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Gradient analysis of urban landscape pattern(Case Study: Isfahan, Iran)

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Abstract

Urban landscape is a heterogeneous mosaic of physical and biological patches. Quantifying the landscape pattern is required to assess and monitor economical, social and ecological functions of a city. This study has been developed by the expansion of the fields such as landscape ecology. In this study a combination of gradient analysis and landscape metrics were used to quantify Isfahan city`s landscape. Therefore the land use maps of 1386 was provided in six levels of manmade, agricultural, green space, barren , road and river. Two transects were directed toward north-south and east-west crossing city center to perform the gradient analysis. Moving window method was used to assess metrics along transects and those metrics were quantified in two levels of class and landscape. In total, the highest percentage of class and patch density and the largest patch index belongs to agricultural lands in Isfahan`s landscape and the mean size of barren and pastures` patches has the highest value. In addition to the change of different uses, the change in the values of different metrics was also observed. Patch density and margin density metrics increased toward city center. In general, the results showed that the mean size of patch is higher around transect`s margins and on the contrary, patch density and margin density are higher in city center. It can be understood that the values of patch density and margin density has increased with urbanization. This study showed that in addition to the change of uses, shape and density of patched have changed and they have a different trend in two transects.

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Introduction

Due to urbanization and population growth, urban landscape is changing rapidly. This phenomenon has a lot of economic, social and environmental consequences. Urbanization causes fundamental changes in the structure and ecological function of a city`s landscape and leads to the gradual change of spatial structure and landscape pattern (Wang *et al*, 2008). Analysis of the spatial and structural characteristics of urban land use in modeling of spatial-temporal changes is one of the important current issues. These studies have developed with the expansion of fields such as as remote sensing, geographic information systems and ecological landscape(Sudhira *et al*., 2004; Herold *et al*., 2005).

Isfahan city is among those areas where need an integrated and comprehensive urban management due to urbanization growth, industrial and agricultural uses and also its historical and cultural values. The study of spatial-temporal changes of city`s landscape and quantifying it using a combination of landscape metrics gradient analysis are important steps in the study of Isfahan`s landscape and will help decision makers and policy makers in a better management of the city. This study aimed at understanding the structure and function of a city landscape. To understand the formation mechanism of landscape pattern a more comprehensive framework based on ecological, social and economic sciences and also geographical and political considerations are required. The aim of this study was to quantify the spatial pattern of Isfahan using gradient method and to understand the changes of different uses and metrics with change of their distance from city center.

Theoretical Foundations

Landscape ecology is landscape studies, especially their composition, structure and functioning (Forman and Godron, 1986). Cities, as a heterogeneous landscape can be studied from the viewpoint to science(Wolff and Wu, 2004). Landscape ecology principles can be applied as a comprehensive approach to be used in the design of urban landscape. This approach not only suggests ecological and environmental issues in landscape design but also deals with issues of economics and sociology and can help in designing certain features which are environmentally and aesthetically more appropriate.

Quantifying spatial patterns of city landscape is needed to understand ecological and socio-economic consequences of urban development. Urban systems are those systems which have a varied land use pattern due to social land economic processes resulted from urban development. For example removing large agricultural patches, results in the fragmentation of habitats and an increase in manmade patches` density and this has an effect on the geochemical cycle of life. Therefore, to understand urban ecosystems, their patterns must be quantified. The understanding of spatial and temporal changes of urban landscape is needed for prediction of projects with different objectives, such as landuse planning, resource management and biodiversity conservation.

Gradient analysis can be used to detect changes in urban landscape pattern. In most studies of urban landscape pattern and analysis of its structure, a combination of gradient analysis and landscape metrics was used (Luck & Wu, 2002 and Zhang *et al*., 2004).

Luke and Wu (2002) for the first time used a combination of gradient and metric analysis to investigate the pattern of Arizona (Luck and Wu, 2002).

Gradient can show the extent of urbanization, ecosystem change and human impacts on the environment(McDonnell and Pickett, 1990).

This method is used for findingan urbangradient, from downtowntoward the suburbs, along guided transects. This method is based on moving window technique, thus moving window method is used for different metric analysis along the guided transects.
Landscapemetrics are developed indicators for finding a pattern for classified maps. Landscape

metrics are algorithms to quantify specific spatial characteristics of patches, classes or entire landscape mosaics (Gustafson, 1998, McGarigal *et al.*, 2002). The issueof scale isone of themost important issues inlandscapestudies. In general there is nooptimalor correct scale to quantify landscape characteristics (Turner, 1989; Wu, 2004). Roads as line a rapplications compared to other uses are more sensitiveto changes inscale (Zhu *et al.*, 2006).

Zhang *et al* (2008) evaluated a 10-30 m pixel size for urban studies (Zhang *et al.*, 2008). Luke and Wu in the city of Phoenix, Arizona used a 50 m pixel size. Zhang and colleagues at the city of Shanghai, used a10 m pixel size (Zhang *et al.*, 2004). Kong and colleagues in the city of Jinan used a pixel size of 10 m (Kong *et al.*, 2007). Weng (2007) evaluated a pixel size of 25 m for the study of Spatial and temporal changes (Weng, 2007). Zhou *et al* (2006) studied the different scales for studying the effects of roads and evaluated an optimal pixel size of 5/7 m (Zhu *et al.*, 2006).

Selecting appropriatemetricsinthis studywasbased onpreviousstudies andliterature reviews. In this studybothmetrics of compositional andspatial distributionin thelandscapeandclasslevelswere used. Due tothe inherentdifferencesinland usedata, the use of different metrics is needed to increase the flexibility and to research more completely(Leitao and Ahern, 2002).

A: studied area

Isfahan city is located at the center of Isfahan province and at the eastpart of Zagrosmountain range; its latitudesare 32" 28' 30◦and its longitudes are 51" 39' 40◦. It is the thirdlargest city after Tehranand Mashhad. Thecityis one of thelargestdry cities inthe world with very little rainfall and its altitudefrom sea levelis about1580meters and it has an arid and cold climate according to Amberje method and it has a cold climate according to Domarten method.

Fig. 1 shows theposition ofIsfahan cityin province andcountry(Shafaghi, 2001 and atlas of Isfahan city 1997).

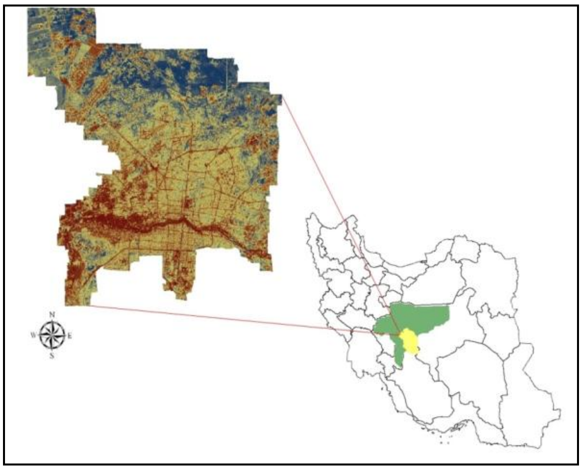


Fig. 1. theposition ofIsfahan cityin province andcountry

Methods

The method used in this study is shown in Fig. 2.

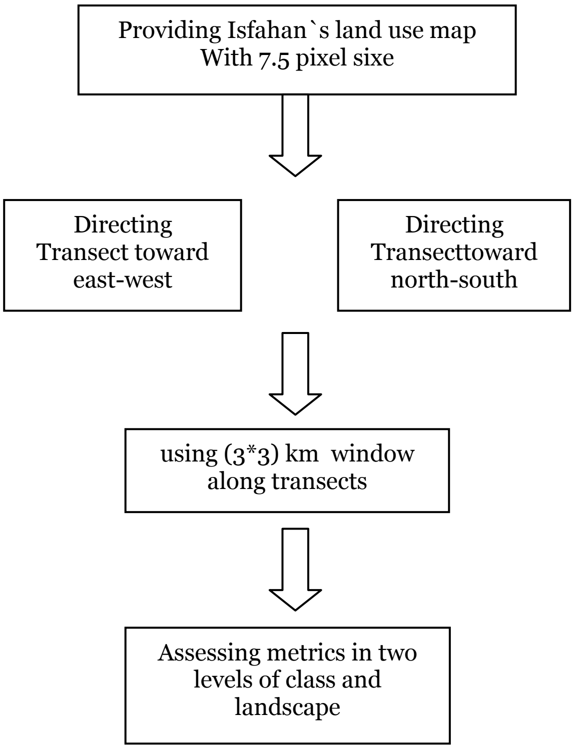


Fig. 2. diagram of gradient study of Isfahan city

Predation of city land use map of 1386

The maps which were provided by city hall`s computer service center were used to make Isfahan`s use map. First all available classes in 1/2000 maps were extracted and then according to table 1, they were re recategorized in 6 classes of urban, green land, agricultural lands, arid lands, roads and rivers. Then theproduced map was updated usingthe IRSPANimages. Inthis study,according toprevious studies, Isfahancitywas divided into 6 groups including manmade lands,green spaces, agricultural land, barrenland, roads and rivers(Table 1).

Table 1. Classification of urban land use map of Isfahan

description	Acronyms	Classification types of patch
Residential areas Facilities Industries Areasunderconstruction Service centers(hospitals, etc.) Cultural andhistorical sites	U	Constructedland
paces reeng rbanu types of	G	Green space
Agricultural lands Fallowland Gardens andvineyards	A	Agricultural areas
aridland Pastures Saline Soils lands without construction	B	area arid
roads	R	roads
Zayandeh_Rud River	W	river

Directing transects in two main directions of city

By observing Isfahan city`s land use map, one can easily understand that the distribution of different uses are different in two directions of south –north and east-west so the gradient analysis should be evaluated in two directions. As it can be seen in fig. 3, two transects were directed north-south and east-west. The passage of these two transects were designed so as to pass the city center (Enqelab Square). The length of north-south transect was 17 km, with a width of 3 km and the length of east-west transect was 15 km while its width was 3 km.

The use of moving window along the transects

North-southtransectis formed of8blocks of3 × 3km and east-west transectis made ofsevenblocks of3 × 3km, with 1 km overlapping, corresponding totables 2 and 3. Using FRAGSTST 3.3 and ARC GIS 9.2 Software, desired metricsare computed in both the landscape and class level.

Table 2. the distance from northern margin of city comparing to the sampling blocks for transect

8	7	6	5	4	3	2	1	Block number
14-17	12-15	10-13	8-11	6-9	4-7	2-5	0-3	Distance from northern margin (km)

Table 3. the distance from eastern margin of city comparing to the sampling blocks for transect

7	6	5	4	3	2	1	Block number
12-15	10-13	8-11	6-9	4-7	2-5	0-3	Distance from eastern margin(km)

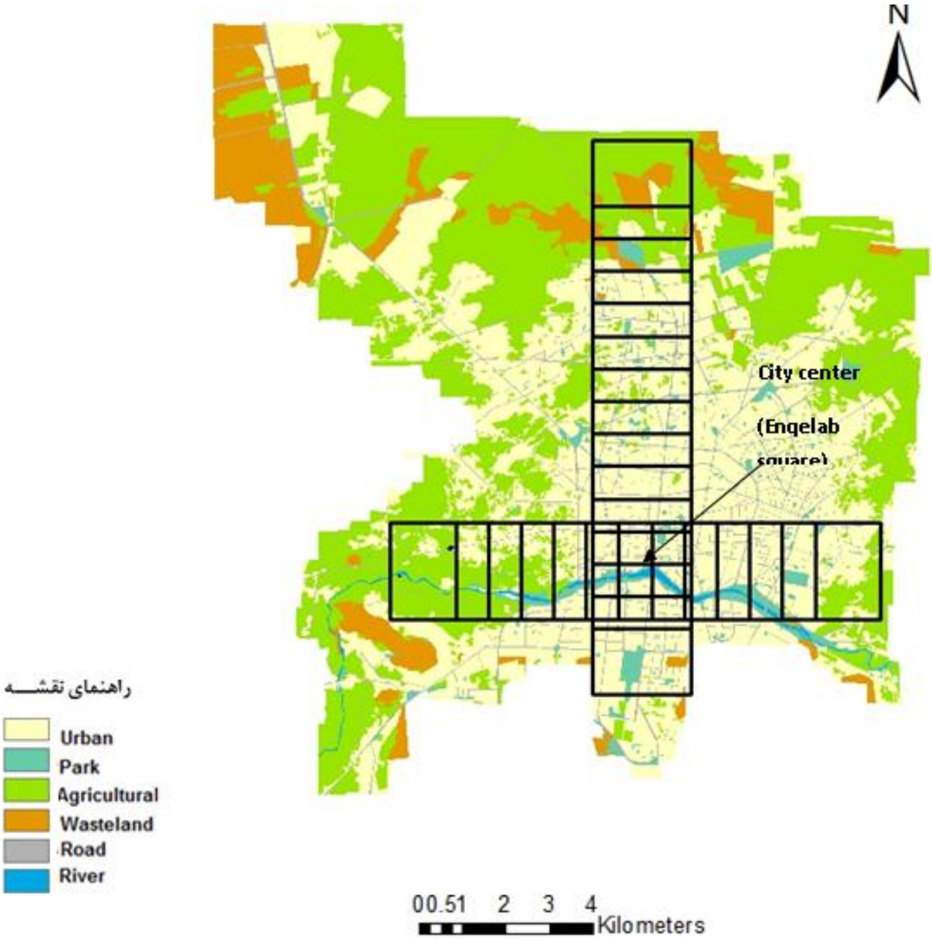


Fig. 3. the position of directed transects in two directions of north-south and east-west

Calculating desired metrics

As it can be seen from Table 4, the appropriate metrics at landscape and class level were selected for this analysis by reviewing similar studies. To show Isfahan city`s landscape changes, both compositional andspatial distribution metrics have been used.These metrics were calculated in at class and landscape levels.

Table 4. Metricsused in thestudy

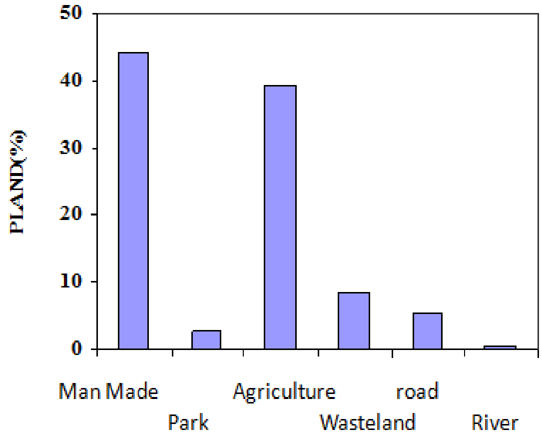
definition	abbreviation	Landscape metrics
The ratio ofthe total areaoccupiedbyapatch		Percentage of coverage
The number of patcheson100acres	PLAND	Patch Density
the wholeMargin(perhectare) foreach classorlandscape	PD	Edge Density
	ED	Largest Patch Index
The ratio ofthe patch the totallandscapearea	MPS	Mean Patch size
mean of patch size(hectare)		

Source: McGarigal *et al.*, 2002

Discussion and results

City landscape orientation

To identify the general characteristics of urban landscape, four metricof land use, density of patches, largest patch in dexand mean patch size were used.



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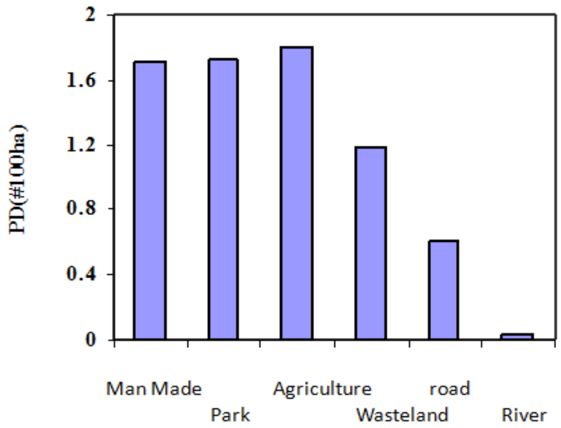

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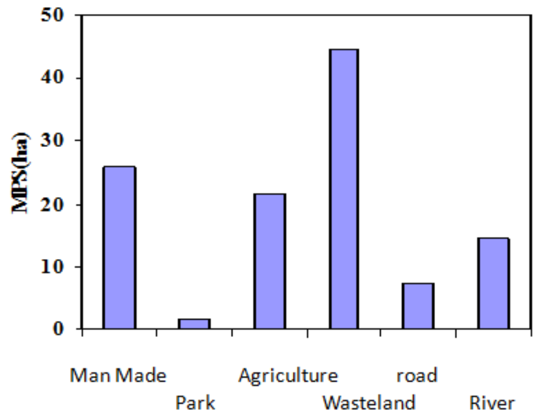

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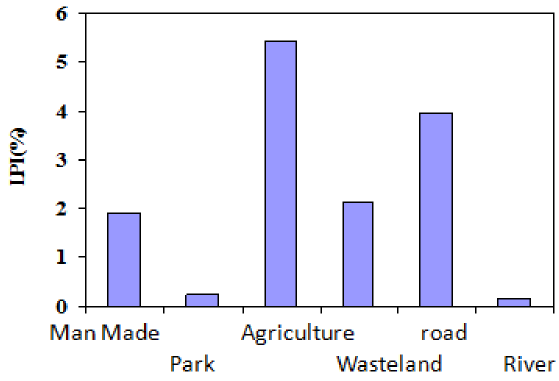

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Fig. 4. Diagram of Isfahan landscape general characteristics

A) The percentage of land use (percentage of total landscape area); B) patch density, c) mean patch size (ha); d)largest patch size (%)

As it can be seen in fig. 4-A, the highest percentage of land use belongs to manmade lands. The percentage of manmade use is about 45 percent of entire Isfahan city. Agricultural lands are the second major use of Isfahan`s lands and they occupy about 39 percent of Isfahan`s landscape. The percentage of green space, roads and river are 3, 6 and 5 respectively.

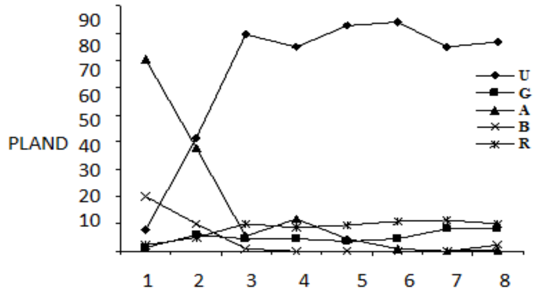
Density of agricultural patch has the highest value in each 100 ha (Fig. 4-(b)).

According to fig. 4-D, the mean of barren land, pastures and manmade patches have the highest amount. The indexes of largest patch of agricultural lands, barren lands and pastures have the highest values (Fig. 4-D).

Transect analysisat theclass level

East West transect analysis at the class level

In this transect, rivers are discarded from the calculations because they occupied less than 1% of entire transect. The coverage percentage of different uses of urban land, agricultural land, green space, barren land and rivers are different as they move away from north to south.



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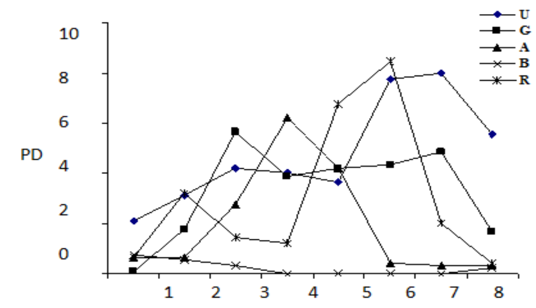

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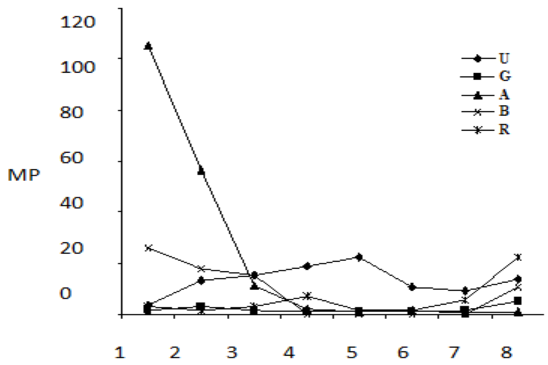

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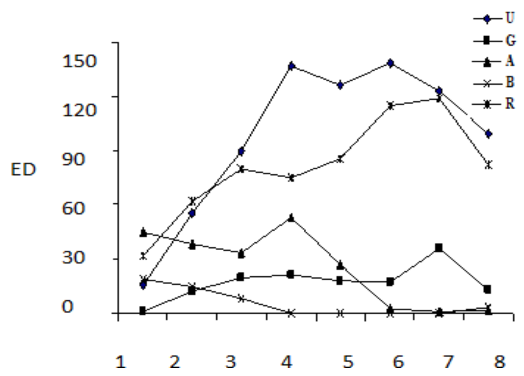

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Fig. 5. Changes in landscape pattern along the north-south transectat grade level

A) The percentage of land use b) patch density c) average patch size, d) marginal density

As fig. 5-A shows, the trend of changes in agricultural and manmade lands are the opposite. From block 1 to block 3, there was a sudden increase of manmade lands and from block 3 onward, these changes did not appreciably increase and this trend was reverse in manmade class. In north-south transect, the highest percentage of manmade land was observed in block 6. In city center block, due to the existence of river patch and occupying a percentage of landscape, the percentage of manmade land was lower comparing to block 6.

The green space`s patches had the highest percentage in blocks close to river i.e. blocks 7 and 8. Agricultural lands had a severe decrease from block 1 to block 3 and after this decrease, there were not many changes seen in their values. The percentage of these lands in blocks 5, b6, 7 and 8 is almost zero.

Percentageofareaoccupied bygreen spaceshas changed along transect.Its highest percentageis inblock7. There arebarrenlands onlyin northern and Southern margin.The maximum and minimum percentage of road uses was observed inBlock7and1, respectively.

According to fig. 5-B, patch density metric has the highest value in a block where center is located at. The value of this metric in manmade class has an increasing trend from northern margin toward southern margin. In green space and agricultural class, the maximum of patch density was observed in blocks 4 and 7 respectively.

In road class, the value of this metric was higher in blocks 6, 7 and 8 than other blocks. According to fig. 5-D, margin density does not have a regular pattern in manmade class. Margin density of green space has the highest value in block 7. Margin density of agricultural class is at its maximum in block 1. The metric of mean patch size (MPS) has the highest value in block 5 in manmade class, i.e. in this block the size of manmade patches is large , but the lowest value was observed in block 4, because in this block due to high density of roads, manmade patches are severely fragmented and their size is small.

In agricultural class, mean patch size is high in blocks 1 and 2 but it severely decreases in following blocks and reaches zero. Maximum value of mean patch size metric in barren class was observed in block 1 (Fig. 5 -(d)).

North- south transect analysis at the class level

Due to the fact that barren land occupies less than one percent of the entire transect, it is not included in the calculations. As it can be seen in fig. 6-A, percentage coverage of manmade land has the highest value in block 4, and from block 4 toward east and west, its value gradually decreases but the amount and speed of this decrease is more toward west than east. Thus its value reaches zero in block 7.

Percentage of agricultural land opposite to city center, is higher in transect's sides. Its value reaches 80% in block 7. From east and west toward center, the amount of agricultural land decreases. Percentage coverage of green spaces has the highest value in city center. Maximum and minimum road class are in blocks 4 and 7 respectively.

Barren lands, were omitted in this transect due to their low values. In this transect, opposite to north-south transect, rivers have occupied some percentage in all blocks.

Patch density index in manmade class, has a symmetrical pattern; its value in block 4 is at maximum and it decreases toward margins. Density of green space and agricultural patches are at maximum in blocks 4 and 6 respectively (Fig. 6 - (b)).

Patch mean size metric in urban class has a decreasing trend from eastern margin to block 4 and then it has an increasing trend to block 6 and then it decreases again.

In agricultural class in eastern and western sides, mean patch size of agricultural land is high but in central blocks this value reaches zero. Mean patch size of green space has the highest value in block 3 (Fig. 6 -c).

According to fig. 6-D, density of manmade margin and green space is at maximum in block 4 and these values decrease from center toward margin. Density of agricultural margin has the highest value in block 6.

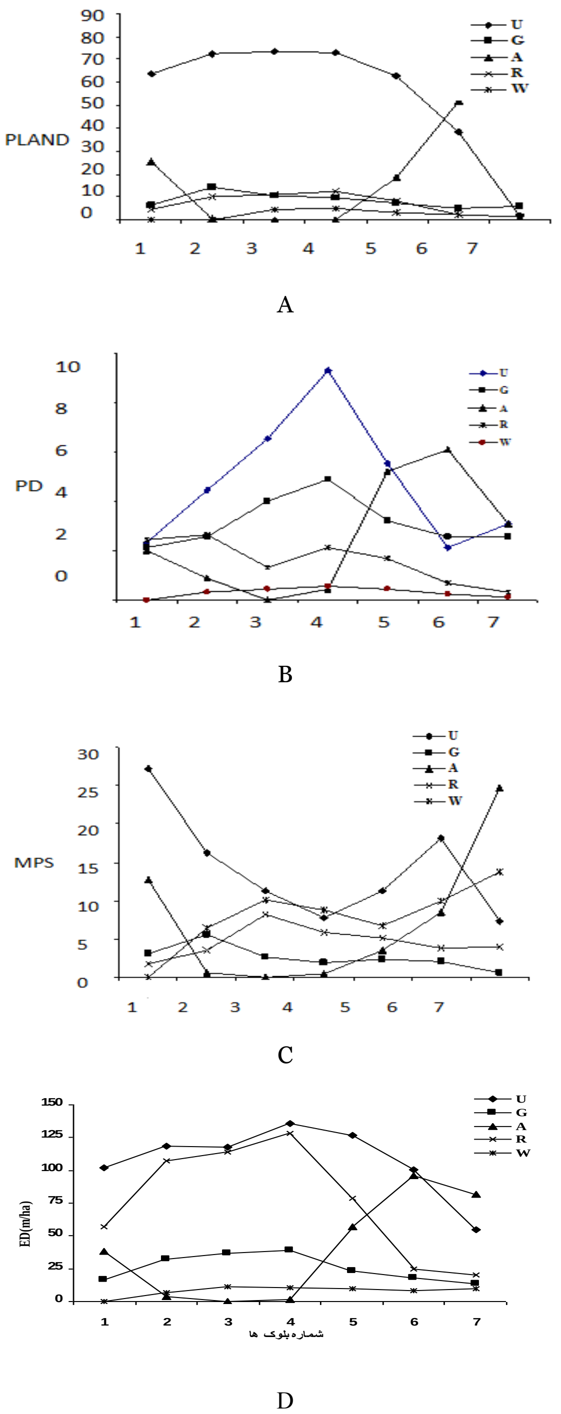
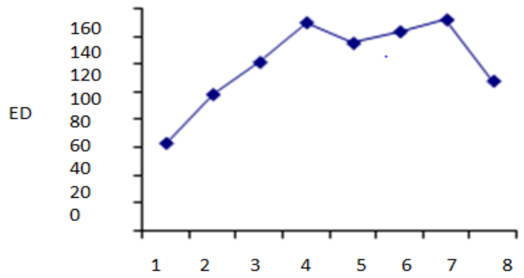


Fig. 6. Changes in landscape pattern along the east-west transectsat grade level

A) The Percentage of land use b) patch density c) mean patch size, d) marginal density

North-south transect analysis at the landscape level

North-south transectanalysisat thelandscapelevel was performed by 4metrics of patch density, marginaldensity,



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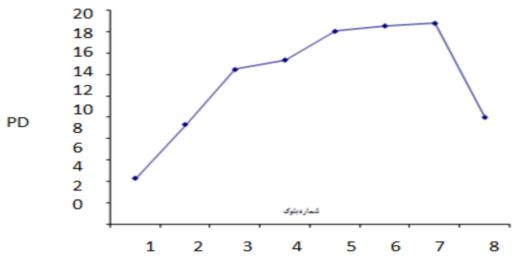

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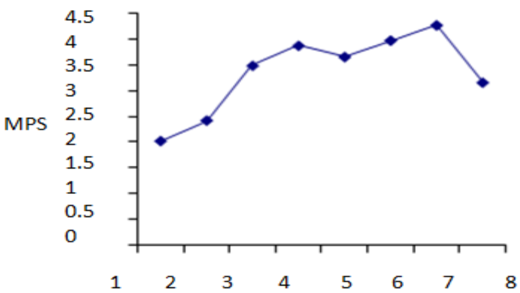

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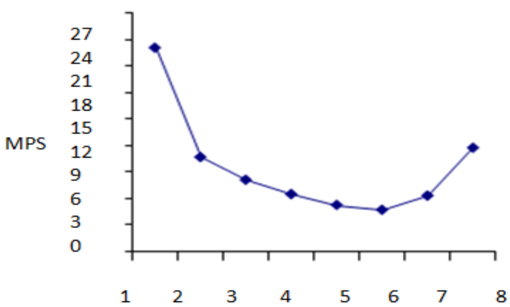

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Fig. 7. theprocess ofmetricchangesalongnorth-southtransectsinlandscape level

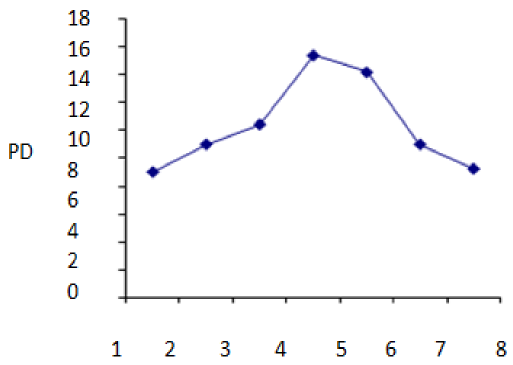
A) Patch density b) marginal density c) average index weighted by thearea of the spot, d) mean patch size

Patch density and margin density have the highest values in block 7 (Fig. 7, a-b). Theaverage weighted index ofthepatchbythetransectareadoes not have a regulartrend(Fig.7-(c)).

Asshown in Fig.4-(d) mean patch size and patch density in contrastto margindensityhave the lowest values in block 4.

East-west transect analysis at landscape level

in East-west transect the trend of patch density and density and margin density is the same as north-south transect (Fig.8-a) and (b). Patch density and marginal density have the highest values in Block 4. The mean weighted by the area of the patch does not have a regulartrend in this transect (Fig.8-c).



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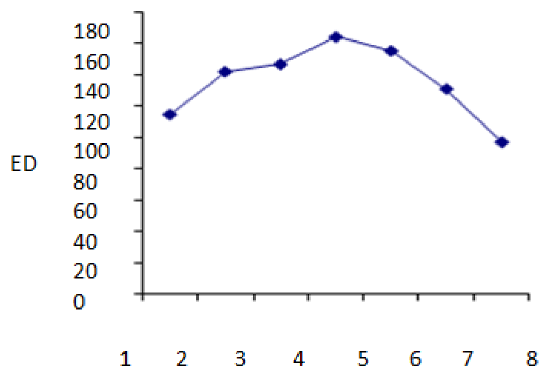

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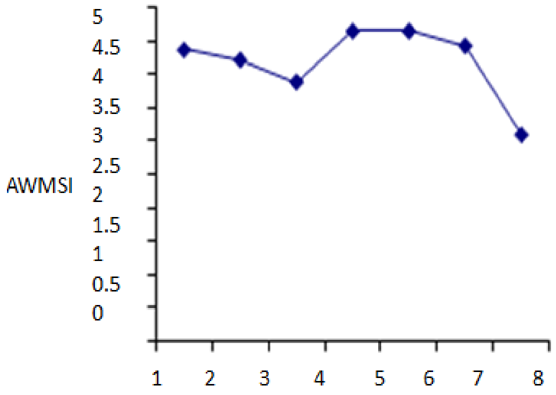

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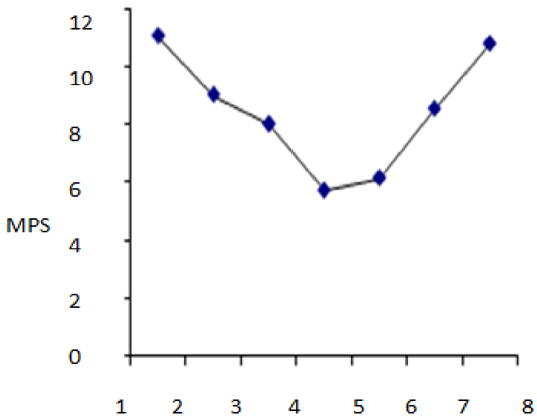

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Fig. 8. the trend of changes in east-west transect in landscape level

A) patch density b) marginal density c) average index weighted by the area of the spot, d) mean patch size

As it can be seen in fig. 8-d, opposite to patch density and marginal density, mean patch size has the lowest value in block 4 and the highest value in block 7.

Discussion and results

Gradient analysis has made an attempt to answer the following questions:

• Are urban gradients detectable by analyzing landscape patterns?

• How land uses differ by distance from city center?

• is there a major difference between the north-south transect and the East and West transect?

• How various metrics at different distances along transects are changing?

Ingeneral, the relativedominanceof different land use showeda certainpattern intransects:

The change of land use is from agriculture to manmade. The distance which is at maxim, is located at city center. Percentage of different land uses of manmade, agricultural, green space, barren land, road and river changes by moving from east to west. Gradient of changes of uses in north-south transect is as the combination of agricultural patches, saline fields and pastures (combination of agricultural and manmade) is completely manmade and this gradient in east-west transect is as the combination of agricultural land and manmade (completely manmade) and the combination of agriculture and manmade is changed.

In this study, the city center is detectable by some metrics. Some of these metrics at landscape and class level have shown considerable changes in landscape near and at city center in both transects Patch density has increased positively toward manmade areas. Patch density, margin density and largest patch index metrics is at maximum in city center. This increase is due to development of areas and loss of agricultural lands.

In this study, patch density and margin density have increased toward city center. Zhang *et al*(2006) intheir study of Shanghaiconcludedthattheincreasein theUrban Development and Human construction, not only the density but also irregularity of patches' shapes increase.

Zhang *et al* proposed that an increase in urban development and construction cause a diverse combination of landscape, thegeometricdisorderand morefragmentation of ecology.

Metric analysis of coverage percentage of lands in class levels in two transects showed that, where percentage of urban land is at maximum and is considered as city center, green space patches have the highest percentage. The number of green spaces in city center is more than other points in transects but the mean sizes of these patches are low.

According to trend of metric changes, one can conclude that pattern of east-west transect is more symmetrical than north-south transect. This study showed that in Isfahan city, changes of uses are not completely symmetrical or linear. The results of gradient analysis in Shanghai showed that trend of distribution of land uses dependent on distance, is not completely symmetrical and linear in shanghai city.

In the study of Veng on Wisconsin city,Shanon diversity index and patch density have increased positively with urbanization and construction while mean patch size has changed negatively with the development of urbanization. In this study, city center is detectable due to a high patch density and small size of its patch.

Changes of landscape`s pattern along the transect has a lot of effects on ecological functions. For example, removing large agricultural patches lead to fragmentation and increase of manmade patches and this phenomenon will affect geochemical cycle of life (Baker *et al.*, 2001).

Transect is the best means forunder standing landscape changes on a large scale throughout the suburbangradient (Luck and Wu, 2001).

Conclusion

This study showed that urbanlandscapepattern can be quantified by metrics of composition and spatial distribution.

This study showed that in addition to changes of land use, shape and density of patches have changed too and the trend of these transects are different.

From this result one can infer that values of patch density and margin density have increased by urban developments. Therefore, trend of pattern changes are more symmetrical in east-west transect. With respect to trend of metrics changes one can suggest that the pattern of east-west transect is more symmetrical than north-south transect. This study showed that the trend of land use changes is not completely linear and symmetric in Isfahan city. To continue this study for understanding formation mechanism of landscape`s pattern needs a more comprehensive structure including geographical ecological, economic, socialand political studies (Luck *et al.*, 2001).

Suggestions

At the end of this study,the following topicsare recommendedforfurther study:

•The relationship betweenlandscapepattern andecologicalprocessescan bestudiedalongtransects.

• In future studies, the relationship betweenland usepatternandthermalandclimaticconditionscan be examined.

•The resultscan be usedto predict thefuture state ofthecitylandscapepattern.

•Spatial measurements can be used to understand the growth and morphology of the city.

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