hazard assessment and prediction must be developed and contour maps must be prepared. To achieve this, hazard prevention related data must be constructed, analyzed and distributed. Consequently, hazard DB (database) construction, are fundamental work to be done. Slide locations of the Merek area were detected. Basic map data were designed and made into an SDB using GIS. Topographic maps, geological maps, hydrographic data, satellite imagery all were collected, processed and made into an SDB (spatial database or Geography database). The relationships analysis between slide and factors was performed. Then, the slide susceptibility map was made by using these relationships. The subject was verified by calculating the correlation observed between slide localities and the slide susceptibility map (Wange *et al*., 2004). Generally, the verification results showed satisfactory agreement between the susceptibility map and the existing data on slide location. The relationship between slide and slide-related factors is as follows. In the case of slope (Table 3), the lower the slope causes the greater slide probability. For example, between 5° and 10°, the contrast is 1.2634, indicating a very high contrast and above 10° and below 5° the contrasts are (0.0606-1.1849), indicating a very low probability (Felicisimon *et al*., 2002; Lee and Choi, 2004). It means that slide probability decreases with slope angle. In the case of aspect (Table 3), the contrast was highest on South-west-facing (0.5903) and North West facing hill slopes (0.5902) and contrast was lowest on south-facing and south-west-facing hill slopes. Thus, slopes facing the northeast are highly susceptible to slides. Curvatures represent the morphology of topography. A positive curvature indicates that the surface is upwardly convex at that cell and a negative curvature indicates that the surface is upwardly concave at that cell. In the case of curvature (Table 3), the more negative (concave) the value, the higher contrast can be seen. An upwardly concave slope has more water and retains it longer. In the case of profile, the contrast was highest. It can be seen both at negative and positives classes (Table 3). That is because of sensitive lithology, fractured zone by tectonic, developed streams, deformed slopes on upwardly concave and upwardly convex slopes. In the case of distance from streams (Table 3), the contrast value is higher in general (0.8313) (see class No. 3 in Table 3); if we divide the streams into two subclasses the contrast value will change. For example, streams data was reclassified according to slope gradient, the results were different. The constrain values is higher in first 0-100 m distance from stream. This means that the slide probability decreases by increasing the distance from the lineaments. In the case of distance from faults, the contrast value is 0.6034 (Table 3). In the case of lithology evidence, the contrast value is higher in flysh and siltstone rocks. As the distance from lineament decreases, the fracture in the rocks increases and degree of weathering also increases.

Table 3: Weights-of-evidence analysis between slide points and factors

No.	Slope degree	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	0-5°	212.2300	17	-0.7457	0.2426	0.4391	0.1374	-1.1849	0.2788	-4.2502
2	5-10	118.4575	41	0.7184	0.1562	-0.5450	0.1857	1.2634	0.2427	5.2054
4	10-15	50.5625	9	0.0530	0.3334	-0.0076	0.1281	0.0606	0.3572	0.1696
4	15-20	19.7750	1	-1.2058	1.0001	0.0345	0.1204	-1.2403	1.0073	-1.2313
5	20-25	8.5950	2	0.3211	0.7073	-0.0080	0.1213	0.3291	0.7176	0.4586
No.	Slope aspect	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	Flat	124.3075	17	-0.2107	0.2426	0.0782	0.1374	-0.2889	0.2788	-1.0363
2	NE	101.4650	18	0.0496	0.2358	-0.0166	0.1387	0.0662	0.2735	0.2422
4	E	45.9625	7	-0.1030	0.378	0.0121	0.1260	-0.1151	0.3985	-0.2890
4	SE	21.8675	4	0.0803	0.5001	-0.0047	0.1231	0.0849	0.515	0.1649
5	S	15.7125	3	0.1232	0.5775	-0.0052	0.1222	0.1283	0.5903	0.2174
6	SW	10.4375	3	0.5324	0.5776	-0.0183	0.1222	0.5508	0.5903	0.9329
7	W	7.9175	0	0	0	0	0	0	0	0
8	NW	25.0025	3	-0.3415	0.5774	0.0184	0.1222	-0.3599	0.5902	-0.6098
9	N	61.9775	15	0.3604	0.2583	-0.0793	0.1349	0.4397	0.2914	1.5091
No.	DIS to Faults	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	1800-2700	21.0625	3	-0.1806	0.5775	0.0089	0.1222	-0.1895	0.5902	-0.3211
2	2700-3600	322.8150	49	-0.117	0.1429	0.3418	0.2183	-0.4588	0.2609	-1.7587
3	3600-4500	61.2500	17	0.4868	0.2426	-0.1166	0.1374	0.6034	0.2788	2.1642
4	4500-5400	3.5375	1	0.5052	1.0004	-0.0057	0.1204	0.5109	1.0076	0.5071
No.	DIS to stream (m)	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	0-100	154.8750	28	0.0686	0.1890	-0.0432	0.1543	0.1118	0.2440	0.4581
2	100-200	121.8050	17	-0.1903	0.2426	0.0696	0.1374	-0.2600	0.2788	-0.9325
3	200-300	65.2400	21	0.6458	0.2183	-0.1856	0.1429	0.8313	0.2609	3.1863
4	300-400	32.3675	2	-1.0053	0.7072	0.0523	0.1213	-1.0576	0.7175	-1.4741
5	400-500	17.1000	0	0	0	0	0	0	0	0
6	500-600	9.5125	1	-0.4738	1.0001	0.0088	0.1204	-0.4826	1.0074	-0.4791
7	600-700	5.8300	1	0.0159	1.0002	-0.0002	0.1204	0.0162	1.0074	0.0160
No.	DIS to stream (0-5°) (m)	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	0-100	267.6775	52	0.1405	0.1387	-0.3211	0.2357	0.4615	0.2735	1.6873
2	100-200	82.2050	10	-0.3278	0.3163	0.0668	0.1291	-0.3946	0.3416	-1.1552
3	200-300	40.8900	8	0.1476	0.3536	-0.0175	0.127	0.1651	0.3758	0.4394
No.	DIS to stream (5-10°) (m)	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	0-100	199.5700	39	0.1466	0.1602	-0.1584	0.1796	0.3050	0.2407	1.2674
2	100-200	122.7525	19	-0.0866	0.2295	0.0343	0.1401	-0.1209	0.2688	-0.4496
3	200-300	47.7100	10	0.2167	0.3163	-0.0320	0.1291	0.2487	0.3417	0.7279
4	300-400	21.5725	2	-0.5993	0.7072	0.0244	0.1213	-0.6237	0.7175	-0.8693
No.	Profile curvature	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	-2.047_-0.92	3.25	1	0.6016	1.0004	-0.0065	0.1204	0.6082	1.0076	0.6036
2	-0.92_ 0.215	70.26	24	0.7055	0.2042	-0.2343	0.1475	0.9398	0.2519	3.7310
3	0.215_ 1.345	318.6	43	-0.2222	0.1525	0.5047	0.1925	-0.7270	0.2456	-2.9599
4	1.345_ 2.476	21.7	1	-1.2977	1.0001	0.0393	0.1204	-1.3371	1.0073	-1.3274
5	2.476_ 3.212	1.2	1	1.6239	1.0011	-0.0116	0.1204	1.6355	1.0083	1.6220
No.	Plan curvature	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	-1.73 _ -0.84	4.1975	1	0.3449	1.0003	-0.0042	0.1204	0.3491	1.0075	0.3465
2	-0.84 _0.047	264.9400	45	0.0063	0.1491	-0.0113	0.2000	0.0177	0.2495	0.0708
3	0.047 _0.934	140.9575	23	-0.0338	0.2086	0.0170	0.1459	-0.0508	0.2545	-0.1994
4	0.934 _ 1.82	3.9350	1	0.4095	1.0003	-0.0049	0.1204	0.4143	1.0075	0.4112

Table 3: Continued

No.	Tangent curvature	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	-2.253 _ 0.471	8425	3	-0.1806	0.5775	0.0089	0.1222	-0.1895	0.5902	-0.3211
2	0.471 _ 1.311	129126	49	-0.1170	0.1429	0.3418	0.2183	-0.4588	0.2609	-1.7587
3	1.311 _ 3.093	24500	17	0.4868	0.2426	-0.1166	0.1374	0.6034	0.2788	2.1642
4	3.093 _ 4.893	1415	1	0.5052	1.0004	-0.0057	0.1204	0.5109	1.0076	0.5071

No.	Height (m)	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	1300-1400	66.5075	1	-2.4169	1.0000	0.1602	0.1204	-2.5771	1.0072	-2.5586
2	1400-1500	121.7550	6	-1.2298	0.4083	0.2574	0.125	-1.4872	0.427	-3.4829
3	1500-1600	84.2800	27	0.6428	0.1925	-0.2606	0.1525	0.9035	0.2456	3.6783
4	1600-1700	57.9050	23	0.8580	0.2086	-0.2483	0.1459	1.1063	0.2546	4.3460
5	1700-1800	50.6125	9	0.0538	0.3334	-0.0077	0.1281	0.0615	0.3572	0.1722
6	1800-1900	22.0400	3	-0.2136	0.5774	0.0107	0.1222	-0.2243	0.5902	-0.3800
7	1900-2000	10.9100	1	-0.6091	1.0001	0.0122	0.1204	-0.6213	1.0073	-0.6168

No.	Lithology	Area (km^2)	No. of slide points	w^+	s-w^+	w^-	s-w^-	C (contrast)	s-c	c/s-c
1	3	105.9575	5	-1.2763	0.4472	0.2215	0.1241	-1.4978	0.4641	-3.2271
2	4	2.7325	0	0	0	0	0	0	0	0
3	5	173.3075	26	-0.1194	0.1962	0.0779	0.1508	-0.1972	0.2474	-0.7972
4	6	55.7325	14	0.3964	0.2673	-0.0786	0.1337	0.4750	0.2989	1.5892
5	11	17592.00	19	0.939	0.2295	-0.2045	0.1401	1.1435	0.2689	2/26
6	12	5092.00	6	1.0262	0.4085	-0.0584	0.125	1.0846	0.4272	2/54

$w+$ = positive weight, w^- = negative weight, s-$w+$ = standard deviation minus positive weight, s-w^- = standard deviation minus negative weight, c = $|W+-W^-|$, s-c = standard deviation minus contrast, C/S = contrast dividing standard deviation

This contribution demonstrates that, the considered factors have had a strong influence on the occurrence of slides in the study area. Method of weights of evidence with the application of GIS-assisted indirect multi-criteria evaluation techniques has been shown to be a relatively simple and cost-effective approach for assessing slide hazard. The relationship analysis between slide and factors was performed. Then, the slide susceptibility map was made by using these relationships. The subject was verified by calculating the correlation observed between slide occurrence location and the slide susceptibility map. Generally, the verification results showed satisfactory agreement between the susceptibility map and the existing data on slide location.

In practice, the number of known slide in regions of interest is usually small and often biased by believing former slides. If, however, the known slides are unbiased and provide an adequate sample of the total population of slides, then the weights are not greatly affected by new discoveries (particularly if the unit cell is small) and the prior (and posterior) logits simply increase by a constant. The rank order of posterior logits as depicted on the favorability map is unchanged. It is often difficult to subset (an often small) number of known slide for training and model evaluation, although the WofE allows the user to do this if desired. If the sample of slide is inadequate for training the weights, it may be preferable to estimate the weights by expert knowledge, an option permitted by the program. The weighting methods employed are simple and understandable, which can make it easier for managers and groups to trust and rely on model predictions and reach a consensus on how to act on the results.

The preparation of slide susceptibility maps are of great interest to planning agencies for preliminary hazard studies, especially when a regulatory planning policy is to be implemented (Phi *et al.*, 2004). Small-scale regional surveys are low cost techniques by which large areas can be covered in a relatively short time permitting an economical and rapid hazard assessment. For the design of prevention and mitigation measures, the role of deterministic techniques should be addressed if analysis that is more detailed is needed for slides mechanism. However, the investigation of geotechnical properties of the various geological formations and their spatial variability in the study area is difficult as these properties have high heterogeneity at regional scale and much generalization should be made in order to achieve readable results. The improvement of such susceptibility maps is possible with definition of more objective weighting system. Examination of individual processes and factors controlling the occurrence of slides by means of statistical analysis (e.g., multivariate, bivariate, factor scoring) provides more realistic results. These approaches however are time consuming and represent essentially the present or absence of slides in each terrain type - simply a more complicated slide map - rather than a susceptibility map.

When attempting to map susceptibility, there is not more information on future slides So the importance of

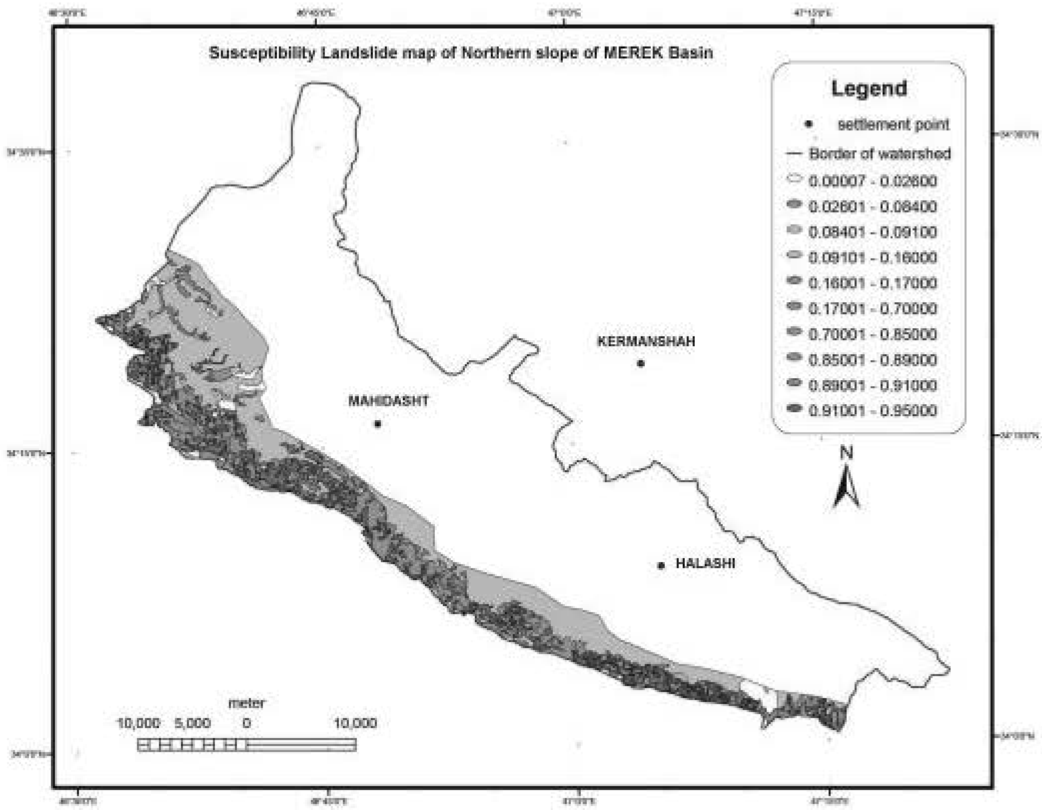

Fig. 3: Susceptibility map, obtained by combination of different effecting factors

defining independent variables that reflect conditions prior to slope movements should be addressed, condition which is not always ensured in statistical techniques. The criticism relating the subjectivity of qualitative methodologies is not necessarily bad, considering that it is based on the opinion of the expert. Establishment of weights for variables was somewhat arbitrary, as long as relative rather than absolute slide susceptibility estimation is attempted.

CONCLUSION

Taking into account previous statistical techniques as complementary information to rank factors and not as a basis to establish the weighting system, allowed the reconsideration in some cases of the weights given. The quality of the final product-slide susceptibility map-at this specific scale was examined by overlaying susceptibility map and slide inventory data for field observation. As far as the verification of the method used shows satisfactory results, this type of studies will provide a numerical basis for exploring slide susceptibility in the future. The scale of the final map (1: 50,000) is strictly depended on the scale of the data used for its generation. This map reveals the relative susceptibility of the Merek area to sliding and earth flow, but not absolute susceptibility.

Finally, it is worth mentioning that the 'weights of evidence' statistical method is not constrained by the straitjacket of rigid theory devices; neither does it impose theoretical restraints on the modeling objects. Since this a wholly empirical approach, its applicability can be extended to further slopes mountain and worldwide, provided that the minimum necessary sets of evidences maps are available (Metternicht *et al*., 2005).

In the study area of the present work, the methodology was tested using consistent slide found in hillslopes of Nesar Kooh valleys. Since most of the information related to slides susceptibility map are geo-spatial, GIS has potential for storing, updating, displaying, processing, analyzing and integrating different geo-spatial data. Based on this study, six appropriate factors were selected for slides potential mapping in the northward slopes in the Merek area.

Results of six selected factors are in a good accordance with recent slides (Fig. 3). The proposed model for susceptibility of the Merek area can be applied in other regions by applying small change in the model (Feick and Brant hall, 2004).

ACKNOWLEDGMENTS

We thank Iranian Space Agency for their assistance in obtaining and allowing us to use the Landsat TM and IRS scenes is gratefully acknowledged for help. This study supported by the Graduate office of Tabriz University. Our sincere thanks are due to Professor Dr. M. Moazzen, Associate Professor of Geology Department of Tabriz University, Iran, for his valuable suggestions during the preparation of revised manuscript. Thanks are also due to the anonymous reviewers for their critical and valuable suggestions, which helped to improve the text in the present form.

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