Turk J Agric For
33 (2009) 305-314
© TÜBİTAK
doi:10.3906/tar-0810-21

Research Article

The use of aridity index to assess implications of climatic change for land cover in Turkey

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Received: 10.10.2008

Abstract: This study was carried out to determine the impacts of climate change on aridity and land cover in Turkey. Data for future (2070s) climate change, according to present conditions (1990s), were estimated from the prediction results of a regional climate model (RCM). The RCM, which was developed in Japan, is based on the MRI model. The potential impacts of climate change were estimated according to the A2 scenario of Special Report on Emissions Scenarios (SRES). Aridity index, the ratio of precipitation to potential evapotranspiration, was computed by using measured data for the present condition and estimated data by the RCM for the future years. Changes in aridity were evaluated by comparing the current and future index values. Aridity variables were interpolated to determine the spatial distribution by means of geostatistical methods. Land cover was modelled and mapped by using the present and future aridity index data.

In the southern regions of Turkey, especially along Mediterranean coasts, projected precipitation for 2070s will be 29.6% less than the present. On the contrary, an increase (by 22.0%) in precipitation was projected along the coast of Black Sea. The model predicted that the temperature might increase by 2.8-5.5 °C in the different regions of the country. This increase in temperature could result in higher evaporative demand of the atmosphere in the future (on the average 18.4 and 22.2% in the Mediterranean and Black Sea coastal regions, respectively and 17.8% in the whole country). Thus, an increase in aridity was foreseen for the whole Turkey except the north-eastern part.

A conversion of deciduous broadleaf forest to evergreen needle-leaf forest is predicted in the northern coastal areas when we compare the future land cover with the present situation. The mixed forest vegetation could spread in the interior parts of East Anatolia and the north-western part of the country in the future.

Key words: Aridity, climate change, land cover, monitoring, Turkey

İklim değişikliğine bağlı olarak Türkiye'deki bitki örtüsünün belirlenmesinde kuraklık indeksinin kullanımı

Özet: Bu çalışma, iklim değişikliğinin Türkiye' de kuraklık ve bitki örtüsü üzerine etkisini belirlemek amacıyla yapılmıştır. Mevcut duruma (1990'lı yıllara) göre gelecekteki (2070'li yılların) iklim değişikliği verileri, bölgesel bir iklim modelinin

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(RCM) tahmin sonuçlarından alınmıştır. Japonya'da geliştirilmiş olan RCM' in temeli, MRI modeline dayanmaktadır. İklim değişiminin potansiyel etkileri, salınım senaryoları özel raporunun (SRES) A2 senaryosuna göre tahmin edilmiştir. Yağışın potansiyel evapotranspirasyona oranı olan kuraklık indeksi, günümüz koşulları için ölçülen iklim verileri ve gelecek yıllar için RCM ile kestirilen veriler kullanılarak hesaplanmıştır. Kuraklıktaki değişiklikler, bugünkü ile gelecekteki indeks değerleri karşılaştırılarak değerlendirilmiştir. Kuraklık değişkenleri, jeoistatistik metodları yardımıyla yersel dağılımı belirlemek amacıyla interpole edilmiştir. Bitki örtüsü, şimdiki ve gelecekteki kuraklık indeksi verileri kullanılarak modellenmiş ve haritalanmıştır

Türkiye'nin güney bölgelerinde, özellikle Akdeniz'in kıyı kesimlerinde, 2070'li yıllar için tahmin edilen yağış, şimdikinden %29.6 daha az olacaktır. Bunun aksine, Karadeniz kıyısı boyunca yağışta % 22'ye ulaşan oranlarda bir artış kestirilmektedir. Model, ülkenin farklı bölgelerinde, 2.8-5.5 °C' lik sıcaklık artışı olabileceğini tahmin etmektedir. Sıcaklıktaki bu artış, atmosferde daha yüksek bir buharlaştırma talebine yol açabilecektir (ortalama olarak Akdeniz kıyı bölgelerinde % 18.4, Karadeniz kıyı şeridinde % 22.2 ve tüm ülkede % 17.8). Böylece, Kuzey-Doğu bölgesi hariç tüm Türkiye için kuraklıkta bir artış öngörülmektedir.

Gelecekteki bitki örtüsü ile şimdiki durumu karşılaştırdığımızda, kuzeydeki kıyı alanlarında yaprağını döken geniş yapraklı ormanlardan herdem yeşil iğne yapraklı ormanlara dönüş olacağı tahmin edilmektedir. Karışık orman örtüsü, gelecekte ülkemizin Doğu Anadolu'nun iç kısımlarına ve ülkenin kuzey-batı kısmına yayılabilecektir.

Anahtar sözcükler: Kuraklık, iklim değişikliği, bitki örtüsü, izleme, Türkiye

Introduction

During the recent decade, the issues of climate variability and climate change have been at the centre of many scientific studies. Global climate variability and change caused by natural processes as well as anthropogenic factors are major and important environmental issues that may affect the world during the 21st century (Hulme et al., 1999; Kenny et al., 2001). Therefore, recent studies have focused on assessments of the potential impacts of climate change on natural resources.

The general circulation models (GCMs) are the best available tools for studying possible future climate (Hood et al., 2006). Based on a range of several current climate models, the mean annual global surface temperature is projected to increase by 1.4 to 5.8 °C over the period of 1990 to 2100 (IPCC, 2001) and there will be changes in the spatial and temporal patterns of precipitation (Southworth et al., 2000; Moonen et al., 2002; Mall et al., 2004). Despite of intensive research efforts, many aspects of climate changes are still uncertain, particularly at specific site scale and regional level (Zhang and Liu, 2005). Climate change is usually estimated by GCMs, however, horizontal resolution of the ordinary GCMs is quite low. Thus, there is a need to make extensive use of regional climate models (RCMs) (Kimura, 2007).

The impacts of climate change and variability on natural resources are important at local, regional and national scales as well as global scales (Alexandrov and Hoogenboom, 2000; Reilly et al., 2000). In the past decade, concerns about possible global climate change and its impacts on water and land resources and agro-ecosystems have stimulated interdisciplinary researches (Quinn et al., 2004; Yano et al., 2007). The sites which are currently at the limit with respect to available water resources in semi-arid regions are likely to be most sensitive to climate change while the humid areas may be less affected (Brumbelow and Georgakakos, 2001; Fuhrer, 2003; Vicente-Serrano et al., 2006). Arora (2002) extended the use of aridity index to assess climate change effect on annual runoff. Lioubimtseva et al. (2005) investigated impacts of climate and land-cover changes in the arid land of Central Asia. The demand and supply of water will be influenced not only by changing hydrological regimes, but also by concomitant increases in future competition for water with non-agricultural users due to the population and the economic growth (Rosenzweig et al., 2004).

Arid and semi-arid regions comprise almost 40 percent of the world's land surface. Most of the inhabitants living in the developing countries are farmers. Crop and livestock production often is limited in these regions of infertile and erodible soils because of insufficient rainfall. The low and erratic precipitation pattern is the single most significant contributor for limiting crop production in semi-arid regions (Aydın, 1995), although these areas have relatively ample water supplies for agriculture in presently prevailing climatic conditions (Rosenzweig et al., 2004; Krol and Bronstert, 2007).

In most parts of Turkey, present precipitation is hardly adequate for good crop yields, and further decrease in precipitation may seriously damage agriculture and ecosystems (Kimura, 2007). In other words, any likely increase in aridity level in Turkey, as a result of future climatic change, may have serious consequences for the economy of the country. Prior knowledge of knowing possible influences of climate change on aridity may help to determine what political and managerial steps are needed to overcome consequences of decreasing crop production and socio-economic hardship that a society could face. Thus, a simulation study was carried out by an interdisciplinary team to explore impacts of climate change projected by the RCM on aridity and consequently land cover in Turkey.

Materials and methods

Study area

Turkey is situated between the Black Sea and Mediterranean Sea, linking Europe and Asia. The climate varies from arid to very humid. About 40% of Turkey's 78 million-ha landmass is semi-arid, and nearly 60% of the total semi-arid area is situated on the country's Central Plato (Aydın, 1995). There are some semi-arid areas scattered outside the central zone. The arid areas are located near the Syria and Iran borders. The temperature regime is mainly first mesothermal climate throughout most of the country. There is a small area of cold climate located in the eastern part (Avcı, 1999). The average annual temperature varies between 18-20 °C on the south coast, 14-15 °C on the west coast, and 4-18 °C in the interior areas. While the weather is hot on the Mediterranean and Aegean coasts, i.e., 27 °C or more during the two hottest months of summer -July and August-, it is much cooler on the Marmara and Black Sea coasts with the mean temperature of 22-24 °C. Most of the interior regions are subject to hot summers. However, cooler summers are noted in the north eastern parts of East Anatolian plateau. The south coast of Turkey is usually warm during winter with the mean temperature of 8-12 °C. The winters are not very severe on the north and west coasts of Turkey, i.e., and the mean temperature in January varies from 5 °C to 7 °C. The East Anatolian and interior parts of Turkey are subject to cold winters. Average temperatures over these areas are between 0 and −10 °C in the winters (DİE, 2000). Turkey is subject both to a continental type of climate characterized by rainy weather throughout the year and a subtropical climate distinguished by dry summers. Average annual rainfall for all over Turkey is 643 mm (DSİ, 1999). In Turkey, heavy rainfalls are generally observed on the slopes of mountains facing the seas. However, towards the interior areas, the rainfall gradually decreases. In general, a precipitation deficit and high air temperature limit biomass accumulation and high crop yields in the country.

Soils with different proportions of sand, silt, and clay fractions are predominantly medium-textured soils. In general, soil organic matter is low (0-2% in 70% of the soils). Most of soils are limited in their water-holding capacity except those located in some alluvial plains (Avcı, 1999).

Climate change scenario

Climate change data obtained by a regional climate model with a grid distance of 25 km (hereafter RCM) developed in Japan were used for the computation of potential evapotranspiration (ETo) and aridity level. The forcing data for the boundary condition of the RCM are given by the general circulation model developed at the Meteorological Research Institute of Japan (MRI). The control run of MRI simulates the current climate condition, while the global warming run is performed based on the A2 scenario of Special Report on Emissions Scenarios (SRES). The RCM was developed to simulate climate change on regional scale (Yukimoto et al., 2001; Kitoh et al., 2005; Sato et al., 2007). The A2 scenario describes a very heterogeneous world of high population growth, slow economic development and strong regional cultural identities. Scenario A2 has a higher rate of atmospheric CO_2 emission (Nakicenovic and Swart, 2000). Data for 1990s were provided by Turkish State Meteorological Service (DMI) and obtained through control run of the MRI/RCM. Data for 2070s were projected by the RCM model.

Aridity index and mapping

One method of depicting aridity is the ratio of annual precipitation to potential evapotranspiration (P/ETo). This ratio is defined as aridity index (AI). It was used by UNESCO (1979) as a tool of classifying arid lands (Cooke et al., 1993; Wolfe, 1997). As reported by Wolfe (1997), the classification scheme of UNESCO has various modifications including a dry sub-humid zone. In this study, however, simple classification scheme was preferred, and the units of variable used for AI computations were modified (i.e., mm/month for precipitation, mm/day for evapotranspiration) to facilitate the drawing of iso-aridity indexes map. Thus, the legend used in our maps is given below:

Hyper-arid Zone	$P / ETo < 0.9$
Arid Zone	$0.9 \leq P / ETo < 6.0$
Semi-arid Zone	$6.0 \leq P / ETo < 15.0$
Sub-humid Zone	$15.0 \leq P / ETo < 22.5$
Humid Zone	$22.5 \leq P / ETo$

The impacts of generated climate data on reference crop evapotranspiration (ETo) was simulated using the CROPWAT model (Smith, 1992; Clarke et al., 1998). Climatic data such as sunshine duration, maximum and minimum temperatures, relative humidity and wind speed were used in the Penman–Monteith equation to calculate ETo for present and the future. In order to compute AI, first, we used the mean monthly precipitation observed from weather stations and the mean daily evapotranspiration calculated from the observed climatic data. This index was computed for 155 locations based on the measured data and mapped for the country. Second, the RCM projections for the present and future were used to calculate AI. Then, changes in aridity were evaluated by comparing the future index to the current one, and the differences between future and present indexes were mapped with kriging which is a GIS based geostatistic tool that was applied for this task. Kriging interpolation, developed by Matheron (1963) and Krige (1966), is based on regionalized variable theory. The basic premise of kriging interpolation is that every unknown point can be estimated by the weighted sum of the known points. When an additional data set becomes available, cokriging is used. Cokriging is an interpolation technique that allows one to better estimate map values if the distribution of a secondary variable correlated with the primary variable is known. If the primary variable is difficult or expensive to measure, then cokriging can greatly improve interpolation estimates without necessity of intensive sampling of the primary variable. Digital Elevation Model (DEM) was used as an additional source of data for the cokriging, because it is correlated strongly with the primary variable (precipitation) of interest. The outputs from this procedure were used as input for the comparison of spatial distribution of present and future AI.

Modelling and mapping the land cover

The classification tree technique is well suited for modelling land cover because, as a non-parametric classifier, it requires no prior assumptions about the distribution of the training data. The basic concept of a decision tree is to split a complex decision into several simpler decisions, which may lead to a solution that is easier to interpret. In a decision tree approach, features of data are the predictor variables whereas the set of classes to be mapped are the target variable (Breiman et al., 1984). When the target variable is discrete (e.g., class attribute in a land cover classification), the procedure is known as the classification tree. In contrast, when the target variable is continuous, it is known as the regression tree.

The methodology for this study consisted of five steps: (i) providing reference land cover data: modelling vegetation distribution relies on the quality of training and testing data. Land cover classification map derived from time-series of the Terra Moderate Resolution Imaging Spectro-radiometer (MODIS) images by Gülbeyaz (2007) was used as reference land cover data needed to train the model (Figure 1), (ii) deriving predictor variables: five variables including DEM (Figure 2), aspect, latitude, distance to sea, present aridity index which are significantly related to land cover were used as predictor variables. Predictor variable selection is very important for the most relevant input variables for the land cover modelling, (iii) fitting classification tree model (predicting the value (category) of the target variable using a classification tree): first, the values of the predictor variables were used to move through the tree until a terminal (leaf) node is reached, then the category shown for that node is predicted. The present land cover data set was split into two subsets; training (80%) and testing (20%). The classification tree model was fitted using the relevant input variables. The relationships between land cover and five variables were modelled using the classification tree technique (Table 1), (iv) undertaking accuracy assessment: the accuracy of the final model was obtained through validation using testing data, (v) producing future vegetation map: the model was used with four variables (DEM, aspect, latitude, distance to sea) in addition to future aridity index. Final output consisted of spatially distributed estimates of land cover at 500 m spatial resolution.

Table 1. Small sample of classification tree model structure for land cover estimation.

```
Decision tree :

band02 < = 0 :
:…...band01 < = 0 :
:  :……..band04 < = 0 : 0 (1152020 / 4224)
:  :…… .band04 > 0 :
:  :       :.......band03 < = 503 :
:  :       :      :…...band03 > 8 :
:  :       :      :      :…...band04 > 18 : 0 (726 / 163)
:  :       :      :      :……band04 < = 18 :
:  :       :      :      :      :…..band03 < = 77 : 6 (138 / 12)
:  :       :      :      :      :     band03 > 77 :
:  :       :      :      :      :     :…..band03 < = 165 :
:  :       :      :      :      :     :………………………………....……..
```

Results

Temperature, precipitation and evapotranspiration

Changes of air temperature, precipitation and evapotranspiration, showing the difference between present and future, are briefly given here. A temperature rise within the range of 2.8 to 5.5 °C over different regions of Turkey is expected by 2070s based on the predictions of the RCM. There could be significant changes in both spatial and temporal patterns of precipitation. The model predicted decrease of precipitation in most parts of Turkey, particularly along the coast of the Mediterranean Sea, but increase along the coast of the Black Sea. A decrease in precipitation by 29.6% was noted over the Mediterranean region, in the southern coastal areas. However an increase of 22.0% over the northern coastal area facing Black Sea is expected. The ETo was higher (as average of 17.8% over Turkey) for the future compared to present in response to an elevated evaporative demand of the atmosphere by the 2070s.

Changes in aridity

The variogram models used for the cokriged maps of aridity are shown in Figure 3. The cokriged aridity map constructed using measured climatic data is shown in Figure 4. As can be seen on the map, the semi-arid areas mostly are situated on the Central Plato. The semi-arid areas covering outside of the central zone are small in scale, located mainly near the Syria and Iran borders under current conditions. The sub-humid areas are generally located along the coast of Mediterranean and Aegean Seas. A small sub-humid area is located in the interior parts of East

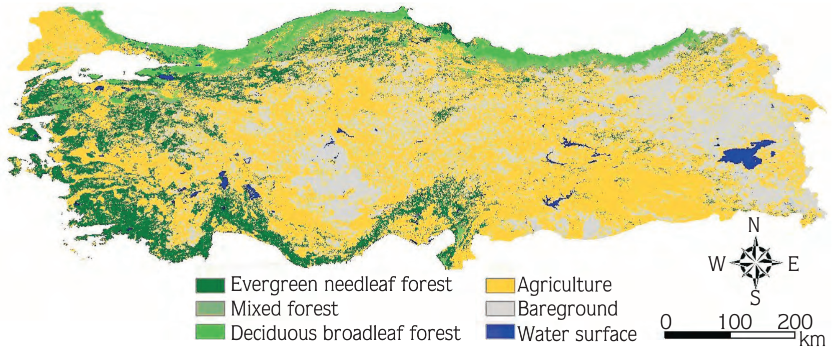

Figure 1. Land cover classification map of Turkey using the MODIS images (Gülbeyaz, 2007).

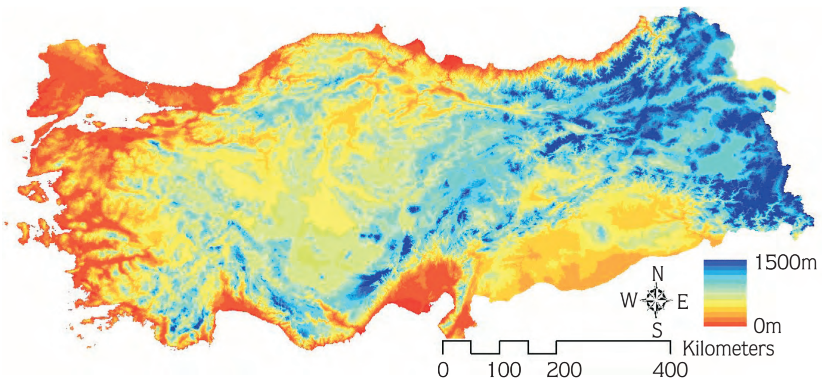

Figure 2. Digital elevation model of Turkey.

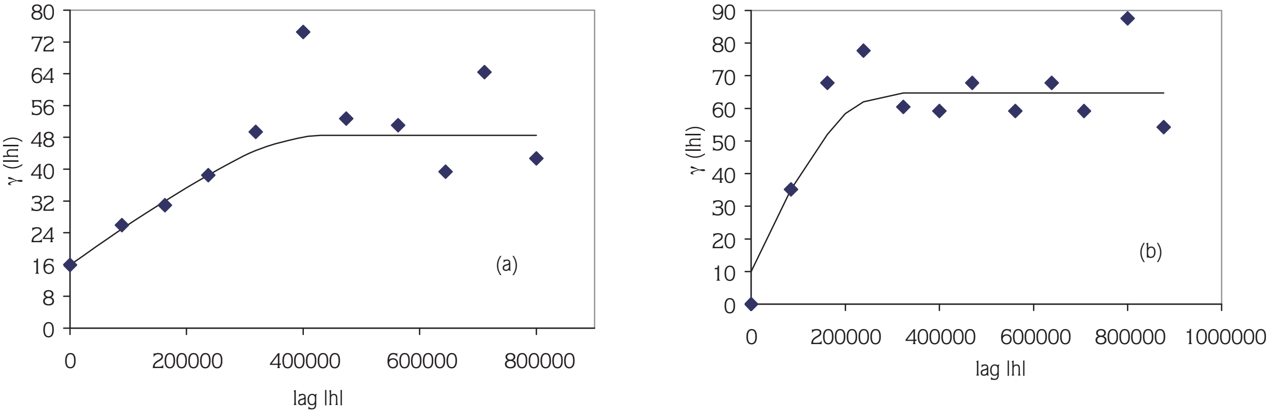

Figure 3. Variogram model of AI for the present (a) and the future (b).

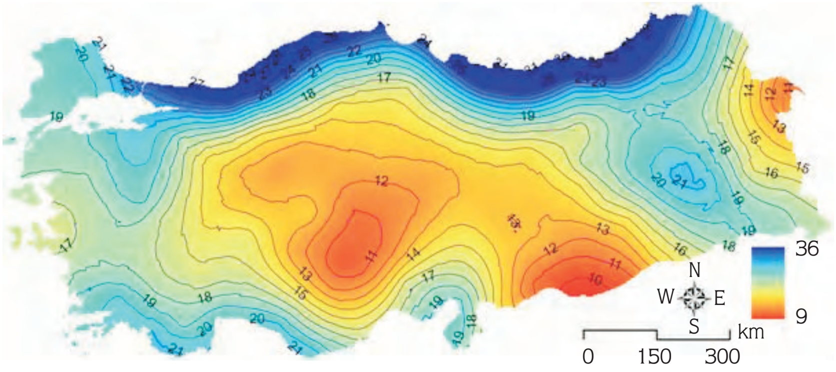

Figure 4. Aridity map of Turkey with iso-aridity indexes computed from observational climate data.

Anatolia. The humid areas are situated along the northern coastal region facing Black Sea.

Analyses of presently observed data and the RCM projections showed an increase in aridity by 2070s compared with 1990s in the southern and western coastal regions of Turkey (Figure 5). In the southern region, projected decrease in aridity index on average was 18.4%, while projected decrease in precipitation

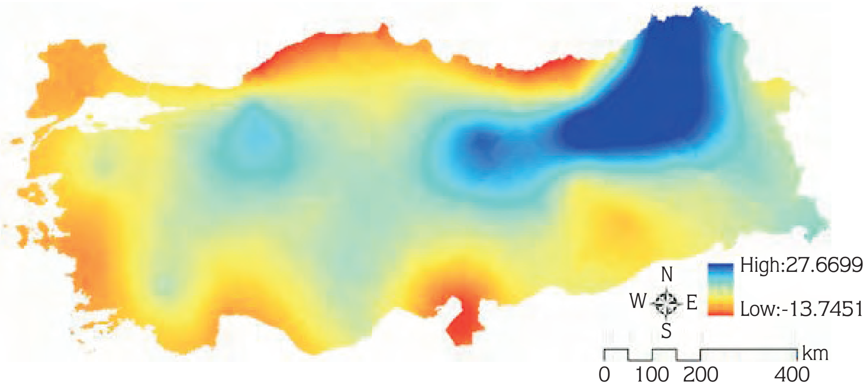

Figure 5. The map of changes in aridity indexes, computed from projected climate data, for the future (2070s) compared to present.

was 29.6%. No considerable change is projected in aridity in the south-eastern zone of the country. The results also showed a decrease in humidity on the northern coastal areas, and a north-eastward shift of the boundary of the humid areas.

Model performance was assessed using the confusion matrix between the predicted and actual land cover types for the set aside test samples. The overall accuracy of confusion matrix can be considered as a measure of precision of the prediction (Table 2).

A map of potential future vegetation in Turkey was derived using future aridity indexes and four main variables (DEM, aspect, latitude, distance to sea). Besides, it was assumed that a natural vegetation distribution would be in equilibrium with long-term climate change, without human interference and cultivated vegetation types (Figure 6). Natural forest is thus separated into three life-forms (evergreen needle-leaf, mixed forest and deciduous broadleaf) and distinguished for tree and shrub covers in terms of leaf phenology (evergreen vs. deciduous) and leaf shape (needle-leaf vs. broadleaf) in the prevailing natural vegetation of Turkey.

Discussion

An increase in temperature is projected in all around Turkey. A large decrease in precipitation was found around the southern coastal region of the

Table 2. Confusion matrix of classification tree model.

		CLASSIFIED DATA*						
		1	2	3	4	5	6	Total
REFERENCE DATA*	1	60 683	2 416	1 585	29 311	2 466	398	96 859
	2	4 080	13 410	3 857	4 350	830	39	26 566
	3	2 235	2 732	18 605	1 184	16	49	24 821
	4	23 951	3 350	1 259	244 161	38 907	1 451	313 079
	5	2 896	475	31	59 943	114 265	358	177 968
	6	649	32	59	2 740	458	7 801	11 739
	Total	94 494	22 415	25 396	341 689	156 942	10 096	651 032
					Overall Accuracy			70.5%

*(1: Evergreen needle-leaf forest; 2: Mixed forest; 3: Deciduous broadleaf forest; 4: Agriculture; 5: Bare-ground; 6: Water surface)

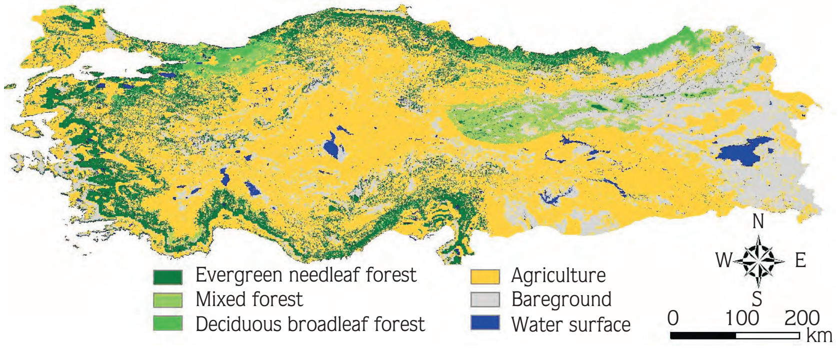

Figure 6. Predicted land cover distribution as a result of future aridity index.

country, particularly in the eastern Mediterranean. There is an increase in precipitation in the northern coastal area facing the Black Sea. Similar results for the same areas were reported by Kimura (2007) and also by Kitoh (2007). Decreasing rainfall trends in Turkey have already been observed in the 20th century (Türkeş, 1996; Türkeş, 1998).

Increases in temperature resulted in a higher evaporative demand of the atmosphere in the future. The increase trends in ETo are comparable to those found by Aydın et al. (2008), Kitoh (2007) and Yatagai (2007). Changes in the water balance and the amount of water available in the soil can be crucial for the crop yield. In grasslands, majority of the variance in primary production can be accounted for annual precipitation (Campbell et al., 1997).

In the southern region, a decrease in precipitation and aridity index, which means an increase in aridity, is expected. The increase in temperature and decrease in precipitation due to climate change could cause an increase in potential evapotranspiration and aridity with severe consequences of water scarcity especially during dry summer months. Although, the northern coastal area facing Black Sea could have higher precipitation in the future compared to present, some decrease in humidity is expected for the future in the same area. This may be attributed to higher percentage of increases in ETo (as average of 22.2%) than that in precipitation.

The index helps to characterize the degree of moistness on the basis of climatic variability but does not include the effects of soil variability, as also indicated by Badini et al. (1997). Thus, the calculated aridity indexes should be interpreted cautiously. In addition, the impacts of climate variability may be more useful for immediate decision making at inter-annual time scales (Schulze, 2000).

A conversion of deciduous broadleaf forest to evergreen needle-leaf forest is foreseen in the northern coastal areas when we compare future land cover with the present map. Mixed forest vegetation could spread in the interior part of East Anatolia and the northern west part of the country in the future. There is no a considerable land cover shift in other regions. However, recovery of vegetation from antecedent one may require 60-80 years. It may take additional 20-30 years to establish new vegetation adapted to climatic changes. Thus, about 100 years are needed to change large part of vegetative species to new ones, as reported by Tamai et al. (2007). In this regard, long-term monitoring is necessary to record changes of vegetation with climate change in the future (Sano et al., 2007). The simple method, used in this work, for predicting likely changes of land cover using aridity index, provides guidance for early assessment of climate change on vegetation.

The case work undertaken here outlines simple and successful approach to use aridity index for estimating change in land cover using climate change simulation. The simulated results showed that the future prospects of crop production in the country is at risk of aridity, and further studies with global and regional climate change projection models may help to assess with high confidence potential impacts of climate change on land cover and crop production and to identify adaptation strategies to ease off the consequences which could be faced by the society.

Acknowledgements

The research was partially supported by the Project–Impact of Climate Changes on Agricultural System in the Arid Areas (ICCAP), administered by the Research Institute for Humanity and Nature (RIHN) of Japan, and the Scientific and Technological Research Council of Turkey (TÜBİTAK).

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