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Environmental risk assessment of the Seyhan watershed using spatial modelling

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Abstract:
The major objective of this research wasto model the current spatial distribution of: i) Net Primary Productivity (NPP); ii) Erosion; and iii) Forest fire risk to assess and understand the environmental risk pattern. These outputs were incorporated and evaluated within a GIS environment using multi-criteria analysis (MCA) to derive environmental risk pattern of Seyhan Watershed.

One of the spatial models used in this study is Carnegie Ames Stanford Approach (CASA), developed by NASA and Stanford University. This model is a biogeochemical approach which designed to model annual NPP amounts to predict carbon budgets at regional scale using satellite images and climate data including, air temperature, precipitation and solar radiation. Also, aFire Risk Model is used to derive regional forest fire risk in GIS environment. This model utilises topography-related information and climate data in MCA process. And last, the Revised Universal Soil Loss Equation (RUSLE) is used to predict soil loss potential on a statistical basis.

The current spatial distribution of climate data were generated from 48 climate stations in and around the study area using co-kriging. Environmental risk map was produced using the outputs of NPP, erosion and forest fire risk modelling with MCA and land cover data.

Keywords: *GIS, NPP, RUSLE, Fire Risk, Multi-criteria analysis.*

1. Introduction

Turkey is characterized by the contrasts between high mountain chains, vast plains, semi-arid lands and fertile lands, and transition between marine and continental climates. There is abundant experimental evidence supporting the assumption that some regions of Turkey, particularly, Mediterranean Coast will severely be affected by climate change. Presence of high gradients in characteristics makes the Eastern Mediterranean Coast of Turkey prone to extremes and relatively rapid environmental changes.

Driving ecosystem models at local, regional and global scales using Earth observation data are becoming increasingly common. Remotely sensed-data, Geographic Information Systems (GIS) and process-based simulation models have provided the capability to assess ecological change at broad spatio-temporal scales. Specifically, process-based simulations will reduce uncertainty in predicting risk pattern under different environmental scenarios, and so will provide a valuable resource for decision-makers in the development of agricultural/environmental policies. In this respect, this research has a great potential to understand the likely effects of environmental changes in a watershed scale in the Mediterranean region of Turkey.

2. Study area and data

The study area is located on the Taurus Mountain chain in the Eastern Mediterranean region of Turkey (Figure 1).

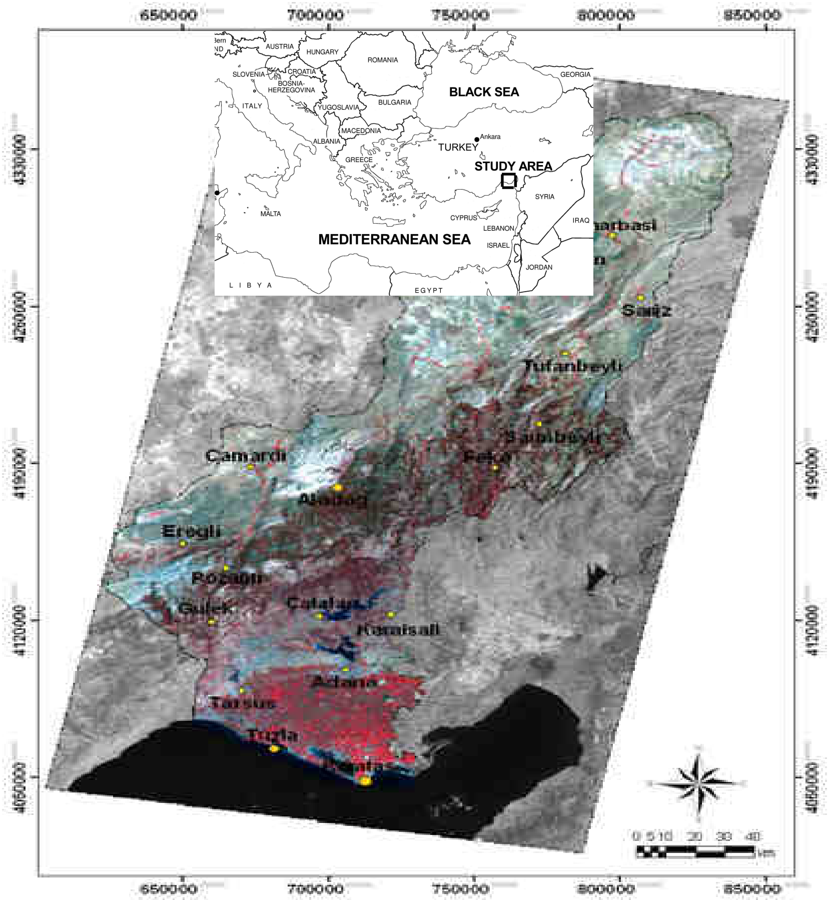

Figure 1. *Location of the study area*

The region covers an area of approximately 21.45 km^2 and comprises pure and mixed conifer forests. These forests are classified as a Mediterranean evergreen cover type and estimated to be approximately 100 years old from tree cores. Dominant tree species are Crimean pine (*Pinus nigra*), Lebanese cedar (*Cedrus libani*), Taurus fir (*Abies cilicica*), Turkish pine (*Pinus brutia*), and juniper (*Juniperus excelsa*) (Davis, 1965). The prevailing climate is

Mediterranean characterized by mild and rainy winters and hot and dry summers. The total annual rainfall is approximately 800 mm. Rainfall is variable in amount and timing in that 75% of rain falls mainly during autumn and winter. The mean annual temperature between 1990 and 2002 was 19 ^oC, with mean minimum and maximum temperatures of 8 ^oC in January and 30 ^oC in July, respectively. Dominant soils of the forest stands are classified as Lithic Xerorthent of Entisol and developed on fluvial and lacustrine materials during the Oligocene Epoch (Soil Survey Staff, 1998).

An Envisat MERIS data set comprising 47 images from March 2003 to September 2005 was selected for modelling NPP. Three sub-scenes of multi-spectral IKONOS imagery representing different types of forest cover recorded in May 2002 were used as training and testing data for percent tree estimation. Other data utilised in the analysis included 1:25,000 scale Forest maps obtained from the State Forestry Department and topographic maps and aerial photographs. Additionally, Fire records of the State Forest Department were used to assess the accuracy of the forest fire risk map.

3. Methodology

3.1. Erosion modelling

Erosion is one of the most important natural disasters that effect global and regional ecology. Estimating the spatial amount, temporal change, conditions, factors and potential effects of erosion was based on computer based technologies and mathematical equations. In this context RUSLE (Revised Universal Soil Loss Equation) methodology has been used to map erosion (Renard et al., 1997; Angima et al., 2003). RUSLE is an empirical soil erosion equation modified from the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). It not only predicts erosion rates of ungauged watersheds using knowledge of the watershed characteristics and local hydroclimatic conditions (Angima et al., 2003), but also presents the spatial heterogeneity of soil erosion. In this study, the mean annual gross soil erosion was calculated at a cell level in a GIS environment based on six factors (Equation 1) (Renard et al., 1997):

$$A = R \times K \times L \times S \times C \times P \qquad \text{(Equation 1)}$$

Where;

- A : average annual soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$);
- R : climatic factor or rainfall erosivity index ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$);
- K : soil erodibility factor ($t\ ha\ hMJ^{-1}\ ha^{-1}\ mm^{-1}$);
- L : topographic factor of slope length;
- S : topographic factor of slope steepness;
- C : crop/vegetation cover and management factor;
- P : conservation or support practice factor.

Slope length and slope steepness factors were calculated using DEM (Digital Elevation Model). Crop/vegetation cover and management factor was generated from average NDVI values of Landsat TM/ETM data set of study area. These factors were derived and integrated in a GIS environment and the output was predicted annual erosion amount per hectare as ton.

3.2. Modelling net primary production

Terrestrial ecosystems are dynamic components of the global carbon cycle. The global cycle of carbon is dependent on the production of plants in terrestrial ecosystems. The production of the plants is the creation of new organic matter by using photosynthesis products. Through the process of photosynthesis, plants assimilate carbon in atmosphere and incorporate it into dry matter, while part of carbon is emitted into atmosphere again. The remainder of photosynthesis and respiration is called net primary production (NPP), which is important in the global carbon budget. NPP is the net amount of carbon captured by land plants through photosynthesis during a certain time period (Haberl et al., 2007). NPP is a fundamental ecological variable because it measures the energy input to the biosphere and terrestrial carbon dioxide assimilation. Additionally, it is an important component of the carbon cycle and a key indicator of ecosystem performance (Lobell et al., 2002).

In this study, CASA model was used to predict annual regional fluxes in terrestrial net primary production at variable degrees of C, depending on the monthly conditions, with terrestrial net production. Calculation of annual terrestrial NPP is based on the concept of light-use efficiency, modified by temperature, rainfall values and solar radiation scalars.

NPP was estimated by the CASA model as a function of the driving energy for photosynthesis, the absorbed photosynthetically active (400 to 700 nm) solar radiation (APAR), and average light utilization efficiency (ε). The equation used to derive NPP is (Berberoglu and Dönmez, 2007):

$$NPP = APAR \times \varepsilon$$

The monthly NPP flux, defined as net fixation of CO_2 by vegetation, is computed in CASA on the basis of light-use efficiency (Monteith, 1972). The fundamental relation in the CASA model is (Equation 2):

$$NPP=f(NDVI) \times PAR \times \varepsilon \times g(T) \times h(W) \qquad \text{(Equation 2)}$$

where APAR (in megajoules per square meter per month) is a function of NDVI and downwelling photosynthetically active solar radiation (PAR) and ε (in grams of C per megajoule) is a function of the maximum achievable light utilization efficiency ε adjusted by functions that account for effects of temperature g(T) and water h(W) stress (Potter et al., 1993).

Climate data, percentage of tree cover, land cover map of the region, soil texture and NDVI (normalized difference vegetation index) were the inputs to CASA model.

Climate data

The climate data used in this study included monthly precipitation, air temperature and solar radiation. These datasets were generated based on 31 years (1975-2006) records from 48 climate stations in and around the Seyhan Basin. Co-kriging method was implemented together with digital elevation data to map climate variables on a monthly basis. The output was 300 m spatial resolution and accuracy was tested by absolute difference analysis with comparison to the original station values.

Land cover data

The CASA model utilises a large and detailed land cover database. Land cover map was derived from four data sources: Landsat TM image dated 17 August 2003, topographic maps, State Hydraulic Works (DSI) land cover records and ground data from field surveys. The Landsat ETM image was geometrically corrected and geocoded to the Universal Transverse Mercator (UTM) coordinate system by using 1:25,000 scale topographic maps.

Image classification was carried out using maximum likelihood algorithm with supervised training. Land cover map was generated from a selection of sample training pixels for each class provided from ground data. The output comprised 27 land cover classes with 30 m spatial resolution initially. The land cover classes were generalized to 7 classes as defined by CASA model data input scheme. These data were then rasterised to 300 m cell size.

Soil texture

The soil texture information was also needed to predict NPP with CASA model (Potter et al., 1998). This information is based on FAO soil texture classification, which has 7 classes. The dominant soil type in a soil unit, the designation "coarse", "medium", "fine", or a combination of these are based on the relative amounts of clay, silt, and sand. The regional soil maps in 1:25.000 scale was utilized for this study and soil texture classes were assigned on the basis of estimated clay content according to FAO.

NDVI

NDVI images were used in a monthly scale within the CASA model. These images were derived from 47 Envisat MERIS images recorded in between March 2003 and September 2005. The monthly composites were created using MERIS standard waveband setting. NDVI images were derived within the range of 0 and 1 using wavebands of 10 and 6.

Percent tree cover map

One of the most important input was percent tree cover for the CASA model. In this study, regression tree technique (RT) was used to derive percent tree cover map. This technique is well suited for percentage tree cover mapping because, as a non-parametric classifier, it requires no prior assumptions about the distribution of the training data (Hansen et al., 2003). The RT method consisted of five steps, i) generating reference percentage tree cover data, ii) deriving metrics from Envisat MERIS data, iii) selecting predictor variables, iv) creating RT model and undertaking accuracy assessment, v) producing final model and map.

i) Modelling percent tree cover relies on the quality of training and testing data. Digital multispectral IKONOS images with a spatial resolution of 4 m were used to derive reference percentage tree cover data needed to train the model. Three sub-scenes of IKONOS images representing different forest cover types were classified and recorded to tree and non-tree pixels at a 4 m spatial resolution. This data set covered an area of 120 km^2. The classification results were then converted to estimate percentage tree cover at the MERIS spatial resolution. The coverage of this IKONOS data set was equal to 1232 Envisat MERIS pixels.

ii) Four vegetation biophysical variables including: normalised difference vegetation index (NDVI), leaf area index (LAI), fraction of photosynthetically active radiation (fPAR), fCover and MERIS terrestrial chlorophyll index (MTCI) were derived in addition to 15 spectral bands of Envisat MERIS data in the 390 nm to 1040 nm spectral range. LAI, fPAR and fCOVER were derived using the Top of Canopy Land Products (TOA_VEG version 3) algorithm developed by Weiss et al. (2006).

iii) Predictor variable selection involved feature selection for the most relevant input variables for the percent tree cover modelling. The Stepwise Linear Regression (SLR) method was used to select predictor variables. In this respect, the best subset of predictor variables were selected to be employed in regression tree modelling using a stepwise procedure which repeatedly alters the model at the previous step by adding or removing predictor variables.

iv) The IKONOS data set was split into two subsets; training (1023 pixels) and testing (209 pixels). The four models were fitted using the most relevant input variables selected using the SLR method and the available training with the reference data derived from IKONOS images, relationships between tree cover density and Envisat MERIS spectral values were modelled using RT technique. The accuracy of the final model was obtained through validation using testing data. Model performance was measured using the correlation coefficient (r) between the predicted and actual tree cover values for the set aside test samples, r can be considered a measure of the precision of prediction.

v) Final output consisted of spatially distributed estimates of percentage tree cover at 300 m spatial resolution and error estimates obtained through validation (Figure 2).

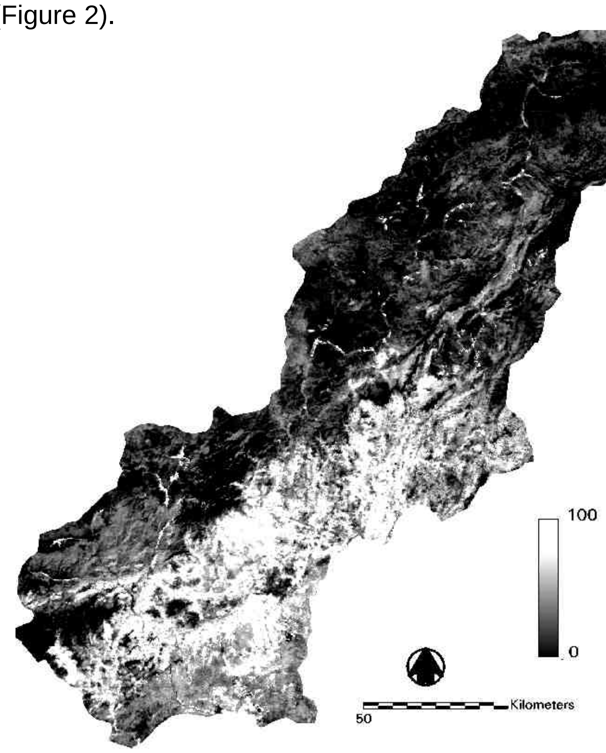

Figure 2. *Percentage tree cover map derived from the RT model.*

3.3. Mapping forest fire risk

DEM, NDVI, slope, aspect, percent tree cover, human population and meteorological data including wind, moisture, air temperature and precipitation were used to produce forest fire risk map on a watershed scale. Impact factors on forest fire risk were defined for each variable and scaled into a standard range within a GIS environment. These impact factors were weighted and used in Multi-Criteria Analysis to derive the final forest fire risk map.

The accuracy of the forest fire risk map was tested using 10 years of forest fire records obtained from local headquarter of Ministry of Forestry.

4. Mapping spatial distribution of ecological risk

Ecological risk potential of Seyhan Watershed was predicted and mapped using NPP, erosion and forest fire risk maps together with GIS analysis. The ecological risk potential was evaluated and predicted using MCA. The input variables were weighted according to risk impact potentials and integrated to the MCA process. The above mentioned input variables were multiplied and the total coefficient of the risk was divided to the impact factors to create the risk map. The resulted risk pattern was predicted with the equation (3):

$$Ai = (wi * xw) + (ei * xe) / te \qquad \text{(Equation 3)}$$

where, A_i : resulted risk value, w_i; impact variable, x_i; impact variable, x; impact coefficient, t_e= total impact coefficient.

5. Results and discussion

Ecological risk potential of Seyhan Watershed was predicted using NPP, erosion and forest fire risk maps within a MCA process. The erosion map resulted from RUSLE equation was given amount of eroded soil in ton/ha year (Figure 3). The erosion amount of the Seyhan Watershed was ranged between 0 and 2971 t ha yr^{-1}. Additionally the average erosion amount was predicted as 21.79 t ha yr^{-1} with a standard deviation of 49.25. The total amount of the erosion was predicted as 40.971.983 ton per year.

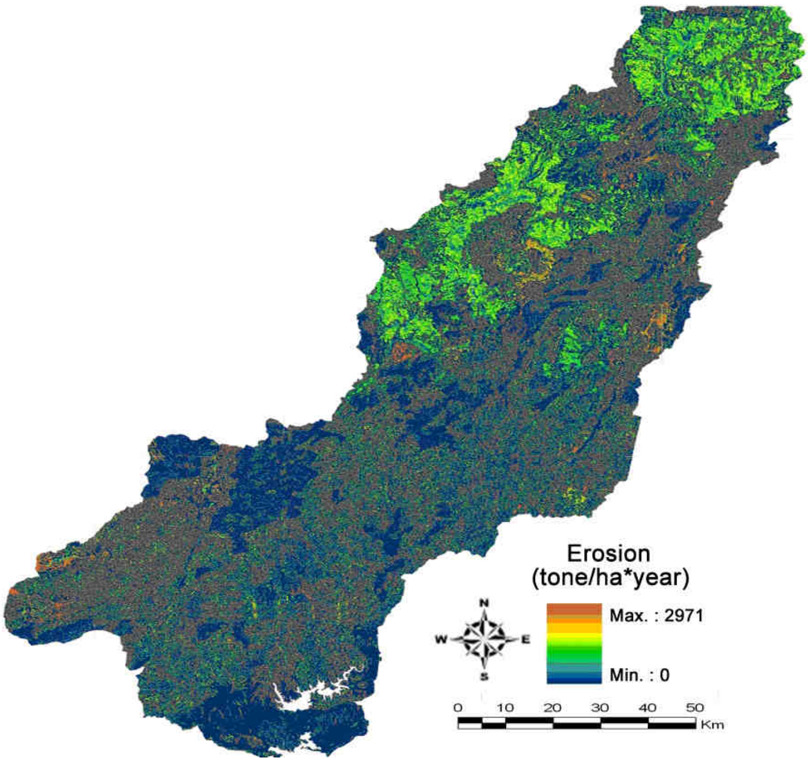

Figure 3. *Erosion map of Seyhan watershed.*

The output of the NPP model was monthly NPP maps. The total NPP was derived using monthly data and differed significantly by regions and ranged from 0 to 996 gC m^{-2} yr^{-1} at the watershed (Figure 4). NPP map shows that Envisat MERIS data may capture the heterogeneity of Mediterranean land cover for estimating NPP. Using the CASA model, we obtained an annual Seyhan watershed regional mean NPP of 328.85 gC m^{-2} yr^{-1}. There are large areas of low productivity (e.g., Northern site of the watershed) and smaller areas of high productivity. In general, estimated NPP rates were related to solar radiation and annual growing degree days as these variables relate to the availability of water and energy. Seasonal variations in NPP corresponded closely with solar radiation and NDVI. These results indicate that solar radiation and precipitation during the growing season are likely major drivers of dynamic changes in terrestrial NPP at the Mediterranean environment.

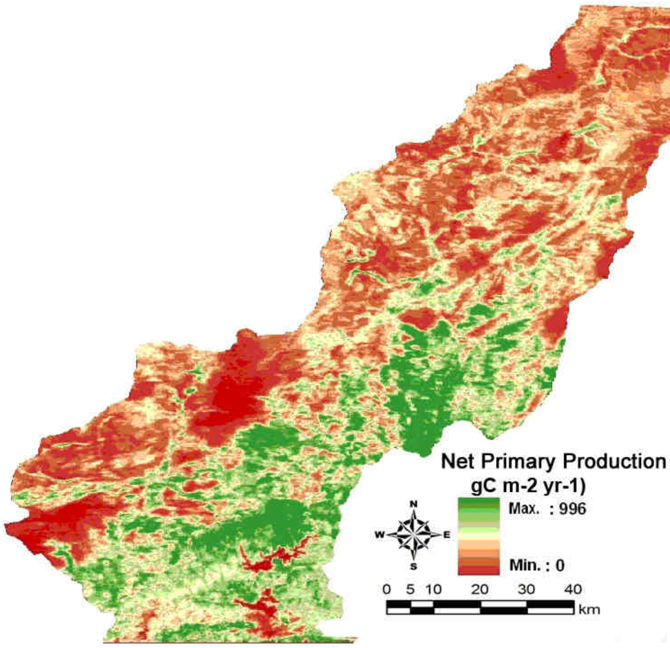

Figure 4. *NPP map of Seyhan watershed.*

Another input map for ecological risk potential was the forest fire risk map for the study area (Figure 5).

It was clearly seen that Southeastern part of the region where, especially, mixed forest stands took place have the highest forest fire risks. Whereas, Northern and Western parts that covered largely by agriculture and grassland are classified as low level of fire risk.

From the proximity point of view, distance to road and settlements have an effect on the fire risk, as the distance of forest stands decreases to the road system, forest fire risk increases together with population within the settlements.

Percent tree cover was another major driving source on the fire spread, the speed of fire spread would increase with the forest cover, and thus sparsely covered areas have a low risk of fire.

The major objectives of this research was to model the current spatial distribution of: i) Net Primary Productivity (NPP); ii) Erosion; and iii) Forest fire risk, and mapping the ecological risk pattern in a watershed scale. These outputs were incorporated and evaluated within a GIS environment using multi-criteria analysis to derive environmental risk pattern of Seyhan Watershed (Figure 6).

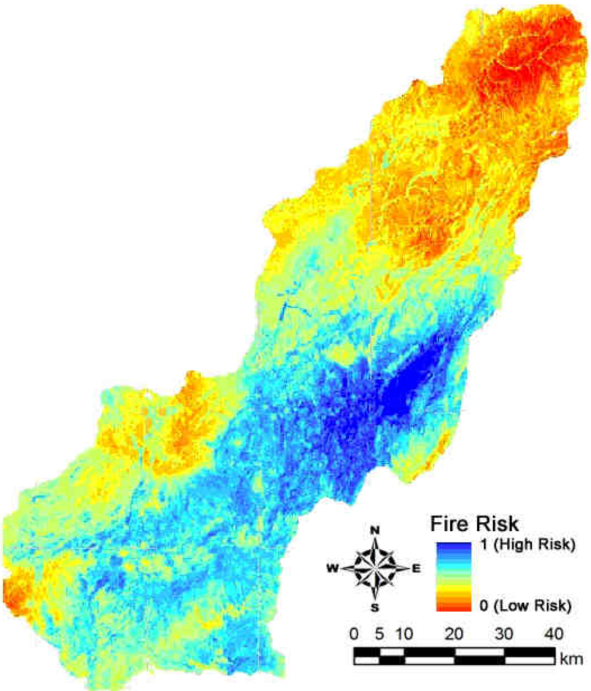

Figure 5. *Forest fire risk map of Seyhan watershed.*

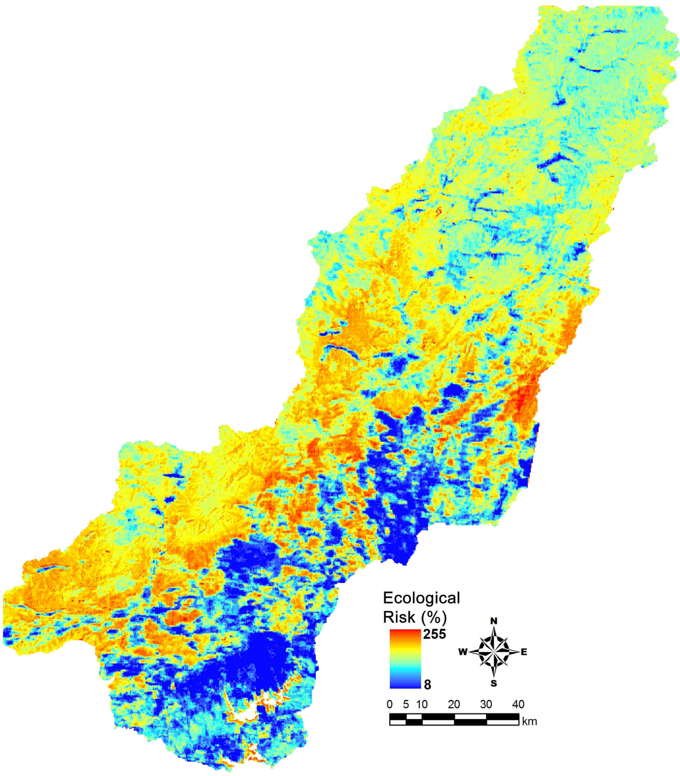

Figure 6. *Ecological risk map of Seyhan watershed*

The scale of risk map of Seyhan Watershed ranged in between 8 and 255. The final risk map was indicated that dense forest areas with a high NPP have the lowest ecological risk. The Northern parts of the area, where there are mostly grasslands and bare grounds, have a higher risk compared to the dense forest areas.

This study emphasized that spatial information technology including, Remotely sensed-data, Geographic Information Systems (GIS) and process-based simulation models were enabled the assessment of ecological change at broad spatio-temporal scales. Additionally, the specific outcomes are listed below:

- This research has the potential to understand the spatial distribution of environmental variables and their interaction within a Mediterranean type watershed.

- Process-based simulations reduces uncertainty in predicting risk pattern under different scenarios and provides a valuable resource for decision-makers in the development of agricultural/environmental policies.

- As the slope, aspect, wind direction, temperature, NDVI, population and percent tree cover increase the magnitude of fire risk also increases. Whereas, moisture, precipitation, DEM, distance to settlements and roads are negatively associated with the fire risks.

- One of the major input of this analysis is NPP derived from Envisat MERIS data. The results indicates that Envisat MERIS data has a great potential for ecological modelling studies in a watershed scale.

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Seyhan havzasında konumsal modelleme ile çevresel risk analizi

Bu araştırma konumsal bilgi teknolojilerini kullanarak Seyhan Havzasında çevresel değişkenleri değerlendirmek ve ekolojik riskleri anlamak için bilimsel bir temel sağlamayı amaçlamıştır. Araştırmanın ayrıntılı hedefleri: i) Net Birincil Üretim (NBÜ); ii) Erozyon; ve iii) Orman yangın riskini, mevcut iklim değerleri altında konumsal olarak dağılımlarını ve olası riskleri modellemektir. Bu verilerin CBS ortamında çok kriterli analiz yöntemleri kullanılarak, arazi örtüsü/kullanımı bazında ilişkilendirilmesiyle Seyhan Havzası için çevresel risk paterni oluşturulmuştur.

Bu araştırmada kullanılacak konumsal modeller: i) CASA yaklaşımı ile NBÜ tahmini: NASA ve Stanford Üniversitesi tarafından geliştirilen Carnegie, Ames, Stanford Yaklaşımı (NASA-CASA) uydu verisi ve meteorolojik verileri kullanarak yıllık bölgesel NBÜ tahmini için karbon döngüsü simülasyonu için tasarlanmış karasal biyokimyasal bir yaklaşımdır. Bu model sıcaklık, yağış ve güneşlenme süresi etkisi altında ışık kullanım etkinliğini ve uydu verilerini kullanmayı temel almaktadır; ii) Yangın risk modeli: Topografya ve iklim verisi gibi konumsal bilgilerin çoklu-kriter analizleri ile değerlendirilmesiyle üretilmiştir; ve iii) Erozyon modellemesi: Revised Universal Soil Loss Equation (RUSLE) toprak kaybını hesaplama amacıyla geliştirilmiş ve yeterince test edilmiş bir istatistiksel modeldir. Bu model basit ve etkin yapısıyla dünya genelinde kabul görmüştür.

Çalışmada, Seyhan Havzası vejetasyonu için ekosistem verimlilik modellemesinde kullanılan; Yaprak Alan İndeksi, Normalleştirilmiş Vejetasyon Fark İndeksi, MERIS karasal klorofil indeksi, ağaç kapalılık yüzdesi ve arazi örtüsü haritası oluşturmak için tam çözünürlü (300 m) Envisat MERIS verisi kullanılmıştır. Envisat MERIS verisi havza ölçeğinde değişkenliği tespit etmede yersel ve yansıma çözünürlüğünün uygunluğu ve çevresel modelleme için yüksek potansiyeli nedeniyle tercih edilmiştir.

Güncel iklim verilerinin dağılımı, Seyhan Havzasının içinde ve çevresinde yer alan 55 iklim istasyonuna ait noktasal veriler ile co-kriging yöntemi kullanılarak üretilmiştir.

Çalışma sonucunda NBÜ, erozyon ve orman yangın risk modellemesi çıktıları CBS ortamında Seyhan Havzası arazi örtüsü/kullanımı haritası ile çoklu-kriter analizi yoluyla ilişkilendirilerek çevresel risk haritası oluşturulmuştur. Bu değerlendirme arazi örtüsü/kullanımı yardımıyla farklı düzeydeki risklerin farklı arazi örtüsü/kullanımlarına olan etkilerini ayırt etme şansı vermektedir.