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Future Land Use/Land Cover Scenarios Considering Natural Hazards Using Dyna-CLUE in Uzungöl Nature Conservation Area (Trabzon-NE Turkey)

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Abstract

This study aimed to determine past and potential future temporal and spatial changes in land use/land cover (LULC) and to evaluate its interactions with natural hazards (especially snow avalanches and rockfalls) in Uzungöl Nature Conservation Area (UNCA) (Trabzon- NE Turkey). The objectives were; 1) to assess past LULC change for last 60 years (1955–2015), 2) to simulate future LULC with Dyna-CLUE by 2050 considering two different scenarios, and 3) to evaluate interactions of past and future LULC change with natural hazards. The analysis of past LULC change showed an increase of 51.03 ha in settlement for last 60 years resulted from conversion fully from agriculture. From future LULC simulations, Scenario 1 resulted that settlement will grow towards areas exposed to snow avalanches, from 68 ha in 2015 up to 97.5 ha in 2035, and 126.5 ha in 2050. Scenario 2 resulted that these settlement areas will grow up to 119.75 ha in 2035 and 137.75 ha in 2050. In addition, Scenario 1 resulted that settlement exposed to rockfall hazard will change from 28 ha in 2015 to 24 ha in 2035 and 28.25 ha in 2050, whereas Scenario 2 resulted that these areas will change to 26.25 ha in 2035, 28.75 ha in 2050. This study showed how LULC dramatically changed since 1955 due to population growth and changes in consumption patterns in society, and how could be changed potentially in the future. It was concluded that an obligatory increase in settlement towards dangerous areas will be observed in future.

1. Introduction

Natural hazards are phenomena that are mostly forgotten immediately when they occur in remote mountainous regions that are more subject to multi-hazards. However, natural hazards are associated with human existence (Gardner and Dekens 2007). In the last decades, more activity of people inhabited in mountain regions has been observed due to population growth and the recent changes in consumption patterns in society resulting from various economic, environmental, institutional, and societal factors (Stürck et al. 2018). One of the main problems resulting from the increased activity of people in mountain regions is the exacerbation of vulnerability caused by the growth of settlements into risky places in terms of natural hazards. The historical shift from traditional economies based on agricultural activities to the service-based society has played a significant role in such a sharp change in land use/land cover (LULC).

When the population growth and its impact on LULC change were evaluated in Turkey, rapid and unplanned urbanization and industrialization have been observed since the 1950s (Dökmeci 1986). Accordingly, the immigration of people from the countryside to metropoles caused a considerable change in demographic structure (Atmis et al. 2007). According to the population census between 1927 and 2000 published by Turkish Statistical Institute (TUIK), the total population of Turkey increased 53.5% between 1927 and 1950, but this rate rose 223.7% between 1950 and 2000. Whereas 24.2% and 75.8% of population in 1927 was in towns and villages, respectively, 64.9% and 35.1% of population in 2000 was in towns and villages. At present, Turkey has more than 82 million people, and only 6.3 million people (7.7% of total population) live in villages/countryside (TUIK 2020a). The projections by TUIK show that the total population of Turkey will be more than 100 million by the 2040s (TUIK 2017). Depending on the population change between 1950 and 2000 in Turkey, a crucial LULC change was also observed. For example, even though agricultural lands in Turkey increased between 1949 and 1980 due to various reasons, such as starting to use agricultural tractors, a decreasing trend has been observed in agricultural lands, especially after 1980 (Bayar 2018). According to TUIK (2020b), the agricultural lands in Turkey decreased by 8% in the last 20 years.

The changes in LULC are going to be inevitable in the future in the case of such growth in the population. Therefore, Many scientific studies about LULC change and its impacts have been conducted for different regions of Turkey (Yıldırım et al. 2002; Turker and Asik, 2005; Kılıç et al. 2006; Esbah 2007; Güler et al. 2007; Sivrikaya et al. 2007, 2011; Coskun et al. 2008; Çakır et al. 2008; Doygun et al. 2008; Kadioğulları and Başkent, 2008; Kurucu and Christina 2008; Reis 2008; Alphan et al. 2009; Kesgin and Nurlu, 2009; Sancar et al. 2009; Sesli et al. 2009; Şanlı et al. 2009; Göl et al. 2010; Hepcan et al. 2011; Sertel et al. 2011; Güneroğlu et al. 2015; Sen et al. 2015; Alphan and Güvensoy, 2015; Satir and Erdogan 2016; Say et al. 2017; Viedma et al. 2017; Bayar 2018, Zadbagher et al. 2018). The LULC maps are mostly generated using remote sensing data (such as satellite images and aerial photography) for the past and recent times based on the data availability. Unfortunately, LULC maps are limited to the past and current time periods. Hence, modelling of LULC change with different methods have become important research

for different aims such as understanding LULC dynamics, exploring future pattern of landscape for developing land management and planning (Verburg et al. 2002; Ren et al. 2019). For these aims, different models have been developed; The Conversion of Land Use and its Effects modeling framework (CLUE) (Veldkamp and Fresco, 1996), SLEUTH (Clarke et al. 1997; Silva and Clarke 2002), artificial neural network cellular automata (ANN-CA) (Li and Yeh 2002; Zeshan et al. 2021), CLUE-S (Verburg et al. 2002; He et al. 2019; Kucsicsa et al. 2019), Environment Explorer (White and Engelen 2000), DINAMICA (Soares-Filho et al. 2002; Yadav and Ghosh 2019), land transformation model (LTM) (Pijanowski et al. 2002; 2006), FORE-SCE (Sohl et al. 2007; Larsen and McComb 2021), Dyna-CLUE (Verburg and Overmars 2009), Cellular Automata (CA)-Markov (Hyandye and Martz 2017; Hamad et al. 2018), and GeoSOS-FLUS model (Liu et al. 2017; Xun et al. 2018).

CLUE model was developed to simulate land use change using empirically quantified relations between land use and its driving factors in combination with dynamic modelling of competition between land use types (Verburg et al. 2021). The different versions of the CLUE model (CLUE, CLUE-s, Dyna-CLUE and CLUE-Scanner) are among the most frequently used land use models globally. The Dyna-CLUE is the most recent version of the CLUE model. In the literature, Dyna-CLUE has been commonly used for varying purposes. For example, Kucsicsa et al. (2020) studied future LULC changes in Romania. Behera et al. (2018) used the Dyna-CLUE for analysing LULC and deforestation trend (1985–2005). Sahoo et al. (2020) integrated the Dyna-CLUE into a study aiming to predict the future surface water availability. Waiyasusri and Wetchayont (2020) was assessed long-term deforestation using the Dyna-CLUE. Wang et al. (2021) was simulated spatial change of mangrove habitat under the impact of coastal LULC change by using MaxEnt and Dyna-CLUE. Adhikari et al. (2020) and Ghimire et al. (2021) used for evaluating impacts of LULC change on spatiotemporal variations in the groundwater recharge. Shrestha et al. (2018) made integrated assessment of the climate and LULC change impact on hydrology and water quality using the Dyna-CLUE. Shresta and Acharya (2021) were assessed the historical and future LULC changes and their impact on valuation of ecosystem services. In addition to this research from recent literature, the Dyna-CLUE has also been used to evaluate how LULC changes interacts with natural hazards. For example, Chowdhuri et al. (2021) used Dyna-CLUE for spatial prediction of landslide susceptibility using projected storm rainfall and land use. Saha et al. (2021) used for modelling multi-hazards threats to cultural heritage sites. Janizadeh et al. (2021) used for mapping the spatial and temporal variability of flood hazard affected by climate and land use changes in the future. In the present study, an assessment of LULC change considering its interactions with natural hazards in Uzungöl Nature Conservation Area (UNCA) was aimed. The objectives were; 1) to assess past LULC change for last 60 years (1955-2015), 2) to simulate future LULC with Dyna-CLUE by 2050 considering two different scenarios, and 3) to evaluate interactions of past and future LULC change with natural hazards.

2. Materials And Methods

The workflow of this study is given in Figure 1. The detailed explanation of the data obtained or created for the study and the applied methods are given following sub-sections.

Figure 1 about here

2.1 Study Area

A study area (7690.5 ha) including UNCA located in the vicinity of the Çaykara District (Trabzon) was selected (Figure 2). Uzungöl was declared as “Tourism Center” in 1990, and also as “Special Environmental Protection Area” in 2004 (Atasoy 2010). The population change in the Çaykara district from 1965 to 2015 showed that total population decreased more than 66% due to migrations. More than 90% of total population was in villages before 1990. While LULC was changing crucially during last 60 years, today the population was transformed from agricultural-based society to service-based society. Although population decreased, an uncontrolled increase in construction activities for settlements in highlands and for touristic facilities especially around the lake, cause environmental problems. UNCA is also located in a mountainous region exposed to multi-hazards, such as snow avalanches, rockfalls, and floods.

Figure 2 about here

2.2 Preparation and Processing of LULC Data

The remote sensing data included historical aerial photographs available since 1955, a SPOT imagery of 2013 (10 m resolution), and an orthophoto of 2015 (30 cm resolution). The historical aerial photographs belong to years of 1955, 1960, 1973, 1986, and 2004. Based on the landscape characteristics of the UNCA, six major LULC classes were identified: forest, agriculture, pasture, settlement, open forest (refers to gaps in forested areas), and water. Manual classification methods (digitizing from remote sensing data) were used in LULC classification. In addition, buildings were vectorised to evaluate how the number of buildings changed since 1955. Moreover, some UAV flights were carried out in 2018 for only mapping actual situation of settlements around the lake. A very high resolution orthophoto (10 cm) was generated from UAV images.

2.3 Data for Natural Hazards in the Study Area

The region is exposed to multi-hazards such as floods, landslides, snow avalanches and rockfalls. Unfortunately, floods were not able to be considered due to lack of a flood inundation/hazard map for the region. Even though the lake was formed due to a historical large landslide, landslides were not common. However, rockfalls are frequent phenomena in the region. UNCA is also frequently exposed to snow avalanches. Thus, only interactions of LULC changes with snow avalanches and rockfalls were evaluated. Snow avalanche hazard indication map with scale of 1/25000 generated through a project made by the General Directorate of Combatting Desertification and Erosion (ÇEM) was used. The potential rockfall source areas were firstly identified via a GIS method using a Digital Elevation Model (DEM) generated from topographical map with scale of 1/25000. The method is based on slope threshold value (α) calculated using the following formula (Dorren and Seijmonsbergen 2003):

$$\alpha = 55 \times \mathrm{RES}^{-0,075}$$

In the formula; RES is resolution of DEM. The pixels having equal or higher slope values than α are identified as potential rockfall source areas. Then, rockfall travel distance was determined by using RollFree software considering an empirical approach called energy line angle (ELA) (Berger et al. 2012; Aydin and Eker 2017). The ELA value was selected 35° due to existence of forest in UNCA. The maps showing rockfall propagation zones and snow avalanche hazard indication is given in Figure 3.

Figure 3 about here

2.4 Simulating future LULC with Dyna-CLUE

In Dyna-CLUE, the probabilities of LULC occurrence are estimated via logistic regression (LR) models. Dyna-CLUE calculates a cell competitive advantage for each land use, based on the demand for each land use and conversion elasticity. Slope, elevation, proximity to lake, proximity to main road and proximity to settlement were selected as driving factors which were resampled to 50 × 50 m (Figure 4). The conversion matrix was created depending on the analysis of past LULC change (Table 1). Conversion elasticities are defined as values ranging from 0 (easy conversion) to 1 (difficult conversion). Lower values were assigned to low capital LULC classes such as agriculture, high values were assigned high capital LULC classes such as settlement (Table 1).

Figure 4 about here

The LR results were evaluated by calculating receiver operating characteristic (ROC). ROC values were obtained higher than 0.85 (Table 1). The model was firstly calibrated before simulating future LULC by running with known LULC demands that correspond annual changes in area for each type of LULC, covering 2004 and 2015. The 2015 LULC was considered as reference. A confusion matrix was created and Kappa index was calculated to compare the model results. Model calibration allowed to find out best conversion elasticities resulting with the best match of simulated and reference map. Conversion

elasticity values were selected as 0.6 (settlement), 0.1 (agriculture), 0.5 (forest), 0.5 (pasture), 0.5 (open forest), and 1 (water) (Table 1). Following calibration, Dyna-CLUE was run for simulating future LULC by 2050.

Table 1 about here

2.5 Future LULC Scenarios

In this study, future LULC demands were created for two different scenarios defined as following:

- Scenario 1, assuming that the change in the speed and trend of land use between 2004 and 2015 continues in the same way.
- Scenario 2, assuming that the change in the speed and trend of land use between 2004 and 2015 continues in the same way when a spatial restriction policy was simply applied by defining a protection zone in the vicinity of the lake Uzungöl (Figure 2). The aim was to estimate how settlement would increase when the situation in 2015 was restricted to be changed.

2.6 Evaluating Interactions between LULC Changes and Natural Hazards

In this study, past and future LULC maps were overlapped with maps of rockfall propagation zones and snow avalanche hazard indication. Thus, it was aimed to determine how settlement evolved from 1955 to 2015 and how will evolve by 2050 depending on the scenarios. The size and its percentage of settlement area overlapping with hazardous areas were evaluated.

3. Results

3.1. Results of Analysis of Past LULC Change (1955-2015)

The analysis of past LULC change was made by comparing the change in areal size of 6 types of LULC such as agriculture, pasture, forest, open forest, settlement, and water. In total, seven LULC maps were created for each year data available (Figure 5). The LULC maps demonstrating the change around the lake where is most increase of settlements was observed are given in Figure 6.

Figure 5 about here

Figure 6 about here

The areal size of each LULC class determined by analysing of past LULC change is given in Table 2. As a typical characteristic of Black Sea Region in Turkey, forests cover largest area in the study area. The settlements are located dispersedly due to topography of the region. In other words, the locations where are suitable for construction activities and for agricultural activities are found scarcely any. The most suitable locations for the settlement and agriculture in terms of topography and in terms of getting required economic incomes for continuation of life of inhabitants could be found around the lake but have any other risks of natural hazards. In the region, in past, the around of the lake was preferred for settling by an agriculture-based population, who engaged in agriculture and/or forestry sector. In addition, there is no any industrial area in the region. While more than 84% of the population of Çaykara District had found in the villages by 2012, the population of the district and the villages decreased by 65% and 70%, respectively, due to the important migrations from the region. Even though migrations in the region settlements in the study showed an increasing trend. While settlement area covers 57.35 ha in 1955, it covers 108.38 ha in 2015. The settlement area increased 51.03 ha within 60 years by conversion fully from agriculture. However, agriculture area decreased by 96.41 ha, i.e. the remaining 43.21 ha of agriculture replaced to forest, while 2.17 ha replaced to LULC class "water". The forested areas also increased by 101.14 ha between 1955 and 2015, by the conversion mostly from pasture area (89.64 ha) and also from open forest (11.5 ha). The change speed of a LULC type from one to other could also be estimated. However, the evaluating the change trend of LULC in a way of single 60 year-period would have not been meaningful due to non-

linearity of trend. Therefore, two sub-periods, one before 2004 and other one after 2004, was defined. The reason for the selection the year of 2004 as reference point in determining sub-periods was a sharp increase observed in the change trend of settlement. The increase speed was 0.24 ha/year between 1955 and 2004, whereas it was 3.57 ha/y between 2004 and 2015.

Table 2 about here

3.2. Results of Simulating Future LULC with Dyna-CLUE

Both simulated LULC of 2015 and reference LULC map of 2015 is given in Figure 7. After Dyna-CLUE was run with past LULC demands, a confusion matrix was created (Table 3). The total accuracy was 0.99, however, both user and producer accuracies of settlement and open forest were obtained relatively low. The low prediction accuracies of settlement and open forest were due to lower number of control points because they cover smaller area in the region.

Figure 7 about here

Table 3 about here

With future LULC simulations, four LULC maps, i.e., two for 2035 and two for 2050, were created (Figure 8). When simulated LULC maps of 2035 were compared, it was observed that almost all agriculture area around the lake is converting to settlements. In Scenario 2, due to area restricted to conversion around the lake, it was observed that settlement area was growth towards other locations where are suitable for settlement as expected (check the red circles in Figure 8). Accordingly, LULC maps of 2050 showed similar results. It is clearly observed that allocation of future LULC demands was made meaningfully by the developed model.

Figure 8 about here

3.3. Results of Evaluating Interactions of LULC Changes with Natural Hazards

An extended period (1955-2050) was evaluated to question how LULC changes could occur by 2050 and interact with natural hazards. Especially, settlement areas were focused (Table 4). While 16.25 ha of settlement area in 1955 was exposed to snow avalanche hazard, this grew up to 68 ha in 2015. It corresponds to 62.9% of total area of settlement in 2015. While 5.75 ha of settlement area in 1955 was exposed to rockfall hazard, 28 ha of settlement area in 2015 was exposed to rockfall hazard. In addition, 1.54 ha of settlement area in 1955 was exposed to both snow avalanche and rockfall hazard, this grew up to 10.12 ha in 2015.

Table 4 about here

The snow avalanche hazard indication map overlapped with future LULC maps are given in Figure 9. Scenario 1 resulted that settlement will grow towards areas exposed to snow avalanches, up to 97.5 ha in 2035, and 126.5 ha in 2050. In other words, the increasing in settlement area could be 43.4% and 85.7% by 2035 and 2050, respectively. Scenario 2 resulted that settlement exposed to snow avalanche hazard will grow up to 119.75 ha in 2035 and 137.75 ha in 2050. The increase in settlement area exposed to snow avalanche could be 76.1% and 102.6% by 2035 and 2050, respectively. In Scenario 2, settlement would grow more into the areas exposed to snow avalanche hazard.

Figure 9 about here

Scenario 1 resulted that 24 ha in 2035 and 28.25 ha of settlement area in 2050 were exposed to rockfall hazard. Scenario 2 resulted that 26.25 ha in 2035, 28.75 ha of settlement area in 2050 were exposed to rockfall hazard. A clear growing of the settlement towards areas exposed to rockfalls was not estimated for both scenarios. In total, 28 ha of settlement area was located exposed rockfall hazard in 2015, and simulations were mapped same areas with small differences. These differences were due to use of Dyna-CLUE with selected parameters, providing about 0.7 of prediction accuracy for the settlement (see Table 3). The rockfall propagation zone map overlapped with future LULC maps are given in Figure 10. In Scenario 2, more area of settlement was obtained as exposed to both hazards than in Scenario 1.

Figure 10 about here

3.4. Results of Analysis of Change in the Number of Buildings and Interactions with Natural Hazards

Remote sensing data provided to extract the information on how the number of buildings changed during the 60 year-period (Figure 11). In 2018, a UAV flight was also carried out for mapping actual situation of buildings only at close vicinity of the lake (Figure 12). Unfortunately, the number of buildings from 1960 aerial photography could not be obtained due to its low-quality resolution not allowing to detect buildings. Table 5 summarizes that how the number of buildings changed between 1955-2018 and how interacts with natural hazards. The number of buildings grew 2 times from 1955 to 2015, whereas it grew 2.7 times around the lake. The high ratio of increase in the number of buildings around the lake is clearly due to growing tourism activities. During the period covering from 1955 to 2015, the number of buildings exposed to snow avalanche hazard grew 2.6 times, whereas the number of buildings exposed to rockfall hazard grew 6.6 times.

Table 5 about here

Figure 11 about here

Figure 12 about here

Discussion

This study was conducted in several phases, including assessing the LULC change for the last 60 years (1955-2015), simulating future LULC with Dyna-CLUE by 2050 considering two different scenarios, and evaluating the interactions of past and future LULC change with natural hazards. In the assessment of LULC change, different remote sensing data sources, including historical black and white aerial photographs, orthophotos generated from coloured overlapped aerial images, and SPOT satellite images, were used. In the literature, remote sensing data is principal source that is efficiently used for mapping and analysis of LULC change (Green et al. 1994; Dewan and Yamaguchi 2009; Kavitha et al. 2021). Especially, aerial photography and imageries have been important data, because it could be available since 1940s. However, they cover smaller area than satellite images, and their quality and amount of availability could be lower than modern data (Varga et a. 2015). But they could be more cost effective. In Turkish Aerial Photogrammetry archives, more than 1 million photographs, both as analogues (before 2007) and digital (since 2013), have been available (Önder 2000). Thus, the historical LULC change analysis could be conducted from 1955 to the present. In the archives, no data with regular intervals could be obtained (only for the years of 1955, 1960, 1973, 1986, and 2004). Even though more frequently acquired imageries is expected for recent period, especially after 2000s, there were no data in the archives. Only aerial imageries for 2004 and 2015 were obtained.

The LULC can be mapped manually, i.e., vectorising from remote sensing data with visual interpretation, or automatically by applying different classification techniques (Hishe et al. 2020). Both approaches have some limitations or advantages. The vectorization process needs to be done carefully by who has experience on interpretation of remote sensing data and knows the area of interest well. Otherwise, the manual classification could have more errors (Varga et al. 2015). Also, as the area of interest is relatively small, and automatic extraction of LULC types by applying automatic classification methods could have errors especially in settlements due to their complex pattern, the vectorization of LULC types can be evaluated as more precise. In other words, the vectorization method, since already can be used for reference in validation of automatic classification methods, does not require accuracy assessment. Therefore, the LULC types were acquired by vectorising from remote sensing data.

Even though the set of remote sensing data that could be obtained covered an extended period, based on annual rates of LULC change between 2004 and 2015, potential future LULC changes were simulated. The reason for the selection the year of 2004 as reference point in determining sub-periods was a sharp increase observed in the change trend of settlement. Considering annual rates of LULC change between certain periods is a common approach that applied in the CLUE model studies (Kucsicsa et al. 2019). One important point is the selection of driving factors because they play important role in prediction accuracy of future LULC (Lima et al. 2011). These factors are site-specific and are determined based on literature review. However, final

decision is made based on observations in the area because LULC changes are resulted from complex interactions between such driving factors. In this study, we selected 5 physical parameters, but not considered any socioeconomic factor such as population, migration, labour forces, GDP, agricultural production, price of agricultural products, agricultural yield, agricultural investment (Dang and Kawasaki 2017). The results could be evaluated satisfactorily. Another point is spatial resolution of the data in Dyna-CLUE model. In literature, different spatial resolutions were used such as 250 × 250 m^2 (Wang et al. 2021) and 500 × 500 m^2 (Kucsicsa et al. 2019). In this study, however, 50 m spatial resolution was used similar to some studies in literature (Luo et al. 2010; Dan et al. 2015).

There have been limited studies using Dyna-CLUE considering LULC change interactions with natural hazards in the literature. Cammerer et al. (2013) analysed spatio-temporal dynamics in flood exposure due to LULC changes. Piazza et al. (2016) analysed LULC change until 2030 based on four scenarios, and cross-checked them with hazard zoning maps. Szwagrzy et al. (2018) forecasted future LULC changes to evaluate impact on flood risk. Janizadeh et al. (2021) used for mapping the spatial and temporal variability of flood hazard. Roy et al. (2021) used Dyna-CLUE model for assessment of future flood susceptibility. Chowdhury et al. (2021) spatially predicted of landslide susceptibility using projected storm rainfall and land use. Saha et al. (2021) focused on multi-hazards (debris and rock falls) susceptibility mapping and evaluation of its risk assessment. Instead of focusing on susceptibility mapping, this study focused on what was the actual situation of LULC types (especially settlements) under multi-hazards, and how their situation can evolve in future. In the present study, snow avalanche and rockfall hazards were considered unlike many other studies in literature. Here, the susceptibility or risk assessment was not carried out. With regard to selected scenarios, since the lake Uzungöl is an UNCA, we aimed to determine more realistic scenarios that could be seen in the future. Therefore, only two scenarios were considered in Dyna-CLUE model. The present study considered only LULC changes without considering climate change. For future study, the effect of climate change should be considered similarly like other studies.

Conclusion

The lake Uzungöl has been exposed to a severe threat causing irrevocable environmental problems due to uncontrolled construction activities resulting from the increased tourism in the last decades. Also, the lake is located in a region where it is exposed to severe natural hazards such as snow avalanches and rockfalls. Therefore, an analysis of interactions of LULC changes with natural hazards was a crucial point for the decision making about future LULC planning in the region. This study proposed an application of Dyna-CLUE in modelling of future LULC for evaluating interactions of LULC changes with natural hazards. One of the important conclusions of this study was a successful analysis of LULC change for a 95 year-period covering from 1955 to 2050. Most conversion among LULC classes was from agriculture to settlement as expected. Especially after 2004, the speed of conversion from agriculture to settlement increased to 2.7 ha/year. However, this realised in an uncontrolled/unplanned way which was not considering natural hazards. In the region, many of settlement has already located in areas where the natural hazards are mainly occurred. This study revealed an answer to the question of how the settlement could interact with natural hazards in the future. It was concluded that even if settlement increased over the agricultural areas, located in relatively gentle slopes, the new settlements will be located at areas exposed to natural hazards. Especially snow avalanches will continue to be a bigger threat on settlement in the future. The findings from this study can be helpful for the authorities of the governmental agencies in decision making and developing policies in the planning of the future LULC for the region.

Declarations

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References

1. Adhikari RK, Mohanasundaram S, Shrestha S (2020) Impacts of land-use changes on the groundwater recharge in the Ho Chi Minh city, Vietnam. Environ Res 185, 109440.
2. Alphan H, Doygun H, Unlukaplan YI (2009) Post-classification comparison of land cover using multitemporal Landsat and ASTER imagery: the case of Kahramanmaraş, Turkey. Environ Monit Assess 151(1), 327-336.
3. Alphan H, Güvensoy L (2016) Detecting coastal urbanization and land use change in Southern Turkey. J Environ Eng Landsc Manag 24(2), 97-107.
4. Atasoy M (2010) Monitoring land use changes in tourism centers with GIS: Uzungöl case study. Sci Res Essays 5(8): 790-798.
5. Atmis E, Özden S, Lise W (2007) Urbanization pressures on the natural forests in Turkey: An overview. Urban For Urban Green 6, 83–92.
6. Aydin A, Eker R (2017) Forest mapping against rockfalls on a regional scale in İnebolu of Turkey. J Fac For İstanbul U 67(2):136-149
7. Bayar R (2018) In terms of land use change in agricultural areas in Turkey (Original in Turkish), Coğrafı Bilimler Dergisi, 16 (2), 187- 200.
8. Behera MD, Tripathi P, Das P et al (2018) Remote sensing-based deforestation analysis in Mahanadi and Brahmaputra River basin in India since 1985. J Environ Manage 206, 1192-1203.
9. Berger F, Clouet N, Toe D (2012) Avalanche and rockfall regional analysis with a special focus on protective role of forest. *Decision support guidelines methods, procedures and tools developed in PARAmount (WP 7). IRSTEA, UR ETGR (Snow Avalanches Engineering and Torrent Control Research Unit)*, *2*.
10. Çakir G, Sivrikaya F, Keleş S (2008) Forest cover change and fragmentation using Landsat data in Maçka State Forest Enterprise in Turkey. Environ Monit Assess 137(1), 51-66.
11. Cammerer H, Thieken AH, Verburg PH (2013) Spatio-temporal dynamics in the flood exposure due to land use changes in the Alpine Lech Valley in Tyrol (Austria). Nat Hazards, 68(3), 1243-1270.
12. Chowdhuri I, Pal SC, Chakrabortty R et al (2021) Spatial prediction of landslide susceptibility using projected storm rainfall and land use in Himalayan region. Bull Eng Geol Environ 80, 5237–5258.
13. Clarke KC, Hoppen S, Gaydos L (1997) A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environ Plann B Plann Des 24(2), 247-261.
14. Coskun HG, Alganci U, Usta G (2008) Analysis of land use change and urbanization in the Kucukcekmece water basin (Istanbul, Turkey) with temporal satellite data using remote sensing and GIS. Sensors 8(11), 7213-7223.
15. Dan W, Wei H, Shuwen Z, Kun B, Bao X, Yi W, Yue L (2015) Processes and prediction of land use/land cover changes (LUCC) driven by farm construction: the case of Naoli River Basin in Sanjiang Plain. Environmental Earth Sciences, 73(8), 4841-4851.

16. Dang AN, Kawasaki A (2017) Integrating biophysical and socio-economic factors for land-use and land-cover change projection in agricultural economic regions. Ecol Modell, 344, 29-37.
17. Dewan AM, Yamaguchi Y (2009) Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. Appl Geogr, 29(3), 390-401.
18. Dökmeci VF (1986) Turkey: Distribution of cities and change over time. *Ekistics*, 13-17.
19. Dorren LK, Seijmonsbergen AC (2003) Comparison of three GIS-based models for predicting rockfall runout zones at a regional scale. Geomorphology 56(1-2), 49-64.
20. Doygun H, Alphan H, Gurun DK (2008) Analysing urban expansion and land use suitability for the city of Kahramanmaraş, Turkey, and its surrounding region. Environ Monit Assess 145(1), 387-395.
21. Esbah H (2007) Land use trends during rapid urbanization of the city of Aydin, Turkey. Environ Manage 39, 443–459.
22. Gardner JS, Dekens J (2007) Mountain hazards and the resilience of social–ecological systems: lessons learned in India and Canada. Nat Hazards 41(2), 317-336.
23. Ghimire U, Shrestha S, Neupane S, Mohanasundaram S, Lorphensri O (2021) Climate and land-use change impacts on spatiotemporal variations in groundwater recharge: A case study of the Bangkok Area, Thailand. Sci Total Environ 792, 148370.
24. Gol C, Cakir M, Edis S, Yilmaz H (2010) The effects of land use/land cover change and demographic processes (1950-2008) on soil properties in the Gokcay catchment, Turkey. Afr J Agric Res 5(13), 1670-1677.
25. Green K, Kempka D, Lackey L (1994) Using remote sensing to detect and monitor land-cover and land-use change. Photogramm Eng Remote Sens, 60(3), 331-337.
26. Güler M, Yomralıoğlu T, Reis S (2007) Using landsat data to determine land use/land cover changes in Samsun, Turkey. Environ Monit Assess 127(1), 155-167.
27. Guneroglu N, Acar C, Guneroglu A, Dihkan M, Karsli F (2015) Coastal land degradation and character assessment of Southern Black Sea landscape. Ocean Coast Manag 118, 282-289.
28. Hamad R, Balzter H, Kolo K (2018) Predicting land use/land cover changes using a CA-Markov model under two different scenarios. Sustainability, 10(10), 3421.
29. He X, Mai X, Shen G (2019) Delineation of Urban Growth Boundaries with SD and CLUE-s Models under Multi-Scenarios in Chengdu Metropolitan Area. Sustainability, 11(21), 5919.
30. Hepcan ÇC, Turan IA, Özkan MB (2011) Monitoring land use change in the Çeşme coastal zone, Turkey using aerial photographs and satellite imaging. Land Degrad Dev 22(3), 326-333.
31. Hishe S, Bewket W, Nyssen J, Lyimo J (2020) Analysing past land use land cover change and CA-Markov-based future modelling in the Middle Suluh Valley, Northern Ethiopia. Geocarto Int, 35(3), 225-255.
32. Hyandye C, Martz LW (2017) A Markovian and cellular automata land-use change predictive model of the Usangu Catchment. Int J Remote Sens 38(1), 64-81.
33. Janizadeh S, Pal SC, Saha A et al (2021) Mapping the spatial and temporal variability of flood hazard affected by climate and land-use changes in the future. J Environ Manage 298, 113551.
34. Kadioğullari AI, Başkent EZ (2008) Spatial and temporal dynamics of land use pattern in Eastern Turkey: a case study in Gümüşhane. Environ Monit Assess 138(1), 289-303.
35. Kavitha AV, Srikrishna A, Satyanarayana C (2021). A Review on Detection of Land Use and Land Cover from an Optical Remote Sensing Image. In IOP Conference Series: Materials Science and Engineering (Vol. 1074, No. 1, p. 012002). IOP Publishing.
36. Kesgin B, Nurlu E (2009) Land cover changes on the coastal zone of Candarli Bay, Turkey using remotely sensed data. Environ Monit Assess 157(1), 89-96.
37. Kilic S, Evrendilek F, Berberoglu S, Demirkesen AC (2006) Environmental monitoring of land-use and land-cover changes in a Mediterranean region of Turkey. Environ Monit Assess 114(1), 157-168.

38. Kucsicsa G, Popovici EA, Bălteanu D, Grigorescu I, Dumitraşcu M, Mitrică B (2019) Future land use/cover changes in Romania: regional simulations based on CLUE-S model and CORINE land cover database. Landsc Ecol Eng 15(1), 75-90.
39. Kudat A, Ozbilgin B, Kuleyin N, Yalcin I, Ayhan O (1999) *Social assessment for the Turkey forest sector review*. World Bank, Washington, DC, pp. 137.
40. Kurucu Y, Chiristina, NK (2008) Monitoring the impacts of urbanization and industrialization on the agricultural land and environment of the Torbali, Izmir region, Turkey. Environ Monit Assess 136(1), 289-297.
41. Larsen AE, McComb S (2021) Land cover and climate changes drive regionally heterogeneous increases in US insecticide use. Landsc Ecol 36(1), 159-177.
42. Li X, Yeh AGO (2002) Neural-network-based cellular automata for simulating multiple land use changes using GIS. Int J Geogr Inf Syst 16(4), 323-343.
43. Liang X, Liu X, Li X, Chen Y, Tian H, Yao Y (2018) Delineating multi-scenario urban growth boundaries with a CA-based FLUS model and morphological method. Landsc Urban Plan, 177, 47-63.
44. Lima ML, Zelaya K, Massone H (2011) Groundwater vulnerability assessment combining the DRASTIC and DYNA-CLUE model in the Argentine Pampas. Environ Manage, 47(5), 828-839.
45. Liu X, Liang X, Li X et al (2017). A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects. Landsc Urban Plan 168, 94-116.
46. Luo G, Yin C, Chen X, Xu W, Lu L (2010) Combining system dynamic model and CLUE-S model to improve land use scenario analyses at regional scale: A case study of Sangong watershed in Xinjiang, China. Ecol Complex, 7(2), 198-207.
47. Önder M (2000) National report of Turkey on photogrammetry and remote sensing 1996–2000. Int Arch Photogramm Remote Sens. XXXIII, B6 412–417.
48. Piazza G, Thaler T, Fuchs S (2016) Influence of land-use dynamics on natural hazard risk. In EGU General Assembly Conference Abstracts (pp. EPSC2016-1306).
49. Pijanowski BC, Alexandridis KT, Mueller D (2006) Modelling urbanization patterns in two diverse regions of the world. J Land Use Sci 1(2-4), 83-108.
50. Pijanowski BC, Brown DG, Shellito BA, Manik GA (2002) Using neural networks and GIS to forecast land use changes: a land transformation model. Comput Environ Urban Syst 26(6), 553-575.
51. Reis S (2008) Analyzing land use/land cover changes using remote sensing and GIS in Rize, North-East Turkey. Sensors, 8(10), 6188-6202.
52. Ren Y, Lü Y, Comber A, Fu B, Harris P, Wu L (2019) Spatially explicit simulation of land use/land cover changes: Current coverage and future prospects. Earth-Sci Rev 190, 398-415.
53. Roy P, Pal SC, Arabameri A, Rezaie F, Chakrabortty R, Chowdhuri I, Saha A, Malik S, Das, B (2021) Climate and land use change induced future flood susceptibility assessment in a sub-tropical region of India. Soft Comput, 25(8), 5925-5949.
54. Saha A, Pal SC, Santosh M, et al (2021) Modelling multi-hazard threats to cultural heritage sites and environmental sustainability: The present and future scenarios. J Clean Prod 320, 128713.
55. Sahoo S, Dhar A, Debsarkar A, Pradhan B, Alamri AM (2020) Future water use planning by water evaluation and planning system model. Water Resour Manag 34(15), 4649-4664.
56. Sancar C, Kadioğullari Aİ (2009) Land use-cover change processes in Urban fringe areas: Trabzon case study, Turkey. Sci Res Essays 4(12), 1454-1462.
57. Sanli FB, Kurucu Y, Esetlili MT (2009) Determining land use changes by radar-optic fused images and monitoring its environmental impacts in Edremit region of western Turkey. Environ Monit Assess 151(1), 45-58.
58. Satir O, Erdogan MA (2016) Monitoring the land use/cover changes and habitat quality using Landsat dataset and landscape metrics under the immigration effect in subalpine eastern Turkey. Environ Earth Sci 75(15), 1-10.
59. Say N, Okten SO, Aysu A, Yalcinkaya NM (2017) Transformation of land use/land cover (LULC) under rapid urbanization in Adana, Turkey. Fresen Environ Bull 26(5), 3479-3485.

60. Sen G, Bayramoglu MM, Toksoy D (2015) Spatiotemporal changes of land use patterns in high mountain areas of Northeast Turkey: a case study in Maçka. Environ Monit Assess 187(8), 1-14.
61. Sertel E, Ormeci C, Robock A (2011) Modelling land cover change impact on the summer climate of the Marmara Region, Turkey. Int J Glob 3(1-2), 194-202.
62. Sesli FA, Karsli F, Colkesen I, Akyol N (2009) Monitoring the changing position of coastlines using aerial and satellite image data: an example from the eastern coast of Trabzon, Turkey. Environ Monit Assess 153(1), 391-403.
63. Shrestha M, Acharya SC (2021) Assessment of historical and future land-use–land-cover changes and their impact on valuation of ecosystem services in Kathmandu Valley, Nepal. Land Degrad Dev 32(13), 3731-3742.
64. Shrestha S, Bhatta B, Shrestha M, Shrestha PK (2018) Integrated assessment of the climate and landuse change impact on hydrology and water quality in the Songkhram River Basin, Thailand. Sci Total Environ 643, 1610-1622.
65. Silva EA, Clarke KC (2002) Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal. Comput Environ Urban Syst 26(6), 525-552.
66. Sivrikaya F, Akay AE (2011) Factors of land use/cover change: A case study from Turkey. Sci Res Essays, 6(17), 3684-3696.
67. Sivrikaya F, Cakir G, Kadioğullari Aİ, Keleş S, Başkent EZ, Terzioğlu S (2007) Evaluating land use/land cover changes and fragmentation in the Camili Forest planning unit of northeastern Turkey from 1972 to 2005. Land Degrad Dev 18(4), 383-396.
68. Soares-Filho BS, Cerqueira GC, Pennachin CL (2002) DINAMICA—a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. Ecol modell 154(3), 217-235.
69. Sohl TL, Sayler KL, Drummond MA, Loveland TR (2007) The FORE-SCE model: a practical approach for projecting land cover change using scenario-based modeling. J Land Use Sci 2(2), 103-126.
70. Stürck J, Levers C, van der Zanden, EH et al (2018) Simulating and delineating future land change trajectories across Europe Reg Environ Change 18(3), 733-749.
71. Szwagrzyk M, Kaim D, Price B, Wypych A, Grabska E, Kozak J (2018) Impact of forecasted land use changes on flood risk in the Polish Carpathians. Nat Hazards, 94(1), 227-240.
72. TUIK (2017) *Turkey in Statistics 2017*. Retrieved January 1, 2020, from https://biruni.tuik.gov.tr/yayin/views/visitorPages/index.zul
73. TUIK (2020a) *Population of province/district centers and towns/villages by years and sex, 1927-2019*. Retrieved January 1, 2020, from http://www.tuik.gov.tr/PrelstatistikTablo.do?istab_id=1587
74. TUIK (2020b) *Agriculture Lands in Turkey.* Retrieved January 1, 2020, from http://www.tuik.gov.tr/PrelstatistikTablo.do?istab_id=1561
75. Turker M, Asik O (2005) Land use change detection at the rural-urban fringe using multi-sensor data in Ankara, Turkey. Int J Geoinformatics 1(3), 27-36.
76. Varga K, Szabó S, Szabó G, Dévai G, Tóthmérész B (2015) Improved land cover mapping using aerial photographs and satellite images, Open Geosci, 7(1), 15-26.
77. Veldkamp A, Fresco LO (1996) CLUE: a conceptual model to study the conversion of land use and its effects. Ecol Modell 85(2-3), 253-270.
78. Verburg PH, Malek Z, Goodwin S, Zagaria C (2021) The Integrated Economic-Environmental Modeling (IEEM) Platform: IEEM Platform Technical Guides: User Guide for the IEEM-enhanced Land Use Land Cover Change Model Dyna-CLUE.
79. Verburg PH, Overmars KP (2009) Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landsc Ecol 24(9), 1167-1181.
80. Verburg PH, Soepboer W, Veldkamp A, Limpiada R, Espaldon V, Mastura SS (2002) Modeling the spatial dynamics of regional land use: the CLUE-S model. Environ Manage 30(3), 391-405.
81. Viedma O, Moreno JM, Güngöroglu C, Cosgun U, Kavgacı A (2017) Recent land-use and land-cover changes and its driving factors in a fire-prone area of southwestern Turkey. J Environ Manage 197, 719-731.

82. Waiyasusri K, Wetchayont P (2020) Assessing Long-Term Deforestation In Nam San Watershed, Loei Province, Thailand Using A Dyna-Clue Model. Geogr Environ Sustain 13(4), 81-97.
83. Wang Y, Chao B, Dong P et al (2021). Simulating spatial change of mangrove habitat under the impact of coastal land use: Coupling MaxEnt and Dyna-CLUE models. Sci Total Environ 147914.
84. White R, Engelen G (2000) High-resolution integrated modelling of the spatial dynamics of urban and regional systems. Comput Environ Urban Syst 24(5), 383-400.
85. Yadav V, Ghosh SK (2019) Assessment and prediction of urban growth for a mega-city using CA-Markov model. Geocarto Int 36(17), 1960-1992.
86. Yildirim H, Özel ME, Divan NJ, Akça A (2002) Satellite monitoring of land cover/land use change over 15 years and its impact on the environment in Gebze/Kocaeli-Turkey. Turk J Agric For 26(3), 161-170.
87. Zadbagher E, Becek K, Berberoglu S (2018) Modeling land use/land cover change using remote sensing and geographic information systems: case study of the Seyhan Basin, Turkey. Environ Monit Assess 190(8), 1-15.
88. Zeshan MT, Mustafa MRU, Baig MF (2021) Monitoring Land Use Changes and Their Future Prospects Using GIS and ANN-CA for Perak River Basin, Malaysia. Water 13(16), 2286.

Tables

Table 1. Conversion matrix, ROC values, and conversion elasticities

		Open Forest	Pasture	Forest	Water	Settlement	Agriculture
Conversion Matrix	Open Forest	1	1	1	0	0	0
	Pasture	0	1	1	0	0	0
	Forest	0	1	1	0	0	0
	Water	0	0	0	1	0	0
	Settlement	0	0	0	0	1	0
	Agriculture	0	0	0	0	1	1
ROC Values		0.995	0.960	0.873	0.995	0.978	0.944
Conversion Elasticities		0.5	0.5	0.5	1.0	0.6	0.1

Table 2. Past LULC change between 1955 and 2015

Years	Open Forest (ha)	Pasture (ha)	Forest (ha)	Water (ha)	Settlement (ha)	Agriculture (ha)	Total (ha)
1955	32.45	3194.36	3954.35	11.82	57.35	440.33	7690
1960	32.45	3194.36	3954.35	11.82	57.44	440.24	7690
1973	30.96	3189.67	3967.96	11.82	61.37	428.88	7690
1986	30.85	3189.74	3969.95	11.82	63.77	424.53	7690
2004	26.57	3173.94	4016.95	11.82	69.14	392.24	7690
2013	21.18	3150.01	4052.37	13.99	103.95	349.16	7690
2015	20.95	3147.93	4055.49	13.99	108.38	343.92	7690

Table 3. Confusion matrix created for model validation

LULC Classes	Agriculture	Settlement	Open Forest	Pasture	Forest	Water	Total	User Accuracy	Kappa Index
Agriculture	197	11	0	0	9	1	218	0.90	-
Settlement	9	31	0	0	0	2	42	0.74	-
Open Forest	0	0	10	0	2	0	12	0.83	-
Pasture	0	0	0	2072	12	0	2084	0.99	-
Forest	0	3	5	21	2605	0	2634	0.99	-
Water	0	0	0	0	0	10	10	1.00	-
Total	206	45	15	2093	2628	13	5000	0.00	-
Producer Accuracy	0.96	0.69	0.67	0.99	0.99	0.77	0.00	0.99	-
Kappa Index	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97

Table 4. Actual LULC in 2015 and Future LULC classes exposed to natural hazards

		LULC Classes exposed to Snow Avalanche Hazard (ha)			LULC Classes exposed to Rockfall Hazard (ha)			LULC Classes exposed to both Snow Avalanche and Rockfall Hazard (ha)		
		2015	2035	2050	2015	2035	2050	2015	2035	2050
Scenario 1	Agriculture	261.75	207.75	179.00	69.75	67.50	63.25	50.97	55.25	51.75
	Settlement	68.00	97.50	126.25	28	24.00	28.25	10.12	9.75	13.25
	Open Forest	9.50	7.25	7.25	8.25	5.25	5.25	6.54	5.00	5.00
	Pasture	1516.75	1530.00	1530.00	115.75	106.75	106.75	94.18	99.00	99.00
	Forest	1385.50	1397.00	1397.00	1212.50	1237.00	1237.00	411.73	449.00	449.00
	Water	7.25	7.25	7.25	2.25	2.25	2.25	1.00	1.00	1.00
Scenario 2	Agriculture	261.75	185.50	167.50	69.75	65.25	62.75	50.97	52.75	50.00
	Settlement	68.00	119.75	137.75	28	26.25	28.75	10.12	12.25	15.00
	Open Forest	9.50	3.75	3.25	8.25	1.75	2.25	6.54	1.75	2.25
	Pasture	1516.75	1528.00	1529.75	115.75	109.00	109.50	94.18	101.50	102.00
	Forest	1385.50	1402.50	1401.25	1212.50	1238.25	1237.25	411.73	449.75	448.75
	Water	7.25	7.25	7.25	2.25	2.25	2.25	1.00	1.00	1.00

Table 5. The situation of buildings in the study

Years	Number of Buildings in whole study area	Number of Buildings around the lake	Number of Buildings exposed to snow avalanche hazard	Number of Buildings exposed to rockfall hazard
1955	688	175	321	41
1960	-	-	-	-
1973	746	220	498	86
1986	860	272	565	85
2004	1020	403	608	114
2015	1382	480	831	272
2018	-	954	-	-

Figures

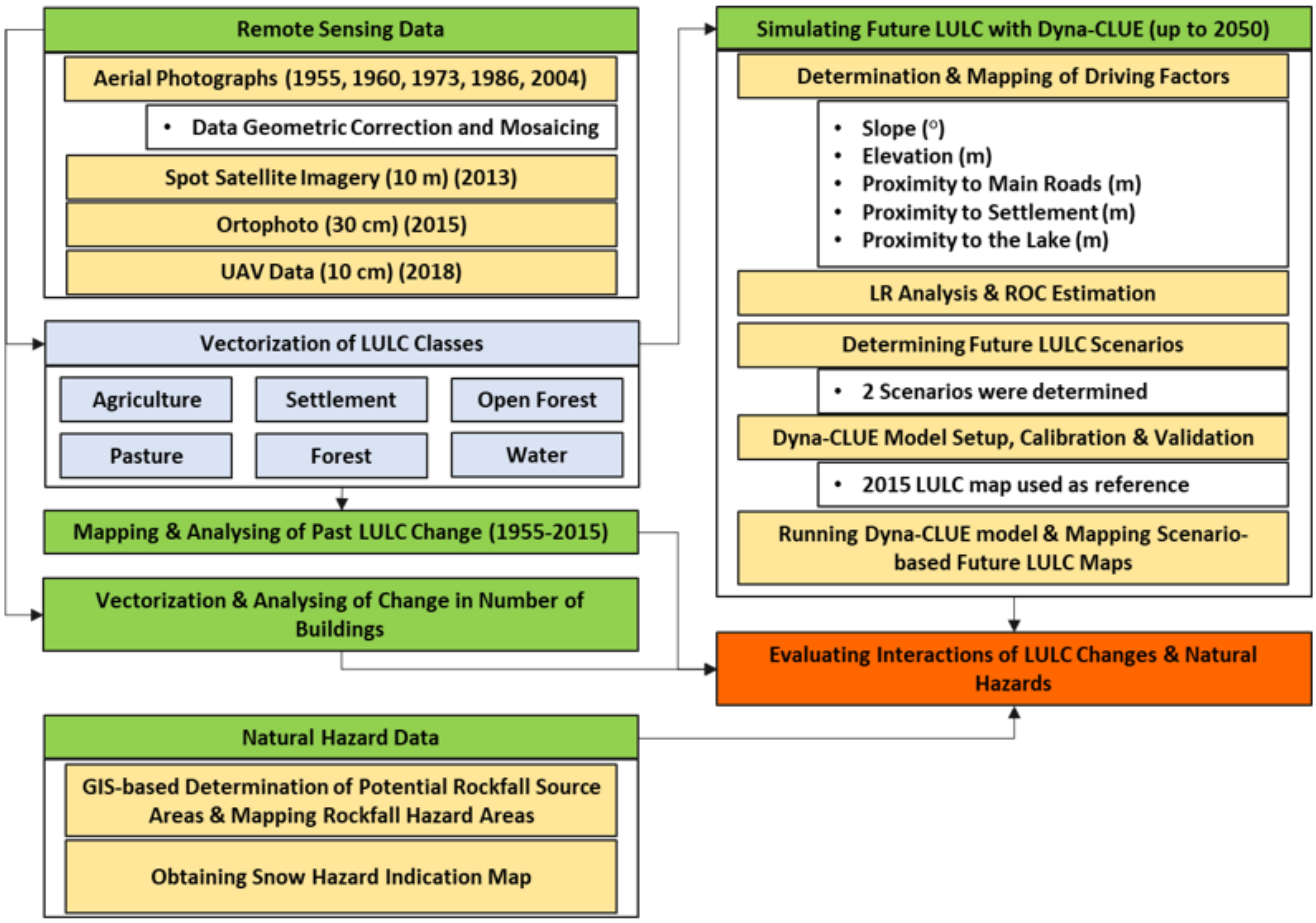


Figure 1

Schematic demonstration of the workflow



Figure 2

Location of the study area

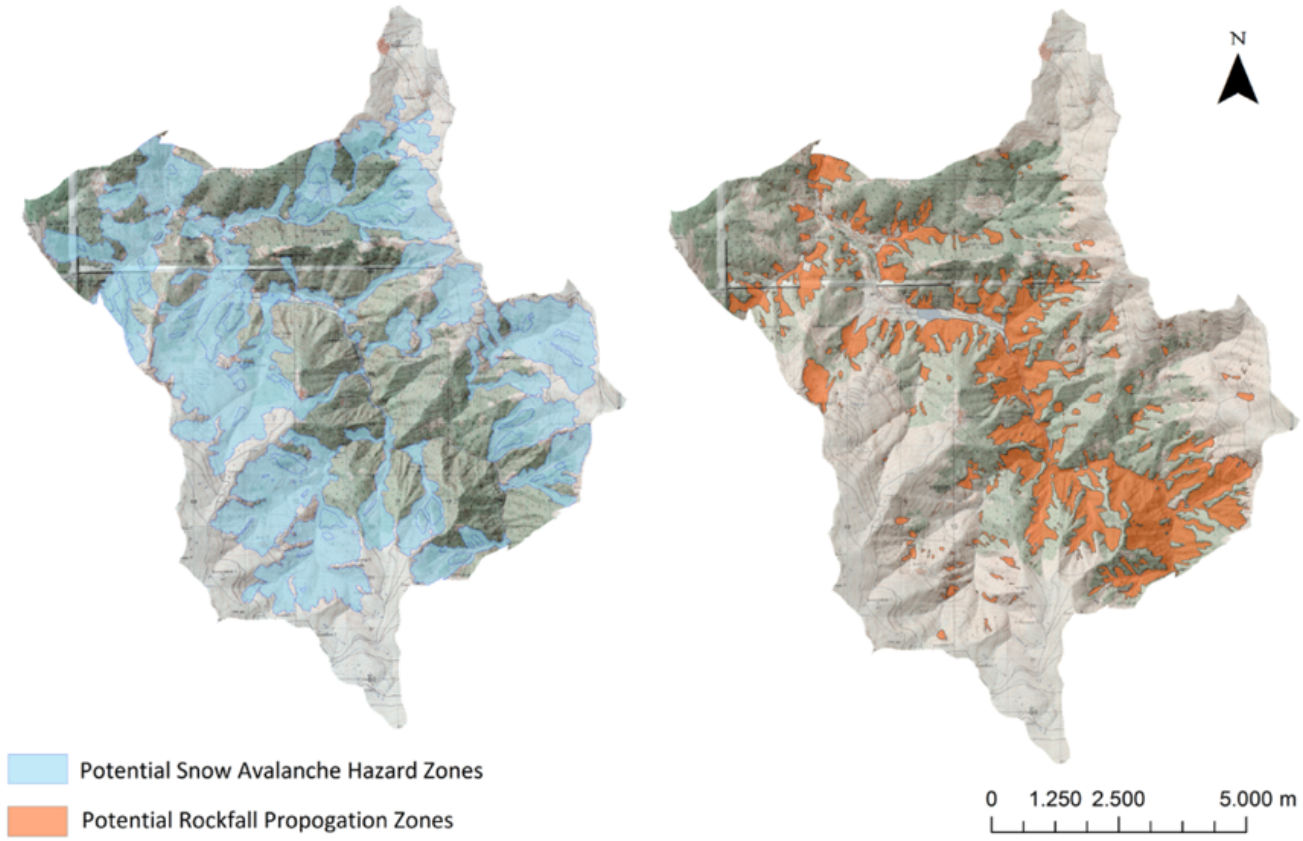


Figure 3

The maps of snow avalanche hazard indication (left) and rockfall propagation zones (right)

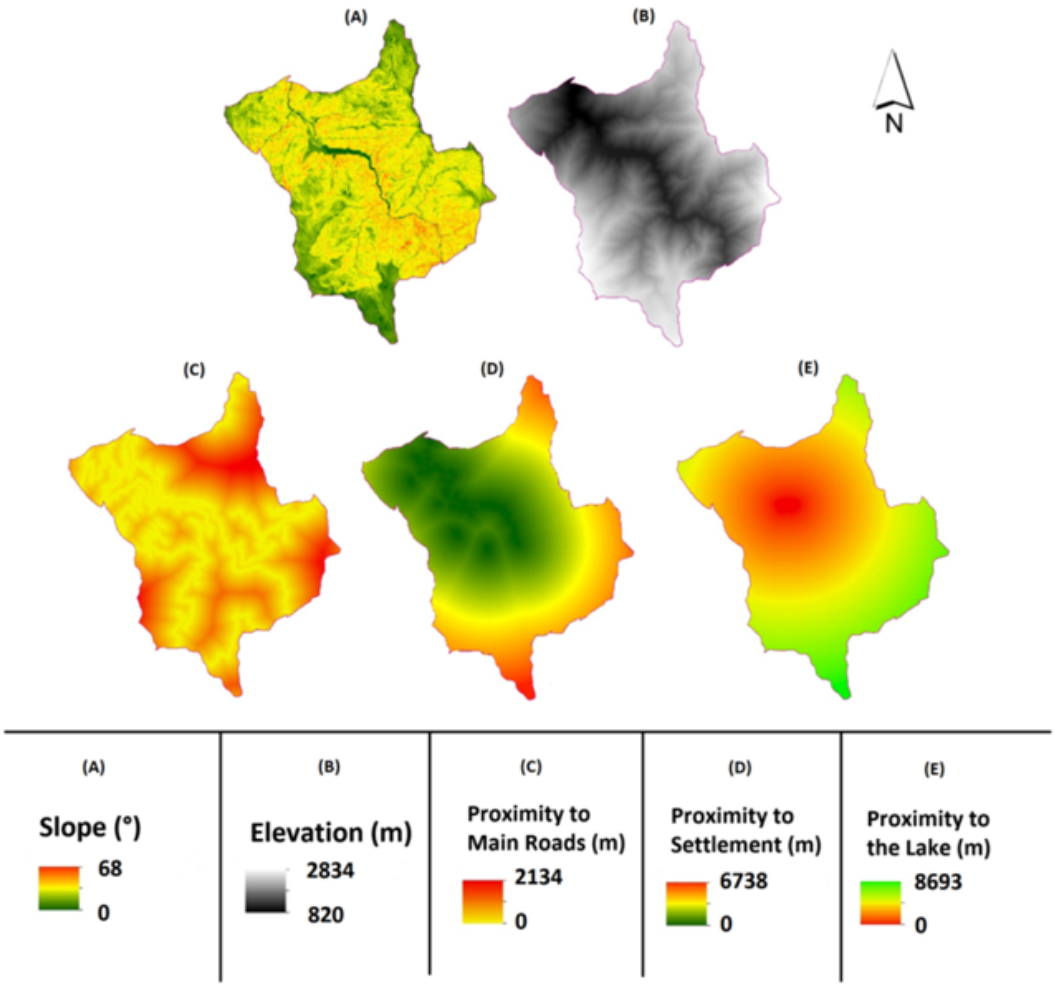


Figure 4

The maps of driving factor used in the model

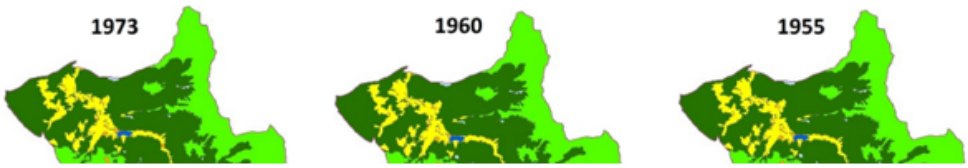


Figure 5

Past LULC change maps between 1955 and 2015

Figure 6

The change of LULC in past around the lake Uzungöl.

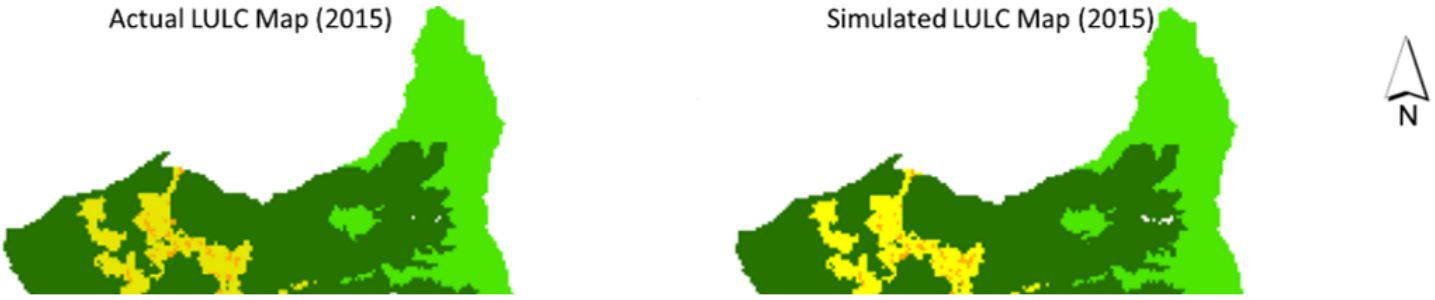


Figure 7

The comparison of actual (left) and simulated (right) LULC maps of 2015

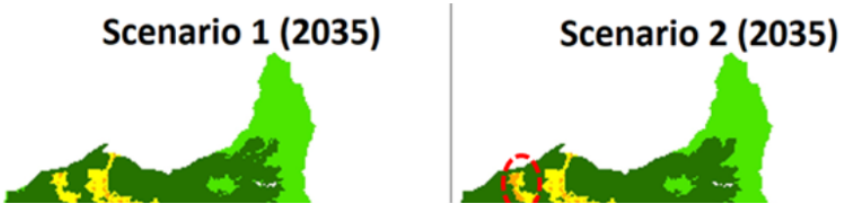


Figure 8

Simulated future LULC maps for two scenarios. Red circles show locations where are suitable for settlement as expected.

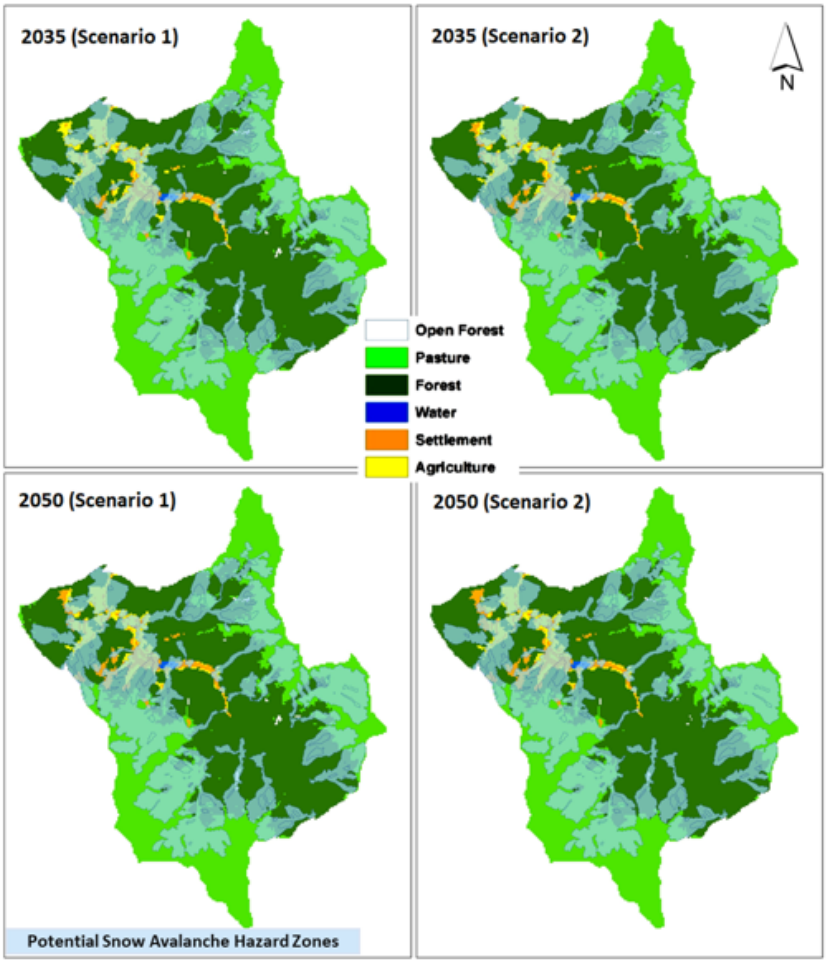


Figure 9

The potential snow avalanche hazard zones overlapped with future LULC maps

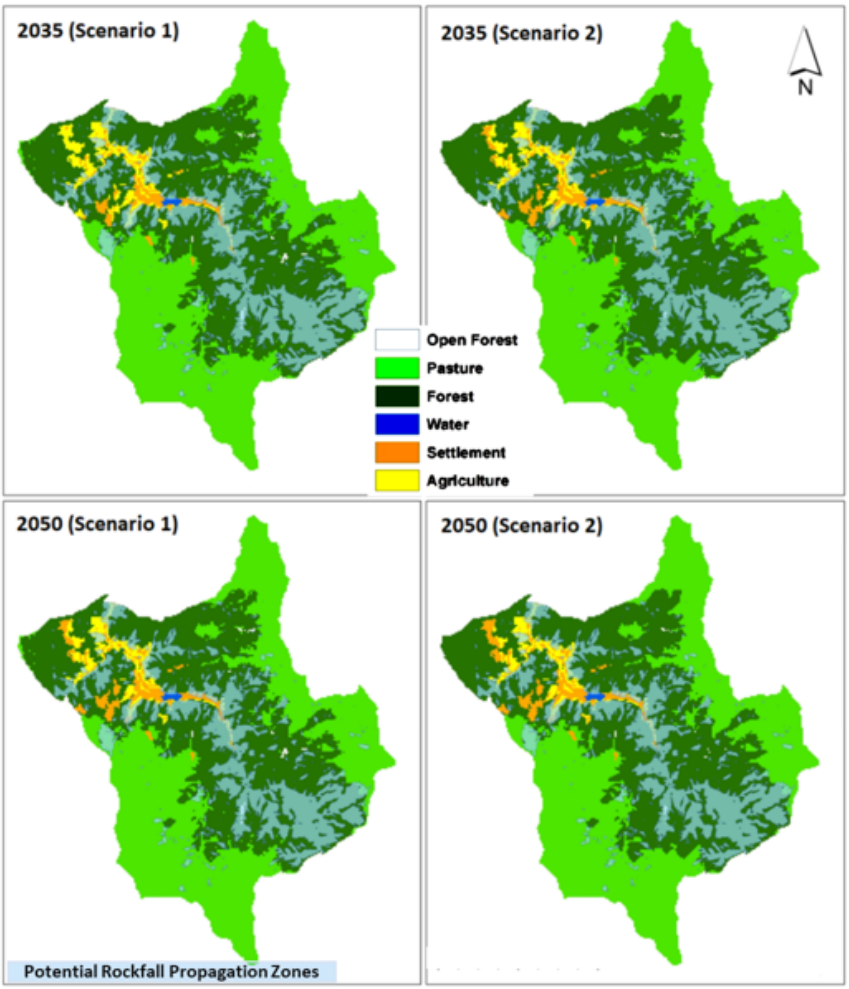


Figure 10

The potential rockfall propagation zones overlapped with future LULC maps

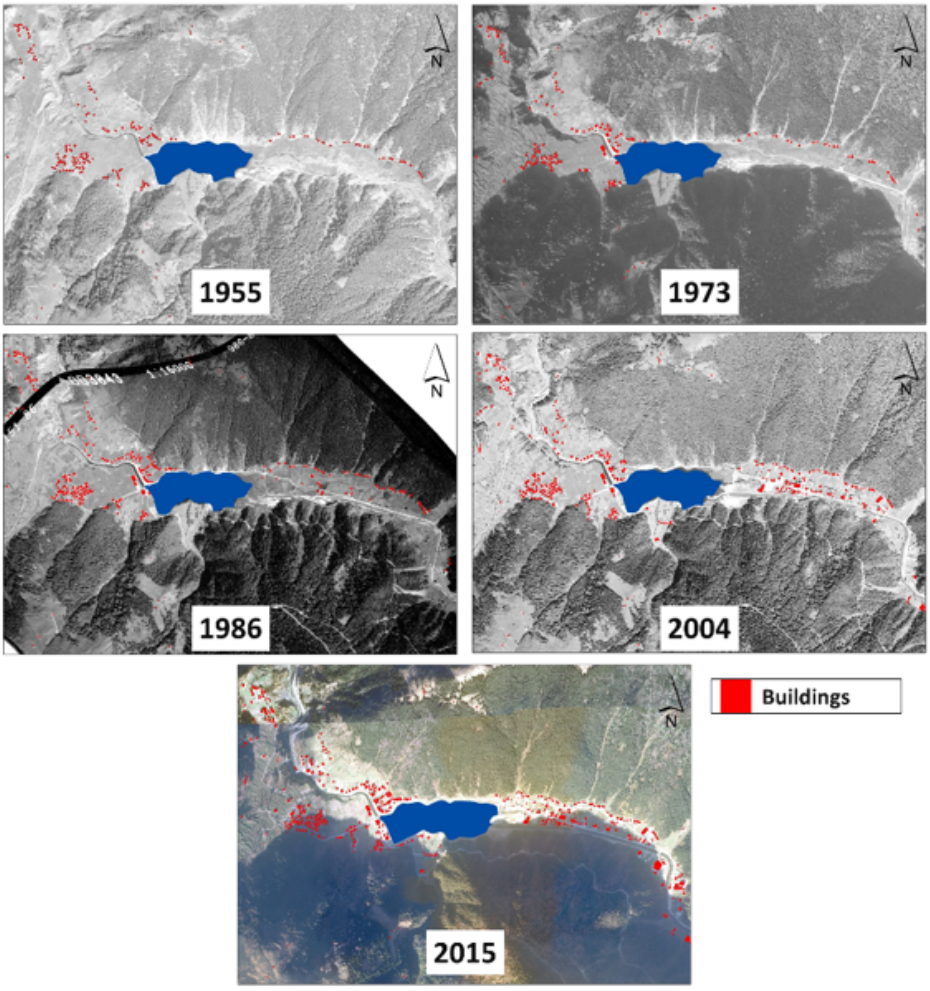


Figure 11

The buildings around the lake for each year of data



Figure 12

The situation of buildings around the lake in 2018