Land Use Policy 67 (2017) 558–572

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Simulating the impacts of future land use change on soil erosion in the Kasilian watershed, Iran

Mohammad Zare[a], Thomas Panagopoulos[b,*], Luis Loures[c]

[a] Faculty of Natural Resources, University of Tehran, Iran
[b] Research Center for Spatial and Organizational Dynamics (CIEO), University of Algarve, Gambelas Campus, 8005 Faro, Portugal
[c] School of Agriculture of Elvas, Polytechnic Institute of Portalegre, P7300-110 Portalegre, Portugal

ARTICLE INFO

Keywords:
Soil erosion
Land use optimization
Land use change
Climate change
Migration

ABSTRACT

Predicting soil erosion potential is important in watershed management. A rapidly growing Iranian population and climate change are expected to influence land use and soil sustainability. In recent years, northern Iran has experienced significant land use changes due to internal migration along the Caspian coast and conversion of forests and rangelands. Considering the effect of these changes in the future, the purpose of this study is to forecast land use patterns and investigate soil erosion scenarios using the Revised Universal Loss Equation and Markov Cellular Automata. Data from 1981 to 2011 were used as a baseline to estimate changes that might occur in 2030. The results reveal that the mean erosion potential will increase 45% from the estimated 104.52 t ha^{-1} $year^{-1}$ in the baseline period. Moreover, the results indicate that land use change from forest area to settlements will be the most significant factor in erosion induced by land use change, showing the highest correlation among erosional factors. Projecting land use change and its effect on soil erosion indicate that conversion may be unsustainable if change occurs on land that is not suited to the use. The method predicts soil erosion under different scenarios and provides policymakers a basis for altering programs related to land use optimization and urban growth. Those results indicated the necessity of appropriate policies and regulations particularly for limiting land use changes and urban sprawl in areas of unfavorable soil erosion risk factors.

1. Introduction

A growing world population and climate change are expected to influence future land use and soil sustainability (Reitsma et al., 2015). Empirical evidence shows that people in developing countries respond to climatic change by migrating internally (Piguet et al., 2011). According to Dun and Gemenne (2008), environmental migrants leave their place of residency due to gradual, long-term climatic change, while environmental refugees leave their place of residency because of sudden environmental change. Climate change and a fast growing population in Iran put pressure on the forests and rangelands of the southern Caspian Sea area due to high demand for agricultural and residential use. In recent years, northern Iran has faced widespread land use change due to rapid development, immigration, and conversion of forests and rangelands into settlements and agricultural land. Land use change can be unsustainable if change occurs on land that is not suited for crop production. Predicting future soil erosion potential is important in watershed management (Laflen and Flanagan, 2013).

Soil erosion is a severe problem in Iran (Arekhi et al., 2012) and one of the most serious environmental problems in the world, as it significantly threatens agriculture, natural resources, and the environment (Rahman et al., 2009a). Soil erosion risk varies from case to case, depending on topography of the watershed, soil characteristics, local climatic conditions, land use, and land management practices. Human-induced land use/land cover change (LUCC) has a significant impact on soil degradation, including soil erosion, soil acidification, nutrient leaching, and organic matter depletion (Sharma et al., 2011). Over the last century, soil erosion accelerated by human activities has become a serious environmental problem (Alkharabsheh et al., 2013). The influence of anthropogenic activities on intensifying runoff generation and flood hazards in northern Iran has attracted the attention of researchers and policy makers (Gholami et al., 2009).

Previous studies have found that vegetation cover can greatly affect the intensity of soil erosion (Zhou et al., 2008; Mohammad and Adam 2010; Anh et al., 2014; Ferreira and Panagopoulos, 2014; Li et al., 2014; Sun et al., 2014; Wang et al., 2016). Vegetation influences soil erosion by means of its canopy, roots, and litter (Gyssels et al., 2005). Soil erosion is directly affected by land use and climate change (García-Ruiz, 2010; Leh et al., 2011; Ferreira et al., 2016). Immigration and conversion of forest lands in agricultural areas, rangelands, and

* Corresponding author at: Research Centre for Spatial and Organizational Dynamics, University of Algarve, Gambelas Campus, 8005-139 Faro, Portugal.
E-mail addresses: Mzare91@ut.ac.ir (M. Zare), tpanago@ualg.pt (T. Panagopoulos), lcloures@esaelvas.pt (L. Loures).

http://dx.doi.org/10.1016/j.landusepol.2017.06.028
Received 29 June 2016; Received in revised form 23 June 2017; Accepted 28 June 2017
Available online 10 July 2017
0264-8377/

residential areas have been followed by development in the northern part of Iran. In addition, the development of road networks and sub-urban recreational residential areas (due to a favorable climate) has increased runoff generation and flood hazard in south Caspian watersheds in recent decades (Gholami et al., 2010). Therefore, the modeling and simulation of land use change are important for predicting soil erosion and land degradation in the future and for a variety of planning and watershed management issues (Deng et al., 2008). This can help in the assessment of the impacts of development, the preparation of land use plans, and for prediction of future soil erosion risk, providing policymakers with a basis for altering programs related to soil conservation policies (Prazan and Dumbrovsky, 2010).

Different approaches to modeling land use change include mathematical models, system models, statistical models (regression), cellular models (cellular automata [CA] and Markov chains), evolutionary models (neural networks), and agent based models (Guan et al., 2011). These approaches are often combined to create an integrated model that determines the probabilities of land use/land cover changes. CA-Markov chain models are among the most frequently used land use change models. The CA-Markov model, integrated into geographic information system (GIS) software, simulates spatial change by identifying local rules using a cellular automaton's local filters and a suitability map (Balzter et al., 1998). Soil erosion is a complex issue with many related factors, so an integrated and systematic approach should be implemented. Spatial technologies, such as remote sensing and GIS, as well as numerical modeling techniques, are powerful tools for watershed management assessment (Krivtsov, 2004; Rahman et al., 2009b).

The aim of the present study is to estimate trends in soil erosion potential, contributing to sustainable watershed management by adequate land use policy. In order to provide predictions for current and future soil erosion, remote sensing data and GIS technologies were adopted, and the Revised Universal Soil Loss Equation (RUSLE) was used. Based on historical spatio-temporal data, a CA-Markov chain analysis was implemented to predict the LUCC regime for the year 2030 and to assess soil erosion vulnerability in the Kasilian watershed of the Talar River in northern Iran.

2. Materials and methods

2.1. Study area

The Kasilian watershed is part of the Talar River basin, which is located in the central region of northern Iran south of the Caspian Sea. The surface area of the basin is 342.86 km^2 and its coordinates are 53°1′ to 53°26′ east and 35°1′ to 36°32′ north (Fig. 1). The minimum and maximum elevations in the basin are 286 and 3289 m, respectively. The area's land type is mountainous with average slope of 15.8% and, according to the Iranian geological classification, this basin belongs to the central Alborz with its surface rocks belonging to the first, second, and third eras. The majority of this basin is covered with different forest species that have land uses such as rangeland and agriculture, in addition to forest land use. The soil in this basin is primarily of the podzolic, brown forest, and sedimentary types.

Iran has a hot, arid climate characterized by long, hot, dry summers. Precipitation is sometimes concentrated in local but violent storms, causing erosion and local flooding, especially in the winter months. A small area along the Caspian coast has a very different climate. Here, rainfall is heaviest from late summer to mid-winter, but, in general, falls throughout the year. The study area has an average annual precipitation of 733.3 mm and the climate is semi-humid and cool. The Kasilian watershed is located in Mazandaran province, which hosts the greatest numbers of individuals engaging in internal immigration (Mahmoudian and Ghassemi-Ardahaee, 2014), mostly due to favorable climate conditions compared to the arid climate in the rest of the country.

In consequence of the above, large areas of rangelands, forests, and agricultural lands have been converted to residential areas in recent years, due to favorable climatic conditions. Therefore, the price of agricultural land has increased and rangelands have been occupied illegally. In this paper, land use types are divided to four classes: agriculture, forest, settlement, and rangeland.

3. Methods

A multi-agent system combining Markov CA with a multi-criteria evaluation (MCE) was used to investigate LUCC scenarios. The RUSLE was used to calculate annual soil erosion (Renard et al., 1997). The RUSLE does not estimate the amount of sediment leaving a watershed, but instead estimates soil movement at a particular site (Yang et al., 2003). Implementation of the study was carried out in five steps:

a Preparation of satellite imagery from three different time periods and performing various corrections.
b Preparation of a land use map by using maximum likelihoods and their validations.
c Running of a Markov chain model in IDRISI Kilimanjaro software (Eastman, 2006) to calibrate the land use map for 2011.
d Transition the suitability map by using the MCE model.
e Simulating the future of land use changes through the integration of the MCE and CA-Markov models.

The C factor was prepared for the baseline years (1986, 2000, 2011) and the simulation (2030) period. The process steps are shown in Fig. 2.

3.1. The RUSLE model

The Revised Universal Soil Loss Equation (RUSLE) is an empirical erosion model designed to predict long-time average annual soil loss by runoff from a place of interest for any number of scenarios involving erosion control practices and predicted erosion (Millward and Mersey, 1999; Kouli et al., 2009; Bonilla et al., 2010; Park et al., 2011; Pradeep et al., 2015). The RUSLE represents how climate, soil, topography, and land use affect rill and inter-rill soil erosion caused by raindrop impact and surface runoff (Fernandez et al., 2003). The RUSLE uses a factorial approach that Renard et al. (1997) employed (Eq. (1)):

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

where A is the average soil loss caused by erosion (t ha^{-1} y^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}), K is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), L is the slope length factor, S is the slope steepness factor, C is the cover and management practice factor, and P is the conservation support practice factor. The L, S, C, and P factors are dimensionless (Tang et al., 2015).

R is a numerical descriptor of the ability of rainfall to erode soil (Toy et al., 2002) and is defined based on maximum rainfall intensity. This factor is calculated with two parameters: total rainfall kinetic energy and 30 min maximum rainfall (Eq. (2)):

$$R = \frac{1}{n}\sum_{i=1}^{n}\left[\sum_{k=1}^{m} KE(I_{30})\right] \tag{2}$$

Where R is rainfall erosivity (MJ mm ha^{-1} h^{-1} y^{-1}), KE is the total kinetic energy of each shower (MJ ha^{-1}) and I_{30} is the maximum intensity of a 30-min rainfall (mm h^{-1}) (Renard, 1994). In addition, the kinetic energy of each shower is calculated using Wischmeier and Smith's (1878) equation (Eq. (3)):

$$KE = (11.98 + 8.73 log_{10} I) \tag{3}$$

One of the major watershed limitations in Iran is the lack of appropriate rainfall registration stations having full statistics. There was only a limited number of rainfall register stations in the Kasilian watershed and the surrounding area, making the rainfall erosivity calculation difficult. Thus, in order to overcome this limitation, the monthly