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Research Paper

Spatial modelling for natural and environmental vulnerability through remote sensing and GIS in Astrakhan, Russia

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ABSTRACT

This research work presents vulnerability mapping with land use/cover change detection in Astrakhan city Russia. This study identifies, assess and classify vulnerability using landscape pattern from multidisciplinary approach based on remote sensing (RS) and geographical information system (GIS) approach. To identify vulnerability we used following thematic layers: land use/cover, vegetation, soil, geology and geomorphology in ArcGIS software. According to numerical results vulnerability classified into five levels: low, reasonable, moderate, high and extreme vulnerability by mean of cluster principal. The results indicated a large presence of area with moderate vulnerability (54.62%). All potentially polluted lands showed more than half of their areas as moderate (54.62%) and reasonable vulnerability (33.56%) regions. In the study area encroachment, population growth, industrialization and governmental polices for environmental protection were found to be the major factors that caused the main changes. This study is helpful for decision making for eco-environmental recovering and rebuilding as well as predicting the future development.

1. Introduction

Astrakhan city locate in southeastern Russia and the administrative center of Astrakhan Oblast state. It is the area of high environmental sensitivity zone. The climate of Astrakhan is mostly continental, semi-arid climate with cold winter and hot summers. Astrakhan is one of the driest cities in European Russia. It is this even distribution of rainfall and the relatively low annual temperature that cause the city to fall under this climate category as opposed to an arid climate. Astrakhan is rich in fuel and power complex, Natural Gas, brimstone, fishing industries and food. The fuel and power production are most important production in Russia. Gas and brimstone production about 70% of the Russian market and the Russian market is largest brimstone exporter in the world market (12% of the world market) (Xavierdasilva et al., 2001). Commercial fishing industries were developed, but due to decrease of the catch, the production is reduced. Fruits and vegetable processing plants increase their output. The food industries plants produce over 13% of all output. The city stands on 11 island of the Caspian depression, on the bank of the Volga River close to the area where it flows into the Caspian Sea. However, some cities have shown that they have the potential to be active parts of Russia's economy (Boori et al., 2015a). Moreover, its landscape, climatic conditions, infrastructure, industrial situation, depopulation, less connectivity, forest and agriculture productions and so on are the main cause to identify natural and environmental vulnerability to make the balance in between physical factors, human activities and economic processes (Kok et al., 2016).

Presently remote sensing and GIS techniques are the powerful tool to investigate, predict and forecast environmental change senior in a reliable, repetitive, non-invasive, rapid and cost effective way with considerable decision making strategies (Amiri et al., 2014). This research work uses a new approach by integrating the above mention potential impacts for vulnerability assessment. Analysis can help to solve the multidisciplinary problems such as most or least vulnerable regions, their comparing, in unassessable and harsh climatic conditions (Bai et al., 2012). In this research work we use geology, geomorphology, soil, bare land, vegetation and land use scenarios for vulnerability assessment (Khosravi et al., 2007). In this context, the objective of this study

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is: (1) build a model of spatial distribution of natural and environmental vulnerability through remote sensing and GIS; (2) knowing the parameters used to obtain clarity of vulnerability; (3) knowing the level of vulnerability in different parts of the study area.

Vulnerability is a function of exposure, sensitivity and adaptive capacity. Where potential impacts are a function of exposure and sensitivity Therefore, vulnerability is a function of potential impacts and adaptive capacity. Where exposure components characterize the stressors and the entities under stress; Sensitivity components characterize the first order effects of the stresses, and adaptive capacity components characterize responses to the effects of the stresses. These measures can be quantitative (e.g., precipitation variability, distance to market) or qualitative (e.g., political party affiliation, environmental preservation ethic). Another slightly different view favored by the hazards and disasters research community is that adaptive capacity consists of two subcomponents: coping capacity and resilience. Coping capacity is the ability of people and places to endure the harm and resilience is the ability to bounce back after exposure to the harmful event, even if the people and places suffer considerable harm. In both cases, individuals and communities can take measures to increase their abilities to cope and bounce back; again depending on the physical, social, economic, spiritual and other resources they have or have access to (Saaty and Vargas, 1991).

Another basic issue in this analysis work is to assign weights to each factor according to its relative effects of factors considered in the vulnerability in a thematic layer. The analytic hierarchy process, a theory dealing with complex technological, economical and sociopolitical problems (Saaty and Vargas, 1991), is an appropriate method for deriving the weight assigned to each factor. The degree of membership within different levels of different indices was integrated using weight and the total degree of membership for different thematic layers was used to calculate the whole study area natural and environmental vulnerability. The application of subjective weightings on the one hand gives us some indication of how the relative importance of different factors might vary with context and can also tell us how sensitive vulnerability ratings are to perceptions of vulnerability in the expert community (Romero et al., 2013).

2. Study area

The study area is located in the Astrakhan city, Southeastern Russia. Astrakhan is in the Volga delta, which is rich in sturgeon and exotic plants. The city lies on two banks of the Volga River, close to where it discharges into the Caspian Sea. The city coordinate is in between 46°20′ N latitude and 48°1′ E longitude and average elevation is −12 m (Fig. 1). The population is 5, 20,339 inhabitants according to 2010 Census. The average annual temperature is semi-arid. Summers in the city can be hot, 40 °C (104°F) and in winter is −3.6 °C (25.5°F). Astrakhan has some industries like fishing, shipbuilding, engineering, oil-refining etc.

3. Data and methodology

3.1. Data

In this research work we used primary (satellite data) and secondary data (ground truth data) for land use/cover classes and topographic sheets. This method yields numerical data that cannot be equated directly with particular physical effects. It does, however, highlight areas where the various effects of sea level rise. The ground truth data were collected were using GPS (Global Positioning system) for the year of 2007 and 2015 (Boori et al., 2016a; Yabuki et al., 2011). The specific satellite images used were Landsat Enhanced Thematic Mapper plus (ETM+) for 2000 and 2007, Operational land Imager (OLI) for 2015.

3.2. Image pre-processing

The method of LULC change detection and analysis was performed using a series of processes including data acquisition, data pre-processing, supervised classification and post classification. Pre-processing image was performed to extract significant information from satellite data (Boori et al., 2016a). Image preprocessing is the initials processing of the raw data and normally involves processes like geometric correction, image enhancement and topographical correction. In the first step the earned data were stacked into composite images. The projection transformation was carried out and assigned the UTM WGS-84, projection (Yabuki et al., 2011). A Trimble hand-held GPS with an accuracy of 10 m was used to map and collect the coordinates of important land use features during pre- and post-classification field visits to the study area in order to prepare thematic layers.

3.3. Image classification

Land cover classes were typically mapped from digital remotely sensed data using some sort of supervised, digital image classification (Romero et al., 2013). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land-cover classes or themes and the maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category's spectral response patterns whenever it classifies an unknown pixel. This is why it is considered to be one of the most accurate classifiers – it is based on statistical parameters. The accuracy of these classified maps was checked using the GIS tools and overall classification accuracy of the study area was more than 90% for all three dates. Supervised classification was performed here using ground checkpoints and digital topographic maps (Young, 2010).

An accuracy assessment for the supervised land use/cover classification was for the 2015 image by using ArcGIS. Each and every point had specific color tone and the pixel value which was recognized by the software itself when the data sets were trained during supervised land use/cover classification. All the randomly generated points were then identified by the user and assigned in different classes. This process was done for the three supervised classification images (2000, 2007 and 2015). The correctly identified points were considered as classified values. An Error matrix and Kappa statistics were also generated from this reference and classified data from the report section of ArcGIS software. In the error matrix, the rows denote the categories as derived from the classified image where columns represent the categories identified from the reference values. Overall accuracy was calculated from the error matrix by dividing the sum of the entries that make major diagonal by the total number of examined pixels. Kappa co-efficient of agreement was also calculated by using following equation:

$$K^A = \frac{P_o - P_c}{1 - P_c}$$

$$\mathrm{P}_o = \sum_{\mathrm{i}=1}^{r} P_{ii}$$

$$\mathrm{P}_c = \sum_{\mathrm{i}=1}^{r} (\mathrm{P}_{i+} * \mathrm{P}_{+\mathrm{i}})$$

Here

r = the number of rows in the error matrix.