Image textural measures as indices for the development of an evaluation and classification model of landscape scenic quality, using GIS

Tsouchlaraki Androniki
Rural and Surveying Engineer, PhD – NTUA
Athens, Greece
tsouchlaraki@tutors.eap.gr

SUMMARY

This study aims to investigate –with the use of a GIS– quantitative indices for the automatic evaluation and classification of landscape scenic quality using digital ground photographs. Based on the texture indices that are commonly used in landscape ecology, quantitative indices are selected and the results from the application of these indices to a sample of ground photographs are described in this paper. Furthermore, this paper investigates the effectiveness of the selected indices as to the classification of the landscape's scenic quality, while the results are compared to the results derived from a research programme. Based on the comparison, comments and suggestions are presented for further investigation. The main conclusion of the investigation is that texture indices are sensitised in the landscape's scenic quality, a fact that is positive and encouraging enough in order to pursue further research for the development of an evaluation and classification model.

KEYWORDS: *Landscape evaluation and classification, textural measures, digital ground photographs, GIS*

INTRODUCTION

Landscape is a decisive environmental variable for which there is an increasing and imperative need to evaluate and measure in view of environmental design, as well as in view of the investigation and monitoring of the environmental impact from various activities.

Landscape is the combined result of physiography, geological formations, vegetation, waters and the various cultural interventions that occur in a given area. This combination attributes shape, line, colour and texture to a landscape, while the aesthetic result is considered on the basis of the variety or the uniqueness offered and is usually classified into three main categories: 1) indistinctive, 2) common, 3) distinctive (Smardon et al, 1986; USDA, 1974; USDA, 1995). This classification determines those landscapes which are most important and those which are of lesser value from the standpoint of scenic quality. The classification is based on the premise that all landscapes have some scenic value, but those with the highest variety or diversity have the greatest potential for high scenic value. A frame of reference is developed by which to judge the physical features of an area as indistinctive, common or distinctive (USDA, 1974; USDA, 1995). Features such as landforms, water forms, rock formations, and vegetative patterns are compared individually or in combination. Through this comparison an area's overall degree of scenic quality and resultant variety class rating is determined.

Of decisive role in landscape evaluation are the observation post and the observation distance, since they determine the way the various objects are observed. Other variables affecting landscape evaluation, probably not to the same extent, are: season, lighting and atmospheric conditions, movement and duration of the observation (Smardon et al, 1986).

The combinations of the variables mentioned above are indefinite in number and it is therefore obvious that the more the characteristics under examination increase, the more complex the landscape's evaluation becomes. Besides, there are many divergent views even among experts. This justifies the demand for creating a conventional and common method for evaluating and classifying a landscape's visual quality.

In May 2002 the Laboratory of Physical Geography and Environmental Impact of the National Technical University (NTUA) completed a pilot research programme entitled "SCAPEVIEWER" (Mougiakakou, 2002; Mougiakakou, 2003). The main objective of this programme was the design of a user friendly and mainly computerised instrument, which would not require specialised knowledge from the user. The methodology pursued was based on the theoretically proven characteristics of the landscape, which were quantified empirically, on the basis of the scientific opinion of a seven-member group, and were applied to a sample of 108 ground photographs, while the results of the quantification constituted the input and training data for a neural network. Photographic material is very often used in visual landscape inventories as a low cost media of presentation (Shuttleworth, 1980).

In the above mentioned research programme, the selected indices were evaluated empirically. An empirical evaluation often includes a sub-optimal dependence on the experience of the evaluator, a time-consuming examination of the large number of attributes and interactions, and the increasing complexity of landscape evaluation as the number of estimated landscape attributes increases. This research effort contributes to the direction of the automated quantification of the landscape's qualitative characteristics. In this paper and on the basis of the textural measurements that have been established in landscape ecology, six quantitative indices are selected and designed and the results from the application of these indices to the same sample of ground photographs that was used in the afore-mentioned research programme are described. Furthermore, we investigate the effectiveness of the indices selected as to the classification of the landscape's scenic quality, while the results are compared to the respective ones from the research programme. Comments and suggestions are also provided for further investigation.

SELECTION AND DESIGN OF QUANTITATIVE INDICES – RESULTS FROM THEIR APPLICATION TO THE SAMPLE OF PHOTOGRAPHS

Photograph Digitisation Data

For the purposes of this research, we used the sample of ground photographs that was also used in the research programme "SCAPEVIEWER". The sample of the 108 photographs was available in the form of slides and it was digitised using the KODAK RFS3570 slides scanner. The resolution was 96 ppi (pixels per inch), and 16 million colours were used.

Given that the processing and management of 16 million colours is a hard task, the colour palette should be reduced to a maximum of 256 categories. This reduction would allow for further data processing and for the calculation of texture indices, while, at the same time, it does not cause an essential problem, in terms of visual perception, taking into account that humans can perceive and assess the quality of a landscape, even based on black and white photographs (Smardon et al, 1986). Moreover, since measurement indices are created from scratch in this research, their application conditions are defined empirically in the most convenient way. From the available colour generalisation choices, the generalisation and standardisation selected was in 216 colour (6x6x6), using 6 levels for each of the basic colours/channels Red-Green-Blue. In this way, the colour category, whose value ranges from 0 to 215, constitutes information that is directly comparable to all photographs and is the arithmetic value "z" of each pixel. The generalisation was effected using the corresponding algorithm availed by the Idrisi GIS. The number of pixels is similar for all photographs, approximately 927X627 pixels.

Selection of quantitative indices, application method and results

Landscape patterns have been studied by various disciplines that investigate landscape from a greater ecological view, through maps and telescopic representations. The main characteristic of the landscape is the heterogeneity of its composing elements, and there are many indices that have been designed for describing this heterogeneity (Milne, 1990; Olsen et al, 1993; O'Neill et al, 1990; Turner et al, 1989; Turner, 1990a,b; Frohn, 1998). The main reasons that leaded to the development of indices for landscape patterns are (Frohn, 1998):

1. The fact that the diversity, complexity and the heterogeneity, in general, of the various patterns observed in a landscape, cannot be verbally and briefly described by an observer.
2. There are patterns that cannot be easily visible and perceivable by the human eye, even that of an expert.
3. By quantifying patterns and their changes, we are given the possibility to evaluate the influence of these factors in the evolution of ecological and environmental processes, in order to understand them and make predictions.

The aforementioned reasons add to the idea of using textural indices for the purposes of landscape visual analysis. This research effort contributes to the direction of the automated classification of the landscape's scenic quality from ground photographs. The use of ground photographs in measurements and researches related to landscape visual analysis has been and still is important, because photographs are the most common, economical and representative means of observing and studying landscape.

The indices selected to be examined are the most essential that prevail in landscape pattern analysis. These are the richness, fragmentation, diversity, dominance, contagion and complexity indices (Frohn, 1998; Hulse, 1991; Milne, 1990; O' Neill et al, 1990; Olsen et al, 1993; Turner et al, 1989; Turner, 1990a,b). It should be noted that these indices examine the heterogeneity that appears in each landscape photograph, by the colour categories that exist each time. Each photograph is regarded as a spatial unit of landscape and the indices are calculated from the total number of pixels that exist in each photograph. Table 1 presents the texture indices investigated and their calculation formula. For the sake of brevity, a codified symbolic name was defined for each index, that is presented in parenthesis. The Idrisi GIS package was used for the calculation of the values, and in the absence of readily available algorithms, these were designed and programmed.

The richness index (n) refers to the number of the present colour categories (Hulse et al, 1991). Its value was determined by the total number of the colours in the content of each photograph. The more colour categories present in one photograph, the greater the richness, namely the variety of the landscape depicted. In the case of this study the maximum possible sum of categories is known and common for all photographs (m_{max}=216).

The diversity index (h) is determined based on the percentage of the pixels belonging to each colour category (Table 1). The absolute maximum value of the index is: $H_{max} = \ln(m)$ and is observed when all colour categories (m) appear with the same percentage (Turner et al, 1989; Turner 1990a,b).

The dominance index (d) is also determined based on the total number of the colours categories in each photograph. "H_{max}" standardises practically the index, in case of comparing different landscapes with a different number of colour categories but in this study is not necessary to be used as the maximum possible number of colour categories remain the same in all photographs. When the values of this index are high, a landscape is dominated by one or some categories, while low values of the index suggest a landscape with many categories that appear with an almost equal probability. This index is zero, when all colour categories are presented with exactly the same probability, or when m=1 (O' Neill et al 1990, Turner 1990a, 1990b).

INDEX	MATHEMATICAL RELATION	EXPLANATION OF SYMBOLS
Richness (n)	n=m	*m* = the number of colour categories appearing in the photograph
Diversity (h)	$h = -\sum_{k=1}^{m} (P_k) \ln(P_k)$	P_k = the percentage of the pixels belonging to colour category *"k"* *m* = the number of colour categories appearing in the photograph
Dominance (d)	$d = H_{max} + \sum_{k=1}^{m} (P_k) \ln(P_k)$	$H_{max} = ln(m)$ P_k = the percentage of the pixels belonging to colour category *"k"* *m* = the number of colour categories appearing in the photograph
Fragmentation (f)	f=g	*g= number of appearing groups*
Contagion (c)	$C = -\sum_{i=1}^{m} \sum_{j=1}^{m} (Q_{i,j}) \ln(Q_{i,j})$	$Q_{i,j}$ = the percentage of category "i" neighbouring with category "j" *m* = the number of colour categories appearing in the photograph
Complexity (Dfm)	$Df_i = 2 \cdot \ln (P_i / 4) / \ln (A_i)$ $Dfm = (\sum_{i=1}^{g} (Df_i))/g$	A_i = the surface area of a group P_i = the perimeter of a group *g* = the number of the appearing groups

Table 1: Textural measurements

The fragmentation index (f) is equal to the number of the appearing groups; the greater the number of groups, the greater the fragmentation of the landscape depicted (Hulse, 1991). These groups derive from the different relative colour categories that appear irregularly and in various ways, resulting to the creation of many individual groups within the same object. There are usually thousands of groups appearing in one photograph that impede their processing.

The contagion index (c) refers to the tendency of the categories to appear as large groups. In theory, high values of the index show that there are many and small groups of objects, in which case the percentage of appearance of all possible adjacencies is almost equal. Respectively, as the values of the index decrease, the groups of objects become smaller in number and larger in size (O' Neill et al, 1990; Turner 1990a,b).

Complexity indices borrow the concept of fractal dimension from the theory of fractal geometry (Mandelbrot, 1982). Fractal geometry describes the physical structures that are characterised by an irregular sharp or fragmented form. Fractal geometry attributes to the structure of the total number of spatial points a number Df, which is called fractal dimension.

O'Neill R. et al, as well as many other researchers utilise the fractal dimension for their studies, in order to determine the geometric complexity of the landscape's patterns (Milne, 1990; O'Neill et al, 1990; Frohn, 1998). Various ways of calculating the fractal dimension Df, have been developed, but the index is usually determined by equation (1) (Olsen et al, 1993):

$$P = k \cdot A^{Df/2} \qquad (1)$$

where:

P = the perimeter of the closed line
A = the surface area surrounded by the closed line
k = a constant

Therefore, by logarithmising the surface area and the perimeter of each object of interest, the fractal dimension derives from the optimum slope of the line that is adjusted to these pairs. The higher the value of the index, the more complex the pattern.

In the case of raster digital data, the simplest item is the single pixel, where Df =1. Therefore, from equation (1) and with regard to a square pixel, k=4, the fractal dimension of the pattern of a group of pixels is determined by the equation (2) (Olsen et al, 1993; Frohn, 1998):

$$P = 4 \cdot A^{Df/2}$$

or

$$Df = 2 \cdot \ln(P/4) / \ln(A) \qquad (2)$$

where:

A = the group's surface area
P = the group's perimeter

In order to be applied, the previous complexity index presupposes the determination of the appearing groups in advance, so as to calculate the perimeter and the surface area of each appearing group, as required by equation (2). Therefore, this index (Df_i) was applied to each group of a photograph and then the weighted average was estimated from the total number of appearing groups (Dfm).

Measurement indices present a variety of correlation degrees, ranging from inexistent to very strong. Table 2 presents the descriptive data of all measurement indices and Table 3 their correlation. Of all indices, the fragmentation index (f) takes impressive values, ranging from 1267 to 17875, with an average value of 5879.95 groups. In other words, of the 216 possible categories, the colour categories that were used in each image are scattered in images in a way that they create thousands of groups. Therefore, it is obvious that in case millions of colours had been used, the calculation of this index would have been practically impossible.

Index	Average	Standard deviation	Minimum value	Maximum value
n	48.91	13.63	27	104
f	5879.95	3272.7	1267	17875
h	2.41	0.31	1.72	3.21
d	1.45	0.27	0.92	2.10
c	3.35	0.62	2.16	5.28
Dfm	1.58	0.08	1.39	1.81

Table 2: Descriptive data of quantitative indices.

	n	f	h	d	c	Dfm
n	1	0.716	0.556	0.313	0.702	0.580
f		1	0.579	0.010	0.829	0.772
h			1	-0.602	0.856	0.627
d				1	-0.313	-0.165
c					1	0.800
Dfm						1

Table 3: Correlation coefficients among measurement indices.

The dependencies among the textural indices have been observed also in other studies and applications of these indices in maps and satellite images (Frohn, 1998). The problem lies in which index to choose and which to ignore, and on the basis of which criteria. Some of these indices may be probably more appropriate for certain applications than others. The criterion in this study is the effective classification of the landscape's qualitative characteristics to the maximum extent possible.

EXAMINING THE ABILITY OF THE SELECTED QUANTITATIVE INDICES IN THE CLASSIFICATION OF THE LANDSCAPE'S SCENIC QUALITY

The following investigation took place with the aim to address the question of whether and to what extent the textural measurement indices selected and examined in this research, either individually or in combination, may assess the final category of the landscapes depicted, with regard to their scenic quality.

The classification was made using linear discrimination method and with the use of the SPSS statistical package. All the classification methods have been developed in order to classify observations, for which we do not know in advance the group they belong to. However, they are frequently used in order to verify the accuracy of a classification. This means that they are applied to observations whose grouping is known, so as to calculate the percentage of the correctly classified observations. This percentage verifies the accuracy of the process and the separation degree of the groups. This is the purpose of the following analysis. The observations, in our case the photographs, are already classified in three categories (C1: Indistinctive, C2: Common, C3: Distinctive) by the scientific opinion of a seven-member group who worked in the framework of the research programme "SCAPEVIEWER". These persons had a good theoretical background in terms of landscape visual analysis. A sample of 108 ground photographs was used for this purpose, which depicted various landscape types, from different places, mainly in Greece. The photographs were taken at various periods, mainly for teaching purposes in issues related to landscape analysis variables. From the sample of 108 photographs, 18 photographs were classified in the first category, 35 in the second and 55 photographs in the third landscape category. An example of each landscape category is presented in Figure 1. Thus the percentage of the correctly classified observations using textural measures and linear discrimination method shows the ability of the measurement indices to classify automatically the scenic quality of a landscape.

The process mentioned above was followed by adopting two different classification techniques. In the first technique all measurement indices took place at the same time as distinctive variables, without having examined in advance their distinctive ability. In the second technique, a stepwise selection of the variables was chosen according to their distinctive ability, which was defined using the Mahalanobis distance as a criterion (Therrien, 1989). According to this technique, a variable that maximises the distance between two successive groups is selected in each step. In order to introduce a variable in the equation, the partial ratio F should be higher than a critical value that corresponds to the distribution value F for a certain significance level (α). For this research, $\alpha=0.05$. The ratio F practically quantifies the distinction achieved by a variable, after taking into account the distinction of groups that has taken place already, using the variables that were previously entered.

(a) (b) (c)

Figure 1: Example of: a) indistinctive category of landscape, b) common category of landscape, c) distinctive category of landscape.

Table 4 presents the percentages of successful classification that were achieved by each measurement index individually as well as in combination. The results from this investigation showed that there are textural measurement indices, such as the fragmentation and the complexity indices, that can correctly classify on their own more than 50% of the observations. The richness, diversity and dominance indices classified in combination 57.41% of the cases, while the major percentage of successful classification achieved was 62.04%, with the use of all textural measurement indices. When applied, the stepwise method chose only one variable for the classification model, i.e. the fragmentation index (f).

Indices	Percentage of successful classification
n	43.52%
h	50.00%
d	50.00%
c	50.93%
Dfm	52.78%
f	56.48%
n,h,d	57.41%
n,h,d,f,c,Dfm	62.04%

Table 4: Percentages of successful classification from the various models that were investigated by linear discrimination.

The results are quite encouraging , although not high regarding successful classification percentage, taking into account that the textural indices derive objectively from mathematical equations and not subjectively from personal evaluations. Therefore textural indices seem to provide a possibility for a reliable and objective classification. It is obvious that the lower the number of the quantitative indices that are used in the classification model, the better the model's functionality. However, the sample of the ground photographs used was small and therefore does not allow for the drawing of conclusions on a possible inappropriateness of certain quantitative indices, by the fact that they were not used in one of the classification models. The remaining indices may probably be used in another investigation with a bigger sample of photographs. Furthermore, in order to develop a reliable classification model, the sample of photographs should be enriched and the research continued.

DISCUSSION

The scientific approach of the landscape's scenic quality and its classification into categories is to date indirect and takes place through the application of Geographical Information Systems that presuppose the existence of a respective computerised and mechanical equipment, qualified personnel, cartographic backgrounds that are rarely available for the multitude of the variables examined (relief, vegetation, waters). The US Forest Service has developed since 1974 an evaluation methodology that assesses indirectly the manageability of the landscape. Also, an extensive bibliography presents various and sometimes complex techniques (Ananiadou, 1982; Daniel et al, 1976; Miller et al, 1992; Smardon et al, 1986; Tsouchlaraki, 1997; US BLM, 1980; USDA, 1973; USDA, 1974; USDA 1995).

The disadvantages of most techniques and methods of determining landscape management potential arise due to a number of factors. These often include a sub-optimal dependence on the experience of the evaluator, a time-consuming examination of the large number of attributes and interactions, and the increasing complexity of landscape evaluation as the number of attributes increases. Besides there are many divergent views even among experts. This justifies the demand for creating a conventional and common method for evaluating and classifying a landscape's visual quality.

The aim of this study was the investigation of quantitative indices for evaluating and classifying the landscape's scenic quality using ground digital photographs. The advantages of using ground photographs in landscape visual analysis are very important; considering that maps, aerial photographs and satellite representations are not what a human observes when moving in a landscape. Issues of perspective, relative position, movement, direction, lighting, seasonality are depicted on a ground photograph and help at interpreting perception.

Furthermore, this study attempted to evaluate and classify the recorded scenic quality, using six textural measures and applying linear discrimination method. The six indices that were selected for application to the sample of the ground photographs, examine the heterogeneity that appears in each landscape photograph, by the colour categories that exist each time. The results from this investigation were quite encouraging for the continuance of the research. The quantitative indices seem to be sensitized in general in the qualitative characteristics of the landscape and can be used for the classification in generic categories with regard to its scenic quality.

Hence, the object-oriented analysis of photographs may probably lead to new and useful quantitative indices. There are many classification algorithms that attempt to cluster the appearing categories of an image. These techniques are based on frequency histograms, but they usually refer to satellite image classification. With regard to ground photographs, only few attempts have been made so far (Vailaya et al, 1998; Vailaya et al, 2001). What is challenging in these techniques is how to group images into semantically meaningful categories based on low-level visual features of the images or in other words to cluster images into groups of visually similar images based on colour and texture features. As mentioned above such efforts may lead to new and useful quantitative techniques for the classification of landscape scenic quality.

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