SPATIAL-TEMPORAL MODELING OF LAND-VEGETATION DEGRADATION, USING WEIGHTED OVERLAY INDEX MODEL. A CASE STUDY ON NINEVEH PROVINCE, IRAQ

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Abstract

Dust storms strike arid and semi-arid regions of the world frequently and the past research studies suggest some of the West Asian countries as the active agents producing such dust storms. Among these countries, Iraq proves to be of greatest contribution to these storms. It seems that vegetation degradation, due to various reasons, is one of the factors increasing the activity of the sources of dust emission. In this work a spatial-temporal modeling of land degradation using satellite images and GIS is employed. Here, the emphasis is on vegetation degradation in Nineveh province of Iraq. Landsat images from 1985, 2001, and 2014 and also other available GIS data were utilized to model the phenomena and predict the vegetation condition in 2027. The required data were gathered and effective criteria of land degradation were determined, i.e. the criteria were calculated using spatial analysis in GIS. The weights assigned to criteria based on experts’ opinion were modeled using Weighted Overlay Index Model (WOIM). Spatial-temporal modeling was carried out using data related to 1985 and 2001 and the results were assessed using data from 2001 and 2014. The vegetation condition of the region was finally predicted for the 2027. According to the obtained results, the average rate of vegetation decrease based on NDVI values indicating the status of land degradation is critical. The average NDVI decrease is 0.136 for the time period 1985 to 2001, while it is 0.197 for 2001 to 2014. If this trend continues, the average will be 0.152 for the time period 2014 to 2027. The obtained results indicate an increase in arid lands and decrease in the vegetation and transformation of vegetated lands to arid lands. The results indicate a severe
desertification phenomenon that has been recognized as the most severe type of land degradation in the literature review of this study. Vegetation degradation, its decreased density, dry climate, increased temperature and strong winds in the region contribute to dust storms.

**Keywords:** Land-Vegetation Degradation, Weighted Overlay Index Model, GIS, Nineveh Province, Iraq.

### 1. INTRODUCTION

The increasing trend of population growth, technological development and transformed economic and social structures on one hand, and climate changes on the other, have caused issues such as considerable degradation of natural resources, increased desertification, gradual degradation of resources and ultimately changes and tensions in social relations and economic principles in the recent century. These changes are unfortunately of a growing trend. They are developing at such a fast pace in arid regions of the world that the phenomena of land degradation and desertification are mentioned as the most significant aspects of ecological degradation and destruction of natural resources in the world. Many attempts have been made at global scale to restrain the development of this phenomenon and mitigate its detrimental impacts. Dust storm as one of the impacts of land degradation strikes arid and semi-arid regions of the world frequently.

The main focus of previous works has been on the assessment of degradation intensity and identification of degradation type. Some studies have employed GIS, RS and decision-making methods for preparing degradation maps. Only few studies have used intelligent methods. The first regional study was carried out in 1976 by Hamburg University researchers to prepare desertification maps for Sudan (A. Mrost, Yu, 1987). The study lasted for 4 years in Darfur region of Sudan. The obtained results were formed into two maps of land use and desertification which were related to one another. Three types of data were combined and overlaid to attain the desertification map. The information used were as follows: Morpho-dynamic activities (Aeolian erosion, reactivation of dunes, fluvial erosion and etc.) which indicate desertification processes, the climate and vegetation conditions (desert, semi-desert, savanna and etc.) that have been considered as desertification process defaults and the risk and damage rate of desertification with regard to human and livestock. The first formal measure taken at a global scale to assess this phenomenon and draft its map for a better understanding was the preparation of the global map of desertification (United Nations Convention to Combat Desertification) which was carried out by FAO, UNESCO\(^1\) and WMD\(^2\) in 1977 after the issue of desertification was raised. This map that was drafted in a 1:25,000,000 shows the desert regions as well as the surrounding areas that are exposed to the serious threat of desertification (F. U. U. WMO, 1977).

In (C. Kosmas, 1999), Kosmas used indices such as vegetation degradation, fluvial erosion, Aeolian erosion, utilization of rangelands, and human habitation. With regard to the latter item, the required information was collected directly in desert and field operations. The desertification risk was ultimately calculated by combining the indices. In (Kharin and Harahsheh, 2000), Karin provided a new map of desertification in Asia in 1:10,000,000 using the FAO-UNEP method. Based on this map, 20 percent of the land is affected by weak desertification, 41 percent by medium desertification, 21 percent by severe and very severe desertification and 18 percent being swamps, salt marshes, non-vegetated lands, stony surfaces, mountains, sand dunes, hyper-arid lands were

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1. United Nations Educational Scientific and Cultural Organization
2. World Map of Desertification
not included in desertification assessments. The Greek National Committee of combat against desertification and Athens Agricultural University drafted the desertification map of Greece during 2001 and 2002. The parameters employed in their method included soil texture, stone and pebble pieces, soil depth, canalization condition, slope degree, rainfall level, dryness index, direction, fire risk, erosion potential, resistance to dryness, vegetation, utility type, utility level, and applied policies in the management section. After calculation of soil properties, climate and vegetation, the desertification map was prepared for different regions of Greece by overlaying layers in GIS. In (Ownegh, 2009), Ownegh introduced a desertification management program for Gorgan plain in the form of physiographic units and 5 key parameters (i.e., salinity, Aeolian erosion, fluvial erosion, water logging and vegetation degradation) based on Analytic hierarchy process by classifying the desertification risk into 4 classes and comparing scenarios. The advantage to this method is quick assessment and consideration of experts’ opinion when laboratory and field data are scarce. In (Rasmey et al., 2010), Rasmey et al. improved the MEDALUS model using a dynamic simulation model for desertification of the western regions of Nile. This model shows the desertification concept through various equations and simulation of external diagrams which shows the interaction between various variables in a circular plan. In (Luis A et al., 2013), Luis A et al. introduced an analytical framework entitled CLDM (Connotative Land Degradation Mapping), a knowledge-based method for assessment of land degradation and to portray the main factors of land degradation. They could assess the land degradation severity in two drainage basins of central Mexico using GIS and multi-criteria decision making analyses, and identify and classify the main factors using ANP method. CLDM is in fact the implementation of multi-criteria GIS-MCDA decision making analyses and its combination with fuzzy pattern categorization for assessment of each observatory units considering a standard created through programming. The results indicate that natural causes intensified by human activities are the main cause of degradation in the region. Three main factors of fluvial erosion and dust storms for natural processes and land vegetation changes for processes caused by human factors were introduced and areas with a slope of less than 6 percent have had the highest degradation. In (D’Odorico et al., 2013), D’Odorico et al. employed a multi-disciplinary approach for a better understanding of factors, feedback and global desertification impacts. They studied people’s growing need for improved food production at a global scale and efficient management of ecosystems with regard to climate change. They considered climate changes such as drought and land use as main factors of transition to desertification or land degradation. They analyzed the mechanism of desertification reactions which include land degradation processes (e.g., losing ingredients or salinity), changes in rainfall regimes due to earth and atmosphere interaction (e.g., rainfall recycling, dust dispersion) or changes in vegetation combinations (e.g., intrusion of shrubs and decreased vegetation) as well as the possibility of their increase by their interaction with socio-economic factors. They concluded that the effect of large scale desertification can be ecological refugees’ migration from degraded lands, climate change, and changes in global biochemistry caused by long-term dispersion of mineral dusts. In (Baroudy and Moghadam, 2014). E Baroudy and Moghadam could design a simple model for assessment of land degradation severity by assessing the potential of RS and GIS for determining the severity and risk of soil degradation in some parts of the Nile river deltas and based on soil equations and climate factors. They extracted the physiographic units of the region from Landsat- ETM+ (2003) and DEM. The results indicated that 48.09 percent of the understudy region is under a high chemical degradation while 51.91 percent of the region is exposed to a low chemical degradation risk. Also, 21.12 percent of total area of the region is exposed to the high
risk of physical degradation in which salinity, Alkalinity and entry to the water system are main degradation factors.

Among the West Asian countries, Iraq proves to be of greatest contribution to dust storms (Darvishi Bolurani et al., 2011). It thus seems that vegetation degradation, due to various reasons, is one of the factors influencing the activity of dust sources. The current study on land degradation with an emphasis on vegetation degradation aims to investigate and assess vegetation changes in 1985 to 2014 and then model the predicted vegetation condition in 2027. After literature review and obtaining expert opinion, effective criteria were identified. Then, the criteria were calculated using GIS, and weights were assigned to the criteria by experts. Weighted Overlay Index Model was finally used to combine the criteria based on their effect and create the vegetation degradation map. Modeling was performed using the information pertaining to the years 1985 to 2001, and assessment of the results obtained from the information of the years 2001 to 2014 and prediction of vegetation degradation in 2027.

2. METHODS AND MATERIALS

2.1 Study Area

The phenomenon of dust storm is striking Middle Eastern countries such as Iran and Iraq frequently. The conducted studies indicate that the violent storms sweeping over western Iran and sometimes penetrating into the central regions of Iran come from north west of Iraq and east of Syria (the first cluster of dust sources) and south west and west of Iraq (the second cluster of dust sources) and only in some cases the storms are stronger in the south west of Iraq (the fourth cluster of dust sources. Figure 1 (Darvishi Bolurani et al., 2011). Thus, this study focuses on the first cluster of dust sources of this region with regard to land degradation and with an emphasis on land-vegetation degradation. Figure 2 shows the region under study which is part of Nineveh province in Iraq situated in the most active sources of dust. The study area is 18,257.76 square kilometers.
When several layers of data are used for modeling, a model for combining them is required. These models include two key components. The first component is the data layers and the second is the weight assigned to each layer. The models that use weights may be capable of weight assignment or weights should be provided as an input (Burrough and Mcdonnell, 1998). With this regard, methods are divided into three groups: the first group only combine data. Weighted Overlay Index Model (WOIM) can be mentioned as one of the instances of such models which is also employed in this study. The weights to be used in this model should be determined by another method. This method can only combine these weights and provide an output accordingly (Bonham-Carter, 1994). The second group are methods capable of estimating the weights using the data and then combining them. Weights of evidence and logistic regression are instances of these methods (Hosmer and Lemeshow, 2000). The third group consists of methods that are solely used for determining weights. Weight determination methods belong to this group. Because they determine, as an expert, the significance of the data and then place the obtained weights in a combinational method to attain the final result (Calcerrada and Luque, 2006).

WOIM, also referred to as Weighted Linear Combination (WLC) or Weighted Index Overlay (WIO) or Index Overlay (IO), is utilized in this study. The layers along with their weights and considering the class scores existing within each layer are combined with one another, Equation (1).

\[
\tilde{S} = \frac{\sum_{i=1}^{n} s_i w_i}{\sum_{i=1}^{n} w_i} \quad \text{Eq. (1)}
\]

Where, is the obtained combinational value for the phenomenon (Polygon or pixel), is the weight of the ith input map, is the score of ith class from the ith map, and n stands for the number of combined maps. In fact, the total of multiplication result of score by the weight in each place is calculated for all layers. Denominator normalizes the obtained criteria and places them between 0 and 1. If the weights are normalized before combination, then the denominator would equal 0 and will be of no effect (Malczewski, 2006). The greatest advantage to this method is that it is quite simple and comprehensible that can be implemented and analyzed quite easily. The easy implementation of this method in GIS has led to its widespread application (Boroushaki and Malczewski, 2010). All introduced models are of their own strengths and weaknesses. The greatest
capability of the recommended model is its simplicity and great potential for modeling. This model receives the required models easily and simulates them. The model recommended for this study is of four key components: effective criteria, calculation of criteria through GIS, determining the weight of criteria through expert opinion, and combination of layers through WOIM. Figure 3 shows the components of the recommended model for modeling land degradation with an emphasis on vegetation degradation. To predict land degradation, a time series with four data sets is used. Figure 4 shows the general methodology utilized for drafting the map and assessing vegetation degradation using the data. In the modeling stage, vegetation degradation level in 2001 is estimated using the data of 1985. Then, using real data, the vegetation condition of 2001 is compared with the modeling results and the accuracy is assessed. Ultimately, the proposed model for vegetation degradation for 2014 along with the accuracy of the model is assessed using the data from 2001. Based on the calculated accuracy, prediction accuracy of vegetation degradation for 2027 is assessed using 2014 data.

Figure 3. General structure of the methodology used for resolving the issue of vegetation degradation
2.2 Data Preparation and Preprocessing

The spatial information and the data used in this study are based on Landsat satellite images from 1985, 2001 and 2014, Table 1. To cover the whole region, two images from Landsat satellite were mosaicked with one another. For instance, Figure 5 shows the mosaic of TM images from Landsat satellite in 1985. The required information layers for these three years were extracted using these images. Figure 6 shows the information layers used for modeling the land degradation with an emphasis on vegetation degradation.
Figure 5. Mosaicked images of 1985

Figure 6. The information layers used in the study

Figure 7 and 8 shows the prepared information layers as input into GIS for 1985. Figure 9 and 10 shows the information layers for 2001 and Figure 11 and 12 shows information layers for 2014.
2.3 Selection of Effective Parameters and Determining Them by GIS

Considering previous research works conducted on this issue as well as expert opinion and available information, this study tries to identify and assess the criteria affecting the subject of the study. Thus, considering the existing inaccessibility to required information on Iraq, almost all required information layers are extracted from satellite images. Table 1 shows the employed effective criteria as well as obtained weights through expert opinion for modeling land degradation with an emphasis on vegetation degradation.

Table 1. Criteria utilized in modelling of land degradation with an emphasis on vegetation degradation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Distance from Rivers</td>
<td>0.06</td>
</tr>
<tr>
<td>C2 Distance from Lakes</td>
<td>0.07</td>
</tr>
<tr>
<td>C3 Distance from Agricultural Regions</td>
<td>0.10</td>
</tr>
<tr>
<td>C4 Distance from Roads</td>
<td>0.06</td>
</tr>
<tr>
<td>C5 Distance from Residential</td>
<td>0.09</td>
</tr>
<tr>
<td>C6 Height</td>
<td>0.13</td>
</tr>
<tr>
<td>C7 Slope</td>
<td>0.07</td>
</tr>
<tr>
<td>C8 Distance from Wells</td>
<td>0.07</td>
</tr>
<tr>
<td>C9 Erosion (Using soil type and stone type)</td>
<td>0.10</td>
</tr>
<tr>
<td>C10 Type of climate (Using rainfall and temperature)</td>
<td>0.10</td>
</tr>
<tr>
<td>C11 NDVI Index</td>
<td>0.15</td>
</tr>
</tbody>
</table>

2.4 Determining Parameters by GIS

GIS can serve as an extremely useful tool for determining different criteria values (Badri et al., 1998). In fact, GIS as a system capable of managing, modifying, displaying, and analyzing spatial information so as to facilitate the modeling of spatial issues (Vahidnia et al., 2009). GIS is used in this study as a framework for preparing spatial data.

2.4.1. Distance from Rivers

Accessibility to rivers affects vegetation changes significantly. Thus, regions close to rivers, in comparison with regions farther from rivers, may be subject to overgrazing, and thus lose the chance for renovation. C1 will represent this criterion. Figures 13, 14 and 15 show the distance from rivers for the years 1985, 2001, and 2014 respectively.
2.4.2 Distance from Lakes

Accessibility to lakes is as effective on vegetation as accessibility to rivers. Thus, regions close to lakes, in comparison with regions farther from them, may be subject to overgrazing, changes in their utility and thus lose the chance for renovation. C2 will represent this criterion. Figures 16, 17 and 18 show the distance from lakes for the years 1985, 2001, and 2014, respectively.
2.4.3 Distance from Agricultural Regions

Dr. Makhoudm’s ecological models, i.e. two utility types of agriculture and range management, are stated as one, as there is no consensus on the border between these two utility types such that it is extremely difficult for the subject matter experts to draw a line between these two utility types (Makhoudm, 2011). These two utility types are considered as one in this study as well considering the methodology employed in Makhoudm’s model. Closeness to these regions cause vegetation degradation, as well. C3 represents this criterion. Figures 19, 20 and 21 show the distance from agricultural regions for the years 1985, 2001, and 2014, respectively.
2.4.4 Distance from Roads

There is a greater potential for land degradation for lands closer to roads. As roads provide better access to these regions and cause higher population density. Thus, distance from roads was also considered as a criterion. C4 represents this criterion. Figures 22, 23 and 24 show the distance from roads for the years 1985, 2001, and 2014, respectively.
2.4.5 Distance from Residential Areas

Another parameter affecting land degradation, and especially vegetation degradation, is distance from residential regions (C5). Areas farther from villages and residential regions are less exposed to degradation. Figures 25, 26 and 27 show the distance from agricultural regions for the years 1985, 2001, and 2014, respectively.
Figure 25. Distance from Residential regions for 1985

Figure 26. Distance from Residential regions for 2001

Figure 27. Distance from residential regions for 2014
2.4.6 Height

Another parameter affecting vegetation quality is the height of the region. Rangelands situated at higher levels from sea surface, due to receiving more rain, are of greater vegetation quality and less exposed to degradation. C6 represents this criterion. Figure 28 shows the height of the region.

![Figure 28. Height information of the region](image)

2.4.7 Slope

Another parameter affecting vegetation quality is slope (C7) of the region as it influences accessibility for human activities. Steeper regions are less accessible to humans and thus less exposed to degradation. Figure 29 shows the slope map of the region.

![Figure 29. Slope of the region](image)
2.4.8 Distance from Wells

Wells as well as aqueducts are parameters that always attract humans. That is why developed agricultural regions and overgrazing of livestock and etc. are commonly seen in these regions. Thus, closeness to wells (C8) can serve as another factor causing vegetation degradation. Figures 30, 31 and 32 show the distance from wells for the years 1985, 2001, and 2014, respectively.

![Figure 30. Distance from Wells for 1985](image1)

![Figure 31. Distance from Wells for 2001](image2)

![Figure 32. Distance from wells for 2014](image3)
2.4.9 Soil Erosion

The type of stones and soil of the region is another parameter affecting vegetation degradation. The type of stones and soil of the region was identified and the soil erosion map of the region was mapped accordingly (Figure 33).

![Figure 33. Slope of the region](image)

2.4.10 Climatic Conditions

The assessment of the climate of a region requires a combinational assessment of several components such as rainfall, temperature and evaporation. These components are directly related determining climate factors such as latitude, height, distance from sea and etc. which create varied and specific climate in the long run. Due to inaccessibility to all information on Iraq and lack of registered data in some weather stations of this country, the De Martonne method was employed for climate classification, Equation 2. Rainfall and temperature are the only data elements required for this method.

\[
I = \frac{P}{(T+10)} \quad \text{Eq. 2}
\]

Where, \(I\) is the dryness coefficient, \(P\) is the annual rainfall average in millimeter, and \(T\) is the annual temperature average in degrees Celsius. The dryness coefficient is calculated using annual rainfall and temperature information. Figures 34 and 35 show the climate type classification of the region for 2001 and 2014. It is noteworthy that the climate type of 2001 was considered for 1985 as no information was available on that year.
The current condition of vegetation is another important and effective parameter in land degradation modeling. Normalized Difference Vegetation Index (NDVI) was utilized in this study to identify the current condition of the vegetation, Equation 3.

\[ NDVI = \frac{(NIR - RED)}{(NIR + RED)} \]  
Eq. (3)

Where, NIR is the fourth band of Landsat images and RED is the third. Figures 36, 37 and 38 show the calculated NDVI's for 1985, 2001 and 2014, respectively.
2.5 Combination of Criteria by WOIM

As mentioned before, WOIM was used in this study to model and predict the vegetation degradation level. Thus, weighted combination of criteria by this method yields an output value for the pixel in question. This pixel predicts the vegetation degradation level. Data pertaining to 1985 was utilized for modeling, and 2001 data was used for comparison of calculated values with the real data. Figure 39 shows the predicted vegetation degradation level for 2001 using 1985 data. Figure 40 shows the real degradation for the years 1985 to 2001. Vegetation degradation was predicted with an error average of 0.112 and accuracy of 0.888. This value is obtained through comparison of degradation level yielded by modeling with the real degradation level.
To assess the proposed model, data pertaining to 2001 was used to predict vegetation degradation for 2014 (Figure 41). The results were achieved with an error average of 0.127 and accuracy of 0.873. Figure 42 shows the degradation map obtained from images for 2001 and 2014.

![Figure 41. Predicted vegetation degradation level for 2001 and 2014](image1)
![Figure 42. Real vegetation degradation level for 2001 and 2014](image2)

Although, modeling was conducted using data pertaining to 1985 and 2001, information from other time periods were needed for the modeling. This issue was resolved by using data from 2001 and 2014. The accuracy of 0.873 indicates the great potential and efficiency of the model.

Considering the proposed model is of great certainty rate, vegetation degradation level for 2027 was predicted using data belonging to the year 2001. The result of the modeling is shown in Figure 43.

![Figure 43. Predicted vegetation degradation level for the year 2027](image3)

**3. DISCUSSION AND CONCLUSION**

Modelling of land degradation with an emphasis on vegetation degradation was implemented in this study using affective criteria, expert opinion, WOIM and GIS. The under study region was located in Nineveh Province, Iraq, which is situated in one of the most active sources of dust storms. The model was first implemented and the results were then analyzed. The data pertaining to years 2001 and 2014 were used for assessment of model. The vegetation degradation of 2027 was ultimately predicted. The obtained results indicated the accuracy and precision of the model for prediction of vegetation degradation. As per the obtained results (Figure 44& Table 2), the
years 2001 and 2014 witnesses the largest area experiencing reduced NDVI. The area of decreased NDVI for this range is 11732.72 km². This range includes 3828.5 km² of decreased NDVI less than 0.1, 3213.59 km² of decreased NDVI between 0.1 and 0.2, 1889.31 km² of decreased NDVI between 0.2 and 0.3, 1569.72 km² of decreased NDVI between 0.3 and 0.4, 1231.6 km² of decreased NDVI above 0.4. For the time period 1985 to 2001, an area of 8904.66 km² was affected. This area included 4623.65 km² of decreased NDVI less than 0.1, 2345.44 km² of decreased NDVI between 0.1 and 0.2, 810.87 km² of decreased NDVI between 0.2 and 0.3, 933.19 km² of decreased NDVI between 0.3 and 0.4, 191.51 km² of decreased NDVI above 0.4. Also, as per predictions made, for the time period 2014 to 2027, a total area of 11575.28 km² will be affected. This area includes 5471.78 km² of decreased NDVI less than 0.1, 3029.1 km² of decreased NDVI between 0.1 and 0.2, 1441.7 km² of decreased NDVI between 0.2 and 0.3, 945.6 km² of decreased NDVI between 0.3 and 0.4, 6871 km² of decreased NDVI above 0.4.

Additionally, the average NDVI decrease rate indicates a critical condition of land degradation in the region. That is because according to the obtained results, the average NDVI decrease is 0.136 for the time period 1985 to 2001, while this average increases to 0.197 for the time period 2001 to 2014. If this trend continues, the average will be 0.152 for the time period 2014 to 2027. As a result, vegetation degradation and their transformation from vegetated lands to arid lands leads to the desertification phenomenon, which is the most severe type of land degradation, causes vegetation degradation, reduction in its density, land dryness, increased temperature along with strong winds in the region that will ultimately pave the way for further and more harsh dust storms.

**Table 2.** The altered areas for NDVI values in different time periods

| The Decrease of NDVI | 1985-2001 (km²) | 2001-2014 (km²) | 2014-2027 (km²) |
|----------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| <0.1                 | 4623.65        | 3828.5         | 5471.78        |
| 0.1-0.2              | 2345.44        | 3213.59        | 3029.1         |
| 0.2-0.3              | 810.87         | 1889.31        | 1441.7         |
| 0.3-0.4              | 933.19         | 1569.72        | 945.6          |
| >0.4                 | 191.51         | 1231.6         | 687.1          |
| **Total Area of NDVI Degradation** | **8904.66** | **11731.72** | **11575.28** |
| **The Average of NDVI Degradation** | 0.136 | 0.197 | 0.152 |
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