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District Selection for Geotechnical Settlement Suitability Using GIS and Multi Criteria Decision Analysis: A Case Study in Denizli, Turkey

Erdal Akyol, Mutlu Alkan, Ali Aydin

Abstract**—**Multi criteria decision analysis (MDCA) covers both data and experience. It is very common to solve the problems with many parameters and uncertainties. GIS supported solutions improve and speed up the decision process. Weighted grading as a MDCA method is employed for solving the geotechnical problems. In this study, geotechnical parameters namely soil type; SPT (N) blow number, shear wave velocity (Vs) and depth of underground water level (DUWL) have been engaged in MDCA and GIS. In terms of geotechnical aspects, the settlement suitability of the municipal area was analyzed by the method. MDCA results were compatible with the geotechnical observations and experience. The method can be employed in geotechnical oriented microzoning studies if the criteria are well evaluated.

Keywords**—**GIS, spatial analysis, multi criteria decision analysis, geotechnics.

I. Introduction

INCREASING uncertainties in business and administration parallel to the globalization make hard the decision process. This process may be intuitive or analytical [1]. These difficulties are being faced both in social and technical areas and involve many hesitations and parameters. Multi criteria decision analysis (MCDA) is used very effectively for solving that kind of problems. The parameters have relative importance and experience is significant as well as data. The employed parameters could be qualitative and quantitative [2]-[5].

Geographical information systems (GIS) are an effective and popular tool to collect, to assess, and to visualize the geographical data. The problems mentioned above can be solved more efficiently when it is engaged with GIS. The combination of these two methods is called spatial multi criteria decision analysis (SMCDA) and it is very common in practice [6]-[10]. SMCDA is also engaged in geotechnical engineering like landfill selection [11], [12], land use and urban planning [13], [14] and microzoning-landslides [15]-[17].

In this study geotechnical settlement suitability is analyzed in the districts of the Denizli municipal area. Some common geotechnical parameters are employed for the analysis measured in laboratory and in-situ.

Erdal Akyol is with Pamukkale University, 20070 Denizli, Turkey (phone: +90-258-2963379, fax: +90-258-2963460, e-mail: eakyol@pau.edu.tr).
Mutlu Alkan is with Denizli Cosmopolitan Municipality, 20010 Denizli Turkey (e-mail: mutlualkan@gmail.com).
Ali Aydin is with Pamukkale University, 20070 Denizli, Turkey (phone: +90-258-2963370, fax: +90-258-2963460, e-mail: aaydinl@pau.edu.tr).

II. Material and Method

The study covers the Denizli municipal area. The area is in a horst-graben system at SW Turkey (Fig. 1A). Quaternary and Neogene units cover the all area as seen in Fig. 1B [18].

Some geological and geotechnical parameters are employed for urban planning studies. Here in this study those are taken from PAU/JEO and it involves 155 geotechnical boreholes (Fig. 2). The average foundation depth is accepted two meters and all the parameters are calculated for that level. The employed parameters in this study are soil type, standard penetration test (SPT) number of blows (N), shear wave velocity (Vs) and underground water level (UWL).

In this study weighted grading, one of the MCDA, is employed. Each criterion is compared with each other based on their priorities and a pairwise matrix is formed. Then eigenvectors and consistencies are calculated. MapInfo®, as a GIS software is engaged for analysis and visualization of the obtained data.

III. Settlement Suitability Analysis

A. Geotechnical Parameters

The following common and popular geotechnical parameters are employed in this study:

i. Soil type (based on Unified Soil Classification)
ii. Underground water level (UWL – meter)
iii. Standard Penetration Test (SPT) blow number (N)
iv. Shear wave velocity (Vs – m/s)

To standardize the parameters they are graded into ten groups. The intervals and corresponding values of the soil type, underground water level (UWL), and standard penetration test (SPT) blow number (N) and shear wave velocity (Vs) are given in Tables I-IV. Soil type is based on Unified Soil Classification. The higher points show higher geomechanical characteristics. SPT and Vs intervals are 5 and 200 m/s respectively. Obviously the higher values indicate firm and solid soil conditions. UWL values are increased at every one meters. In this study threshold value of risky UWL is 10 meters that has the lowest grade. The list of the districts is given in Table V.

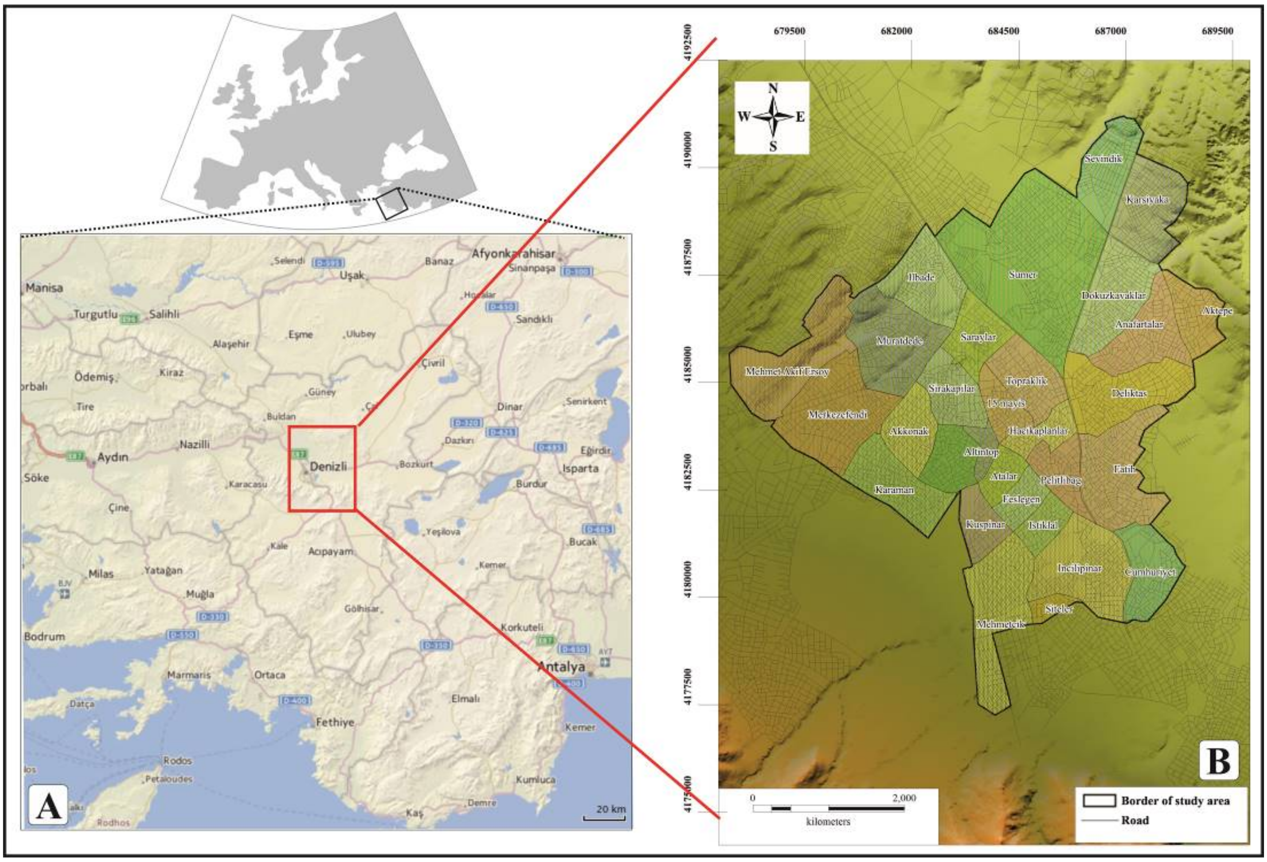

Fig. 1 Location map of the study area (A: Here Maps) the districts (B)

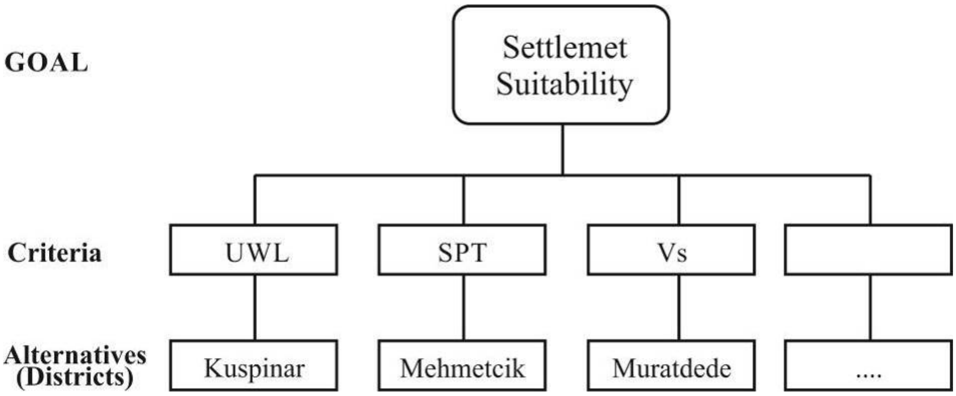

Fig. 2 Structure of multi criteria decision

TABLE I
SOIL TYPES AND GRADES

Soil type	Grade
Pt (turba)	1
OL-OH	2
CL	3
ML-MH	4
SM	5
SC-GC	6
GM	7
SP-GP	8
SW-GW	9
Rock	10

TABLE II
SPT AND GRADES

SPT	Grade
1-5	1
5-10	2
10-15	3
15-20	4
20-25	5
25-30	6
30-35	7
35-40	8
40-45	9
>45	10

TABLE III
VS AND GRADES

Vs	Grade
0-200	1
201-300	2
301-400	3
401-500	4
501-600	5
601-700	6
701-800	7
801-900	8
901-1000	9
>1000	10

TABLE IV
UWL AND GRADES

UWL	Grade
0-1	1
1-2	2
2-3	3
3-4	4
4-5	5
5-6	6
6-7	7
7-8	8
8-9	9
>9	10

B. MCDA

The intensity scale of Saaty (1980) was used and the rating scales were determined based on the geotechnical experience of the authors. The ratio matrix was formed and intensity importance values were listed in Table VI. Normalizing the weights was figured out by dividing the weights to sum of column (Table VII).

TABLE V
LIST OF THE DISTRICTS

No	District Name
1	Akkonak
2	Aktepe
3	Altintop
4	Anafartalar
5	Atalar
6	Cumhuriyet
7	Degirmenonu
8	Deliktas
9	Dokuzkavaklar
10	Fatih
11	Feslegen
12	Hacikaplanlar
13	Ilbade
14	Incilipınar
15	Istiklal
16	Karaman
17	Karsiyaka
18	Kuspinar
19	Mehmet AkifErsoy
20	Mehmetcik
21	Merkezefendi
22	Muratdede
23	OnbesMayis
24	Pelitlibag
25	Saraylar
26	Sevindik
27	Sirakapılar
28	Siteler
29	Sumer
30	Topraklik

TABLE VI
RELATIVE IMPORTANCE WEIGHTINGS

	Soil type	UWL	SPT	Vs
Soil type	1	1/3	1/9	1/5
UWL	3	1	1/7	1/3
SPT	9	7	1	3
Vs	5	3	1/3	1
Sum of column	18,00	11,33	1,59	4,53

TABLE VII
PRIORITY VECTOR VALUES OF THE CRITERIA

	Soil type	UWL	SPT	Vs	Priority vector
Soil type	1/18	1/34	7/100	3/68	0,05
UWL	1/6	3/34	1/11	5/68	0,10
SPT	1/2	21/34	46/73	45/68	0,60
Vs	5/18	9/34	17/81	15/68	0,24
Sum of column	1	1	1	1	1

"Consistency Ratio" (CR) is 0.10. CR, maximum eigenvalue (Λ_{max}) and randomness index (RI) were computed. Then the Consistency Index (CI): (1).

$$CI=(\Lambda_{max} - n)/(n - 1)= 0,0298 \quad [1]$$

where CI : Consistency index
Λ_{max} : Maximum eigenvalue
n : Number of criteria

Randomness Index (RI) is a value based on the number of criteria (n) and it is equal to 0.9 as suggested by Saaty [19]. "Consistency Ratio" (CR) is the ratio of Consistency Index (CI) to Randomness Index (RI) and it is equal to 0.033. A weighted value has been calculated by multiplying the eigenvector of each criterion to the defined points of this criterion in the alternatives. The final point of the borehole location was computed by summing of these values at each locality and the map of settlement suitability is based on those.

C. Settlement Assessment

The computed values were divided into five zones and they were described as follows: very favorable, favorable, moderate, unfavorable, very unfavorable. The distribution of the zones is illustrated in Fig. 3. "*Very favorable*" and "*favorable*" districts on this map are S, SW and N of the study area. Firm Neogene units, like rock looking fan sediments with high bearing capacity are outcropped on these areas. Not surprisingly, UWL is very deep (>10 meters) at those parts. That means they are appropriate for the construction. "*Very unfavorable*" and "*unfavorable*" districts are located around central part of the study area where the altitude is lower. Therefore, the soils have loose structure with higher fine contents, shallow UWL (<10 meters) and low bearing capacity. In other words this part of the municipal area is not appropriate for the construction. The moderate districts lie between these two groups.

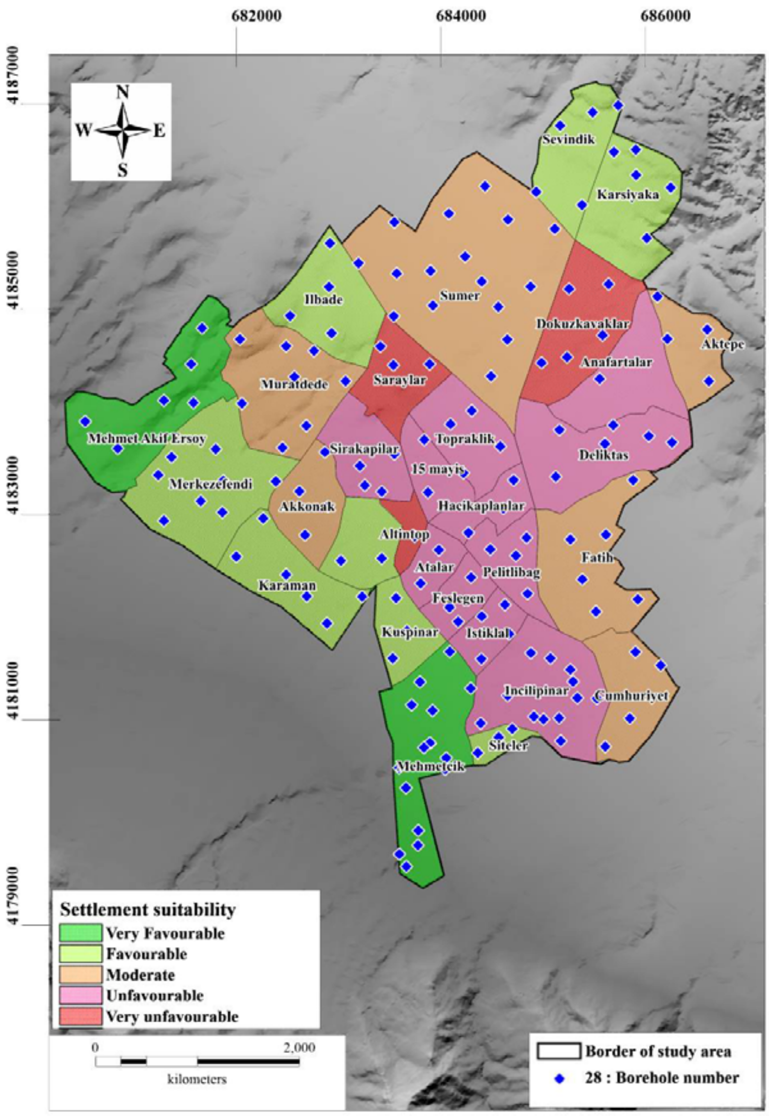

Fig. 3 Map of settlement assessment

IV. CONCLUSION

SMCDA was employed to assess the geotechnical settlement suitability of the Denizli municipality districts. Common and popular geotechnical parameters namely soil type, UWL, SPT and Vs have been used for the zoning. These data were classified into 10 groups and graded based on these classifications. The area was divided into five zones using by weighted values: very favorable, favorable, moderate, unfavorable and very unfavorable.

"*Very favorable*" and "*favorable*" districts are located at S, SW and N of the study area. Firm Neogene units, like rock looking fan sediments with high bearing capacity are outcropped on these areas. Not surprisingly, UWL is very deep (>10 meters) at those parts. That means they are appropriate for the construction. "*Very unfavorable*" and "*unfavorable*" districts are located around central part of the study area where the altitude is lower. Therefore, the soils have loose structure with higher fine contents, shallow UWL (<10 meters) and low bearing capacity. In other words this part of the municipal area is not appropriate for the construction. The moderate districts lie between these two groups. The results validate that the SMCDA descriptions are matching to the geotechnical observations. The study proved that the method can be employed in geotechnical assessment studies.

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