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Tree risk assessment in the urban environment: Investigating relationships between measurement variables through multivariate statistical analyses

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ABSTRACT: *As an important part of the urban environment, trees have certain risks while living in harmony with humans. The risks are mainly due to structural defects and deviations from their typical shape. Tree risk management involves the process of inspecting and assessing trees for their potential to injure people or damage property. The objective of the study is to develop a tool for tree risk assessment in the urban environment, as well as to present and analyze the results through appropriate multivariate statistical methods. The specific tool can be a useful "weapon" in the hands of geotechnical* municipal *officers regarding the risk assessment of trees that growing in the cities, as well as for making the appropriate management decisions. However, it would be useful to carry out other such records and evaluations on suitable samples of urban trees, to revalidate the tool and make possible improvements.*
KEY WORD*: Urban greenery, tree risk assessment, Thessaloniki*

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I. INTRODUCTION

As an important part of the urban environment, trees have certain risks while living in harmony with humans. The failure of trees in extreme weather may cause casualties and damage to public and private (Haibin et al, 2022). So, in many cases, trees show various structural defects and deviations from their typical shape, a fact that made them dangerous (Vassios, 2023a). In addition, important variables that affect the stability of trees are the height, the slenderness index, as well as variables related to the tree crown (Kontogianni et al., 2011). Many studies have been carried out about tree risk assessment (Kolarik, 2003; James et al., 2006; Coder, 2007; Kontogianni et al., 2011) which however, require specialized knowledge and instruments, while generally being time-consuming. The methods of assessing the risk of trees vary. Basic methods are (a) Visual Tree Assessment, (b) Systematic Tree Risk Assessment and (c) Risk Assessment Based on Tree Mechanics (Haibin et al, 2022).

Risk management is a well-established concept in the management of public spaces. Tree risk management involves the process of inspecting and assessing trees for their potential to injure people or damage property. The tree risk management plan should be fully integrated with tree planting and tree pruning programs, and share a common goal of promoting healthy and structurally sound trees. The main ways to reduce or eliminate tree risk focus on (i) removing the "target", (ii) pruning and (iii) cutting down the tree (Pokorny, 2003).

II. RESEARCH OBJECTIVES

The objective of the study is to develop a tool (form) for tree risk assessment in the urban environment, as well as to present and analyze the results through appropriate multivariate, mostly, statistical methods. With this tool, the assessment can be done quickly and easily without the use of specialized and complex instruments, but macroscopically and visually.

III. RESEARCH METHODOLOGY AND DATA ANALYSIS

The tool (form) includes 7 relatively easily assessable and measurable variables related to structural defects, deviations from standard shape, age, robustness, crown and also, slenderness index (H/D). Variables are measured on an ordinal scale of 1 to 5. 1 corresponds to findings of zero/negligible risk, 2 to findings of mild risk, 3 to findings of moderate risk, 4 to findings of high risk, while 5 to findings of very high risk. Further information and instructions are given for the convenience of the evaluator for slope, age and height to diameter ratio. The sum of the score of each variable constitutes the total risk score of each tree (VAR8). From a score of 15 and above, interventions on the tree are considered, from mild pruning to cutting, always depending on the individual score and in combination with the overall macroscopic image of the tree, the species, the total growth space and the general conditions as well.

In addition, in the form there is the variable "Characterization of risk" (VAR9) with which the evaluator assesses the risk in general based on the overall macroscopic image of the tree, combined with the type of the tree, the total growing space, the general conditions of the space, as well as the stability of the tree. The values of the variable are 1: Negligible, 2: Low, 3: Moderate, 4: High and 5: Very high. Also, there is the "Recommended interventions" variable (VAR10). The values of the variable are 1: No intervention, 2: Minor pruning, 3: Crown reduction, 4: Hard pruning and 5: Cut down.

A total of 101 trees (elms/*Ulmus* sp.) growing on Stratou Avenue were evaluated. Stratou Avenue is a central road of the Municipality of Thessaloniki and most of the trees show strong defects and deviations mainly due to the chronic infestation by the *Galerucella luteola* insect. The evaluations of the trees were carried out in August 2023.

Data handling and analyses were conducted using the IBM SPSS Statistics 21. More specifically, statistical analysis included:

Descriptive statistics. Descriptive statistics deal with methods of organizing and presenting data (Anderson & Finn, 1996).

Reliability. The reliability of a measuring tool relates to the consistency with which it measures the concept that it claims to measure. One of the most common reliability coefficients is Cronbach's alpha (Bland & Altman, 2002).

Validity. The term validity refers to whether a questionnaire measures what it is intended to measure and how well it measures (Babbie, 2011).

Cluster analysis. Cluster analysis is about identifying groups with similar characteristics (Manly, 1994).

Mann-Whitney U. The non-parametric Mann-Whitney U test is used when the groups being tested are 2 and independent of one another and do not follow the normal distribution (Dawson and Trapp, 2004).

Categorical regression. Categorical regression quantifies categorical variable data by assigning numerical values to the categories for the purpose of the best linear regression of the transformed variables (Van der Kooij and Meulman, 1997). With categorical regression it is possible to predict values of a dependent variable for any combination of independent variables (Androulidakis and Siardos, 1999).

IV. FINDINGS

Descriptive statistics:

The ratings of 101 trees are presented in total in Table 1.

Variable	**1**	**2**	**3**	**4**	**5**
	Percentage (%)				
Cavities (VAR1)	68.3	6.9	22.8	2.0	0.0
Crown asymmetry/crown size (VAR2)	27.8	45.5	25.7	1.0	0.0
Other defects (bend/warp, forks, twists, base swelling etc.) (VAR3)	9.9	67.3	22.8	0.0	0.0
Vitality/robustness (VAR4)	4.0	56.4	34.6	5.0	0.0
Deviation from the vertical axis (VAR5)	69.3	27.7	3.0	0.0	0.0
Age (VAR6)	1.0	36.6	62.4	0.0	0.0
Slenderness index (H/D) (VAR7)	13.9	44.5	41.6	0.0	0.0

Table 1: Trees' ratings

The total score (VAR8) is depicted in Figure 1.

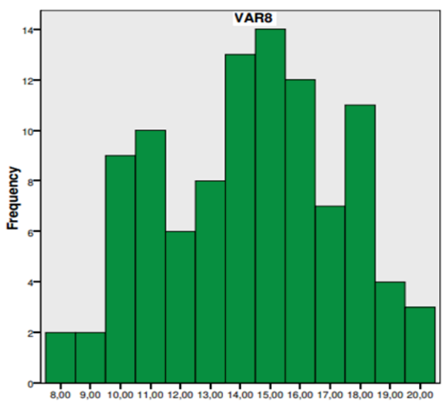

Figure 1: VAR8

VAR9 and VAR10 are depicted in Figure 2.

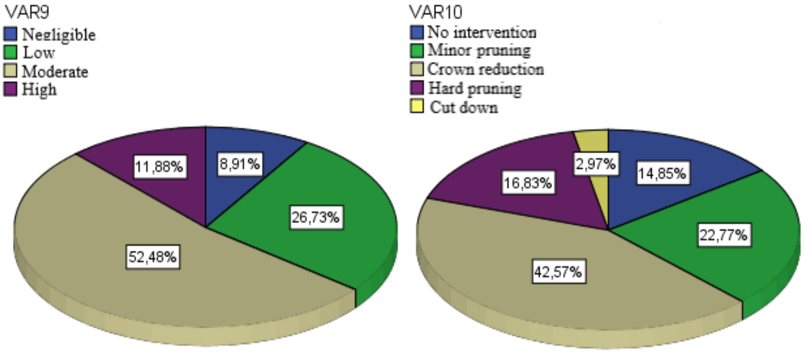

Figure 2: VAR9 and VAR10

Reliability analysis/Construct validity:

The tool was tested for its reliability and validity. Concerning the reliability, the entire tool has a Cronbach's alpha coefficient of 0.759 which is acceptable. The construct validity check was performed by using the Factor Analysis. The extraction of factors was done by Principal Component Analysis and the rotation of the axes by Varimax Method. The analysis met the appropriate factorization criteria (KMO, Bartlett's Test of Sphericity, Communalities). A 3-dimensional solution (3 factors), gave characteristic values of 2.125, 2.010 and 1.359 respectively, which state that 30.36% of the explained variance is explained by the first factor, 28.72% by the second and 19.41% by the third, accounting for 78.49% of the total explained variance. The first factor can be called "Dimensions & asymmetries" and shows high loadings from the variables VAR2, VAR6 and VAR7. The second factor can be called "Robustness/health" and shows high loadings from the variables VAR1 and VAR4. The third factor can be called "Deviations & structural defects" and shows high loadings from the variables VAR3 and VAR5. The 3 factors explain a very large percentage of the total variance, while each variable loads highly on only one factor. In more detail, the results of reliability and validity were presented in a previous study (Vassios, 2023a).

Cluster analysis:

The variables chosen to perform the cluster analysis are VAR1, VAR2, VAR3, VAR4, VAR5, VAR6 and VAR7. Two clusters emerged. Cluster 1 includes 55.4% of the trees and cluster 2 includes 44.6% of the trees (Figure 3).

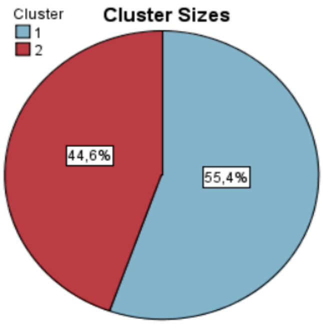

Figure 3: Cluster analysis

Cluster 1 includes trees with a higher degree of risk concerning VAR8, VAR9 and VAR10, compared to cluster 2 (Figure 4).

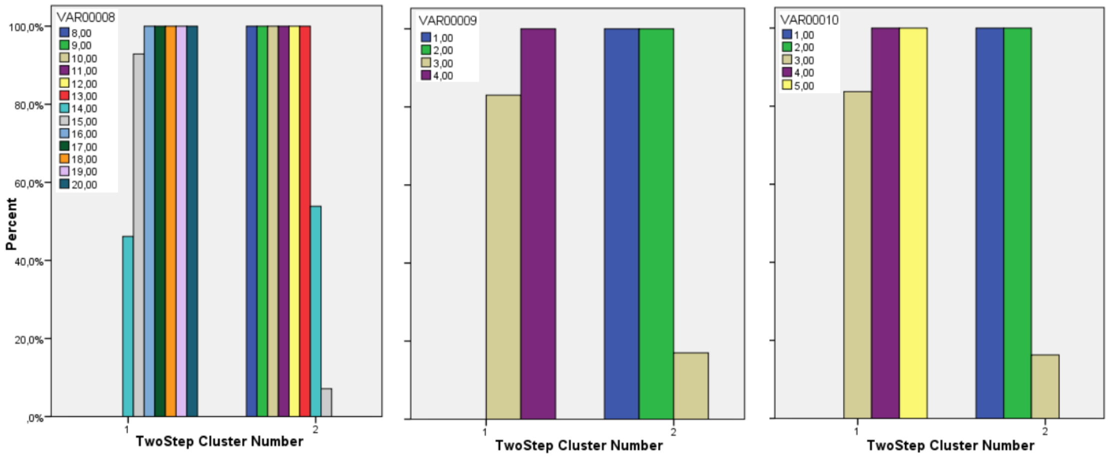

***Figure 4: Distribution of variables VAR8, VAR9 and VAR10 by* cluster**

In a corresponding statistical analysis, where for the cluster analysis were used variables VAR8, VAR9 and VAR10, a slightly larger cluster emerged with similar characteristics but additionally including all trees with a score of 15, the majority of trees with a score of 14 and a few with a score of 13 (Vassios, 2023b). More specifically, cluster analysis using variables VAR1, VAR2, VAR3, VAR4, VAR5, VAR6 and VAR7 compared to cluster analysis using variables VAR8, VAR9 and VAR10, yielded somewhat more distinct clusters as to how dangerous the trees are and also the operations that must be done to remove the risk.

Mann-Whitney U:

With Mann-Whitney U test, it was investigated whether there is a statistically significant difference (at significance level 0.05) between the values of the variables VAR8, VAR9 and VAR10 and the variable "Two step cluster" according the cluster analysis.

VAR8: Statistically significant differences emerged between the two clusters (sig<0.001, Mann-Whitney U=33.500, Z=-8.425). The mean rank of the first cluster is equal to 72.90, while the mean rank of the second cluster is equal to 23.74.

VAR9: Statistically significant differences emerged between the two clusters (sig<0.001, Mann-Whitney U=198.000, Z=-7.945). The mean rank of the first cluster is equal to 69.96, while the mean rank of the second cluster is equal to 27.40.

VAR10: Statistically significant differences emerged between the two clusters (sig<0.001, Mann-Whitney U=126.000, Z=-8.154). The mean rank of the first cluster is equal to 71.25, while the mean rank of the second cluster is equal to 25.80.

Categorical regression:

In this analysis, VAR1, VAR2, VAR3, VAR4, VAR5, VAR6 and VAR7 are the independent variables while the Cluster number is the dependent variable. Categorical regression yielded a multiple correlation coefficient R value of 0.935 and a multiple determination coefficient R^2 of 0.874 indicating that 87.4% of the variance in the transformed values of the dependent variable is explained by the transformed values of the independent variables. The analysis of variance for a significance level α equal to 0.001 gave an F value equal to 55.954 which corresponds to a zero significance level, showing the very good fit of the model to the data.

At a significance level 0.01, the absence from the equation of variables VAR2, VAR3, VAR4 and VAR5, with the presence of the others, does not reduce the exploratory capacity of the equation. The rest variables are statistically significant (sig<0.01). The standardized regression coefficients are all negative. VAR6, VAR7 and VAR1 have the bigger coefficients. VAR2, VAR3, VAR4 and VAR5 have the smaller coefficients. Table 2 presents the standardized coefficients along with the F values.

	Standardized Coefficients	**df**	**F**	**Sig.**
	Beta			
VAR1	-0.216	1	9.025	0.003
VAR2	-0.035	2	0.237	0.789
VAR3	-0.091	3	2.185	0.095
VAR4	-0.081	2	0.996	0.373

VAR5	-0.045	1	0.590	0.444
VAR6	-0.490	1	19.344	0.000
VAR7	-0.331	1	15.202	0.000

Table 2: Standardized coefficients and F values

Concerning the correlation coefficients, all of them are negative. VAR6 and VAR7 have the higher correlation coefficients and then VAR1. Regarding importance, VAR6 has the higher value and then VAR7 and VAR1. Table 3 presents the zero-order correlation coefficients, partial correlation coefficients, part correlation coefficients, importance and tolerance values of the independent variables.

	Correlations			**Importance**	**Tolerance**
	Zero-Order	**Partial**	**Part**		
VAR1	-0.610	-0.344	-0.130	0.151	0.362
VAR2	-0.268	-0.076	-0.027	0.011	0.595
VAR3	-0.417	-0.225	-0.082	0.044	0.810
VAR4	-0.479	-0.150	-0.054	0.045	0.440
VAR5	-0.157	-0.105	-0.038	0.008	0.713
VAR6	-0.866	-0.675	-0.325	0.486	0.441
VAR7	-0.675	-0.549	-0.233	0.256	0.496

Table 3: Correlations, importance and tolerance

The transformation plots of Cluster number, VAR1, VAR6 and VAR7 are depicted in Figure 5.

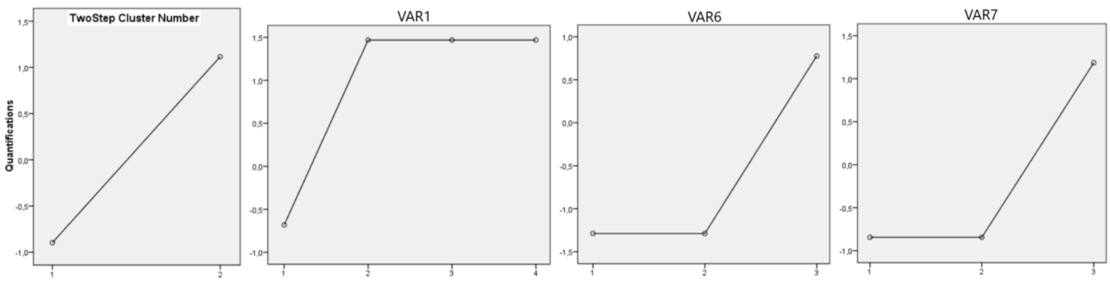

Figure 5: Transformation plots

V. DISCUSSION

According to the results of the study, it appears that:

- The specific form can be a useful "weapon" in the hands of foresters and agronomists who deal with urban greenery regarding the risk assessment of trees that growing in the cities, as well as for making the suitable management decisions. Of course, the appropriate training of the staff should be preceded.

- Most trees have a score of 15. The range is from 8 to 20. Only 3% have the highest score. In general, these trees show moderate risk findings. Half of them have a score of 15 and above, which means that some operations will have to be done on them, from mild to severe pruning mainly, while those with a high score should be scrutinized.

- The results are highly encouraging regarding the reliability and validity of the tool. More specifically, the tool shows satisfactory reliability, as well as 3 very distinct factors which strengthen its construct validity. Nevertheless, it would be useful to carry out other such recordings and evaluations in a representative sample of an appropriate size in all tree lined avenues and streets of the Municipality of Thessaloniki in order to recheck the tool and make possible improvements and also to be able to generalize the results.

- According to the cluster analysis, all the trees with a score of 16 and above are characterized by high to very high risk and are required as interventions, mostly pruning and in 3% of cases cutting. In many cases, the same applies to trees with a score of 14 and 15. This was roughly the initial estimation of the score above which interventions on trees are required. Cluster 1 includes all trees with a score of 16 and above, the majority of trees with a score of 15 and some with a score of 14. The trees of the first cluster present a higher risk than those of the second cluster. Also, statistically significant differences emerged between the two clusters and variables VAR8, VAR9 and VAR10.

- Concerning the categorical regression, the variables VAR6 and VAR7 are the ones that influence the predictive model to a great extent and VAR1 secondarily. So, the trees belonging to the first cluster show a high score in the specific 3 variables. The other 4 variables show very little predictor importance and therefore do not affect the regression model. In conclusion, the trees of the first cluster are older and taller compared to trees of the second cluster, with higher slenderness index. This is apparently due to the fact that many trees were recorded with findings of moderate risk regarding VAR6 and VAR7. As for VAR1, no safe conclusions can be drawn as to how much it affects, as too many trees with few cavities have been recorded, and so there is not an even distribution across all scale gradations.

- Stratou Avenue provides very good conditions for the growth of trees as the width of the sidewalk is large, while cars are not parked under the trees. Also, there are no houses at all. Therefore, the risk rating is more lenient than if the trees were growing in a spot with more limited growth space.

-As future research, it is proposed to re-validate the tool by adding two new variables that will be related to the location of the tree as well as its growing space so that it is even more accurate for trees that grow near buildings and on narrow sidewalks. Furthermore, adding those variables will likely increase the reliability of the tool even more.

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