Land Use/Cover and Vulnerability Mapping Through Remote Sensing and GIS In Astrakhan, Russia

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Abstract

The main aim of this research work is to identify natural and environmental vulnerability distribution in Astrakhan, Russia. This paper identifies, assess, and classify natural and environmental vulnerability using landscape pattern from multidisciplinary approach, based on remote sensing and Geographical Information System (GIS) techniques. A model was developed by following thematic layers: land use/cover, vegetation, geology, geomorphology, and soil in ArcGIS 10.3 software. According to numerical results vulnerability classified into five levels: low, reasonable, moderate, high and extreme vulnerability by mean of cluster principal. Results are shows that in natural vulnerability maximum area covered by moderate (54.62%) and environmental vulnerability concentrated by moderate (54.00%) vulnerability. So, study area has at medial level vulnerability. In the study area encroachment, population growth, industrialization and governmental polices for environmental protection are main cause for vulnerability. This study is helpful for decision making for eco-environmental recovering and rebuilding as well as predicting the future development.

Keywords: Geology; Natural and environmental vulnerability; Remote sensing; GIS; Vulnerability

Introduction

Astrakhan is a city in Russia, the capital of the Astrakhan region, located about 1,411 km southeast of Moscow. The city is an important railway hub, sea, and river port. The population of Astrakhan is about 532,000 in 2015, the area - 208 sq-km. Astrakhan fertile area (the Volga River delta) was the region of the Golden Horde and Khazaria states capitals. First written mentioning of Astrakhan settlement was made by travelers in the beginning of the 13th century. Mongol leader Tamerlane destroyed the town in 1395. In 1459-1556, it was the capital of Astrakhan Khanate. Archaeologists found the remains of it about 12 km from present Astrakhan. Tsar Ivan the Terrible Conquered Astrakhan Khanate and its capital in 1556. The town became the main Russian gate to Orient in the 17th century. It was the place where merchants from Armenia, Persia, India and other counties of the East met. The city stands on 11 islands of the Caspian depression, on the banks of the Volga River close to the area where it flows into the Caspian Sea. Astrakhan is the oldest economic and cultural center of the Lower Volga and the Caspian region. Often called the southern outpost of Russia and the Caspian capital, it is included in the list of historical Russian cities. Astrakhan has long been considered a multicultural city. Today, more than 100 nationalities of 14 confessions live here. The climate is semi-arid, dry, warm. In winter, rare precipitation falls as rain or snow, which usually melts quickly [1]. Summer is usually hot; the hottest month is July (average temperature: +25.6°C). Winters are mild, the coldest month - February (average temperature: -3.7°C). Astrakhan Airport offers regular flights to Moscow, Saint Petersburg, Sochi, and international flights to Aktau (Kazakhstan), Istanbul (Turkey).

Natural resources of the region include natural gas, oil, salt, gypsum. The industrial complex of Astrakhan, the economic center of the region, includes shipbuilding, pulp and paper industry, fish processing industry. The leading industries are fuel industry, mechanical engineering, power engineering, food industry. Astrakhan gas condensate field, the largest in the European part of Russia, is in the area. Astrakhan Gas Processing Plant produces gas for cars, diesel, and boiler fuel, Agric. Weight table to each unite in a thematic layer

cultural lands make up more than 3.4 million hectares - the cultivation of tomatoes, peppers, aborigines, courgettis, cucumbers, carrots, beets, onions, cabbage and watermelons. Rice is traditionally grown along the Volga. The leading branch of livestock is sheep breeding. The region stretches for over 400 km in the form of a narrow stripe on both sides of the Volga-Aktyubinsk flood-lands. Flooded for a long time, the territory of the delta serves as spawning-ground for such fish as sturgeon, stellate sturgeon, white sturgeon, and others (Tables 1 and 2) [2].

Moreover, its landscape, climatic conditions, infrastructure, industrial situation, increasing population, 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 (a diversity of natural processes), human activities (exploitation and development of the region) and economic processes [3]. So overall very high explorations of natural resources are the main cause of natural and environmental vulnerability study in the Astrakhan region, Russia [4].

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 [5]. This research work use 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 un-assessable and harsh climatic conditions [6]. In this research work

Unit	Pedogenesis/morphogenesis Relation	Value
Stable	Prevails pathogenesis	1
Intermediate	Balance between pedogenesis and morphogenesis	2
Unstable	Prevails morphogenesis	3

Table 1: Stability values of landscape units [13].

Thematic maps/classes	Vulnerability grade levels
Land use/cover	
Forest	1.8
Agriculture	1.5
Bare land	1
Mangroves	2
Settlements	3
Waterbody	0.5
Vegetation	
Mangrove	2
River	0.5
Agriculture	1.5
Bare soil	1
Dunes	1.7
Forest	1.8
Urban area	3
Water	0.5
Ocean	0.5
Soil	
Alluvial soil	3
Chestnut+Solonetz soil	1.9
Chestnut soil	1.6
Podzol	2
Sands	2.7
Ocean	0.5
Geomorphology	
Costal trays	2
Dunes	1.7
River plains	2.5
River	0.5
Ocean	0.5
Urban area	3
Geology	
Alluvial	2.5
Eluvium and deluvium of massive rocks	2
Eluvium of massive-crystal rocks and sandstones	1
Marine saline	2.6
Ocean	0.5
Lithspecs	3

Table 2: Weight table to each unite in a thematic layer.

we use geology, geomorphology, soil, bare land, vegetation, and land use scenarios for vulnerability assessment [7]. In this context, the main aim of this study 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.

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Study Area

The study area is in the Astrakhan region, South-west part of Russia. Astrakhan is on the delta of Volga River, 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 coordinates are 46°21′N to 48°03′E (Figure 1).

Data and Methodology

Data

In this research work we used primary (satellite data) and secondary data such as ground truth for land use/cover classes and topographic sheets. The ground truth data were collected using Global Positioning System (GPS) for the year of 2007 and 2015 in the month of June to August for image analysis and classification accuracy. A selection of multi-sensor, multi-resolution and multi-temporal images was used in this study. The specific satellite images used were Landsat ETM+ (Enhanced Thematic Mapper plus) for 2000 and 2007, Landsat OLI (Operational Land Imager) for 2015, an image captured by a different type of sensors to know the changes in different dates [11].

Vulnerability concept

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 [12].

Another basic issue for the evaluation a model is to assign weights to each factor according to its relative effects of factors considered on the vulnerability in a thematic layer. The analytic hierarchy process, a theory dealing with complex technological, economical and sociopolitical problems [13], 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
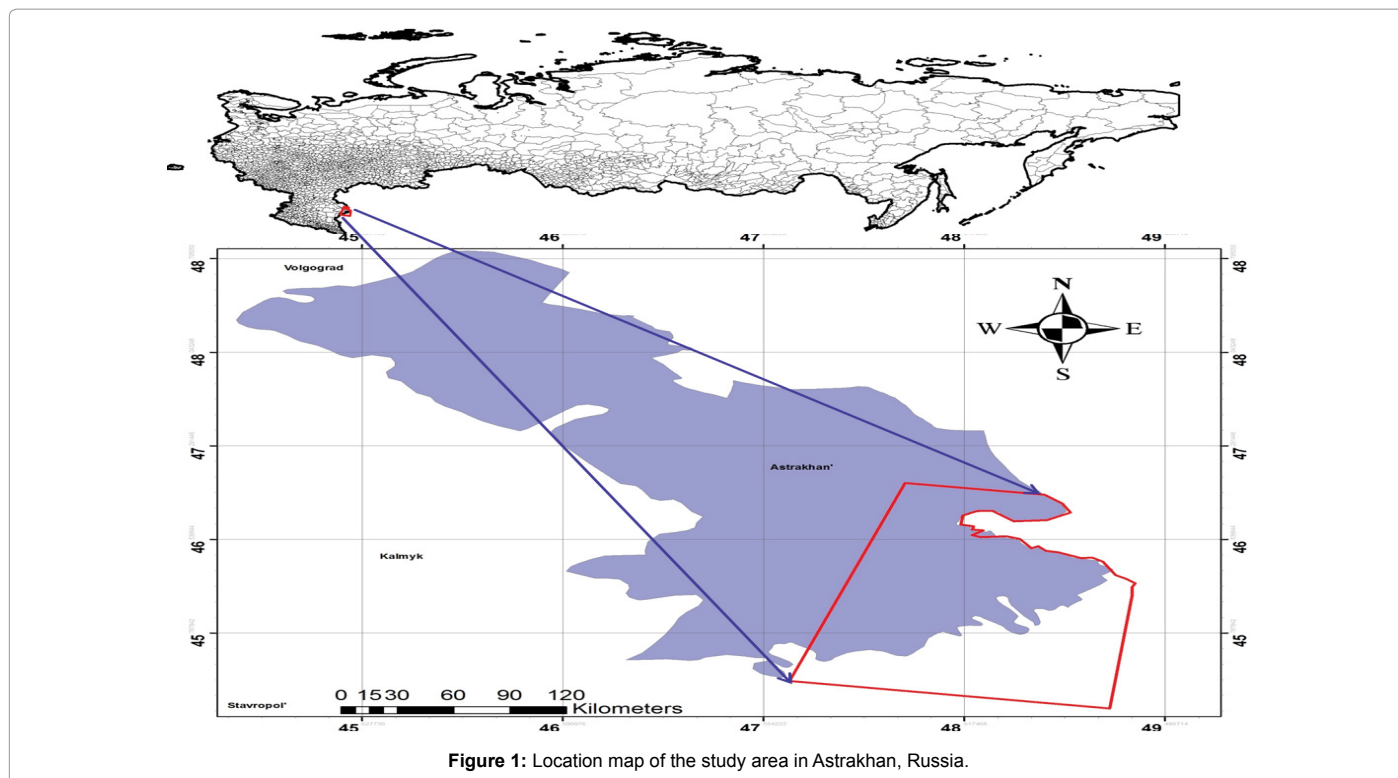
Figure 1: Location map of the study area in Astrakhan, Russia.

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 [14].

Data analysis

In this research work, we used multi-spectral and temporal data; both data were georeferenced based on topographical sheets with the help of ArcGIS 10.2 software. To improve the quality of research analysis we used different band ration, image enhancement techniques, principal component analysis and supervised classification.

Thematic maps (Figure 2) of geology, geomorphology, soil, wetland, vegetation, and land use/cover were prepared from Landsat ETM+ and OLI imageries. The weight of all landscape units based on [6,14] stability concept, where stability was classified per Table 1. The weights of a landscape unit indicate the importance of any factor in relation to others [10]. In natural vulnerability, all thematic layers give same weight but in environmental vulnerability all thematic layer was given different weight based on their sensitivity or effectiveness in the study area (Table 2) [15].

The degree of vulnerability for all units was range from 0 to 3. The vulnerability ranked as extreme, high, moderate, reasonable, and low vulnerability [15]. The weights of compensation indicate the importance of any factor in relation to others, as seen in the formula below for Natural Vulnerability map:

[(Theme 1) + (Theme 2) + (Theme 3) + (Theme 4) + (Theme 5)]/5

For Environmental Vulnerability, we use following formula:

1.1　X [Theme 1] + 0.1 X [Theme 2] + 0.1 X [Theme 3] + 0.1 X [Theme 4] + 0.1 X [Theme 5]

Where:

Theme 1: Geomorphology map.

Theme 2: Geology map.

Theme 3: Soil map.

Theme 4: Vegetation map.

Theme 5: Land use/cover map.

The results were distributed in following five vulnerability classes:

1. Low vulnerability: Less than 1.00

2. Reasonable vulnerability: 1.1 to 1.50

3. Moderate vulnerability: 1.51 to 2.00

4. High vulnerability: 2.1 to 2.50

5. Extreme vulnerability: Greater than to 2.51

Results

After assiging the risk value based on each specific data variable to each section of the land use/cover. The vulnerability ranges from 0.0 to 3. The vulnerability score were diveded into low, reasonable, moderate, high and extreme vulnerability (Figure 3).

Natural vulnerability

The map shows that maximum area is in safe zone as 54.62% area is in moderate vulnerability type and 33.56% area in reasonable vulnerability zone, which shows that around 85% area of the total study area is safe. 6.05% area goes in high vulnerability, Low vulnerability is 5.62% and extreme vulnerability is 0.15%. Low vulnerability is present in sea, river and water body areas and high vulnerability area is close to costal line and near to river basin. Vegetation area and close

Figure 2: Vegetation, soil, geomorphology, geology and land use/cover map.
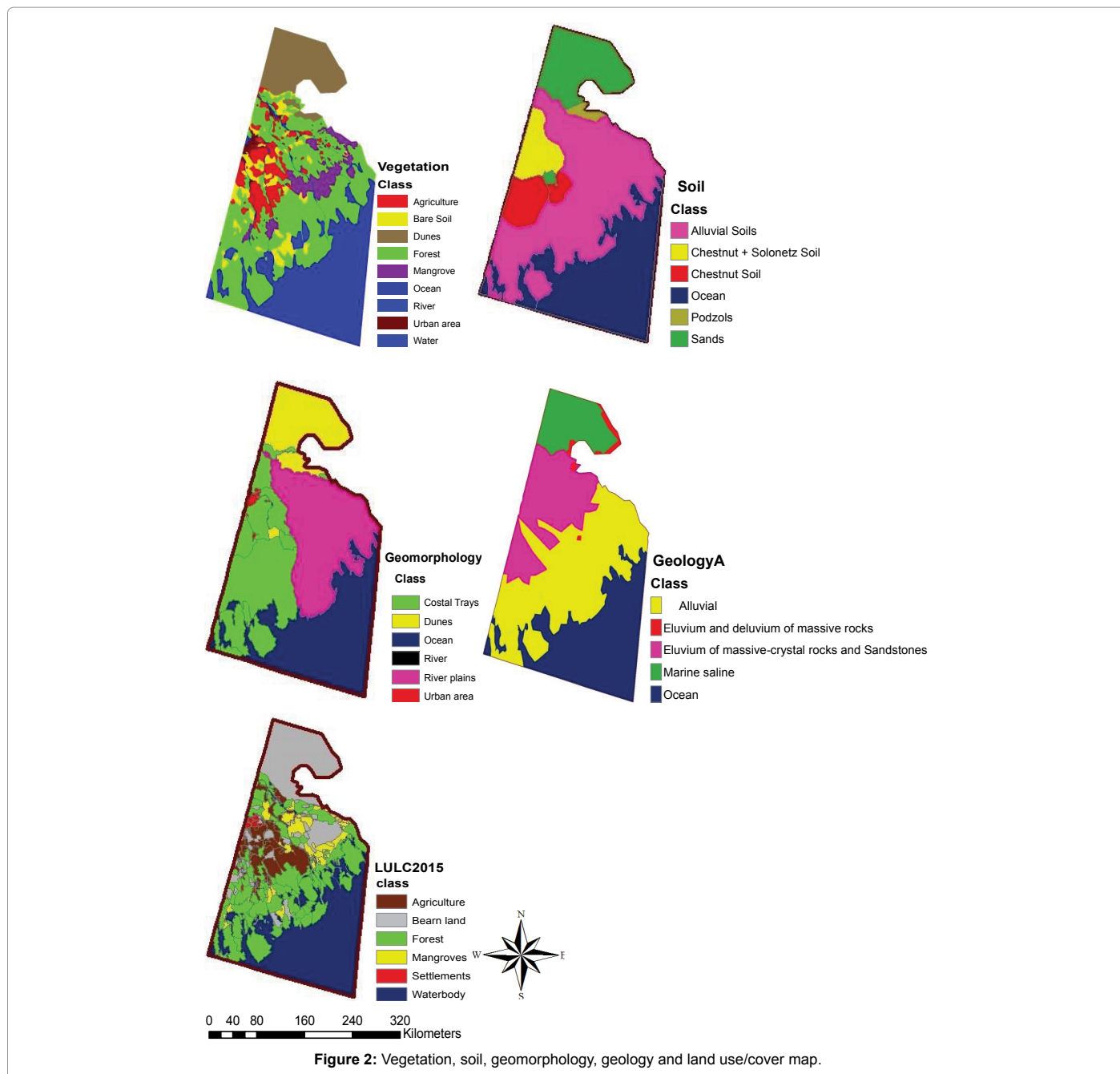
to river basin area are under the moderate vulnerability zone. Low vulnerability and sensible Vulnerability area are the most safe area in the study region,which is under the vegetation, bearland and wetland classes (Figure 3).

Environmental vulnerability

Around 54% area under the moderate vulnerability zone but high and extreme vulnerability is higher than natural vulnerability. Here 6.11% area is under high vulnerability and 0.15% under extreme vulnerability. Reasonable vulnerability is 7.03% and low vulnerability is 32.71%. Sensible vulnerability shows in bearland and some parts of vegetation and low vulnerability is present in sea, river and water bodies. Moderate vulnerability area covered a big part of the study

area, which present in vegetation and costal line. High vulnerability is presenting in the river water area and extreme vulnerability is present in coastal line and close to river (Figure 3).

Discussion

Vulnerability maps demonstrate the great fragility of natural area, supported by the intense action of coastal processes and economic activities in the region. The activities of mining in the region create instability of natural resources [9]. In addition, with the excessive consumption of natural resources and the gradual increase in population, some prominent environmental problems need to be solved urgently. Among them, deforestation and forest degradation are the major environmental and ecological issues in the study area.
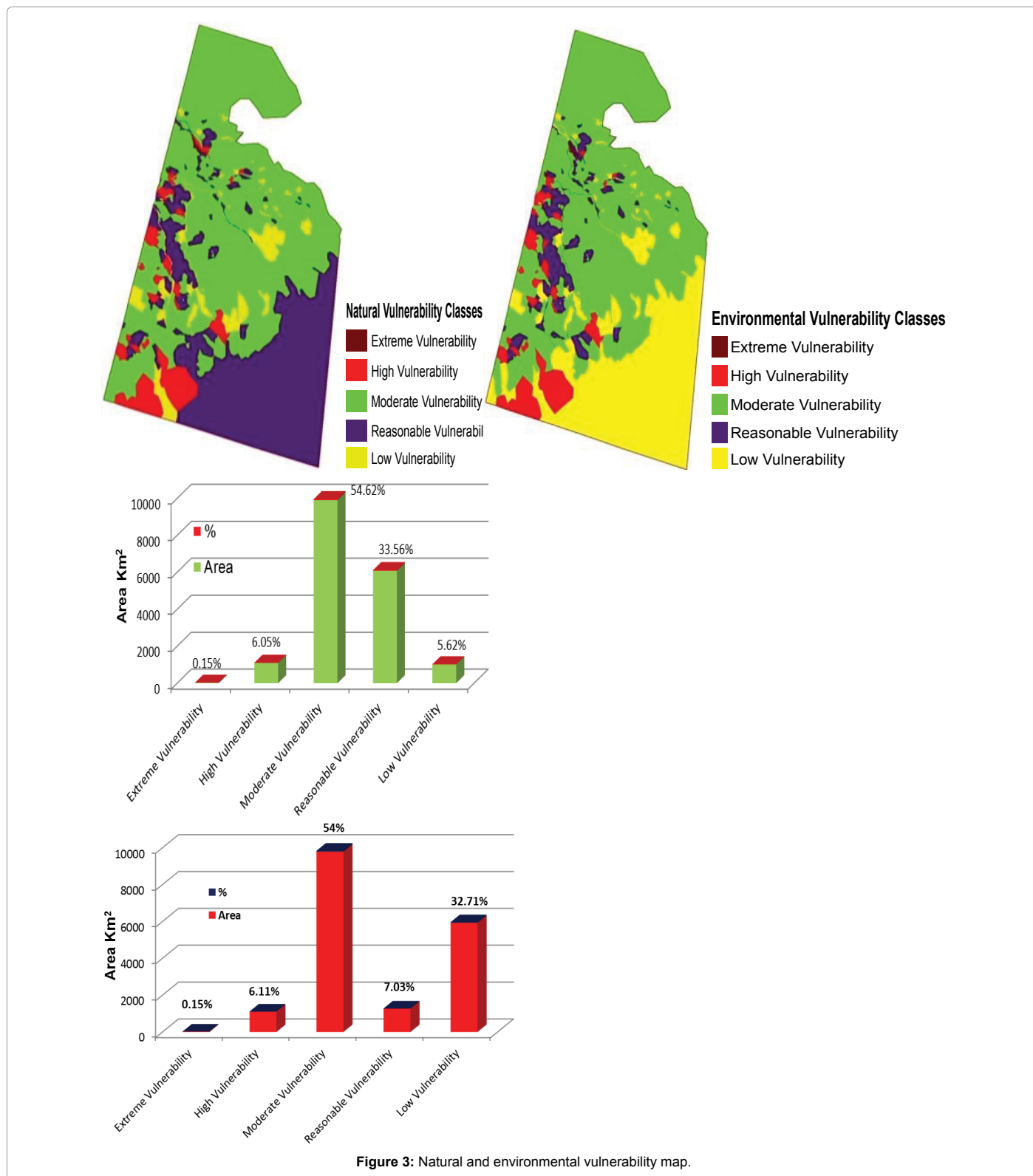
Figure 3: Natural and environmental vulnerability map.

A substantial amount of forest has been lost due to the conversion of forest to farmlands, high grading, industrializations, and other logging practices due to market demand. Despite the high levels of current effort in forest conservation, degradation of forests caused by unsound exploitation is still a serious threat [12].

In addition, soil erosion has also seriously affected the sustainable development of the environment in the study area. Currently, this area is increasing at a rate of 100 km²/year. Deforestation is the chief cause of soil erosion and the adverse geology and climatic conditions intensify the erosion.

Moreover, the Astrakhan is one of the main unmanaged regions of Russia with economic decline and poor environmental awareness. Over the years, with population increase, demand for food, fuel and timber has exceeded local production levels, leading to an imbalance between humans and their environment. Inappropriate land use has generated a huge area of sloped farmland, vegetation destruction and soil loss, leading to gross deterioration of the environment.

An important goal of environmental assessment is to provide assistance to policy makers and practitioners in environmental protection. To protect and maintain the ecological environment in those areas, a population control policy might be needed and some regulations such as "convert slope farmland into forest or pasture" and laws (e.g. 'Environmental Protection Act', 'Land Act', 'Forestry Act', 'Grassland Act', etc.) could be established and implemented. Areas of higher ecological vulnerability should be protected over all others, for moderately vulnerable areas, integrated small watershed management should purposefully focus on sustainable utilization of natural resources, water and soil and sustainable protection of the environment.

In addition, it should develop ecological agriculture and industry combining traditional and modern practices to realize the coordinated development of both the environment and economy. In the areas immediately surrounding the Volga River, the importance of environmental protection should also be emphasized because of its significant geographical position. In addition to increasing vegetation coverage, enhancing the capacity for soil and water preservation and strengthening controls on nonpoint pollution, the establishment of special ecologically functional reserves, such as the river national wetland nature reserve, is a matter of priority. Human migration due to the water and industry project itself must also be noted. Ecological protection measures must be adopted to prevent soil erosion, prevent and control pollution, and to protect water, air and soil quality during emigrant movement and settlement within the study area.

However, strengthening environmental protection alone without alleviating socioeconomic and environmental ignorance can only be a temporary measure. Therefore, it is necessary to address the problems of socioeconomic and raise public environmental awareness as well as scientific understanding. Generally speaking, proper protection of the ecological environment of the study area would be significant not only for the protection of water resources, the ecological system and biodiversity in Astrakhan, but also for social progress, economic development and improvement in standards of living, national prosperity of the water source areas and the region at large.

Conclusions

As a result of the present analysis, we can say that vulnerability is the result of considerable changes in ecosystems and would lead to significant economic hazards. After this analysis we find following vulnerability results:

1. Natural and environmental vulnerability can be modelled by using Remote sensing and GIS techniques.

2. Maximum area covered by moderate vulnerability zone.

3. Natural and enviromental vulnerability is highely effected by bad climate conditions, less agriculture cover, land degradation and high socio-economic activities.

The vulnerability analysis is an indicator which show that where we are more or less uncertain. It helps in indicating how society and policy can have an important role to play in future development pathways.

Acknowledgement

References

1. Amiri F, Rahdari V, Najafabadi SM, Pradhan B, Tabatabaei T (2014) Multi-temporal landsat images based on eco-environmental change analysis in and around Chah Nimeh reservoir, Balochestan (Iran) Environ Earth Sci 72: 801-809.

2. Alves FL, Coelho C, Coelho CD, Pinto P (2011) Modelling coastal vulnerabilities tool for decision support system at inter-municipality level. J Coastal Res 64: 966-970.

3. Abuodha PAO, Woodroffe CD (2010) Assessing vulnerability to sea level rise using a coastal sensitivity index: A case study from southeast Australia. J Coastal Cons 14: 189-205.

4. Syarifuddin M (2013) Penentuan indeks erosivitas metode Lenvain dan Bols.

5. Montarcih LL (2001) Studi optimasi pengelolaan dan pengembangan sub daerah aliran sungai (DAS) Lest Kabupate Malang.

6. Barbosa CCF (1997) Álgebra de mapas e suas aplicações em sensoriamento remoto e Geoprocessamento.

7. Boori MS, Vozenilek V, Choudhary K (2015) Land use/ cover change and vulnerability evaluation in olomuc, czech republic. ISPRS: Ann Photogramm Remote Sens Spatial Inf Sci 8: 77-82.

8. Saaty TL, Vargas LG (1991) Prediction, Projection, and forecasting.

9. Shao H, Liu M, Shao Q, Sun X, Wu J, et al. (2014) Research on eco-environmental vulnerability evaluation of the Anning River Basin in the upper reaches of the Yangtze River. Environ Earth Sci 72: 1555-1568.

10. Boori MS, Amaro VE, Targino T (2012) Coastal risk assessment and adaptation of the impact of sea-level rise, climate change and hazards: A RS and GIS based approach in Apodi-Mossoro estuary, Northeast Brazil. Internat J Geomat Geosci 2: 815-832.

11. Nayak S (2004) Role of remote sensing to integrated coastal zone management. 7: 8.

12. Boori MS, Ferraro RR, Vozenilek V (2014) NASA EOS Aqua Satellite AMSR-E data for snow variation. J Geol Geosci 3:116.

13. Tricart E (1977) Revista Brasileira de Geomorfologia.

14. Grigio AM, Castro AF, De-Souto MVS, Amaro VE, Vital H, et al. (2004) Use of remote sensing and geographical information system in the determination of the natural and environmental vulnerability of the Guamaré municipal district – Rio Grande do Norte – Northeast of Brazil. J Coast Res 39:1427-1431.

15. Boori MS (2011) Avaliação de impacto ambiental e gestão dos recursos natuarias noestuário Apodi Mossoró, nordeste do Brasil.