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Modeling land use/land cover conversion risk

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Abstract:
Unsustainable conversions of land use and cover constitute the biggest threats to world's ecosystems, therefore, understanding the past and future changes are critical in sustainable landscape planning. This study aims to generate a risk model of land use/land cover (LULC) conversions at a watershed scale. Big Meander Basin in Aegean Region of Turkey is the case study area. There are four analytical steps in the present work; (i) detecting LULC change in the basin between 1986 and 2002, (ii) generating a risk map of LULC conversions until 2002 (iii) determining the probable LULC conversions in the future, and (iv) generating an inclusive risk map by overlaying the up to date and probable LULC conversion risk maps. The results of the classifications demonstrated an increase of Water surfaces, Maquis, Fruit Orchards, Urban areas, and Bare soil areas. Meanwhile, Croplands and Forests decreased. The most critical conversions occurred in the form of agricultural intensification on wetland ecosystems. Also, the diminishing quality in the vegetation structure is requiring attention. LULC conversion risk analysis not only displayed the areas with high change risk but also displayed the priority areas for the protection, restoration and planning. Thus, this information can be used for generating more effective land use decisions especially at the urban rural interface.

Keywords: *Risk modeling, Land use/cover change, Big Meander Basin.*

1. Introduction

Change is an inherent character of any landscape. It has social, ecological, economic and physical dimensions, all of which are interrelated. Land is a fundamental element of many human activities such as agriculture, industry, forestry, energy production, building settlements, and recreation. As an inevitable result of these activities, change in the land use and land cover occurs. Land use represents the human employment of the land, and is shaped by demographic factors, institutional environment, economic factors, ownership, norms and codes of conduct, level of affluence, and even by technology. Land cover indicates the physical and biotic character of the land surface and is is shaped by environmental factors such as soil characteristics, slope, aspect, elevation, vegetation and climate. Thus, the process of land use and land cover change is a complex phenomenon.

Studies have showed that landscapes have been going through large scale land use and land cover (LULC) changes all over the world (Meiyapan and Jain, 2012). Subsequently, a considerable part of natural ecosystems have been transformed into managed areas (Foley et al., 2005). This process has biogeophysical (Bala et al., 2007), biogeochemical (Bonan, 2008) and climatic implications, along with social and economic impacts (Wu, 2008). Sustainable planning practices involve understanding the mechanism of change and the impacts of policies. GIS provides an ideal environment to perform LULC change detection (Scott, 2001), hence becoming an indispensable tool for landscape planning. Moreover, LULC change models help us to understand the complexities in the spatial systems and provide insights into possible land use configurations in the future (Koomen et al., 2007).

Unsustainable conversions of LULC constitutes the biggest threats to world's ecosystems, therefore, studying the LULC change trends are important before the developments take over an area (Esbah, 2007). Tracking LULC conversions rather than net changes in land use and land cover facilitates better understanding of trends, and its ecological implications (Meiyapan and Jain, 2012). There exist number of models dealing with different aspects of ecological risks such as erosion (Jaiswal et al., 2002), drought (DePaw, 2005)), loss of primary production (Berberoglu et al., 2007), fire (Bonazountes, 2005; FAO, 2001), pollution (Daly and Zannetti, 2007), succession (McGarigal, 2012, Jopp et al., 2011), fragmentation, and so on. There are, however, no models exclusively taking into consideration the LULC conversion risks. Thus, the purpose of this study is to generate a risk model of land use/land cover conversions at a watershed scale. The significance of this case study comes in the form of treating the LULC conversion as one of the key indicators of ecological risks.

2. Study area

Big Meander Watershed is located in the Aegean Region of Turkey. It is one of the 25 river basins of Turkey. Its approximately 26.000 km^2 surface comprises 3,2% of the country. Starting from Dinar, Afyonkarahisar, 584 km. long Big Meander River traverses the extremely fertile valley and reaches to the Aegean Sea at the Big Meander Delta in Aydin. The basin includes lands from 10 different provinces. More specifically, three major cities of the Aegean Region, namely Aydin, Denizli and Uşak, are located in the region to account for a population of more than 2,1 million.

Big Meander Basin houses many ecologically sensitive ecosystems; hence there are 8 legally protected areas along with hundreds of natural, historical and archeological sites with special protection status. Because of the fertile soils of the Big Meander Valley, the major activity in the basin is agriculture. However, the area is rich not only in terms of agriculture but also in terms of industry and tourism. For instance, the Ministry of Tourism has announced 6 Tourism Protection and Development Zones in the basin to promote international tourism. Industrial sector is growing rapidly due to government policies prioritizing economic growth. These activities have generated migration of population from the rural areas of Aegean region and the Eastern part of Turkey. Rapid, uncontrolled and unplanned population growth in the last decade has caused rapid change in LULC, thus conversion of the land has occurred especially from natural to anthropogenic. Coupled with the impacts of global warming, this process has resulted in regional scale risks of erosion, aridity, wildfire, vegetation productivity loss, population growth and land use/cover change (Erdoğan, 2012) along with .pollution, habitat fragmentation, and loss of biodiversity (Esbah, 2009). Except for urban scale planning efforts, the landscape level comprehensive planning efforts are limited only to Aydin-Mugla-Denizli Environmental Plan. Another landscape scale planning and management attempt is The Big Meander River Watershed Protection Action Project. In order to comply with the European Union's Water Framework Directive, the Project was conducted in the early 2000's by the Ministry of Environment and TUBITAK-MAM. As an outcome of this project "the River Basin Management Plan" was generated with the main focus on pollution. Nevertheless, the LULC conversion risks in the basin are currently unknown and underestimated in the planning efforts, hence exposing the basin to even further ecological risks.

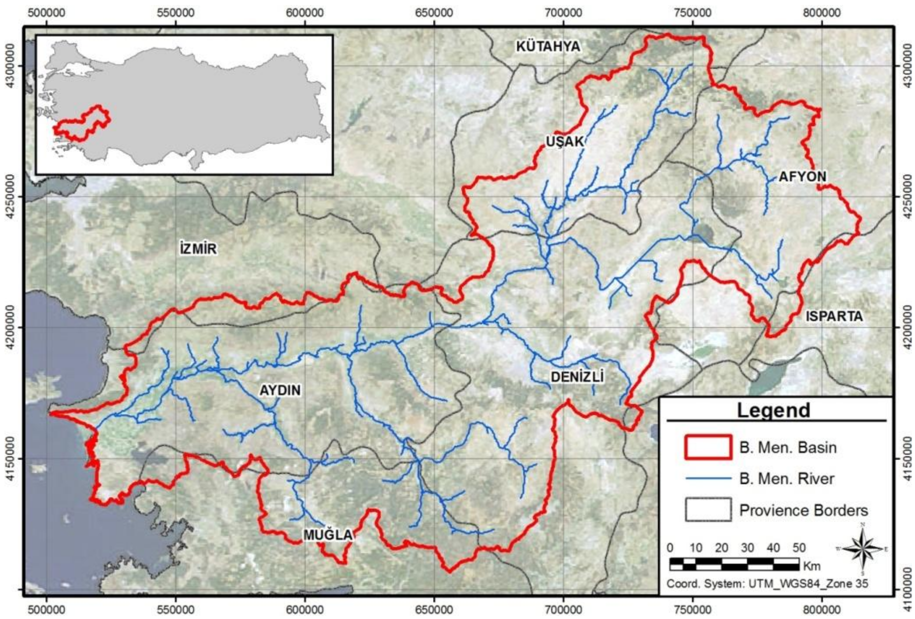

Figure 1. *Study area (Big Meander - Menderes - Basin).*

3. Material

LANDSAT TM/ETM satellite images were selected for LULC classifications of the study due to its optimal temporal and spatial resolution, large frame coverage, suitable band number and calibration, rich archive and free cost. BMB was covered by three LANDSAT TM/ETM image frames of 179/33, 179/34 and 180/34. Depending on this frames LANDSAT TM/ETM archive of GLOVIS was searched and for past and actual time the most suitable nine images reflecting three different seasonal period of a year are selected.

4. Method

The purpose of this study is to generate a model to spatially elaborate the land use/land cover conversion risks in the Big Meander Basin. There are four analytical steps in the present work; (i) detecting LULC change in the basin for a 16 year period (between 1986-2002), (ii) generating an risk map of LULC conversions until 2002 (up to date risk map) (iii) determining the probable LULC conversions, and (iv) generating an inclusive risk map by overlaying the up to date and probable LULC conversion risk maps.

***Table 1**. Selected LANDSAT TM/ETM images.*

Period		179/33	179/34	180/34
Past	1	1986/11/18	1986/11/18	1986/10/08
	2	1987/05/29	1987/05/29	1987/05/20
	3	1987/08/01	1987/08/01	1987/08/08
Actual	1	2002/02/07	2002/02/07	2003/01/16
	2	2003/05/01	2003/05/01	2003/05/08
	3	2003/08/13	2003/08/13	2003/07/19

4.1 Detecting LULC change in the basin between 1986-2002

Selected LANDSAT TM/ETM images were layer stacked and combined to single image of 18 bands (thermal bands excluded) for each past and actual time periods. Each image was classified using maximum likelihood classification method. Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed, and calculates the probability that a given pixel belongs to a specific class. Unless a probability threshold is set, all pixels are classified. Each pixel is assigned to the class that has the highest probability (Richards, 1999). The total of 8 classes is utilized for this study: Water surface and wetlands, Evergreen and deciduous forests, Maquis, Grasslands, Bare soils and rock, Olive/fruit orchards, Arable fields, and Urban/settlement areas. Both past (1986) and present (2002) classifications have reliable accuracy values of kappa 0,62 and 0,66, respectively.

4.2 Generating an up to date risk map of LULC conversions

In this step the method is two fold: (i) obtaining the rate of conversion through a cross tabulation technique, (ii) assigning weights through a multi criteria approach. Classified past and actual LULC images were used in cross-tabulation change detection analyses to produce LULC change image. Cross-tabulation (Cross Tab) analyzes the spatial distribution of different land use/cover classes and land use/cover changes. Cross tab performs two operations: 1-The image cross tabulation, in which the categories of one image are compared with those of a second image, and tabulation is kept of the number of cells in each combination. The result of this operation is a table listing the tabulation totals as well as several measures of association between the images. And 2- Cross-classification which can be described as a multiple overlay showing all combinations of the logical AND operation; the result of cross classification is a new image showing the locations of all combinations of the categories in the original images (Shalaby and Tateishi, 2007).

Once the change of each LULC class to other class is elaborated through cross tabulation change detection, each conversion types (e.g. from class A to B) was assigned a weight in terms of its implications to ecological integrity on the site (Table 2). Because the ecological consequences of each conversion vary, weighting of the conversions was necessary. An expert group of 10 people with different backgrounds (landscape architects, soil scientists, forest engineers and planners) assigned the weights. The weights ranged between 0 and 10, from no risk (0) to increasing levels of risk.

Table 2. *LULC change risk weights.*

(%)		1986-1987							
		Wetland.	Forest	Maqui	Grassln.	BareSoil	Orchard	Arable	Urban
2002-2003	Wetland.	0	0	0	0	0	0	0	0
	Forest	1	0	0	0	0	0	0	0
	Maqui	3	2	0	0	0	0	0	0
	Grassln	5	4	2	0	0	0	0	0
	Bare soil	7	6	4	2	0	0	0	0
	Orchard	9	8	6	5	2	0	0	0
	Arable	9	9	8	7	4	2	0	0
	Urban	10	10	9	9	6	5	3	0

Landscape ecology approach is pursued in assigning weights. Landscape ecology sees reciprocal relationship between landscape structure and function, thus, change occurs as an outcome of this interaction. If the structure or pattern of a landscape changes, the function or processes in that landscape also changes. Different LULC classes denote varying structure in a landscape. If the structural compatibility is high between LULC classes, there is a higher chance that ecological process continues through material and energy exchange, hence higher ecological integrity.

4.3 Determining the probable LULC conversion

In addition to the risks associated with the LULC change between 1986 and 2002, the possible LULC change in the future is also considered as a risk in the present study. The distances of each class to other classes were utilized in order to determine the probable LULC conversions in the future. In the change probability assessment, first, the Euclidian minimum distance for the pixel of one class to other classes are determined as separate images. Second, distance images of each class is standardized between the values of 0 (least probable) and 1 (the most probable) using fuzzy inverse relation technique with the “closer, the more probable” rule. And then, change probability of each pixel in an image (CP) can be calculated as a weighted average of the fuzzy distance of this pixel to all classes as follows (Equation 1).

$$CP = \frac{\sum_{i=1}^{N} r_i \times FD_i}{\sum_{i=1}^{N} r_i} \tag{1}$$

where N: number of classes ($N \geq 2$)
r_i: change risk weight for I’th class
FD_i: fuzzy distance of the pixel to its i’th class

Finally, the calculated change probability images of each LULC class are merged to create a final image of probable LULC conversion map.

4.4 Generating a final LULC conversion risk map

In order to obtain an inclusive LULC conversion risk map, the up to date and probable LULC conversion risk maps were merged in the GIS environment. The up to date conversion risk map had to be normalized before this process. The final map displays the cumulative risk of past and future LULC conversions. Moreover, the low, medium and high conversion risk levels are presented in a tabular format.

5. Results

5.1 LULC change and major conversions

Big Meander Basin has witnessed 67.82% increase in its urban and settlement areas between 1986 and 2002. The results of the LULC classifications also demonstrated an increase of Water surfaces and wetlands, Maqui areas, and Bare soil and rocky areas (Table 2). Increase in the bare soil category points out higher possibilities of erosion. Vegetation clearing is common with the anticipation of imminent urban development, or due to gaining land for cultivation. Together with the decrease of grasslands (-9.96%), this type of change may lead to loss of biodiversity. Maqui vegetation increased 12.16% within a 16 year period. Unlike maqui vegetation, evergreen and deciduous forests decreased 13.14% in the study area. This decline is most obvious in the areas the North of Nazilli in Aydın, the East of Guney in Denizli, and the Northwest of Kızıloren in Afyon (Figure 2,3).

The cross tab change detection showed that urban and settlement areas have mostly occupied the bare soil and rock surfaces (which, initially, had relatively more natural structure), followed by arable lands and grasslands. The results also indicated 13,82% decline in the amount of arable fields. This change has occurred especially in Usak and Afyon (Figure 2,3). Even though arable fields in Aydın and Denizli has expanded, the degree of the expansion is less than that of in the north eastern areas of the Big Meander Basin. The rise of the olive and fruit orchards (15.2%) is one of the most striking changes in the study area (Table 2). This change especially has taken place in Nazilli, Kuyucak, Bozdogan towns of Aydın. The growing olive oil industry continues to trigger this change.

Arable lands have been mostly transformed into grasslands (19.48%) and bare soil surfaces (18.76%). This is attributable to the abandonment of agricultural activities and lands due to migration to urban areas. The transformation of agricultural activities from crop agriculture to fruit grows are evident in the results: 6.18% of the arable lands have been converted to olive and fruit orchards. These conversions prevail mainly in Aydın (Figure 4). Meanwhile, the results have displayed agricultural expansion over

***Table 3**. Cross tabulation table of land use/cover change.*

Classes		**1986 (%)**							
		1	2	3	4	5	6	7	8
2002 (%)	1	88,82	0,11	0,11	0,24	0,14	0,30	0,10	0,10
	2	0,66	66,74	18,86	5,18	1,98	2,20	0,23	0,30
	3	0,05	20,51	45,27	8,44	11,12	8,44	0,43	0,74
	4	0,10	1,52	6,25	23,14	9,30	2,51	19,48	3,46
	5	0,88	10,20	21,28	48,99	65,50	5,96	18,76	22,15
	6	0,15	0,50	5,14	1,14	2,53	48,10	6,18	8,60
	7	9,25	0,26	2,56	9,47	7,58	29,75	52,85	15,63
	8	0,07	0,17	0,53	3,40	1,85	2,74	1,97	49,01
	Class Change	11,18	33,26	54,73	76,86	34,50	51,90	47,15	50,99
	Image Difference	13,36	-13,14	12,16	-9,96	5,60	15,02	-13,82	67,82

(1) water surfaces and wetlands, (2) evergreen and deciduous forests, (3) maquis, (4) grasslands, (5) bare soil and rocky areas, (6) olive/fruit orchards, (7) arable fields, and (8) urban/settlements areas

ecologically sensitive wetland habitats, thus 9.25% of the wetland ecosystems are converted into agricultural lands. This makes a significant change in the ecological process and environmental quality in the wetland ecosystems.

Even though the net changes in the LULC indicates improvement in the amount of the maqui cover, LULC conversion information yield more realistic insights with regards to the fate of the LULC change. Total of 54.73% of the maqui cover was converted into different LULC classes. The most major transformation was to the bare soil class: together with the transformation to

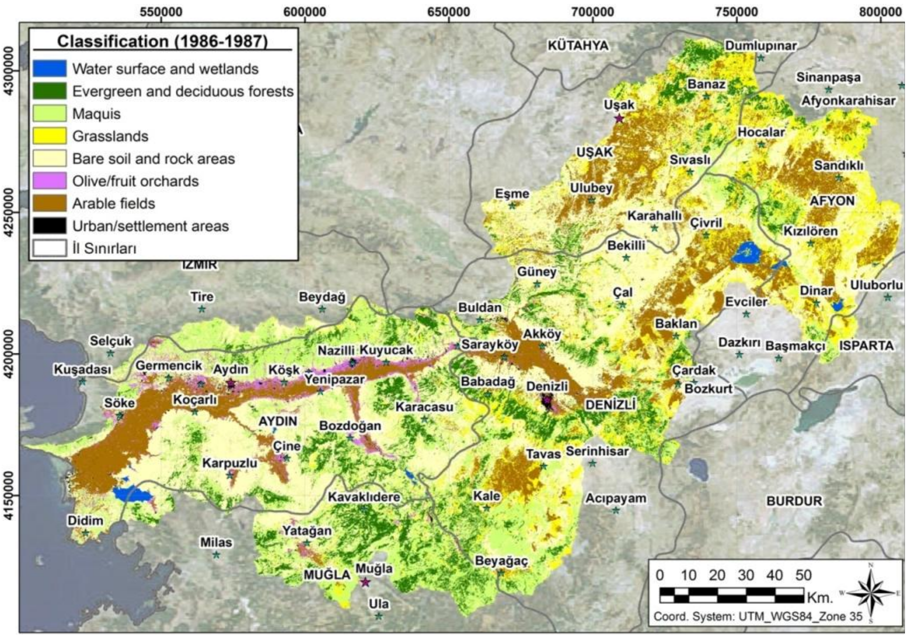

Figure 2. *Land use/cover of past (1986-1987).*

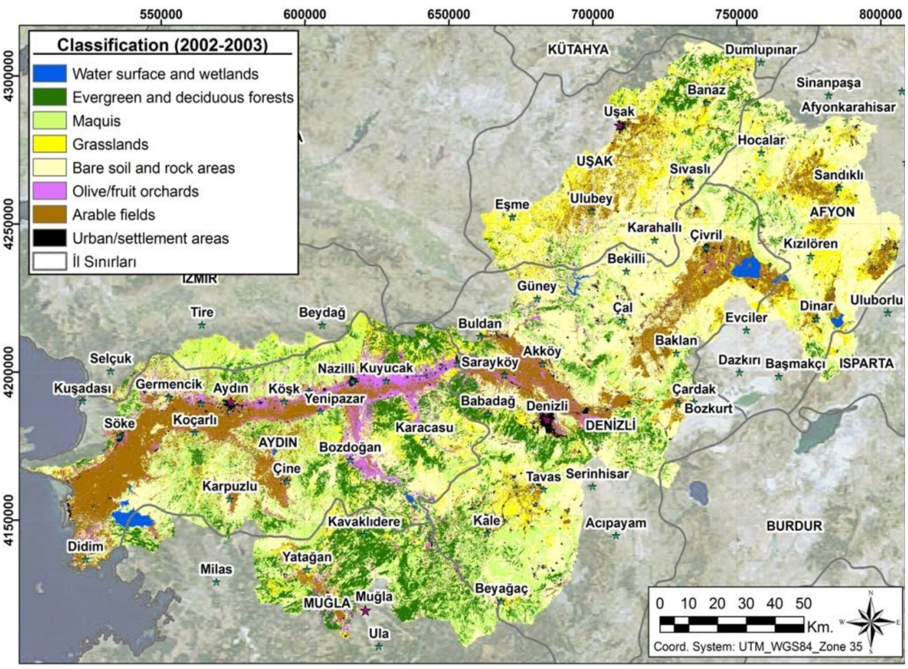

Figure 3. *Land use/cover of actual (2002-2003).*

the grasslands, 27.53% of the maqui cover was converted into significantly poor vegetation structure. The areas mostly affected by this trend are towns of Beyağaç and Kale in Denizli, the north of Kosk and Nazilli, Didim Peninsula, and the south slopes of Dilek Peninsula National Park in Aydın (Figure 4). The main drivers of these changes can be listed as climate change, antropogenic land clearing and fragmentation, and fires, respectively. Decline in the vegetation diversity and structure is even more problematic due to the fact that 20.51% of the evergreen and deciduous forests and 48.99% of the grasslands are transformed into structurally less complex maqui and bare soil covers, respectively.

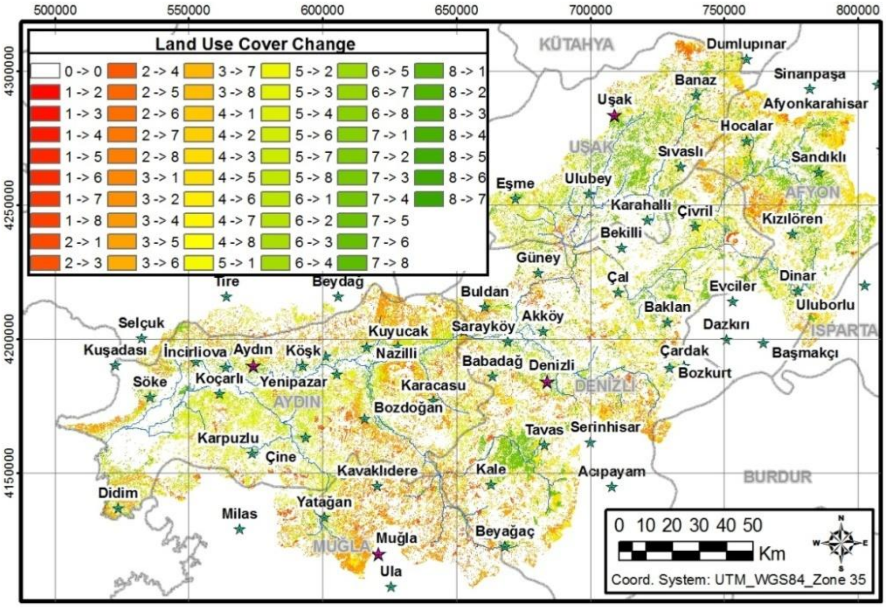

Figure 4. *Land use/ land cover change map (1986-2002):(1) water surfaces and wetlands, (2) evergreen and deciduous forests, (3) maquis, (4) grasslands, (5) bare soil and rocky areas, (6) olive/fruit orchards, (7) arable fields, and (8) urban/settlements areas.*

5.2 LULC conversion risk

The risk model pertaining to the changes occurred up until 2002 yielded low levels of risk in the 81% of the Big Meander Basin (Table 4). The areas with high conversion risks (4%) include Didim Peninsula due to the conversion of maqui and forest covers to urban and settlement areas; and Dilek Peninsula and Big Meander Delta National Park due to the transformations of wetlands and forests to agricultural lands and bare surfaces. Similarly, Işıklı Lake and its surroundings were rated as high risk area due to the agricultural encroachment over the wetland. Also, areas close to Dumlupinar, Kutahya faced high risk due to the alteration of forest cover to grassland (Figure 5).

Table 4. *Low, Medium and High levels of LULC conversion risk.*

Change risk		Until 2002	Probable	Final
Low	Range	0-0,3	0-0,3	0-0,6
	%	**81**	**41**	**61**
Medium	Range	0,3-0,6	0,3-0,6	0,6-1,2
	%	**15**	**36**	**26**
High	Range	0,6-1	0,6-1	1,2-2
	%	**4**	**23**	**13**

The probable LULC change risk, which considers the proximity to other LULC classes in the area, indicates rising risk in the Big Meander Basin landscapes. For instance, the percentage of the areas with low change risk decreases to half, whilst the percentage of high risks increases more than five times (Table 4). Those areas (especially with forest and maqui cover) neighboring with urban/ settlements and agricultural areas are subject to highest change risks. The probable change risk map displays high level change risk along the major highways which are traversing Civril, major urban areas of Denizli and Aydin, and also Didim (Figure 6).

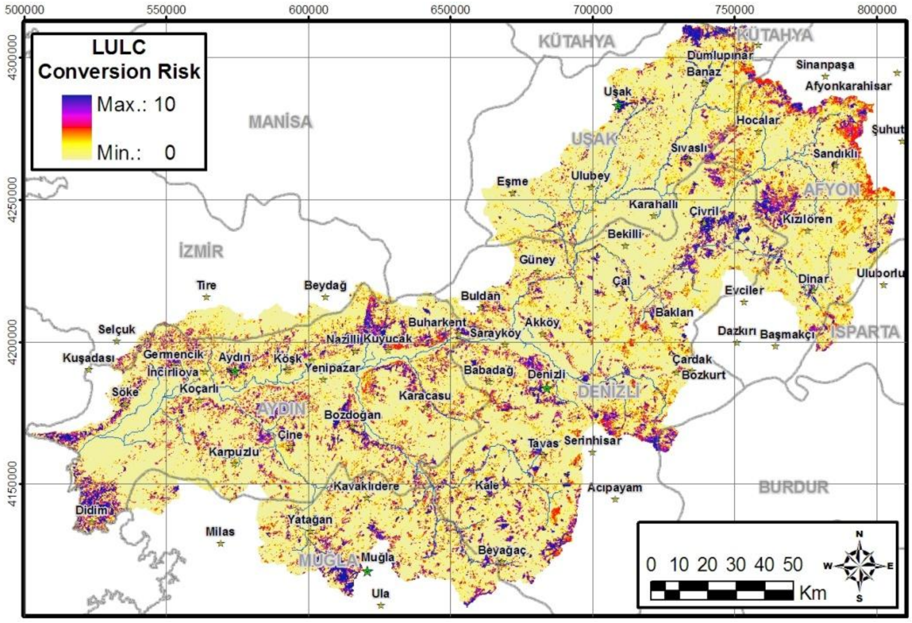

Figure 5. *LULC conversion (1986-2002) risk map.*

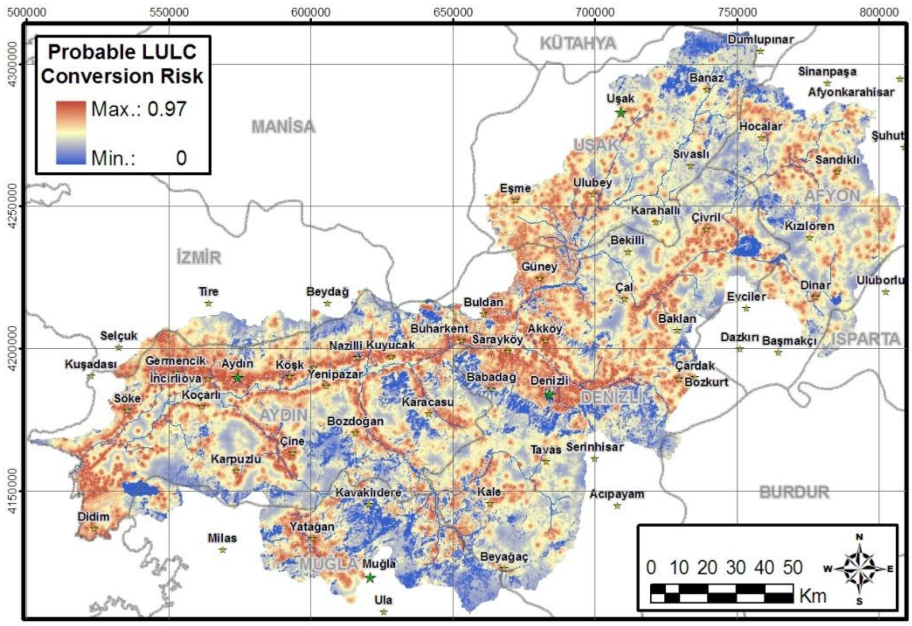

Figure 6. *Probable LULC conversion risk map.*

The results of the final LULC change risk map displays increase in the percentages of areas with medium and high risk levels. High risk areas include ecologically important wetlands and water surfaces. For instance, Big Meander Delta, Isikli Lake and Bafa Lake and their surroundings are subject to high risk due to the conversion of these areas into antropogenic uses such as agriculture and urban. Likewise, the areas between maqui or forest areas and agricultural lands will face high risks: this will occur especially along the major roads (Figure 7). Moreover, the natural and open areas in and around the urban developments will change their status into urban uses. Therefore, landscapes in and around Aydın, Didim, Denizli, and Çivril urban area will face the higher risks of land conversion. The transformation of agricultural lands into urban areas also yields high levels of risks.

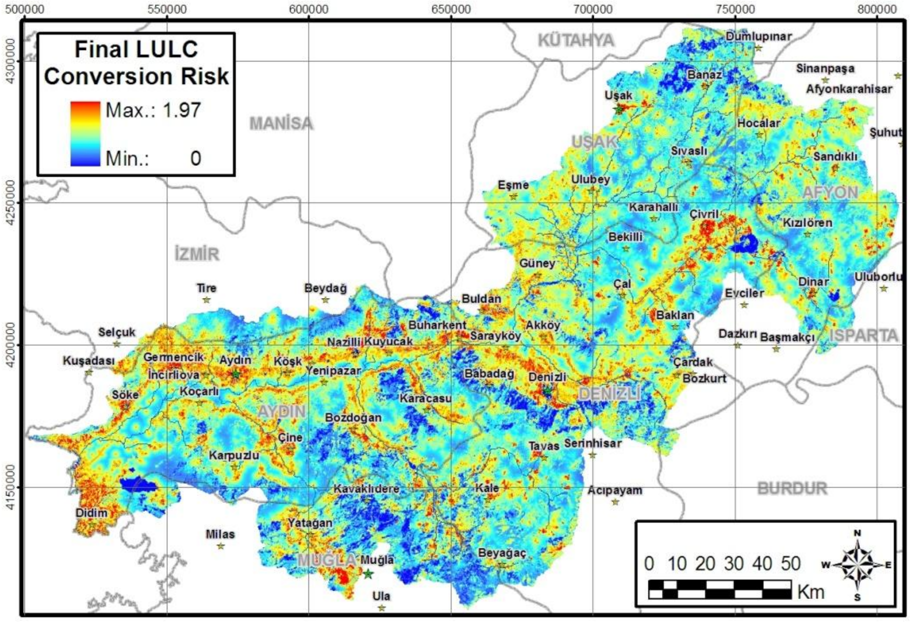

Figure 7. *Final LULC conversion risk map.*

Overall, in the Big Meander Basin, the trend for land transformation is from natural to anthropogenic. Higher the structural compatibility between the neighboring land use/land cover, lesser the pressures of associated conversions, hence less degrees of risks for the sustainability of the landscape.

6. Planning implications

This study has attempted to document the land use/land cover conversion risk in the Big Meander Basin, Turkey. The use of the LULC conversion risk model could be helpful to the Ministry of Environment and Urbanization, Ministry of Forestry and Water and other entities that are concerned with increasing effects of LULC changes. There are three primary potential applications that result from this study.

First, integrated planning and decision making systems involves many professions and the use of land use models, transportation models, economic models, and environmental impact models (EPA, 2000). Landscape models such as the one employed in this study can be used to monitor changing land uses to provide empirical evidence of potential negative affects on the ecological integrity. Biological studies with field investigations are costly. While the use of GIS and modeling as a surrogate biological field surveys to determine ecological integrity is not an equal substitute, is a practical and less costly method. Big Meander Basin has no comprehensive empirical evidence of the ecological changes; LULC conversion risk model can provide evidence of the longer term changes that affect ecological integrity of the basin.

Second, understanding the implications of LULC conversion can inform future planning efforts for protection of natural areas. Recent planning efforts for the Aydın–Mugla-Denizli (AMD) Environmental Plan have incorporated a number of strategies that are intended to promote balanced and sustainable development while preserving legally protected areas (Anonymous, 2008). Prepared with the 2025 projection, the plan aims to create sustainable and livable environments; to preserve agrarian, touristic and historic values; and to promote planned development and growth in line with the sectoral development goals of Turkey's development policies. The plan regards the sustainable use of the water resources, however, overlooks the ecological risks which will jeopardize the sustainability of the natural resources and ecosystems. AMD Environmental Plan indicates that most of the settlement areas have urban plans, however, more land has been developed than anticipated in these plans, hence exceeding population projections. This indicates even higher chances of threats to the ecological integrity of the protected areas close to urban areas. Dilek Peninsula-Big Meander Delta National Park that is adjacent to the rapidly expanding Kusadasi urban area is one example to such case. Despite its protection status, the National Park is subject to increasing edge effects which is generated by the surrounding land use trends (Esbah et al., 2009). By showing the risk levels associated with different land use allocations, the LULC conversion risk model can help planners to allocate more compatible and suitable land uses around the National Park, hence mitigating the edge effects.

Third, the LULC conversion risk model can play an important role during the preparation of the "Basin Protection Action Plan". Turkey has ratified the Water Framework Directive in 2000 as part of the harmonization process with the European Union. Water Directive commands the development of action plans from the member and candidate countries. Thus, the Ministry of Environment, together with TUBITAK, has initiated a project to understand the current land use dynamics in general, and water pollution in detail at the Big Meander Basin (TUBITAK-MAM, 2010). Considerable effort was made to model the hydrological structure and water pollution, however, the lack of broader and more comprehensive ecological risk analysis approach has undermined the effectiveness of the action plan. Accordingly, the Big Meander Basin Protection Action Plan falls short on providing actions for the prevailing issues of erosion, drought, fire, and land use change in the basin (Erdoğan, 2012). LULC conversion risk model can display the risks generated by the incompatible LULC conversions hence help in developing efficient and ecologically sound actions to safeguard the aquatic and terrestrial ecosystems along the Big Meander River Corridor.

This study utilized a landscape ecology approach to model the risk associated with the LULC conversions. By seeking to develop an integrated, holistic understanding of environments at different scales, landscape ecology generates a better understanding of complex patterns and processes. It analyzes parts of the whole in terms of their connections rather than separately. The resulting analysis focuses on the spatial patterns of landscape elements (structure); the movements of organisms, energy, and nutrients across these elements (function); and ecological changes over time. More specifically, it deals with how spatial patterns influence ecological processes, and how landscape mosaics change over time (Esbah, 2007). Landscape ecology is important for planning because it explicitly pays attention to spatial patterns and processes, provides a common language shared by ecologists and planners, and offers theory and empirical evidence that help planners understand and compare different spatial configurations of land uses. This approach also enables the prediction of the ecological consequences of plans (Leitao and Ahern, 2002), thus allowing planners to generate more realistic and comprehensive solutions.

7. Conclusions

The Big Meander Basin ecosystems are experiencing a rapid land use and land cover change due to increasing levels of antropogenic uses. The direction and magnitude of this inevitable LULC change impose pressure on natural systems and generate various degrees of risks to ecological integrity in the basin. This study, first, elaborated LULC changes in the Big Meander Basin between 1986 and 2002, and then modeled LULC conversion risk generated by the past and probable future LULC conversions.

The risk modeling approach helped in the spatial understanding of the conversions from natural to more antropogenic. It also helped in understanding the location and the magnitude of different risk levels, hence elaborating the incompatible land use transformations. The following points are critical for future applications: (i) the use of multi temporal images, (ii) selection of proper and adequate image sets representing different periods of a year, (iii) selection of appropriate classification technique, (iv) utilization the distance of each land use classes as an indicator of future changes, (v) utilization of landscape ecology perspective in the weighting of conversions.

LULC conversion risk model yielded highest risks for the Dilek Peninsula-Big Meander Delta National Park and its surroundings. The risks in the national park area are attributable to the conversion of sandy coastal areas to agricultural uses. Moreover, there is a high conversion risk in those maqui, forest and grassland areas which are close to urban and agricultural lands. This constitutes high LULC change risk around the major cities of Denizli, Aydın and Usak.

LULC conversion risk analysis not only displayed the areas with high change risk but also displayed the priority areas for the protection, restoration and planning. Thus, this information can be used for generating more effective land use decisions especially at the urban rural interface. For those areas with high ecological quality such as wetlands and protected areas, information about the LULC conversion risk can help promoting effective protection strategies.

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Alan kullanımı/arazi örtüsü değişim riskinin modellenmesi

Ekolojik açıdan sürdürülebilir olmayan alan kullanımı/arazi örtüsü değişimleri dünya genelinde ekosistemleri tehdit eden unsurlar arasında yer almaktadır. Bu sorunla etkin şekilde baş edebilmek ve uygun planlama ve yönetim kararları alabilmek için peyzajda olan değişimlerin tespit edilmesi ve ileriye dönük modellenmesi önem arz etmektedir. Bu çalışmada Ege Bölgesi'nde yer alan Büyük Menderes Havzasında alan kullanımı/arazi örtüsü (AKAÖ) değişimleri riskinin modellenmesi amaçlanmıştır. Çalışma, AKAÖ değişimlerini bir ekolojik risk göstergesi olarak ele alması ve geleceğe yönelik değişim olasılığında AKAÖ'lerinin birbirlerine olan mesafelerini hesaba katan bir yaklaşımla geliştirdiği model ile özgündür. Çalışmada 4 analitik yaklaşım takip edilmiştir: (i) Havzadaki AKAÖ değişimlerinin 1986 ve 2002 yılları arası için tespiti, (ii) 2002 ye kadar olan değişimlerin risk haritasının oluşturulması (iii) gelecekte muhtemel AKAÖ değişimlerinin risk haritasının oluşturulması and (iv) bu iki haritanın çakıştırılması ile daha kapsamlı bir risk haritası elde edilmesi. Sonuçlar havzada 16 yıllık periyotta kentsel alanların, maki alanlarının, meyve bahçelerinin, su yüzeyleri ve sulak alanların ve ayrıca boş toprak ve kayalık alanların arttığını göstermiştir. Tarla tarımı yapılan alanlar ve ormanlarda bir azalma olmuştur. Tarımsal kullanımların sulak alanlar üzerinde yaptığı değişim dikkate değerdir. Sonuçlar aynı zamanda bitki dokusunda genel bir cılızlaşma süreci yaşandığını göstermiştir. Bunun sonucu bir takım orman alanları makilik dokusuna, bir grup makiliklerde otsu açıklıklara dönüşmüştür. Bu tür dönüşümler ekosistemlerin işleyişleri konusunda sürdürülebilir olmayan sonuçlar doğurabilmektedir. Çalışmada öne çıkan bir diğer konu ise Havza Yönetim Planı ve Çevre Planı gibi girişimlerde, peyzajda bu sözü geçen değişimlerin dikkate alınmadığı ve dolayısı ile bu planların havzadaki ekolojik riskleri çözmeye veya yavaşlatmaya yönelik etkin planlama ve yönetim kararları getiremediğidir. AKAÖ değişim risk modeli kapsamında elde edilen bilgiler sadece yüksek riskli alanları belirtmekle kapmayıp, planlamada öncelikli olarak odaklanılması gereken lokasyonları ilişkileri ortaya koymaktadır, bu açıdan da özellikle de kent-kır geçişlerinde sürdürülebilir planlama kararlarının alınmasında önemli bir araç olabilir.