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Sinkhole Susceptibility Mapping Using a Frequency Ratio Method and GIS Technology near Karapınar, Konya-Turkey

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Abstract

The purpose of this study is to produce a sinkhole susceptibility map of the Obruk Plateau in central Turkey, based on a frequency ratio method within a Geographic Information System environment. Using field surveys, the locations of the 182 sinkholes were determined in the study area. In this study, 30 sinkhole-related factors were determined and used in the analysis. The values of the frequency ratio were estimated using frequency ratio analysis and were used to calculate the sinkhole potential for the entire study area. For model validation, the constructed sinkhole occurrence potential map was overlaid onto the 182 observed sinkholes, showing that 169 sinkholes (93 % of all sinkholes) were determined to be in the high and moderate sinkhole occurrence potential areas. In addition, the predictive capabilities of the models were determined by the area under the relative operating characteristic (ROC) curve. The area value under the ROC curve was 0.953. These results indicate that the model is a good estimator of the sinkhole potential in the study area. The sinkhole potential map shows that the areas of very low or no, low, moderate and high sinkhole potential classes are 712.31 km^2; 641.15 km^2, 572.45 km^2; and 438.01 km^2, respectively. The interpretations of the potential map showed that geology (lithology), elevation, aspect, fault density, distance to fault, and decline of the groundwater level play major roles in sinkhole occurrence and distribution in the Obruk Plateau. The resulting sinkhole potential map can aid planners and engineers in development plans and land-use planning.

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Keywords: Doline; obruk; sinkhole; susceptibility; GIS; Karapınar.

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1. Introduction

The dissolution of soluble rocks and deposits at the surface or in the subsurface combined with internal erosion and deformational processes can produce closed depressions called sinkholes (locally known as obruks) or dolines (Gutiérrez et al., 2008). "Obruk" is an internationally recognized Turkish geomorphic term (UNESCO, 1972), describing the collapsed dolines which are commonly observed in the currently semiarid and almost flat land of Konya Closed Basin (KCB) in central Turkey (Bayarı et al., 2009). Sinkholes are widespread at the Obruk Plateau in central Turkey, where there are carbonate bedrock outcrops. However, other sinkholes in the same region, which seem related to karst dissolution, have been identified in plain areas with sedimentary cover over buried carbonate bedrock. There are many sinkholes near Karapınar, showing dimensions ranging from a few meters to hundreds of meters in width. Several geologic, geomorphologic, hydrogeological and anthropogenic factors were identified in the Karapınar region that influences sinkhole development. Many geologic, geomorphologic and hydrologic studies (Bayarı et al., 2009; Doğan ve Çiçek, 2002; Doğan and Yılmaz, 2011; Yilmaz, 2010) have been conducted on the formation of sinkholes at the Obruk Plateau. All of these studies were performed in relation to sinkhole formation in this area but there is no study on the sinkhole susceptibility mapping for this region. The main objective of this study is the development of a sinkhole susceptibility map in a GIS environment that can help to differentiate between high and low susceptibility areas as an aid for regional land use management and the selection and application of mitigation measures near Karapınar. In this study, the author shows the procedure for establishing of the sinkhole susceptibility map for the vicinity of Karapınar based on the "Frequency ratio method."

2. Study area

The study area is located in the Central Anatolia Region of Turkey, in the eastern portion of the province of Konya (Fig. 1). The region under investigation has a total area of about 2369.112 km^2 (5922794 grid) and extends from latitude 4,153,000 to 4,208,000 m North and from longitude 507,000 to 576,000 m East. The location map of the study area is given in Fig. 1.

3. Materials and method

This manuscript investigates sinkhole susceptibility and the effect of sinkhole formation-related factors in the vicinity of Karapınar, using the FR and the GIS. Thirty two important causative factors for the formation of sinkholes were selected, and corresponding thematic data layers were prepared in GIS. Input data were collected from the topographic maps, borehole logs, and field study investigations or observations. Numerical values for different categories of these factors were determined based on a statistical approach and then integrated into the GIS environment to produce a sinkhole susceptibility map of the area. The sinkhole susceptibility map classifies the area into four classes of sinkhole susceptible zones, i.e., high, moderate, low and very low or not susceptible.

3.1 Sinkholes

The source of the sinkhole data included topographic maps, field surveys, and reports of sinkholes. Much of the sinkhole research near Karapınar has been applied in nature, and many studies have focused on the geological, geomorphological and hydrogeological aspects of sinkhole formations, and how human activity influences sinkhole formation (Bayarı et al., 2009; Doğan ve Çiçek, 2002). There was no detailed sinkhole inventory map for the study area. Therefore, a sinkhole location map was prepared for this study for the year 2010 on a topographical map at a scale of 1:25,000, and this was confirmed by the field survey. Totaly 182 sinkholes were found in the study area (Fig. 2). Forty-five randomized numbers were generated between 1 and 182, and the sinkhole numbers corresponding to these generated numbers were used as the test sinkholes.

3.2 Factors related to sinkholes

Different thematic maps of the study area, such as geology, topography, geomorphology, hydrogeology, and land use/land cover, have been produced and used in this study. Sinkhole-related factors are (1) elevation, (2) slope, (3) slope steepness, (4) aspect, (5) topographic wetness index, (6) distance to drainage line, (7) density of drainage line,

(8) geology (lithology), (9) fault density, (10) distance to faults, (11) thickness of Insuyu formation, (12) top and (13) bottom levels of Insuyu formation, (14) type of caprock, (15) thickness of caprock, (16) Groundwater Level (GWL) in October 1970, (17) GWL in April 2010, (18) GWL in October 2010, (19) differences in GWL between October 1970-2010, (20) differences in GWL between April 2010 and October 2010, (21) hydraulic gradient of GW in April 2010, (22) differences in GWL between April 2010 and October 2010, (23) Ratio (R) of differences in GWL between April 2010 and October 2010 divide by GWL in April 2010, some ions of GW such as, (24) Ca^{+2}, (25) Mg^{+2}, (26) Na^{+}+K^{+}, (27) Cl^{-}, (28) $SO4^{-2}$, (29) $CO3^{-2}$+$HCO3^{-}$, (30) total hardness of GW, (31) Electrical Conductivity of GW (EC), (32) P^{H}, (33) Dissolved Oxygen of GW (DO), (34) well density, and (35) land use/land cover. The main factors considered in the present study and those which are influential in the occurrence of a sinkhole are described below.

The study area geologically consists of sedimentary, metamorphic, and volcanic rock units. The stratigraphic sequence of the study area ranges in age from Triassic to Holocene (Fig. 2). Based on studies by Ulu (2009a, b), the geological units, which have been simplified for this study, are divided into fourteen classes. The distribution of these units/formations within the study area is provided in the geological map (Fig. 2).

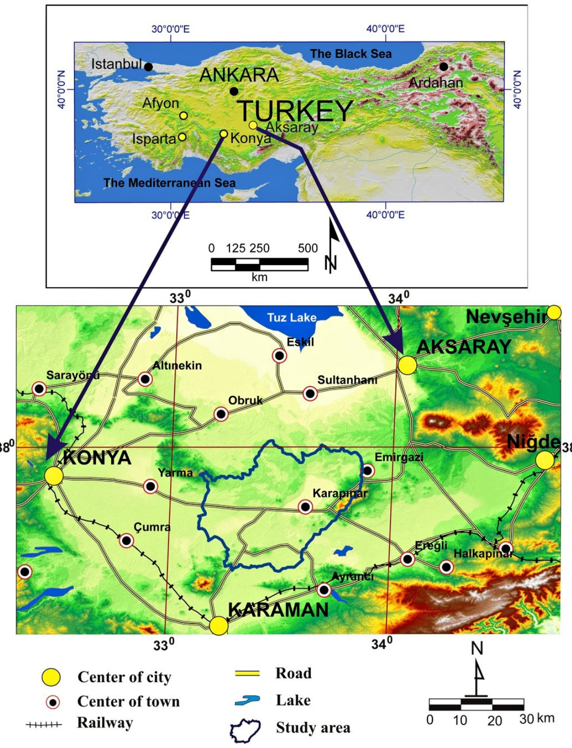

Fig. 1 Location map of the study area.

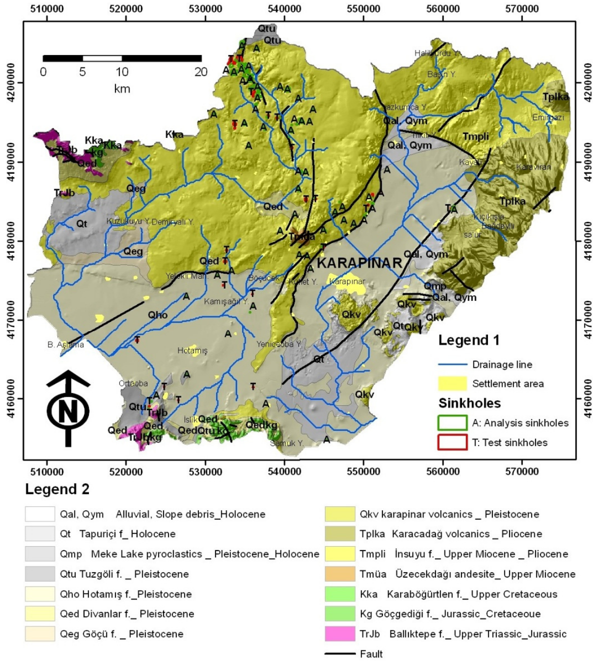

Fig. 2 Geological map of the study area (modified from Ulu, 2009a, and b).

3.3 Frequency Ratio Method and its application

The FR method has also been applied to many studies (Lee and Pradhan, 2007; Mezughi et al., 2011; Ozdemir, 2011; Vijith and Madhu, 2008; Yilmaz 2007). In this study, the FR model was used for sinkhole analysis using thirtyfive thematic layers. The calculation steps for an FR for a class of the sinkhole-affecting factors are below:

$$FR = (A/B)/(C/D) \tag{1}$$

Where: A is the number of pixels in the class of the dependent factor; B is the total number of pixels of the dependent factor; C is the number of pixels in the class of the independent factor; D is the total number of pixels in the study area; (A/B) is the percentage for area with respect to a class for the factor; (C/D) is the percentage for the

entire domain; and FR is the FR of a class for the factor.
To obtain Sinkhole Occurrence Potential Index (SOPI), frequency ratings of the factors were summed as:

$$SOPI = \sum_{i=1}^{n} FR_i \quad (i = 1,2,3,...,n) \tag{2}$$

Where; SOPI is the sinkhole occurrence potential index; FR is the frequency ratio of a factor; and n is the total number of input factors. In determining FR, the area ratio for sinkhole occurrence was calculated for the range of each factor, and the area ratio for the range of each factor to the total area was calculated. Finally, FRs for the range of each factor was calculated by dividing the sinkhole occurrence ratio by the area ratio. The FR of sinkhole occurrence was created using the overlay functions in the GIS, which were used to merge different factors that were assigned to the ratio (Oh et al., 2011). The SOPI was used to map of the sinkhole susceptibility (Fig. 3).

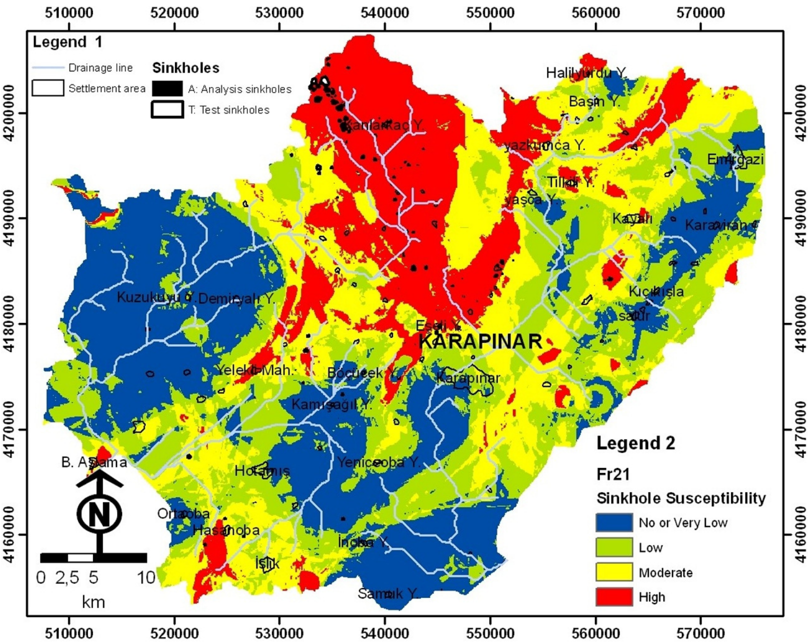

Fig. 3 Sinkhole susceptibility map.

4. Results and Discussions

In this study, sinkhole susceptibility maps were prepared using the FR method, and the accuracy of the model was evaluated by calculating the relative operating characteristic (ROC) (Oh and Lee, 2010). The value for the area under the ROC curve for the FR method was found to be 0.953, with an estimated standard error of 0.006. These results indicate that the FR model is a good estimator of sinkhole susceptibility in the study area. The FR model showed 94.2 % accuracy, indicating that it can be used for sinkhole occurrence potential mapping. The scores obtained from the FR model range from 6 to 61. These values were reclassified into four sections using the quintile classification scheme, i.e., no or very low, low, moderate, and high sinkhole occurrence potential classes. The FR method, which helped produce the sinkhole potential map, and the suitability of the model were also evaluated by comparing the map with the known sinkhole locations. The 45 test sinkholes, 137 training sinkholes and 182 total sinkhole locations were overlaid onto the SOPI map produced by the FR analyses and the percentages of existing sinkholes within the different sinkhole occurrence potential classes were determined. By overlaying the predicted SOPI map produced by the FR method with the test, training and total sinkholes, the results indicated that 75%, 84% and 82% of the observed sinkholes were concentrated in the high potential class, respectively. Comparing the observed sinkhole map with the sinkhole occurrence potential, 94% of sinkholes fall into the high and medium potential class. The sinkhole potential map obtained from the FR method contains 30.13% of the total area, which is designated to be of very low or no sinkhole potential zone. Low, moderate and high sinkhole potential zones constitute 27.12%, 24.21% and 18.56% of the total area, respectively. The evaluation of the prediction accuracy of the observed training and test sinkholes shows that the sinkhole occurrence potential maps produced through the FR method can be considered highly reliable because most of the observed sinkholes are correctly predicted by their medium and high sinkhole occurrence potential classes.

5. Conclusions

The analysis identified many major trends in sinkhole occurrence: (1) Sinkholes were most abundant on east, northeast, and southeast facing slopes. (2) In the case of slope angle, steeper slopes have greater sinkhole probabilities. (3) Sinkholes are sparse near streams, and most abundant 2000 to 3000 m away from surface streams. (4) Karapınar karst growth has a close relationship with the faults and lithology. (5) Sinkhole occurrence increases with proximity to fault lines and density of faults. (6) Sinkholes are more abundant in the Insuyu, Hotamış, and Tuz Lake formations. (7) The sinkhole occurrence probability increases with the thickness of carstification bedrock (Insuyu formation). (8) Most sinkholes occur at the cover thickness between 0 and 50 m and especially at the thickness between 20 and 40 m. (9) Regional declines of ground-water levels increase sinkhole occurrence in sinkhole-prone regions. (10) Sinkholes are abundant in the areas where hydraulic gradient is high or low. (11) Decreases in ground water level and the frequency of sinkhole formation have significantly increased since 1970. (12) The increasing incidence of induced sinkholes is expected to continue as our demand for groundwater grows. (13) The changing type of agriculture is often associated with increasing demands for water supplies, which may lead to increases in ground-water pumpage and the lowering of local and regional ground-water levels. (15) The lowering of local and regional ground-water levels increases the formation of sinkholes in the carst prone area. This map could help citizens, planners and engineers reduce losses caused by existing and future sinkholes by means of prevention, mitigation and avoidance.

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