MULTIPLE CRITERIA ANALYSIS FOR FLOOD VULNERABLE AREAS

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Abstract:

Cell-based Multicriteria Evaluation (MCE) methods are used to analyse the flood vulnerable areas. Geographical Information System (GIS) is integrated with Multicriteria Decision Analysis (MCDA).

In ArcView 8.2 all data are stored and the criterion values are generated for all criteria that are seen as map layers. The criterion maps are converted into grids and the mathematical processes are applied to the criteria with MapCalculater. *Ranking Method* which is used to rank the every criterion under consideration in the order of the decision maker's preferences and *Pairwise Comparison Method* (PCM) which is designed as a user interface to calculate the weights from input preferences with Visual Basic Application (VBA) program embedded in ArcGIS 8.2 are used.

At the end of the application, the composite maps are created using Boolean Approach, Ranking Method, PCM and Ordered Weighted Averaging (OWA) Method –including fuzzy concept on standardization of the criterion values- are compared.

Keywords: Floods, GIS, Analysis, Decision Support, Disaster, Multicriteria Evaluation (MCE), Vulnerability, Uncertainty.

1. Introduction

Natural disasters such as floods have constituted a major problem in many developing and developed countries. In recent years, the growth of population and diffusion of settlements over hazardous areas have sharpened the impact of the floods worldwide. Floods have caused immense economic and social losses, mainly as a result of unplanned urbanization, uncontrolled population density and not strictly inspected construction by authorities. Floods kill thousands of people and destroy billions of dollars worth habitat and property each year.

The main aim of this study is to generate a composite map for decision makers by using some effective factors causing flood. The study reviewed the role of GIS in decision-making and then outlined the evaluation approach for many criteria in decision process. The design of multicriteria environment attempted to use a variety of evaluation techniques to data from GIS and presented them in a manner familiar to decision makers. By integrating the evaluation techniques with GIS, it was intended that the effective factors would be evaluated more flexibly and thus more accurate decision would be made in a shorter time by the decision makers. By evaluating the criteria, the values of the criteria were classified to explain the opinions and preferences. Boolean and WLC approach were used in integrating MCE with GIS. The uncertain knowledge in multicriteria decision making was held by considering standardized criteria as fuzzy measures, where fuzzy set theory was emphasized. Different weights were given to the criteria in fuzzy extent with the Ordered Weighted Averaging (OWA) method. Finally all the composite maps created with these approaches were compared with the flooded area obtained from a hydraulic model.

In the analyses, some of the causative factors for flooding in watershed are taken into account as annual rainfall, size of watershed, basin slope, gradient of main drainage channel, drainage density, land use and the type of soil. A case study of flood vulnerable areas determination in Bartın Basin in the West of Black Sea Region in Turkey is employed to illustrate the different approaches.

2. Methodology

Basically two phases are applied in this study to analyse the flood vulnerability: to determine the effective factors causing floods and to apply several approaches to MCE in a GIS environment to evaluate in finding the flood vulnerable areas.

The first step in determining the factors is on the basis of an analysis of existing studies and knowledge. Here, judgments made by experts on hydrology and hydraulics can be applied. These factors are used as criterion separately. A criterion is a basis for a decision that can be measured and evaluated (Eastman et al., 1995). Then map layers representing the criteria and referring to as criterion maps are produced. A GIS application is used for managing, producing, analyzing and combining spatial data. The data needed in this study are produced from collected or existing data by using different kinds of spatial functions and analysis.

To evaluate the flood vulnerable areas, two approaches are used: Boolean Approach and Weighted Linear Combination (WLC) Approach. While Boolean Overlay is used for Boolean Approach, in WLC approach two of many methods are used: Ranking Method and Pairwise Comparison Method.

2.1 Boolean Overlay

The vulnerable areas are produced by numerically overlaying a map layer describing the study area. This overlay is carried out as a Boolean overlay. All criteria are combined by logical operators such as intersection (AND) and union (OR).

2.2 Ranking Method

In Ranking Method, every criterion under consideration is ranked in the order of the decision maker's preference. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance for causing flooding. The inverse ranking was applied to these factors. 1 is the least important and 8 is the most important factor as in Pramojanee et al. (2001). The criteria with their raw data were typically noncommensurate. To make the various criterion maps comparable, a standardization of the raw data was usually required (Malczewski, 1999a; Lin et al., 1997; Jiang and Eastman, 2000; Eastman et al., 1995). Linear Scale Transformation was adopted as a standardization procedure, because it is the most frequently used method for transforming the input data into commensurate scale. 0 is the worst-standardized score and 1 is the best-standardized score (Malczweski, 1999a).

2.3 Pairwise Comparison Method

Pairwise Comparison Method is another one in determining the weights for the criteria. This method involves the comparison of the criteria and allows the comparison of only two criteria at once. This method can convert subjective assessments of relative importance into a linear set of weights (Heywood et al., 1993). It was developed by Saaty (1980) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (Malczewski, 1999a; Eastman et al., 1995; Malczewski, 1996). The criterion pairwise comparison matrix takes the pairwise comparisons as an input and produces the relative weights as output, and the AHP provides a mathematical method of translating this matrix into a vector of relative weights for the criteria. (Malczewski (1996) and Eastman et al. (1995) have evaluated this procedure very clearly.

2.4 Decision Rule

A decision rule is a method of weighting or scoring criteria to assess their importance (Heywood et al., 1993). It is the procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon (Eastman et al., 1995). The aim of MADM analysis is to choose the best or the most preferred alternative. There are many decision rules that can be used in MCDM process. Weighted Linear Combination (WLC) is the most often used techniques for tackling spatial MADM and this approach was used as a decision rule in this study.

2.5 Sensitivity Analysis

The main purpose in sensitivity analysis is to examine how sensitive the choices are to the changes in criteria weights. This is useful in situations such as where uncertainties exist in the definition of the importance of different factors. Sensitivity analysis with examples can be found in Lowry et al. (1995).

3. Case Study

3.1 Study Area

The West of Black Sea in the north of Turkey has the heavy local rains and snow melting, especially in springs. In this region, there are two main river basins: Filyos Basin and Bartın Basin. Being a floodprone area, Bartın is selected as the study area (Figure 3.1). It covers the subbasins of Ovacuma and Ulus Creeks, which are two of the upstream branches of Bartın River. Black Sea climate is dominant in the basin and heavy rainfall and variable plant cover are observed in the basin. The mean annual rainfall observed at Ulus meteorological station is 984.5 mm (Türkiye Akarsu Havzaları Taşkın Yıllığı, 1998).
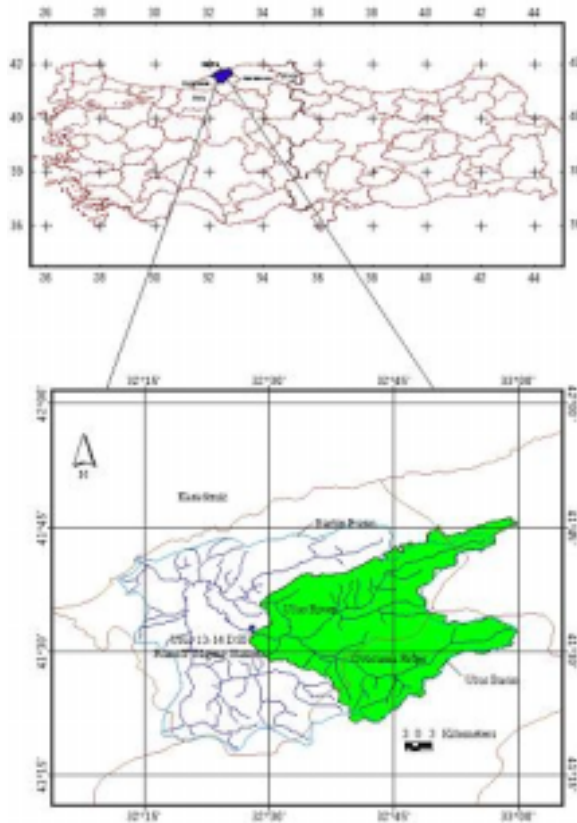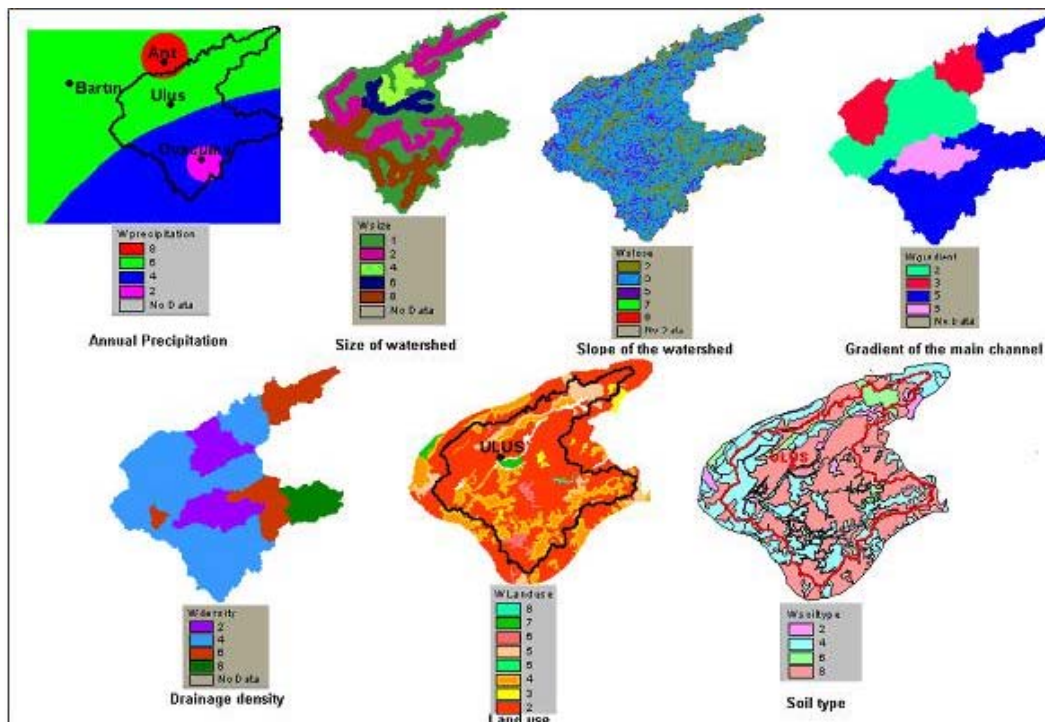

Figure 3.1: Study area

3.2 Criteria Evaluation

The causative factors for the flooding in every watershed like annual rainfall, size of watershed, basin slope, gradient of main drainage channel, drainage density, land use and the soil type were taken into account according to the literature surveys (Eimers et al., 2000; Henderson et al., 1996; and Pramojanee et al., 2001). After all criteria were determined and prepared with their raw data using GIS functions, the first step for the map layers were completed for the evaluation. Thus the criteria were generated in GIS environment. For criterion values in flood vulnerability analysis, each grid cell in the

database is taken as a unit to be evaluated. Therefore, the region is divided into grids to illustrate the spatial variability in the criteria values. All weighting values will be determined according to these grid cells. The preparation of input data for the implementation of the technique was performed by using GIS raster images. The DEM with a resolution of 5 or 10m provides a dataset that can be handled with ease due to its reasonable file size, and that can provide sufficient detail for most regional risk assessment requirements (Galy and Sanders, 2000). Therefore all the layers were converted with the same output grid cell size, as 10-meter. The criterion maps are classified according their classification values of the criteria (Table 3.1 and Figure 3.2). The original values and the details of the processes can be found in Yalcin (2002).

Table 3.1: The classification values of the criteria.

Class	An.Prec.(mm)	Value
1	>1200	8
2	1000-1200	6
3	800-1000	4
4	<800	2

Annual precipitation

Class	Size (km2)	Value
1	>350	8
2	250-350	6
3	150-250	4
4	70-150	2
5	<70	1

Watershed size

Class	Slope%	Value
1	>80	8
2	80-45	7
3	30-45	5
4	15-30	3
5	<15	2

Slope

Class	Gradient %	Value
1	>5	8
2	4- 5	7
3	3- 4	6
4	2- 3	5
5	1- 2	3
6	<1	2

Gradient of the main channel

Class	Dn. (m/km2)	Value
1	100-250	8
2	250-300	6
3	300-350	4
4	350-400	2

Drainage density

Class	Landuse	Value
1	irrigated area	8
2	non-irrigated fallow	7
3	without fallow	6
4	Meadow	5
5	Pasture	5
6	Shrubbery	4
7	Forest	3
8	left area	2

Land use

Class	S.type (Cn Value)	Value
1	85-94	8
2	80-85	6
3	75-80	4
4	70-75	2

Soil type

Figure 3.2: The classified seven factors.

3.3 Assigning Criteria Weights

The purpose of the criterion weighting is to express the importance of each criterion relative to other criteria. The more important criterion had the greater weight in the overall evaluation. In this study ranking method and pairwise comparison method were introduced and applied. The results were compared with the Boolean Overlay Approach.

To generate criterion values using Ranking Method for each evaluation unit, the values between 1 and 8 were given, where 8 indicates higher vulnerability and 1 indicates low vulnerability depending on the criteria's class values.

The criteria with their raw data are typically noncommensurate. The scales of all the criterion maps are different. To make the various criterion maps comparable, a standardization of the raw data is usually required. Also, standardization is another way to generate criterion values for each evaluation unit. The standardization equation is applied to all the criteria in standardization process (Malczewski, 199a). This mathematical process is applied to all criteria with MapCalculator in ArcView GIS program. All the raw data in the seven factors were calculated to derive commensurate criterion maps. Through standardization, criterion scores were expressed according to a consistent numeric range, 0 and 1000, by multiplying with the constant number 1000. In fact, the aim was to get the range between 0 and 1, but GIS program accepted the calculation as only 0 and 1 as if it was a True/False evaluation. At the end of the standardization process, each factor had an equivalent measurement basis before any weights were applied.

Using PCM the criterion weights were calculated as 0.26, 0.21, 0.17, 0.16, 0.10, 0.06, and 0.04 respectively for annual rainfall, size of watershed, basin slope, gradient of main drainage channel, drainage density, land use and type of the soil. With the input values in pairwise comparison and weights calculated, consistency ratio (CR) was found as 0,042. This indicated a reasonable level of consistency in the pairwise comparison of the factors. GIS should act as the interface between technology and the decision maker with integrating MCE methods into the GIS (Heywood et al., 1993). Different decision makers may apply different criterion and assign different weights for each criterion according to their preferences. The decision maker selects the criteria and compares them in a comparison matrix. The weights of the criteria and the consistency ratio of weighting procedure were calculated in interface module.

Three composite maps showing the flood vulnerable areas were created using multicriteria evaluation methods with GIS, namely Boolean Method and two WLC Methods are presented in Figures 3.3 - 3.5. To classify the actual cell values into groups, Natural Breaks Classification Method in ArcView GIS Program was used. Natural Breaks classification can be used on changing the labels in the Legend Editor from numeric to text labels and it is a better option. The number ranges labeled "high", "medium", or "low" can be more easily comprehended by the average map reader. Grids are either integer or floating point. In this application, the range numbers are designated as "High, Medium-High, Medium, Low-Medium, Low" on the output map. For classifying the layers as Natural Breaks in the Graduated Color, the layers are needed to be converted into integer from floating with MapCalculator operation. The data must be integer, not floating.

Figure 3.3: With Boolean Method.   **Figure 3.4:** With Ranking Method.   **Figure 3.5:** With PCM Method.

The user interface was designed such that a decision maker could step through a weighting process with pairwise comparison that would result in the calculation. This interface and the processes were presented in Figure 3.6. It involves: Viewing all criteria in a list box and each criteria pair in a matrix, Entering his or her preferences and ranks for each criteria pair, Calculating weights from the input ranks and preferences with Visual Basic Application VBA program embedded in GIS environment, Calculating consistency ratio on weights and input ranks, Modifying the ranks or preferences according to the user's choice.

Figure 3.6: All calculations with weights and consistency ratio.

3.4 Fuzzy Measure Application in MCE

Zheng and Kainz (1999) have stated that uncertainty is endemic in GIS and it is best to draw attention to it because of its complexity and potentially damaging effects on decision making. The OWA decision rule is based on the principles of the fuzzy set aggregation (Malczewski. 1999a; Malczewski, 1999b). In GIS and decision making context, vulnerability was considered as a fuzzy concept expressed as a fuzzy set membership. Jiang and Eastman (2000) presented an example paper about suitability as a fuzzy concept. In Boolean, all criteria are assessed by thresholds to produce Boolean maps. To rescale the range to a common numerical basis is unclear and involves fuzziness. The criteria were standardized to a common numeric range and then combined by weighted averaging. In WCL, criterion weights and ordered weights were used. This concerns a decision risk. In this case study, the alternatives are evaluated on the basis of n=7 criteria, respectively annual precipitation, watershed size, basin slope, channel drainage, drainage density, land use and the type of the soil. The following sets of ordered weights are specified: $W^* = MIN = [1, 0, 0, 0, 0, 0, 0]$ and $W_* = MAX = [0, 0, 0, 0, 0, 0, 1]$ as the fuzzy MIN and MAX operations (Malczewski, 1999a). $W_e = [0.143, 0.143, 0.143, 0.143, 0.143, 0.143, 0.143]$ gives the AVERAGE position (Table 3.2). The illustrations classified areas according to varying degrees in Figure 3.7 give an evaluation of vulnerability of flood hazard. The result of OWA method for MAX showed the most vulnerable areas (red areas) and MIN showed the least vulnerable areas (blue areas). AVERAGE fell midway between two extreme cases of fuzzy MIN and MAX operation and had a full tradeoff. Many other solutions are possible. The solutions are the effects of the distribution of risk and tradeoff. With this method, the aim is not to ignore the poor qualities, but they can be compensated for. Different illustrations give important idea to planners for location solutions. By compensating one criterion, decision maker can create different solutions.

Table 3.2: The ordered weights for the alternatives.

MIN	A1	A2	A3	AVERAGE	A4	A5	A6	MAX
1	0,42	0,30	0,23	**0,143**	0,07	0,06	0,03	**0**
0	0,17	0,19	0,20	**0,143**	0,08	0,07	0,05	**0**
0	0,15	0,17	0,19	**0,143**	0,11	0,10	0,08	**0**
0	0,10	0,11	0,12	**0,143**	0,12	0,11	0,10	**0**
0	0,08	0,10	0,11	**0,143**	0,19	0,17	0,15	**0**
0	0,05	0,07	0,08	**0,143**	0,20	0,19	0,17	**0**
0	0,03	0,06	0,07	**0,143**	0,23	0,30	0,42	**1**
	1,00	1,00	1,00	1,001	1,00	1,00	1,00	

Table 3.3 shows the AND*ness*, OR*ness* and TRADEOFF according to the alternatives and their ordered weights in Table 3.2. It explains alternative A1 is the most risk averse alternative and alternative A6 has the most risk (except MINIMUM and MAXIMUM). Yet, only alternative AVERAGE has full tradeoff.

Table 3.3: AND*ness*, OR*ness* and TRADEOFF.

	MIN	A1	A2	A3	AVERAGE	A4	A5	A6	MAX
ANDness	1	0,747	0,672	0,633	0,5	0,367	0,328	0,253	0
ORness	0	0,253	0,328	0,367	0,5	0,633	0,672	0,747	1
TRADE-OFF	0	0,651	0,776	0,833	1	0,833	0,776	0,651	0
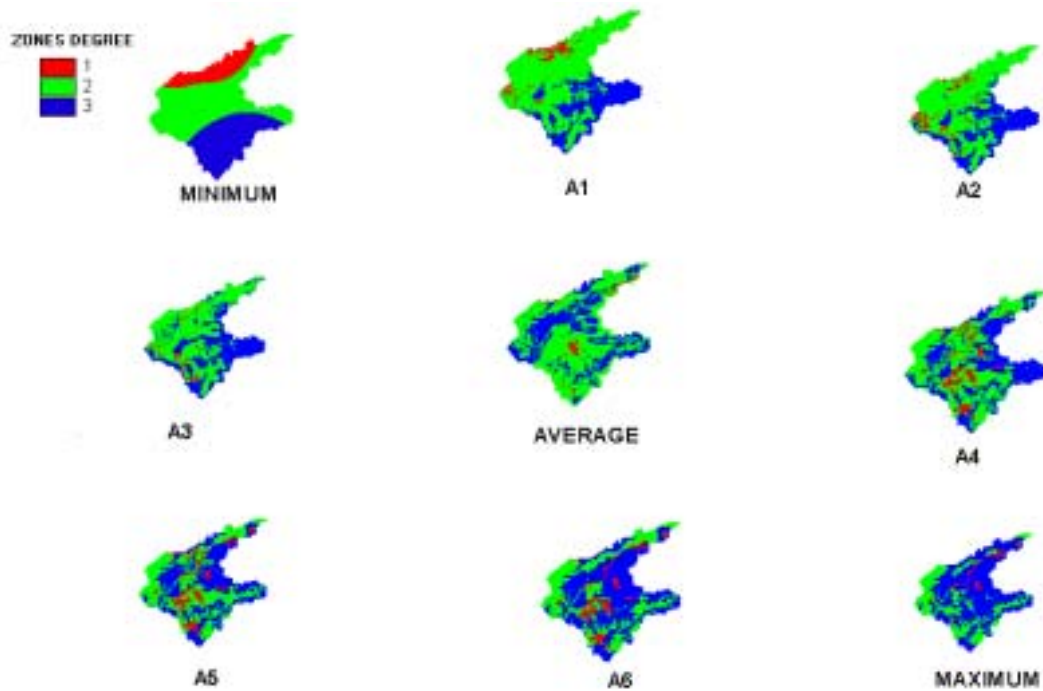
Figure 3.7: Classified areas according to varying degrees. (OWA Method)

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3.5 Sensitivity Analysis

Sensitivity analysis depends on the error in the input data as criterion weights and criterion attributes. The sensitivity between the criteria basin slope and main channel gradient was analyzed. With addition of small perturbations to the weights for 10 cells, the ranking has changed for only one cell. This result indicates that those two criteria are not so sensitive for this analysis. When the sensitivity of criterion values was analyzed, it was also seen that there were no significant changes in the ranking with small perturbations on the gradient of the main channel criterion (Yalcin, 2002).

4.   COMPARISON OF MCE APPROACHES

The criterion maps wee combined by logical operators such as intersection and union in the Boolean approach. The vulnerable area distribution in the flooded area was compared with each other. To compare the methods (Ranking Method, Pairwise Comparison Method, Boolean Method), the percentages of the area in five classes namely; high, medium-high, medium, low-medium, low were calculated. The percentages in Table 4.1 gave a general idea about the vulnerability of the basin to the flood. Which method represents the closer zonation to the real flooded area? To answer these question the 100-year flood depth and area obtained by Usul et. al. (2002) was overlaid with the composite maps. According to the overlays the percentages in Table 4.2 were not similar to each other. It was obvious that the Boolean method was not suitable for analyzing the flood vulnerable areas. Because flood vulnerable areas, where flood was seen in the model outputs could not be obtained by Boolean approach. The results obtained with ranking method and especially with the pairwise comparison method were more suitable. Because the flooded area obtained by the model was also determined by pairwise comparison method.

By using fuzzy logic the error due to the standardization and classification of the values are reduced. The OWA method is an extension and generalization of the WLC method based on the uncertainty. It provides a consistent theoretical link between the two common MCE logics of Boolean overlay and WLC, and opens up the possibilities for aggregation of criteria. The poor qualities can be compensated for. The application of fuzzy measures in MCE in general and OWA in particular require further research.

Table 4.1: The percentages of vulnerable area zones.

ZONE	RANKING	PAIRWISE	BOOLEAN
1	8,4	16,5	3,7
2	14,1	27,2	16,4
3	23,3	22,0	28,7
4	34,5	16,5	27,4
5	19,7	17,8	23,8

**Table 4.2:** The percentages of vulnerable area zones on the flooded area that are intersecting with three composite maps.

ZONE	RANKING	PAIRWISE	BOOLEAN
1	86	43	0
2	12	55	~0
3	1	2	35
4	1	0	54
5	0	0	11

After the flood vulnerable areas were determined, the areas at risk were obtained by overlaying the vulnerable areas with the cadastral parcels according to the risk degree and the percentage (Figure 4.1 and Figure 4.2). Determination of the areas at risk is needed for flood warning and floodplain development control. In order to represent the information of the parcel at risk, a database was created. Block Number, Parcel Number, total area of the parcel, flooded area, owner name-surname, address had been entered in the database.
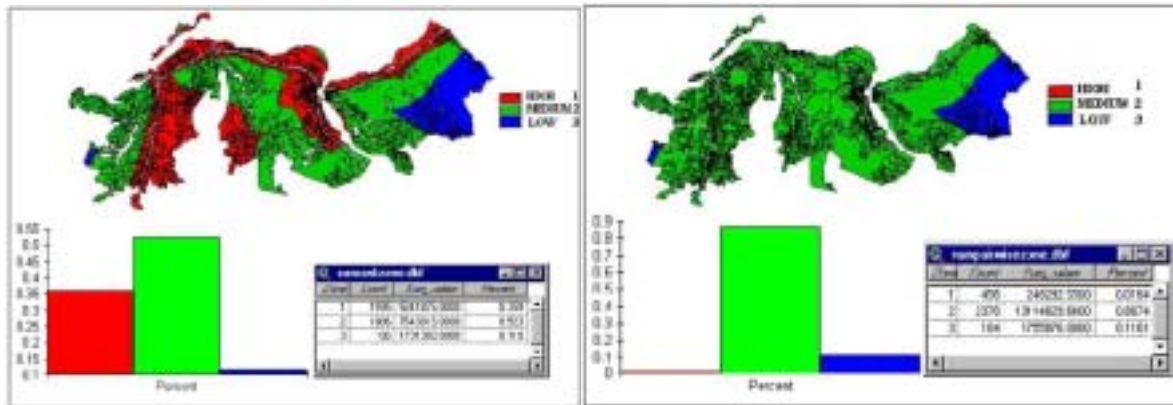
Figure 4.1: Areas at risk (Ranking Method)   **Figure 4.2:** Areas at risk (PCM)

5. CONCLUSION AND RECOMMENDATION

The flood vulnerable areas in the study area were evaluated in five classes. Since the methods take into account some example conditions of the region, the results can be as realistic only for this condition. When the characteristics change, the results will show the different conditions. The subjective numbers in the weights and the values of the criteria can be changed according to the study area characteristics and experts' opinions. Performing the sensitivity analysis on all the criterion weights, it was seen that the accuracy in estimating weights should be examined carefully. Sensitivity analysis helps to see if and how attribute and weight uncertainties play a role. Geographical sensitivity analysis is the study of how imposed perturbations of the inputs of geographical analysis affect the outputs of that analysis. The flood vulnerability maps can give planners, insurers and emergency services a valuable tool for assessing flood risk. Each of them needs to assess risk for more than one scenario. A project including these vulnerability maps should be used on land planning, use and management alternatives. The information in database should be obtained with an interface. In future this interface should be automatic in disaster related studies, because the amount of the insurance is needed to be calculated with the area under risk. The interface may be generated using a point-and-click operation window, with a reference map to navigate and highlight the area shown in the main map as in Sanders et al. (2000).

User interface allows users to evaluate and compare weights/alternatives and to speed up the calculation. For this kind of application, a required software program should be developed, new tools should be generated in the interface and the program with its interface and tools should be multi-user. The interface should provide query and drive all the necessary information. In the view of the total cost of flood, Flood Insurance Studies (FIS) must be strengthened and National Flood Insurance Program (NFIP) must be established by the national flood insurance acts. Flood Insurance Rate Map (FIRM) should be produced for the private insurance industry and the state. This map should provide the divides for the area studied into flood hazard zones that are used to establish insurance rates.

Some arrangements must be developed and evaluated to deal with the problems:
• The flood vulnerable areas should not be in the concept of ownership. They should be in the authority and the possession (use) of the state and counted as ownerless land such as parks, areas between the coast-edge lines.

• A wide region should be considered in the concept of rural area arrangements. The arrangement should be done through the non-vulnerable areas. The vulnerable areas should be out of the arrangement.

• If the flood prone area cannot be expropriated, especially because of the economic reasons, the vulnerable areas might be evaluated in the concept of Arrangement Partnership Part. Thus, 35 per cent of the total area is left directly and can be used as green area. The area in the arrangement can be provided by the exchange of the treasure goods instead of expropriation.

• Aforestation on the area which is left as green part during the arrangement is one of the most favorable method to mitigate the risk on the flood vulnerable area. In addition, special conditions might be applied on these areas by proposal of Ministry of Agriculture and by compulsion of Province Public Works Directorate.

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