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Using Remote Sensing and GIS to Assess Environmental Hazard Degradation in Jeddah City, Saudi Arabia.

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Abstract

Environmental degradation is one of the greatest hazards appearing in the Kingdom of Saudi Arabia. The core aim of our study is to determine the environmental degradation in Jeddah city and to predict the growth of degradation in 2030. The study uses the Maximum Likelihood Classification method to categorize images after preprocessing by identifying the changing land cover and urban. The classification is done based on three classes: Urban, Sand, and Vegetation. The results of the research show that the Urban and Vegetation land cover classes are increasing, whereas the Sand area is decreasing. Based on the classification results for land degradation, about 271579 km^2 was converted to Urban and 106494 km^2 to Vegetation while there was around 1082159 km^2 reduction in the Sand class.

1. Introduction

Environmental degradation is the destruction of the ecosystem via decreases in supplies, for example sand, air, and water [1]. The problem of ecological vulnerability has become important because of the rapid growth of the global population and extreme land use variations [2]. The Saudi financial system increased in 2019 because of the support of the non-oil sector, which recorded a great performance [1]. These manufacturers cause a lot of ecological vulnerabilities, which impacts on Urban, Street, Soil, and Vegetation areas. The evaluation of ecological vulnerability has been carried out for years and has collected significant consideration for the analysis of hazards to the economy [4], agriculture [5], and ecology [6].

The Arab region covers an area of around 14.2 million km^2, of which around 90% is characterized by restricted water resources, rough ecosystems, and unstable environments [7]. In Jeddah city, environmental degradation can be a result of any instability in one of the resources: air, water, or soil. This instability can be a result of human activities or natural evolution. Every year, more than two million religious tourists gather in Makkah ahead of the annual Hajj. Jeddah is one of the biggest cities of Saudi Arabia. It has a major seaport for receiving millions of pilgrims to complete their Hajj. Accordingly, it has become a main commercial centre, which has led to significant changes in land cover. This can accelerate urbanization and create a lot of obstacles because it leads to massive requirements for land water, accommodation, and health care [8]. The annual increase in the number of pilgrims has led to the development of infrastructure for housing and natural life resources such as agriculture, industry, and water. Based on it, this development has led to a change in the composition of the environment in the structure of Jeddah city.

The primary aim of this research is to calculate the degree of degradation in Jeddah city using Remote Sensing (RS) and Geographic Information Systems (GIS). The research measures, monitors, models, and maps environmental hazards degradation to find a way to control natural resources for the sustainable development of the province. RS and GIS have been applied to evaluate environmental vulnerabilities for decades. RS provides robust information on plant coverage, sand dune formation, soil erosion, and land changes and is normally employed to measure vulnerabilities. Applying GIS for spatial evaluation allows us to obtain the results of assessment.

Several researchers have developed methods of determining vulnerabilities, such as the fuzzy evaluation method [9], the artificial neural-network assessment technique [10] [11], the landscape estimation approach [12] [13], and the analytical hierarchy process (AHP) [14]. Liou et al. [14] used a combination of 12 variables recovered from satellite data with incorporation of AHP to calculate eco-environmental vulnerability. They established potential vulnerability levels such as slight, light, medium, heavy, and very heavy to describe variations of vulnerability. Fang et al. [15] used RS and GIS to overcome ecosystem degradation in Fuzhou region (China) and showed that socioeconomic technology put pressure on ecological functions. They indicated that the main ecological risks in Fuzhou region (China) consisted of river flooding, soil erosion, and coastal droughts. Mohamed et al. [16] examined threat assessment of soil types and land degradation in the Eastern Nile Delta region, Egypt. Their investigation performed soil degradation evaluation by employing DEM and Landsat 7 ETM+ data, and they presented a soil degradation evaluation of the whole research region. El-Gammal et al. [17] performed sand degradation evaluation in Damietta Governorate, Egypt using GIS. They applied spatial analysis methods and found significant indications of a high risk of soil salinization.

Youssef et al. [18] applied spatiotemporal RS data to evaluate the rockfall hazard at Al-Noor Mountain, Makkah city (Saudi Arabia). They found that there are several unstable areas at separate altitudes alongside Al-Noor Mountain. They also warned that in some weather conditions these unstable regions could collapse. Abd El Aal et al. [19] used GIS and RS to investigate the environmental risks of land change in Najran City, Saudi Arabia. The study analytically examined variations in land cover by means of multi-temporal RS of Najran City between 1975 and 2019. They found that there was increased risk of flooding and several untenable practices with significant land pollution. Ayman et al. [20] employed RS efficiency for urban analysis of Makkah. They investigated multi-temporal satellite images to measure and analyse the evolving land cover and urban morphology composition.

The mentioned studies overcome land degradation using different techniques in Saudi Arabia and elsewhere. Our study tries to fill the gap between GIS and RS data to measure environmental degradation vulnerabilities in Makkah province. First, we investigated some parameters of key environmental degradation involving Urban, Soil, and Vegetation land cover areas. Each parameter was assigned a weight to create an index of land degradation vulnerability. Thus, conclusions could be drawn about how to reduce land degradation in vulnerable areas.

2. Study Area

As shown in Figure 1, the study area covers Jeddah city area, which is a part of Makkah province in the Kingdom of Saudi Arabia (KSA). Jeddah is in the central part of the western region and has an area of around 1,600 km^2. It is located at an elevation of 15 m above sea level. Its geographical coordinates are 21° 32' 35.9988" N and 39° 10' 22.0044" E. According to the Population Characteristics Surveys conducted by the General Authority of Statistics [21], Jeddah’s population was about 3.976 million in December 2017. Jeddah city is the only city in the KSA with a well-preserved famous downtown region [20]. It is one of the biggest commercial cities for Muslims around the world. According to the Tourism Information and Research Centre [22], it is home to a good portion of the tourism industry in the Kingdom. This portion comprises around 55% of the hotels and 18% of the furnished apartments for tourists.

3. Satellite data

This project uses the Landsat TM sensors to moderate a high spectral resolution to isolate areas of water, soil, and vegetation concentrations within the study area. The dataset contains Landsat images LC 2000, 2003, 2005, 2006, 2015, 2016, 2010. Some examples of the dataset are shown in Table 1.

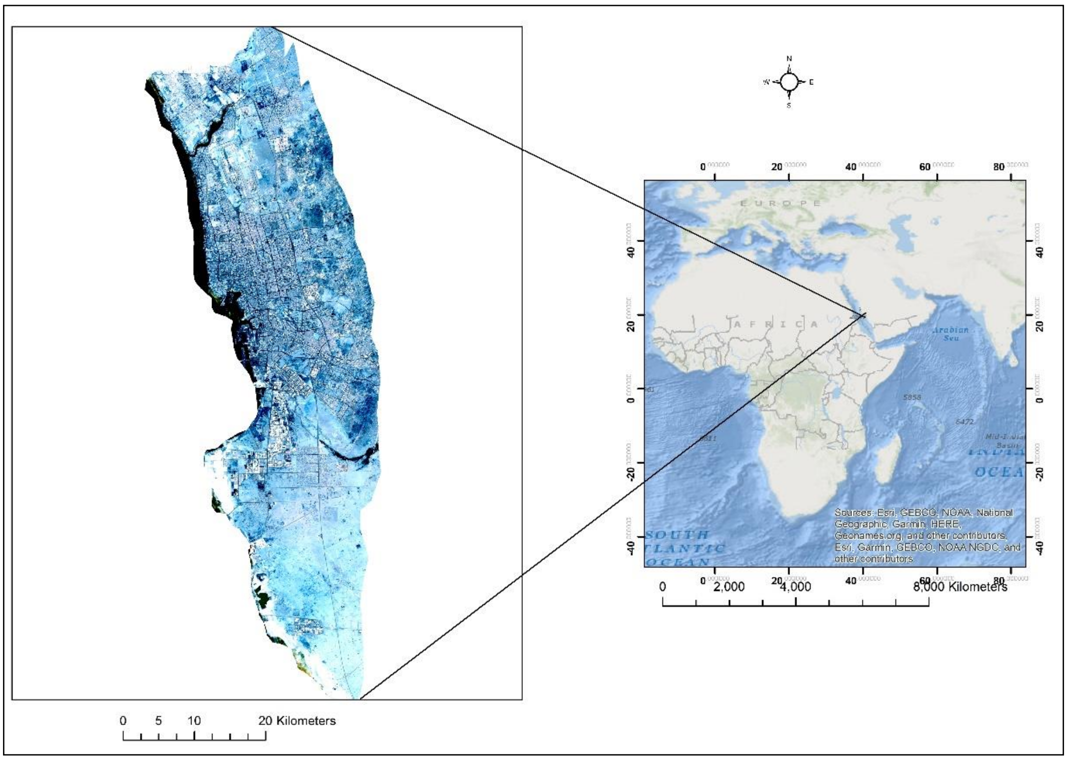


Figure 1 Study area location

Table 1 Remote sensing data used in the study

Respective year	Date Acquired (day/month/year)	Sensor	Resolution	Image Format
2000	03-02-2000	Landsat ETM+ 7	30 m	Geo TIFF
2003	10-01-2003	Landsat 7	30 m	Geo TIFF
2006	17-10-2006	Landsat 7	30 m	Geo TIFF
2016	20-10-2016	Landsat 8	30 m	Geo TIFF

4. Methodology

The objective of this research was to measure the land degradation in the Jeddah area using a supervised learning algorithm. It uses the maximum likelihood classification (MLC) method to categorize images after preprocessing.

4.1 Maximum Likelihood Classification

MLC is one type of supervised classification method. It is obtained from the Bayes theorem. In MLC, the a posteriori distribution $P(x|\theta)$, that is, the probability that a pixel with feature vector θ belongs to class x, is given by:

$$P(x|\theta) = \frac{P(\theta|x)P(x)}{P(\theta)} \quad (1)$$

In MLC, cells in each category section in the multidimensional room are routinely circulated and then Bayes' theorem of decision making is applied. After classification has been done, the images are investigated for accuracy. The classification is done based on three classes: Urban, Soil, and Vegetation, as shown in Table 2.

Table 2 Land cover types and their description

Land Cover Type	Description
Urban	Urban infrastructure, houses, roads, irrigation, schools, clinics, villages, road network, residential, commercial, public buildings, and industrial areas
Soil	Sand, bare soils, rocks, open spaces, excavation sites, developed land.
Vegetation	Herbaceous and grassland, agricultural lands, natural vegetation, trees, gardens, parks, and playgrounds.

The MLC raster image and pixel geometry are used to calculate the change in the area for different categories. The detection of changes is calculated from 2000 to 2016. The classification is conducted using ArcGIS 10.8 Desktop by creating a group of polygons and rectangles for gathering training test data. For MLC, using the stratified random sampling method, 228 points are randomly selected from the images to represent the classification of the Sand class, 86 points are selected for the Urban class, and 57 points for the Vegetation class. The latest imagery from Google Earth was used as a character reference to improve the training data. Some classification counts are shown in Table 3.

Table 3 Classification count

	Value	Count			
		2000	2003	2016	2020
Vegetation	57	84234	85286	90241	101540
Urban	86	496541	507126	622998	768120
Sand	228	1384325	1343802	1257818	1104531

4.2 Degradation Modelling

The changes that happened in the land cover during 20 years in Jeddah are very helpful for recognizing the reasons for the environmental degradation in this area. This recognition helps to manage and control the study area simply and sustainably. In this project, the weighted cover method is used to generate integrated outcomes. The weight value of degradation relies on the judgements of experts to derive a priority scale for three land cover classes. The criteria of the experts are as follows:

- The urban areas on Earth are growing exponentially, with degradation of the environment.
- Urban areas are an essential source of growth; however, they are a main source of environmental degradation.
- Vegetation has a large variety of impacts on the environment. The greater the increase in vegetation, the greater the decrease in degeneration.

Based on the above criteria, we can suggest a new formula to evaluate the degree of degradation D_y for a specific year y as follows:

$$D_y = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{u_{iy} - u_{i0}}{u_{i0}}\right) \tag{2}$$

where N represents the number of land cover classes, u_{i0} represents the value of land cover for the initial year of the study, and u_{iy} represents the value of the land cover class for a specific year of the study.

4.3 Exponential smoothing

This method is suitable for forecasting data with no clear trend or seasonal pattern. Exponential Smoothing (ES) is one of the easiest smoothing strategies to use to predict a future event. This technique is appropriate for estimating information with no reasonable pattern or occasional examples.

In this method, the recent observations are weighted more strongly than older ones. Each observation is weighted with a smoothing parameter β. The prediction of the event $y^{\sim}_{t+1}$ associated with a data set with t observations is calculated as follows:

$$y^{\sim}_{t+1} = \beta y_t + \beta(1-\beta) y_{t-1} + ... + \beta(1-\beta)^{t-1} y_1 \tag{3}$$

where $0 < \beta \leq 1$. It is additionally basic to come to use the segment type of this model, which uses the accompanying arrangement of conditions.

$$y^{\sim}_{t+1} = l_t \tag{4}$$

$$l_t = \beta y_t + (1-\beta) l_{t-1} \tag{5}$$

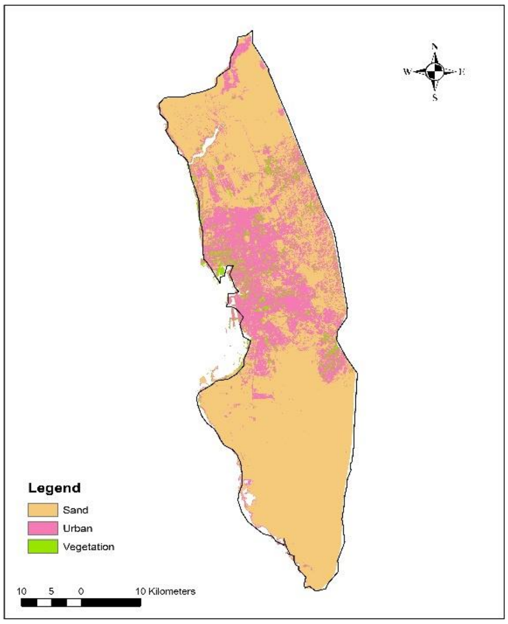
In the two conditions, we can see that the most weight is given to the latest perception.

5. Results and Discussion

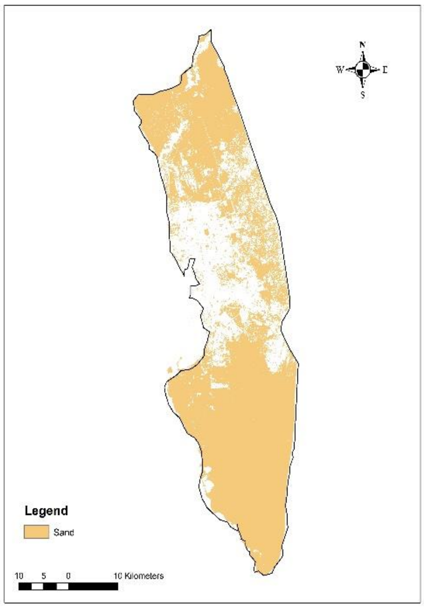
The process of obtaining the results of classification using MLC consists of four stages. The MLC technique is used to classify Landsat data for the years 2000, 2003, 2016, and 2020.

4.1 Areal Distribution Results

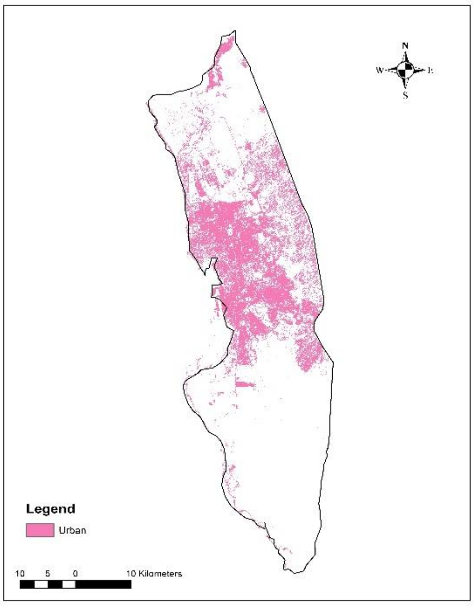
Figure 2 summarizes the areal distribution results for the three major land covers of Jeddah. As shown in Figure 2, Sand covers 1384 km^2 (~87% of the whole area of Jeddah city), Urban land covers 496 km^2 (~31%), and Vegetation covers 84 km^2 (~5%).



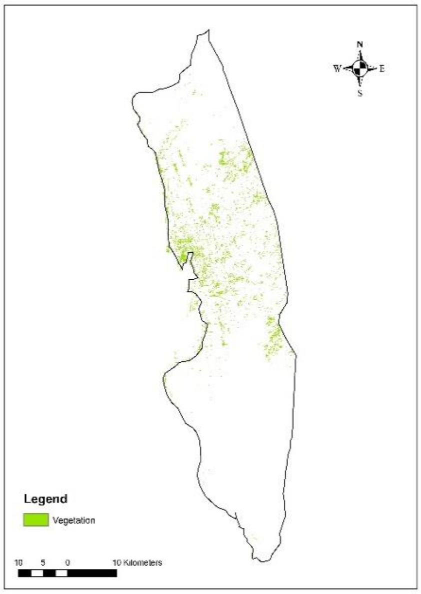
a) MLC classification for the three land covers



b) MLC results for the Sand class



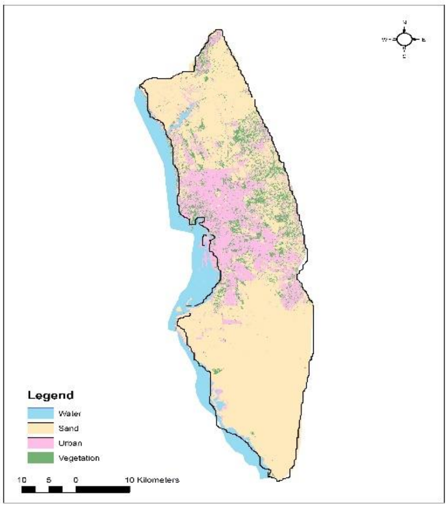
c) MLC results for the Urban class



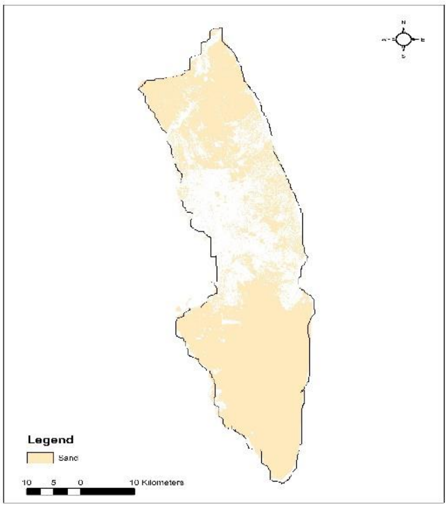
d) MLC results for the Vegetation class

Figure 2 Distribution of land cover classes within the study area for 2000.

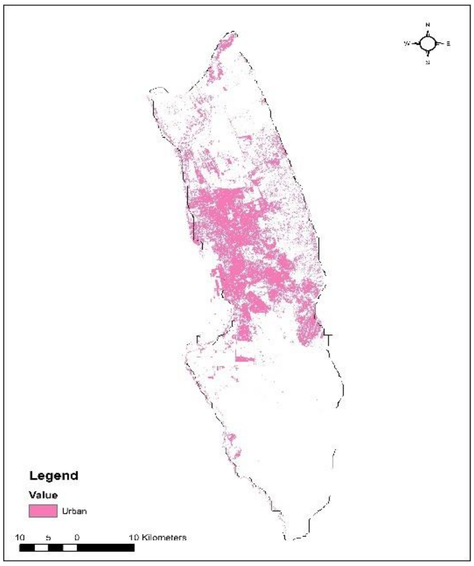
Figure 3 presents the classification results of our targets for the three land cover classes in 2003. As shown in the figure, Sand covers 1343 km^2 (~84% of the whole area of Jeddah city), Urban land covers 507 km^2 (~32%), and Vegetation covers 85 km^2 (~5.3%).



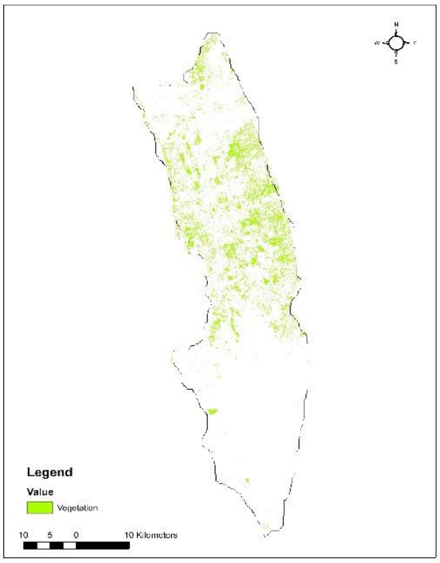
a) MLC classification for the three land covers



b) MLC results for the Sand class



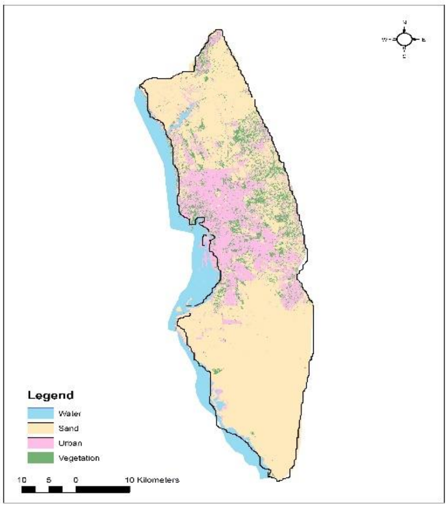
c) MLC results for the Urban class

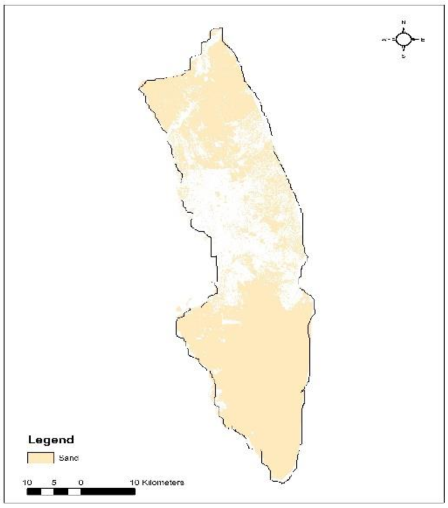


d) MLC results for the Vegetation class

Figure 3 Distribution of land cover classes within the study area for 2003.

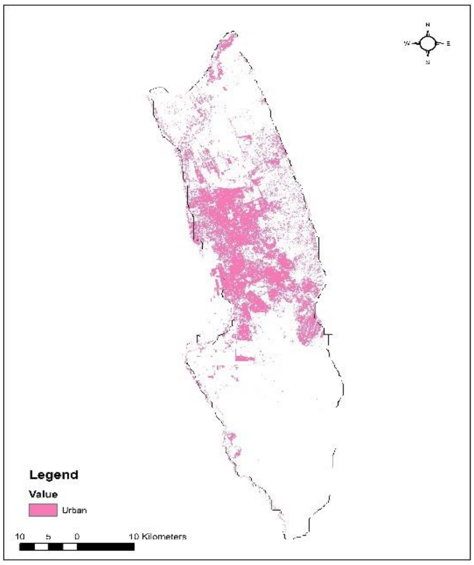
Figure 4 presents the classification results for the year 2010 for our target of three land cover classes. As shown in the figure, the Sand class covers 1312 km^2 (~82% of the whole area of Jeddah city), the Urban class covers 545 km^2 (~34.1%), and the Vegetation class covers 88 km^2 (~5.53%).

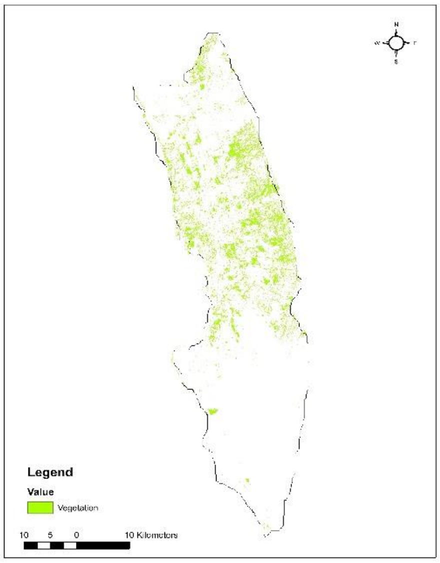




a) MLC classification for the three land covers

b) MLC results for the Sand class



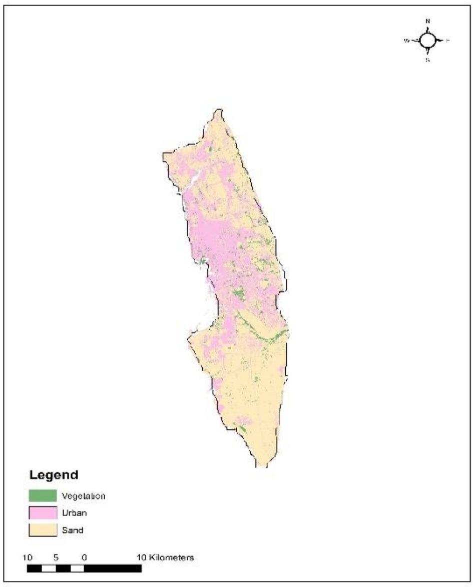


c) MLC results for the Urban class

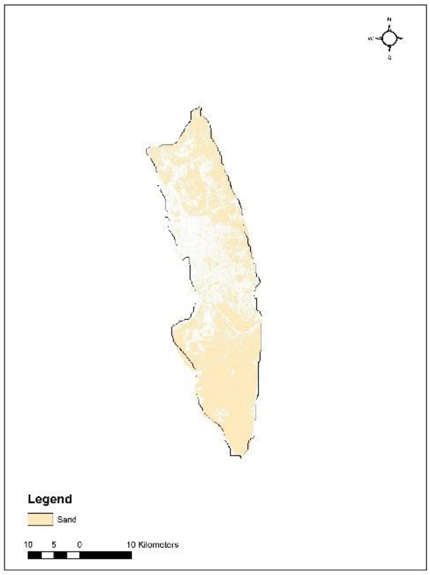
d) MLC results for the Vegetation class

Figure 4 Distribution of land cover classes within the study area for 2010.

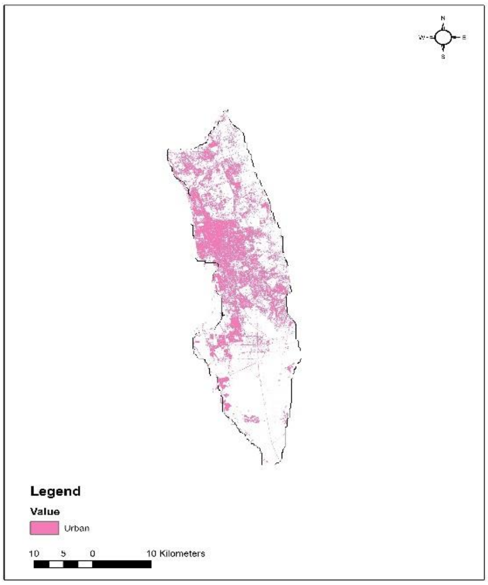
Figure 5 presents the classification results for the year 2016 for our target of three land cover classes. As shown in the figure, the Sand class covers 1257 km^2 (~79% of the whole area of Jeddah city), the Urban class covers 622 km^2 (~38.9%), and the Vegetation class covers 90 km^2 (~5.6%).



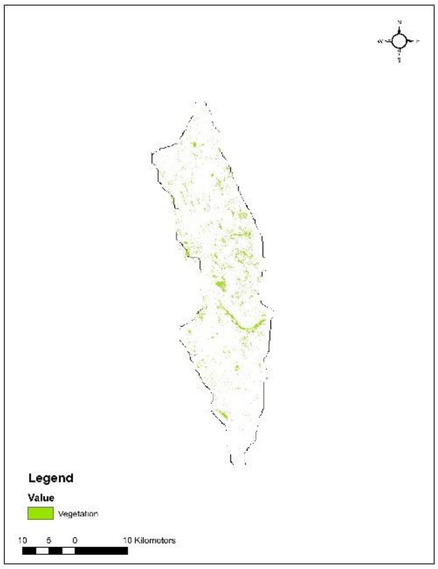
a) MLC classification for the three land cover classes



b) MLC results for the Sand class



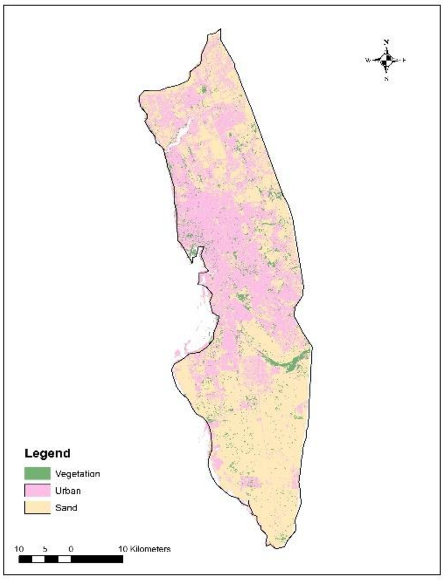
c) MLC results for the Urban class



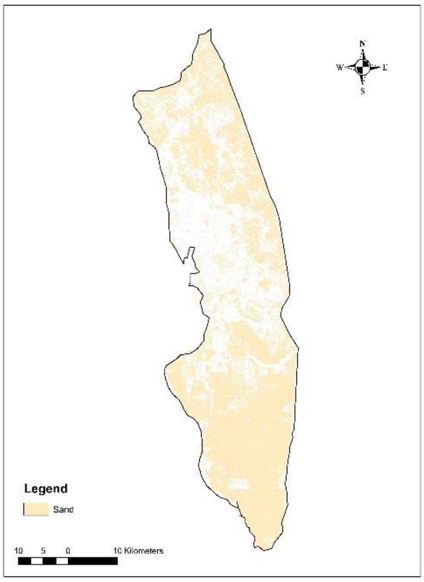
d) MLC results for the vegetation class

Figure 5 Distribution of land cover classes within the study area for 2016.

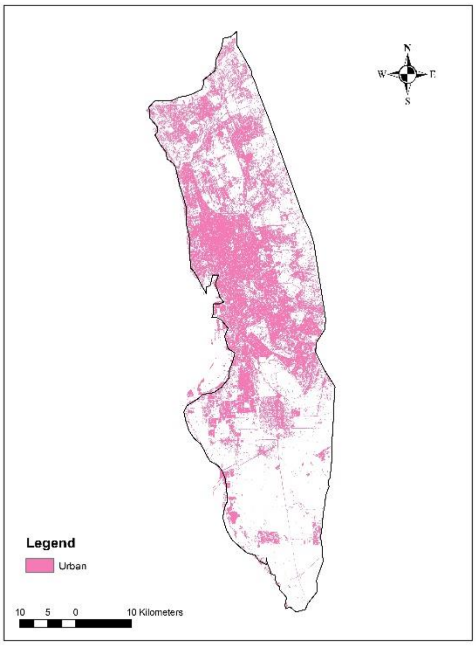
Figure 6 presents the classification results for the year 2020 for our target of three land cover classes. As shown in the figure, the Sand class covers 1104 km^2 (~69% of the whole area of Jeddah city), the Urban class covers 768 km^2 (~48.9%), and the Vegetation class covers 101 km^2 (~6.3%).



a) MLC classification for the three land cover classes



b) MLC results for the Sand class



c) MLC results for the Urban class

d) MLC results for the Vegetation class

Figure 6 Distribution of land cover classes within the study area for 2020.

Figure 7 shows the changes that happened during the period from 2000 to 2020. In 2020, the changes in the Vegetation, Urban, and Sand classes were 1.08, 16.97, and 17%, respectively.

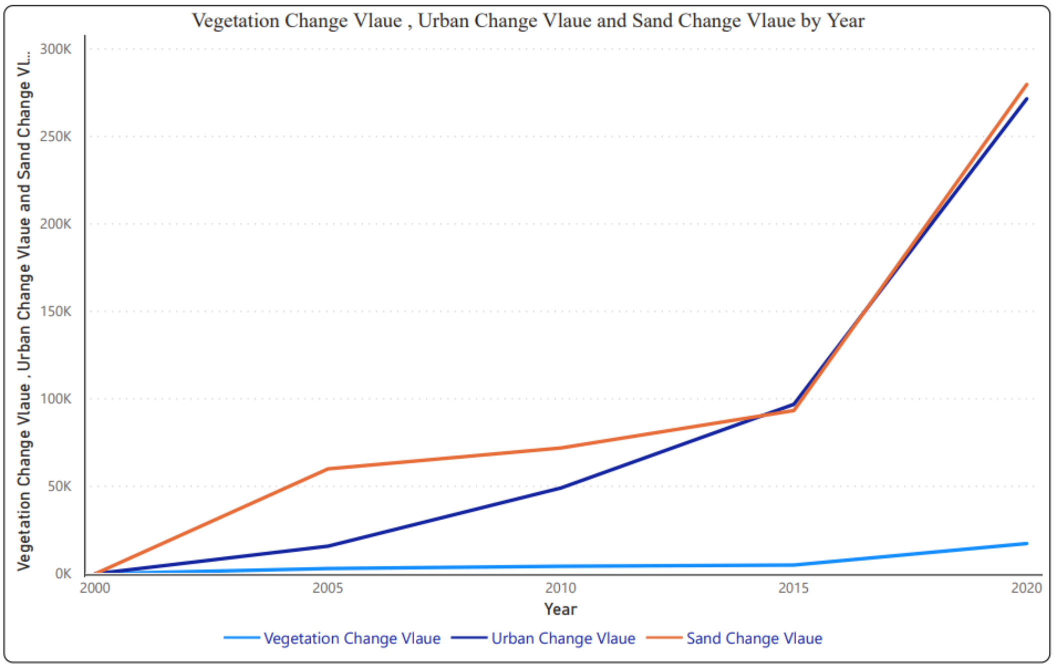


Figure 7 Changes that happened during the period from 2000 to 2020.

4.2.1 Discussion of degradation

Vegetation facilitates in loss of biodiversity and halts natural corruption. The MCL results for the study area from 2000 to 2020 showed that there was low inclusion of vegetation in the north and south of Jeddah. As shown in Figure 6, vegetation increased by 0.33% each year, with increments of 0.19, 0.27, 0.31, 0.38, and 1.08% for the years 2005, 2010, 2015, 2016, and 2020, respectively.

Based on the MLC classification, in 2020 approximately 174685 km^2 was converted to Urban area. Around 1104531 km^2 remained as Sand, with a decrease of 153287 km^2 compared with the amount of Sand in 2016. The Urban cover increased by 5.09% each year, with increments of 0.99, 3.07, 6.06, 7.90, and 16.97% for the years 2005, 2010, 2015, 2016, and 2020, respectively. We found that the Sand cover decreased in proportion to the increase in Urban cover. Sand cover decreased by 4% each year, with increments of 3.75, 4.50, 5.83, 7.91, and 17.49% for the years 2005, 2010, 2015, 2016, and 2020, respectively. Based on Equation (1), the degradation found by our study can be evaluated as follows:

$$D_y = \frac{1}{3}\left(\frac{u_y - u_0}{u_0} + \frac{s_y - s_0}{s_0} + \frac{v_y - v_0}{v_0}\right) \tag{6}$$

where u_0, s_0, and v_0 represent the Urban, Sand, and Vegetation land covers, respectively, for the initial year of the study. Furthermore, u_y, s_y, and v_y represent the Urban, Sand, and Vegetation land covers, respectively, for a specific year of the study. In our study, we used Equation (6) for the years 2000, 2005, 2010, 2015, and 2020. The results are shown in Figure 8.

The degree of degradation differs from year to year. The change in degradation for each year over the past four decades gradually increased.

The apparent discrepancy of degradation has led to concern that there is such a hazard due to the land degradation arising in Jeddah. This degradation could be arising because of inherent natural processes and extreme events. The worst value of degradation is for 2020, when the area of degradation was 568679 km^2, representing 36% of the area of Jeddah and 32% with respect to the degradation in other years. The results of degree of degradation are 2, 4, 7, 11, 14, and 32% for 2005, 2010, 2015, and 2020.

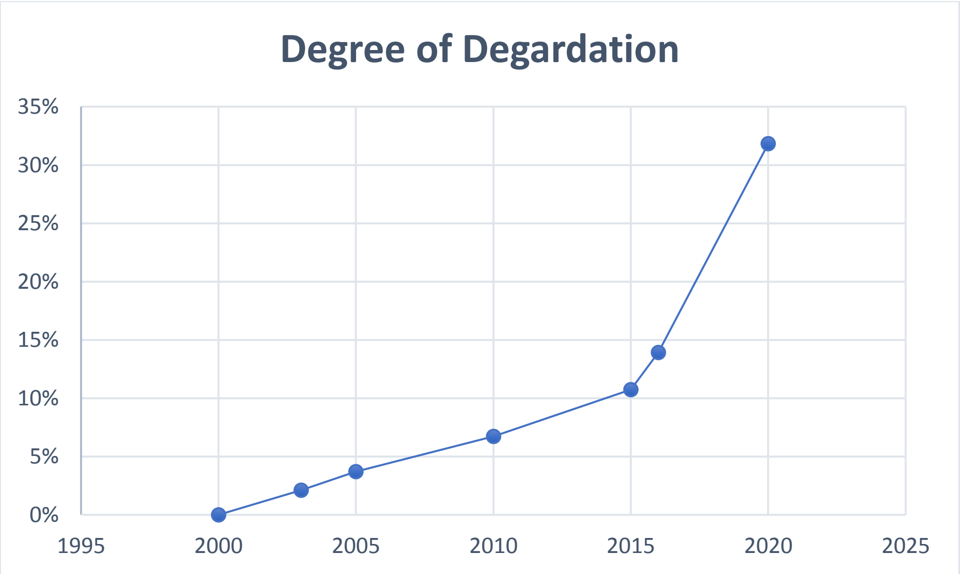


Figure 8. The value of degradation

4.2 Prediction of degradation for Jeddah in 2030

To forecast the degradation for 2030, we applied the forecasting model in Power BI Desktop version 2.88.1144.0. The model is based on a collection of methods for time series prediction called Exponential Smoothing (ES). The raster classification results of 2000, 2005, 2010, 2015, and 2020 must be entered into the ES model. Based on the classification data, the model then predicts the land cover growth in 2030.

Figure 9 shows a detailed result for the prediction of each land cover class for 2030. The grey area represents the prediction area for each class. For 2030, the ES model for Jeddah found that approximately 89548 km^2 will change to Urban area (an increment of 4954 km^2 from 2020). The Sand area in the region will be reduced to 1082159 km^2 (a decrement of –22372 km^2 from 2020). Vegetation zones will show a minor growth to 106494 km^2 (an increment of 4954 km^2 from 2020).

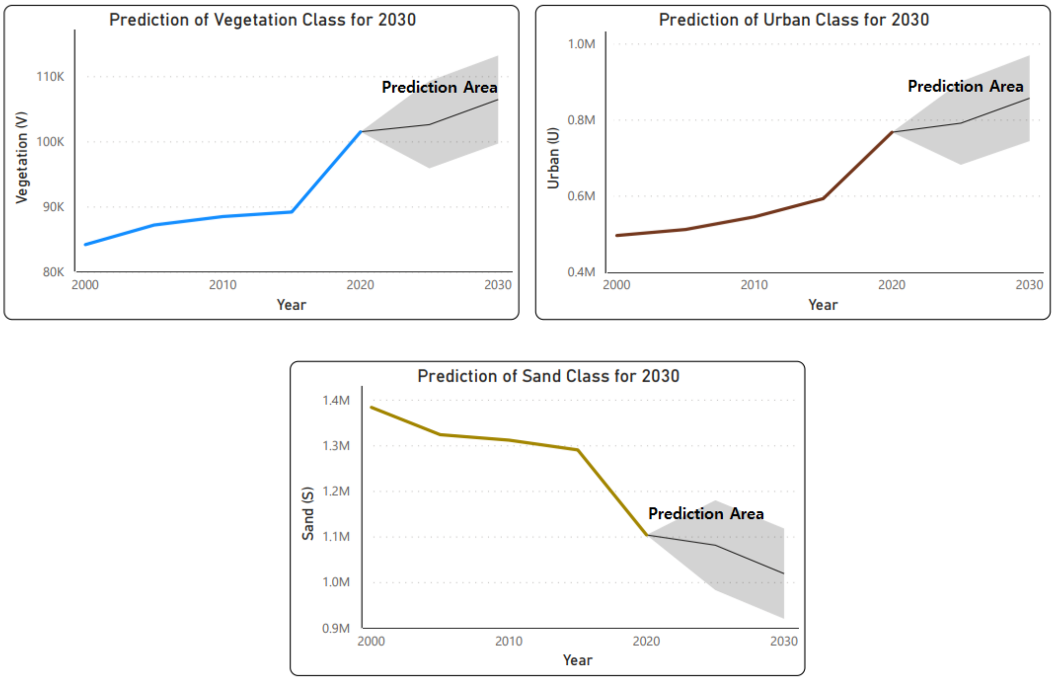


Figure 9. Prediction of land cover classes for 2030

Figure 10 shows the prediction of the degradation based on the ES forecasting model.

In 2020, the degradation will increase to reach 0.41 with 41% (an increment of 9% from 2020). The grey area represents the predicted degree of degradation for the year 2030.

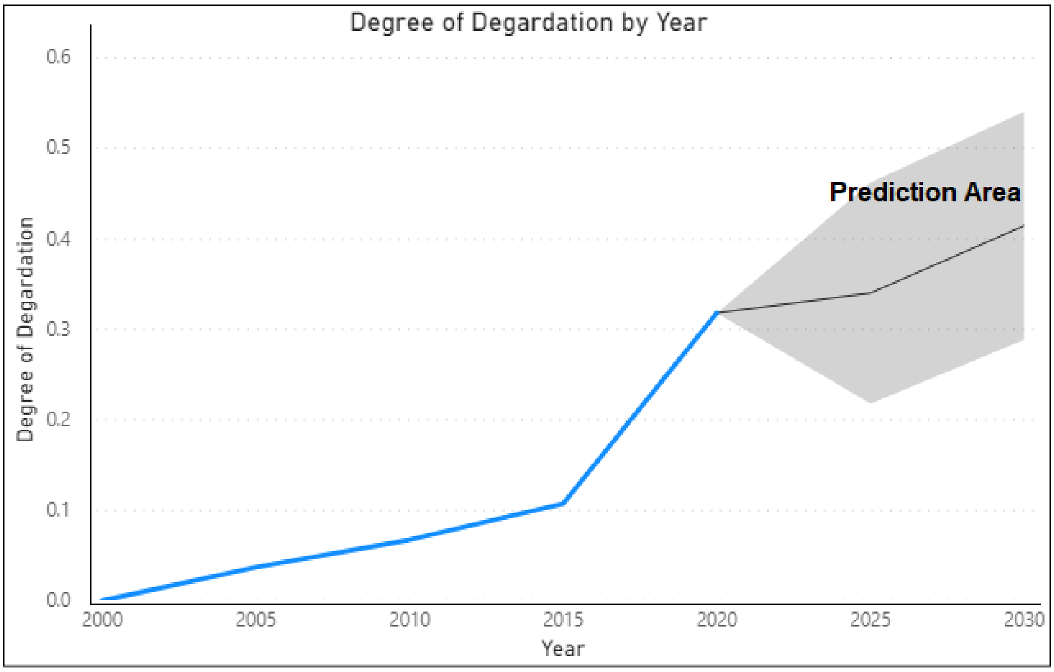


Figure 10 The prediction of degradation for 2030

Figure 11 shows the spatial distribution of the land degradation vulnerability levels within the study area.

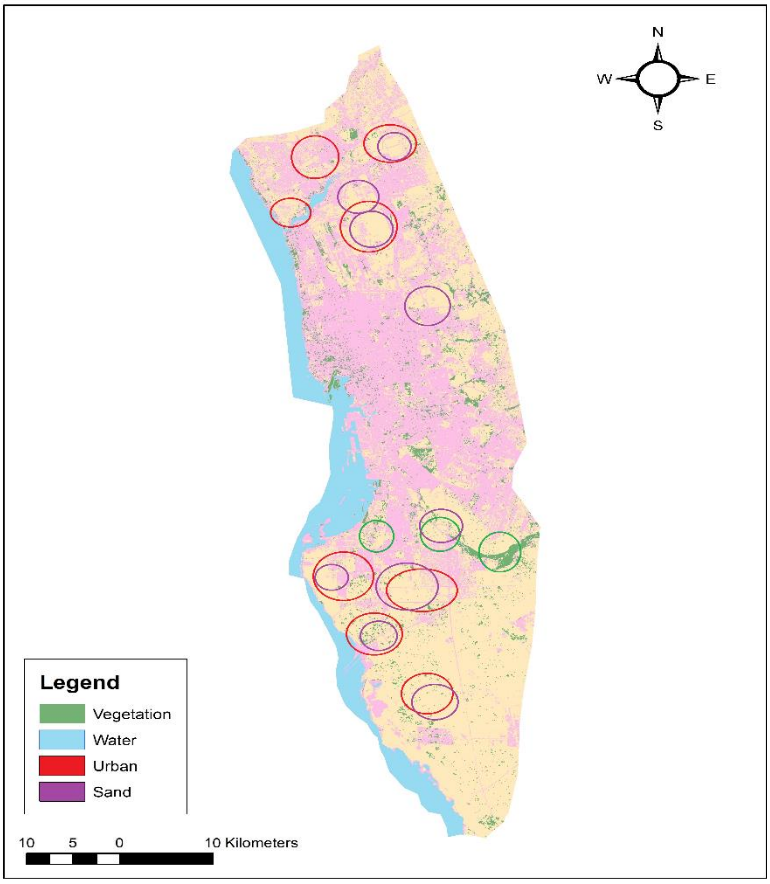


Figure 11 Spatial distribution of the land degradation vulnerability levels within the study area.

The red, purple, and green circles show the expected area in which the distribution of urban, sand, and vegetation will take place in 2030.

These vulnerabilities could be used by developers in Jeddah to control degradation in the future. To guarantee that the development of Jeddah city takes place in a reasonable way, we make some recommendations. This examination will make a few proposals. The city urgently needs to set up spatial data infrastructures to create a valuable tool for engineers to collect information related to growth and perform consequently.

Conclusion

The change in degradation in each year over the past four decades has gradually increased. This study has used RS imagery and the GIS platform to analyse the land cover changes within the city of Jeddah between 2000 and 2020. Using this study and the results of MLC classification, a new way to evaluate the degree of degradation was suggested. The prediction of the growth for 2030 is calculated with ES using Power BI Desktop software. The experiment discovered that the urban areas within Jeddah city had grown by approximately 174685 km^2 in 2020. The sand cover had decreased by 153287 km^2 compared with the amount of Sand in 2016. The apparent discrepancy of degradation has led to concern that there is such a hazard regarding land degradation arising in Jeddah. We can see that the most far-reaching drivers of land degradation in Jeddah are those that are straightforwardly connected to human activities such as new buildings, new manufacturers, and new businesses. The degradation arising could be due to inherent natural processes, the population growth rate, migration and population mobility, economic demand, and consumption. Based on the ES forecasting method, the percentage of degradation will be 41% in 2030.

References

[1]. Johnson, D.L., S.H. Ambrose, T.J. Bassett, M.L. Bowen, D.E. Crummey, J.S. Isaacson, D.N. Johnson, P. Lamb, M. Saul, and A.E. Winter-Nelson. 1997. Meanings of environmental terms. Journal of Environmental Quality 26: 581–589.

[2]. R. Venkatesh, S. Abdul Rahaman, R. Jegankumar, P. Masilamani, 2020. Eco-environmental vulnerability zonation in essence of environmental monitoring and

management, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLIII-B5-2020.

[3]. Saudi Arabian Monetary Authority. 2020. 56th Annual Report 1441H, Government of Saudi Arabia. https://www.sama.gov.sa/en-US/EconomicReports/AnnualReport/Annual_Report_56th-EN.pdf [accessed December 2020].

[4]. Armatas, C., Venn, T. and Watson, A. 2017. Understanding social-ecological vulnerability with q-methodology: a case study of water-based ecosystem services in Wyoming, USA. Sustainability Science, 12(1): 105–121.

[5]. Jayanthi, H., Husak, G.J., Funk, C. et al. 2013. Modeling rain-fed maize vulnerability to droughts using the standardized precipitation index from satellite estimated rainfall-southern Malawi case study. International Journal of Disaster Risk Reduction, 4: 71–81.

[6]. Micheli, F., Mumby, P.J., Brumbaugh, D.R. et al. 2014. High vulnerability of ecosystem function and services to diversity loss in Caribbean coral reefs. Biological Conservation, 171: 186–194.

[7]. Abahussain, Asma & Abdu, Anwar & Zubari, Waleed & El-Deen, Nabil & Abdul-Raheem, Mahmmod. (2002). Desertification in the Arab Region: Analysis of current status and trends. Journal of Arid Environments, 51: 521–545. 10.1006/jare.2002.0975.

[8]. Asadis, T., Nick, A., Xiaoyang, Z. 2007. Modeling soil erosion at global and regional scales using remote sensing and GIS techniques. Advances in Remote Sensing and GIS analysis. John Wiley and Sons, London, pp. 241–261.

[9]. Adriaenssens, V., De Baets, B., et al., 2004. Fuzzy rule-based models for decision support in ecosystem management. Sci. Total Environ. 319: 1–12.

[10]. Alizadeh, Mohsen & Ngah, Ibrahim & Hashim, Mazlan & Pradhan, Biswajeet. 2018. A Hybrid Analytic Network Process and Artificial Neural Network (ANP-ANN) model for urban earthquake vulnerability assessment. Remote Sensing, 10: 975. 10.3390/rs10060975.

[11]. Alizadeh, Mohsen & Alizadeh, Esmaeil & Kotenaee, Sara & Shahabi, Himan & Panahi, Mahdi & Ahmad, Baharin Bin & Lee, Saro. 2018. Social vulnerability assessment using Artificial Neural Network (ANN) model for earthquake hazard in Tabriz City, Iran. Sustainability, 10: 3376. 10.3390/su10103376.

[12]. Darabi, Hassan & Farsani, Islami & Behbahani, Irani. (2019). Evaluation of ecological vulnerability in Chelgard mountainous landscape. 4, 597–610. 10.22059/poll.2018.262881.486.

[13].Vilchek, G. 2008. Ecosystem health, landscape vulnerability, and environmental risk assessment. Ecosystem Health, 4: 52–60. 10.1046/j.1526-0992.1998.00070.x.

[14].Liou, Y.A., Nguyen, A.K., and Li, M.H., 2017: Assessing spatiotemporal eco-environmental vulnerability by Landsat data. Ecological Indicators, 80: 52–65, https://doi.org/10.1016/j.ecolind.2017.04.055.

[15].Fang, L., Yang, Z.D., and Wang G. et al. 2015. Probe into the sustainable development prospect of the coal-mining dominant city by taking Yima, Henan as a sample. Journal of Safety and Environment, 15(5): 361–366.

[16].Baroudy, A.A.E. and Moghanm, F.S. (2014) Combined use of remote sensing and GIS for degradation risk assessment in some soils of the Northern Nile Delta, Egypt. The Egyptian Journal of Remote Sensing and Space Sciences, 17, 77–85. http://dx.doi.org/10.1016/j.ejrs.2014.01.001.

[17].El-Gammal, M.I., Ali, R.R. and Samra, R.M.A. (2015) GIS-Based land degradation risk assessment of Damietta Governorate, Egypt. Egyptian Journal of Basic and Applied Sciences, 2, 183–189. http://dx.doi.org/10.1016/j.ejbas.2015.01.001

[18].Youssef, Dr. Ahmed & Pradhan, Biswajeet & Al-Kathery, Mohamed & Bathrellos, George & Skilodimou, Hariklia. (2015). Assessment of rockfall hazard at Al-Noor Mountain, Makkah city (Saudi Arabia) using spatio-temporal remote sensing data and field investigation. Journal of African Earth Sciences. 101. 309–321. 10.1016/j.jafrearsci.2014.09.021.

[19].Abd El Aal, Ahmed & Abd elghany, Mostafa & Alyami, Saleh. (2020). Environmental analysis of land use and land change of Najran City: GIS and remote sensing. Arabian Journal for Science and Engineering, 45. 10.1007/s13369-020-04884-x.

[20].Ayman Imam, Bahaa Alhaddad c, Josep Roca, 2016, Remote sensing efficiency for urban analysis of mecca and surrounds, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B8, XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic.

[21].General Authority for Statistics (Saudi Arabia), 2017. Population Characteristics Surveys, 2017 [accessed 7 January 2019].

[22].Tourism Supply and Demand Indicators in the Kingdom of Saudi Arabia for the Third Quarter 2019, available at http://www.mas.gov.sa/publications/1097 [accessed 18 December 2020]

[23].M. Minwer Alkharabsheha, T.K. Alexandridisa, G. Bilasb, N. Misopolinosb, N. Silleosa, 2013. Impact of land cover change on soil erosion hazard in northern Jordan using remote sensing and GIS, Procedia Environmental Sciences 19, 912–921.