Suitability Analysis of Urban Green Space System Based on GIS

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by

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Abstract

Suitability analysis of green space system is designed to identify and measure the suitability of potential sites for green space system development. Such analysis can be regarded as a relatively difficult task partially due to large number of factors and large volume of data that may be required for the determination. The purpose of this research is to develop an approach of GIS-based suitability analysis to identify suitable sites for urban green space system development. This approach identifies seven major steps involved in the suitability analysis, which include selecting, scoring, weighting suitability factors, generating suitability scenarios using GIS, ranking suitability scenarios, making sensitivity analysis, and output evaluation.

Selecting suitability factors is mainly based on stakeholder analysis and desirable environmental quality. Four groups including urban planners, environmentalists, local residents and local government officials are involved in the stakeholder analysis. The desirable environmental quality is proposed from two aspects: existing situation and greening indices. As such, seven suitability factors including air quality, landscape quality, surface water quality, historic culture value, water system influence, noise influence, and existing land use, will be selected to carry out the GIS-based suitability analysis. These seven factors are set as 'high suitability', 'moderate suitability', and 'no suitability'. Ratio values are applied in scoring these three classes within the suitability factors, and the establishment of certainty factor is introduced to improve the traditional GIS-based suitability analysis model. After that, three weighting methods including statistic integration, hierarchic analysis of nine-degree and hierarchic analysis of three-degree are used to define three sets of weighting systems.

All the above data are integrated into a raster-based GIS software and spatial analysis is performed using an overlay technique to generate six suitability scenarios. Then weighted summation and electre method are used to make a ranking among these six suitability scenarios. Sensitivity analysis is carried out to test the validity of scores, weights used and the ranking of the scenarios. As such, the best suitability scenario comes out and it needs to be evaluated by comparing it with the urban master plan, with the aim of finding the commons and differences between them and then to validate the proposed approach.

Suitability analysis is a powerful tool for green space system planning. Continued development and refinement of suitability analysis, particularly with GIS technology, can enable urban planners to help local government officials and local residents to create a suitable green space system in the urban environment. In order to advance the art of the suitability analysis, it is important that not only the suitability output is replicable within a study area, but also the approach is transferable, or at least adaptable in other places. This research provides an example of such transferability. In general, GIS is a toolbox capable of providing support for spatial problem-solving and decision-making, and it should be integrated with the decision support system (DSS) to make the suitability analysis in a more systematic way.

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1. Introduction

1.1. Background

Land suitability analysis is the process of determining the fitness of a given tract of land for a defined use (Steiner, McSherry et al. 2000). In other words, it is the process to determine whether the land resource is suitable for some specific uses and to determine the suitability level. In order to determine the most desirable direction for future development, the suitability for various land uses should be carefully studied with the aim of directing growth to the most appropriate sites. Establishing appropriate suitability factors is the construction of suitability analysis.

Initially, suitability analysis was developed as a method for planners to connect spatially independent factors within the environment and, consequently to provide a more unitary view of their interactions. Suitability analysis techniques integrate three factors of an area: location, development activities, and biophysical/environmental processes (Miller, Collins et al. 1998). These techniques can make planners, landscape architects and local decision-makers analyse factors interactions in various ways. Moreover, such suitability analysis enables elected officials and land managers to make decisions and establish policies in terms of the specific landuses.

Even though suitability analysis is a well-known tool among planners, landscape architects and local decision-makers, there are relatively few examples where a process used in one place has been transferred or adapted in another place (the few examples include the work of McHarg, 1969 and Lyle, 1985). Applications of suitability analysis can be found in many fields, such as site selection for cropland (natural resource management field), flooding control, sustainable development (environment management field), etc. This method covers broad topics and develops continuously. However, specific applications on the green space system cannot be found very often. This research provides such an example that uses seven factors to carry out the suitability analysis of urban green space system, as will be critically explained in Chapter 4.

Since suitability analysis came into being, there have been many analytic methods that primarily include the method of sieve mapping, landscape unit method, grey tone method (map overlay) and computer method (GIS). The method of sieve mapping is to use a series of ‘sieves’ (factors) to exclude those areas that are not suitable for the specific landuse. Once passing all the ‘sieves’, it is easy to eliminate all the assumed unsuitable areas, and what is left is suitable for some specific uses. The landscape unit method is absolutely different from sieve mapping. First it needs to classify landscape units according to a set of geographic characteristics, the land’s potentials and limitations are then identified in each landscape unit. Finally the suitability analysis is finished after all the landscape units are identified. Grey tone, also named map overlay, is created by professor McHarg (1996). This American landscape architect has systematically expatiated on such method in his book Design With

Nature. Grey tone wants to make use of gradual colours to represent the suitability levels in the same scale, and overlay all the single factor maps in a certain order. As such those supposed useful areas would be displayed after the above process.

Grey tone method has made some excellent effects in North America, even all over the world. But it also has some disadvantages: (1) It neglects the relative influence among the factors; namely, it assumes that each factor is independent. (2) If large number of factors must be involved, it is a time-consuming task to do the analysis by manual operations. (3) Worse is that grey tone method cannot carry out arithmetic operations. However, computer methods were developed to solve these problems, particularly the analytic method depending on GIS. The GIS technique can transfer the suitability level into numerical value, and assign the weight to each factor according to their relative importance. So finally we can achieve the composite suitability levels by summing up the multiplication.

The limitation of GIS-based computer method is that it needs a complicate expert system, which can precisely select, assess the suitability factors and set up a weighting system. This is the most important and difficult step in the suitability analysis. In general, GIS-based computer method can overcome those difficulties that other methods can't. It enables landscape architects and urban planners to use and to process more information, to plan more complicate landuses, and then to push the suitability analysis method to a new stage.

1.2. Problem statement

City is a multiplex ecological system made up of social, economic and natural these three sub-systems (Huang and Chen 2002). Green space system is the foundation of the natural system. It is also the principal part of the natural productivity in the urban structure. A suitable green space system can play an effective role in cleaning air, adjusting climate, eliminating noise, beautifying surroundings, etc. It is dispensable for constructing a high quality human settlement and a high standard ecocity.

A number of studies proved that increasing population and enhancing urbanization processes are converting more and more soft green spaces into impermeable hard concrete surface. Particularly in a developing country, this trend is more serious (Shi 2002). China is a large country with almost 1.3 billion population in East Asia. With the fast economy growth in the past two decades, China is facing a rapid urbanization, especially due to the rural-urban migration. The growing urban population wishes a better living environment, and puts an enormous pressure on the demand for green spaces. At the same time, rapid economy growth has resulted in the loss of valuable land resources. This does not only destroy sustainable economy and human settlement, but also lead to environmental degradation and reduction of green spaces.

In Dongguan municipality, some green spaces are being converted to other land uses every year. This has caused some serious environmental consequences: increased soil temperature, local climate change, instability in hydrological regime, and the loss of important species, all of which ultimately have negative effects on the ecological environment and human settlement. In order to reduce such harm, the Dongguan government has taken some activities to increase green spaces in the urban areas such as 'Greening Dongguan', 'Horticultural city with water and mountains', 'Sustainable Dongguan', with the aim of improving the environmental conditions. It is generally believed that such activities can bring more green spaces and make the integration of trees, parks, lawns, etc., as an element of urban landscape. However, they are affected by many factors including natural conditions, social-economic conditions, technical factors and so on. The result is that these activities cannot play a good ecological function to the urban environment.

In this research, an approach that integrates suitability analysis with geographic information system (GIS) technology will be developed and implemented to identify suitable sites for the urban green space system development, in order to play a good ecological role and create an elegant landscape in the study area of Gongguan municipality. Now the GIS-based traditional suitability analysis model is not very precise for some specific factors analyses. It can't meet the needs of new ecological planning. Therefore, an approach to establish certainty factors is introduced to improve this GIS-based traditional suitability analysis model. After that, some suitability scenarios are generated and a ranking is made among them. Sensitivity analysis is used to test the validity of this ranking to find the best suitability scenario. Finally, the research compares this best suitability scenario with the urban master plan and analyses their commons and differences.

1.3. Research objective

1.3.1. Main objective

The main objective of this research is to develop an approach of GIS-based suitability analysis to identify suitable sites for urban green space system development.

1.3.2. Specific objectives

1. To understand the definition and conceptions of the urban green space system.
2. To analyse the strengths and weaknesses of current suitability analysis methods.
3. To evaluate the GIS-based traditional suitability analysis model.
4. To generate suitability scenarios of the urban green space system by integrating suitability analysis with geographic information system (GIS) technology.
5. To carry out the ranking and sensitivity analysis to find the best suitability scenario.
6. To compare the best suitability scenario with the urban master plan.

1.4. Research questions

To realize the above stated objectives, the following research questions shall be answered:

1. *Understand the definition and conceptions of the urban green space system.*
    - What is the urban green space system?
    - What are the classifications of the urban green space system and what are the comprehensive benefits of the urban green spaces?

2. *Analyse the strengths and weaknesses of current suitability analysis methods.*
    - What are the current suitability analysis methods and their strengths and weaknesses?

3. *Evaluate the GIS-based traditional suitability analysis model.*
    - What is the GIS-based traditional suitability analysis model? What are the strengths and weaknesses?
    - Which method can be used to improve the GIS-based traditional suitability analysis model?

4. *Generate suitability scenarios of the urban green space system by integrating suitability analysis with geographic information system (GIS) technology.*
    - How to select factors for the suitability analysis and how to determine their weights and certainty factors in the study area?
    - How to overlay all single factor maps to generate the suitability scenarios of the urban green space system based on GIS?

5. *Carry out the ranking and sensitivity analysis to find the best suitability scenario.*
    - What are the evaluation methods for ranking of the suitability scenarios?
    - What is the sensitivity analysis and how to use it to test the validity of the ranking?

6. *Compare the best suitability scenario with the urban master plan.*
    - What are the commons and differences between the best suitability scenario and the urban master plan? What are the reasons?

1.5. Workflow

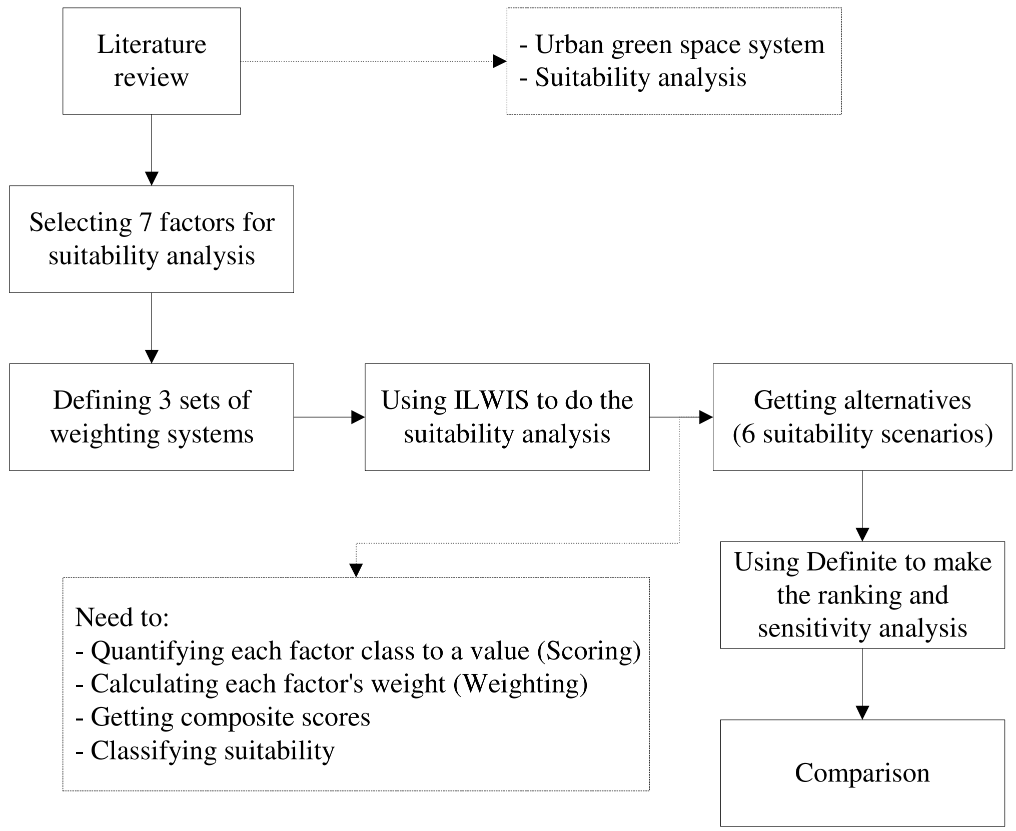


Figure 1.1 Research workflow

The workflow above summarizes the main idea of this research. First, the literature review will focus on the urban green space system and suitability analysis, such as their definitions, study methods, development processes, etc. Then after a combination of the stakeholder analysis, published literature, and fieldwork, this research will select seven factors for the suitability analysis, including **air quality**, **landscape quality**, **surface water quality**, **historic culture value**, **water system influence**, **noise influence** and **existing land use** (see section 4.3.2). Nowadays there are many methods used to calculate weights for the suitability factors. This research wants to use three typical and efficient methods to define three sets of weighting systems. These three weighting methods are **statistic integration**, **hierarchic analysis of nine-degree** and **hierarchic analysis of three-degree** (see section 3.5). Afterwards, ILWIS, a GIS software is used to carry out the suitability analysis. And then six suitability scenarios will be generated according to different sets of scores, weights and **certainty factors** (see section 3.4.2). Each suitability scenario can be regarded as an alternative, so a ranking will be carried out among these six alternatives (scenarios), and sensitivity analysis is carried out by Definite (a multiobjective decision support system software) to test the validity of scores, weights used and the ranking of alternatives (see section 4.5). Finally, a best suitability scenario will come out and we can compare this best scenario with the urban master plan, in order to find the differences and commons between them.

1.6. Structure of the thesis

This thesis focuses on the suitability analysis of urban green space system based on GIS, and sensitivity analysis that is to test the validity of scores, weights used and the ranking of alternatives by using DSS (decision support system), with the aim of developing an approach of GIS-based suitability analysis to identify suitable sites for urban green space system development. This thesis is structured into five chapters:

Chapter 1 states the research background, problem, objectives and questions as well as a workflow.

Chapter 2 presents a literature review about the definition, classifications of the urban green space system and comprehensive benefits of the urban green spaces.

Chapter 3 states the research methodology including the definition, methods of suitability analysis, GIS-based traditional suitability analysis model and its improvement. In addition, weighting methods, evaluation methods for ranking, and sensitivity analysis are involved in this chapter. Based on the above analysis, a methodology flow chart will come out to direct the case study in Dongguan municipality.

Chapter 4 describes the case study in Dongguan municipality, which includes the introduction in the study area, data collection, and data processing as well as data analysis. Afterwards, six suitability scenarios will be generated by using some GIS techniques; a ranking and sensitivity analysis is used to get the best suitability scenario and test its validity.

Chapter 5 gives a conclusion about the suitability analysis. Some recommendations are provided as well in this chapter.

2. Definition and conceptions of urban green space system

2.1. Definition of urban green space system

Green spaces refer to those land uses that are covered with natural or man-made vegetation in the built-up areas and planning areas (Wu 1999). It has been long argued about the definition of green space system. Different disciplines have proposed different definitions from their own professional angles, such as Horticultural Greenland System, Urban Greenland System, Ecological Greenland System, Urban Green Space, Green Open Space. The meaning of green space system has also been continuously developing with the development of city theory, which mainly involves horticultural, ecological and spatial these three meanings. Figure 2.1 obviously shows the developmental skeleton of green space system. It is a process gradually developing from non-existence to existence, from simplicity to complexity.

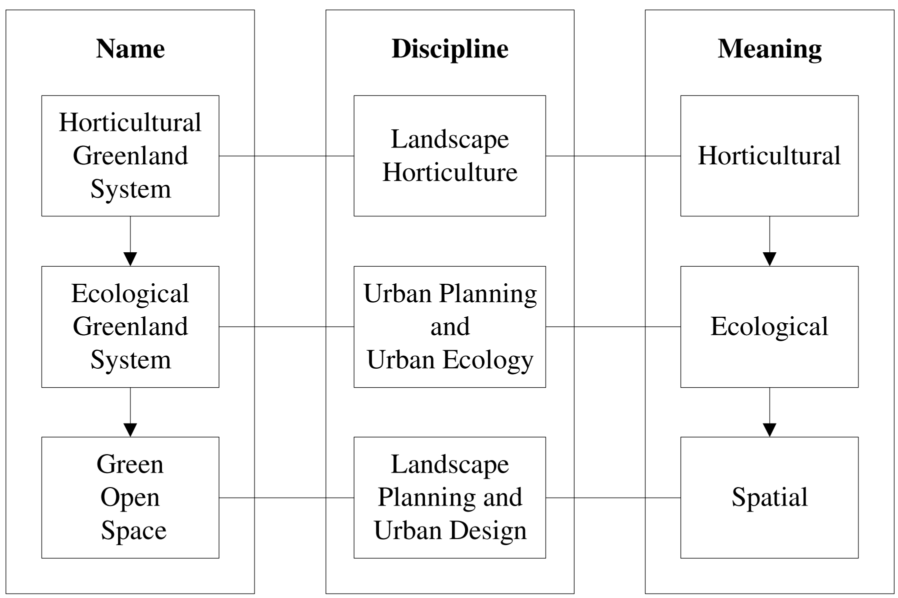


Figure 2.1 Developmental skeleton of green space system

Echoing the opinions of A.R Beer (1997), green spaces are: 'Places where contact with animals and birds and the more attractive insects like butterflies', 'Places with visual variety', 'Places are children can learn about nature and social life through contact with animals', 'Places to loiter in and watch the world go by', 'Places to chat while children play' (Mugenyi 2002). Referring to some definitions from other countries such as Britain, America, Japan (Table 2.1), some scholars have proposed the definition of Green Open Space from the angle of landscape planning and urban design. Lingzhang (2001) defines green open space as all the areas within the city and its surrounding regions, enabling people to contact the nature. Thus green space system is endowed with spatial meaning.

Table 2.1 Definitions of green open space

Country	Form	Purpose or function
Britain	Residential land that the area for architectural-use is lower than 1/20 of the whole area (excluding wasteland)	Courtyard, recreational land
America (1)	Land with natural environment	Recreational land, land for adjusting urban construction
America (2)	Non architectural-use land (e.g. air, land, water)	Recreational land, landscape area, national forestry, roadside green belt
Japan (1)	Non architectural-use land	Park, square, gym, zoo, botanic garden (excluding road and canal)
Japan (2)	Non architectural-use land	Park, game land, gym, graveyard, farmland, forestry land

Source: Gaoyuan Rongzhong, Yang Zhengzhi et al. translate, 1983, Urban green space planning, P_5, Table 1-1.

This study wants to propose its own definition of green space system by referring to some published literatures, with the aim of integrating horticultural meaning, ecological meaning with spatial meaning. The detailed **definition of urban green space system** in this study is that, in the urban spatial environment, there are some good green areas (green space per capita must be over 9.0 square meters), which are mainly covered with natural or man-made vegetation and can function as ecological balance, playing an active role to urban environment, landscape, and residents recreation. They also include those water areas enabling people to contact the nature and those greenways that can connect parks, productive and defensive green spaces, residential green spaces, landscape areas and suburban forest.

2.2. Classification of urban green space system

Green space system can be grouped in different classes according to different classifying standards. As to the element of terrain, it can be classified into mountain, water, forestry, farmland and road these five classes. Green space system can also be classified into patch, area, line and point by its forms. However, the most practical and efficient method to classify green space system is based on its functions. Both China and other foreign countries adopt this method to classify their national green space systems.

2.2.1 Classification in foreign countries

There is not a uniform method to classify green space system in the world till now. Different countries have proposed different classifications based on the function, size, and physical characteristics of green space system. America classifies the park according to its service radius (Table 2.2).

Table 2.2 Classification of parks in America

Class	Area	Serving population	Service radius
Children's park	200 ~ 400 m^2	500~2500	Neighbourhood
Small pleasance	200 ~ 400 m^2	500~2500	Neighbourhood
Neighbouring park	2 ~ 8 ha	2000~10000	400 ~ 800 m
District park	8 ~ 40 ha	10000~50000	800 ~ 5000 m
Large urban park	≥40 ha	≥ 50000	Riding distance within half an hour (by car)
Regional park	≥100 ha	Serving a larger region	Riding distance within an hour (by car)
Specific facility	Including avenue, seashore, square, historic relic, floodplain, small park, lawn, forestry land, etc.		

Modified from: Jia Jianzhong, 2001, Planning and design of green space system, P_{17}, Table 2-3.

Japan has carried out the Establishment Of Green Comprehensive Planning since April 1977, in order to apply a green comprehensive planning in the urban planning areas, construct and protect urban parks, green lands and public spaces. This planning was modified every five years. In addition, with the help of those subsidiary laws such as Natural Parks Law, Metropolitan Parks law, Children Parks law, etc, an integrated urban green space system was formed. (Table 2.3)

Table 2.3 Classification of urban green space system in Japan

<table>
<tr><th></th><th>First class</th><th>Second class</th><th>Third class</th></tr>
<tr><td rowspan="15">Gaoyuan Rongzhong classification</td><td rowspan="9">Public green space</td><td rowspan="3">Public green space</td><td>Park green land, playground, park road, footway, bikeway</td></tr>
<tr><td>Square</td></tr>
<tr><td>Park graveyard</td></tr>
<tr><td rowspan="3">Natural green space</td><td>River, lake, waterway</td></tr>
<tr><td>Seashore, riverside, lakeside</td></tr>
<tr><td>Mountain forestry, weald, farm-land</td></tr>
<tr><td rowspan="3">Open green space</td><td>Churchyard, graveyard and its affiliated land</td></tr>
<tr><td>Affiliated garden plot of com-monweal facility</td></tr>
<tr><td>Garden plot of individual facility</td></tr>
<tr><td rowspan="7">Private green space</td><td rowspan="4">Sharing green space</td><td>Sharing residential garden plot</td></tr>
<tr><td>Sharing recreation facility</td></tr>
<tr><td>Enterprise welfare facility</td></tr>
<tr><td>School playground, other garden plots</td></tr>
<tr><td rowspan="3">Specific green space</td><td>Individual garden plot</td></tr>
<tr><td>Testing land of nursery</td></tr>
<tr><td>Water supply, drainage and other facilities</td></tr>
</table>

Spatial classification of urban green space system	Park	Park for ordinary use	
		Park for district use	
		Park for special use	
		Park for regional use	
		Park with special forms	
	Graveyard		
	Traffic space	Street tree	
		Pavement tree	
		Park avenue	
		Expressway	
		Sharing road	
	Other green space	Pleasance	
		Golf course	
		Industrial green space	
Classification of green comprehensive planning	Public green space	Park and green land	
		Square and playground	
		Graveyard	
		Other similar green spaces	
	Other green space	Including water area, riverside belt, farmland, forestry weald, churchyard, public affiliated green space, pleasance, school, agricultural experimental land, etc. (their areas must be over 1000 square meters)	

2.2.2. Classification in China

Chinese classification of green space system is also developed step by step. Urban And Rural Planning (1961) classified green space system into four classes: public green space, quarter and street area green space, specific green space, landscape and recuperation green space. In 1973, National Construction Committee classified green space system into public green space, courtyard green space, street tree, suburban green space and defensive green space these five classes. Urban Horticultural Green Space Planning (1981) had six classes: public green space, residential green space, affiliated green space, traffic green space, landscape area green space, productive and defensive green space. There are seven classes in Urban Greening Byelaw (1992), which included public green space, residential green space, departmental affiliated green space, defensive forestry, productive green space, landscape forestry and main road green space. Urban Landuse Classification And Standard, a national standard, only has two classes: public green space, productive and defensive green space.

In the past few years, some scholars have proposed different practical classifications of green space system to meet the new needs of urban constructions. Meanwhile, the government has also established the Classification Standard Of Urban Green Space System as a national standard since 1993. (Table 2.4)

Table 2.4 Classification of urban green space system in China

	First class	Second class
Jia Jian-zhong (2001)	Park	Municipal comprehensive park, district comprehensive park, residential comprehensive park, botanical garden, zoo, children park, etc.
	Street side green space	Small pleasance, avenue, garden belt, square green space, etc.
	Residential green space	Green space in residential district, green space in residential quarter, green space in street area, etc.
	Departmental affiliated green space	Affiliated green space in the factory, school, hospital, hotel, warehouse, municipal public facility, etc.
	Roadside green space	Roadside tree, affiliated green space of road.
	Defensive green space	Defensive forestry of health, industry, railway, etc, wind-defensive forestry, cuneal green space, water and soil conservation forestry, etc.
	Productive green space	Nursery, flower garden, grass garden, etc.
	Landscape green space	Landscape forestry, forestry parcel, and other independent forestry parcels.
	Suburban ecological green space	Landscape area, forestry garden, natural conservation forestry, waterhead conservation forestry, farmland forestry network, orchard, and other forestry lands.
Wu Renwei (1999)	Park G_1	Skeleton park G_{11}, specific park G_{12}, historic relic park G_{13}, park belt G_{14}, street corner green space G_{15}, square green space G_{16}.
	Productive green space G_2	Nursery and flower garden G_{21}, orchard and forestry land G_{22}.
	Defensive green space G_3	Urban wind-defensive forestry belt G_{31}, health-defensive forest belt G_{32}, safety-defensive forest belt G_{33}.
	Residential green space R_0	
	Roadside green space S_0	
	Affiliated green space G_0	Industrial green space M_0, warehouse green space W_0, public facility green space C_0, municipal sharing facility green space U_0, external traffic green space T_0, affiliated green space for specific landuse P_0.
	Suburban ecological landscape conservation B_1	
	Suburban ecological forestry land B_2	
	Suburban defensive forestry B_3	

Draft national standard (1999)	Park G_1	Comprehensive park G_{11}, specific park G_{12}, park belt G_{13}, street side pleasance G_{14}.
	Productive green space G_2	
	Defensive green space G_3	
	Residential green space G_4	
	Affiliated green space G_5	Public facility green space G_{51}, industrial green space G_{52}, warehouse green space G_{53}, external traffic green space G_{54}, roadside green space G_{55}, municipal facility green space G_{56}, specific green space G_{57}.
	Ecological landscape green space G_6	

Table 2.4 has presented three typical classifications of urban green space system in China. It can be showed that there are two obvious tendencies in this table:

(1) These three classifications use the name of Park (green space) instead of the name of Public green space that has been used in urban planning and green space system planning for a long time, in order to combine it with international terminology. Meanwhile, this name can be better to embody the green space functions rather than only represent its affiliated relation and serving object. As such, the greening index of "Public green space per capita" used in the past ten years will also be replaced by "Park area per capita".

(2) These three classifications regard the urban green space system from the regional perspective. They concern more on those suburban green spaces that can play a good ecological role to the city (e.g. Suburban ecological green space proposed by Jia Jianzhong, Ecological landscape green space in the Draft national standard). Wu Renwei classifies these suburban green spaces into Suburban ecological landscape conservation, Suburban ecological forestry land and Suburban defensive forestry. The common is to elicit such a conception to integrate suburban green spaces into planning system, but they don't be counted in urban landuse balance and urban greening indices.

There are some differences in the detailed classes because these three classifications are based on different perspectives. It is obvious that the classification of Jia Jianzhong (2001) has a good link with the traditional landscape horticultural classification, but it has no detailed classes and indices for explanation. The classification of Wu Renwei (1999) and draft national standard pay more emphasises on the practice, and separately has detailed functions and indices for explanation. From the view of authority, it is more practical to take the draft national standard into application. However, it is feasible to adopt other two classifications for the second class. For example, it can adopt the classification of Wu Renwei for the second class of Productive green space G_2 and Defensive green space G_3. As to the Residential green space G_4, it can use the classification of Jia Jianzhong (2001) and explain it with corresponding indices. Ecological landscape green space G_6 can also be replaced by B_1, B_2, and B_3 from the classification of Wu Renwei. In addition, Allowing for the function of green space system, it is feasible to change Square green space belonging to the second class of Street side pleasance G_{14} into a new second class of G_{15}. Likewise, it can cite the foreign conception of Greenway to convert the External traffic green space G_{54} and Roadside green space G_{55} into a new class of G_{17}.

2.3. Comprehensive benefits of urban green spaces

Green space system has a great effect on the urban feature. Only a good concordance between the man-made environment and natural environment can generate a suitable human settlement. As a recycling organization of urban ecological system, green space system has been prevalently concerned by the society. People instinctively have intimate psychology to green spaces at the beginning, and now they have transferred to rationally study the benefits of green spaces. Western scholars concern more on the quality of green space benefits. W.Miller (1996) has grouped the functions of urban green spaces in three classes: architecture and aesthetics function, climate function, engineering function. In our country, the scholars are affected by the theory of sustainable development. They emphasize on ecology, society, and economy these three aspects (Ping 1994). This research will expatiate on the comprehensive benefits of urban green spaces by using the method of Chinese three classifications, including ecological benefits, social benefits and economic benefits.

2.3.1. Ecological benefits

1. Clean air

(1) Balance carbon and oxygen: Vegetation can release O_2 and absorb CO_2 in the photosynthesis, which play an important role in balancing carbon and oxygen. In the urban environment, such balance needs to be maintained much more by green spaces because of the more oxygen consumptions. It has been measured that 1 hectare broadleaves can consume 1 ton CO_2 and release 0.75 ton O_2 everyday in the growing season. If an adult resident absorbs 0.75 kilogram O_2 and releases 0.90 kilogram CO_2 every day, the balance between carbon and oxygen for one person will need 10 square metres forestry or more than 25 square metres lawns to maintain (Lingzhang 2001). Some German experts have proved that, as to people's breath plus fuel's burning, only 30~40 square metres green spaces for every resident can keep the balance between O_2 and CO_2 within the city. Based on this theory, some countries determined that green space per capita should be 40 square metres when planning the urban green space system.

(2) Absorb toxic gas: There are more and more toxic gases existing in the air with the improvement of industrial level, which mainly include SO_2, NOx, Cl_2, HF, NH_3, Hg, etc. Under some concentrations, however, many kinds of vegetation can absorb toxic gases into their bodies through the laminas' pores and tresses' lenticels, and use redox to transfer them into non-toxic gases, or exclude those toxic gases out of their bodies by the root system or get them together in some organs. As such, vegetation can play a cleaning function to air pollutions. Some researches have showed that 1-hectare Japan cedars can absorb 720 kilogram SO_2 every year. The concentration of HF will be reduced to 47.9% when going through a green belt of 40-metre width.

(3) Trap dust: Dust is one of the main air pollutions besides toxic gases. Vegetation, particularly trees, can effectively hold up, filtrate and absorb dusts. This is because trees have strong crowns and their leaves are covered by hairs and excretive greases, which enable trees to play an active role in trapping dusts. For example, it can slow down the wind through the trees shielding function. The polluting dusts particles will be eliminated after they fall down to the ground. It was reported that in Hamburger (1966), the annual average value of dusts was over 850 milligram per square metres in the urban areas almost with no trees. While in the suburban areas, this average value around the parks with flourishing trees was lower than 100 milligram per square metres. It has been measured in Beijing, when the greening coverage rate (see section 4.2.3) was 10%, the total number of suspending dusts particles was reduced 15.7%. While the greening coverage rate was 40%, this number was reduced 62.9%.

2. Adjust and improve urban climate

(1) Adjust "Urban Heat Island": Large areas of paved surfaces dissipate the heat of the sun very slowly. This results in the urban heat island effect where a city heats up rapidly and then maintains a high temperature (World Bank Report on green space use, May 1997). Trees and other vegetation can use their transpiration to dissipate steams into the air. During this process, the temperature on the leaves and surrounding temperature will drop because of consuming heat. At the same time, trees can slow down the wind and play a shielding function to reduce the energy requested by the buildings. Thus green spaces can effectively reduce the urban energy consumptions (W.Miller 1996). In Phoenix (1992), America, Akbari used computer to simulate and predict that when the greening coverage rate reached 25%, the temperature would drop 6~10^{0}F at 14:00PM in summer (July). In China, The Ministry of Land and Resources has measured that, when the greening coverage rate is lower than 20%, energy consumption in the vegetation transpiration is lower than the energy attained from the sun radiation. While the greening coverage rate reaches 37.38%, this situation is on the contrary. This time green spaces absorb energy from the urban environment, so they will have a good effect on the environment.

(2) Improve urban climate suitability: According to W.Miller (1996), there were four elements influencing urban climate: sun radiation, air temperature, humidity, and airflow. The frontal two elements have been mentioned before. Here it primarily concerns about the latter two elements. Vegetation leaf surface can play a transpiration function that can not only drop down the temperature but also increase the humidity. Some researches have proved that 1-hectare forestry can transpire 8000-ton water and absorb 4 billion calorie heat every year. So green spaces can improve 4%~30% air humidity. Generally the range where massive green spaces can adjust the humidity, is equal to the distance around the green spaces that is 10~20 times than the tree height, even enlarging to the neighbouring districts of 500-metre service radius. Moreover, green spaces can hold back, lead, rotate, and filtrate airflow (Li 1999). In order to prevent the wind hazard, it can use green belts that are vertical to the main wind direction to form a barrier. The density, highness of green belts and the distance of conserved areas are the most important to influence on the wind speed. Those green spaces in riverside and lakeside can be used to lead the natural airflow from suburbs to the inner city. As such, the air convection is improved.

3. Prevent and reduce hazard

(1) Prevent earthquake and fire

Urban green spaces can be used to evacuate the residents when earthquake or fire takes place. According to the needs for protecting environment and preventing hazards, urban green spaces area should be higher than 30% of the total urban area. In addition, vegetation leaf contains plenty of water and can slow down the wind, so it can play an effective role in preventing fire. Green spaces should be more than 3 hectare as a refuge location, and it will be more effective to plant those non- inflammable trees around the refuge location. In 1970, Japanese construction bureau has investigated in the Report for Earthquake and Fire in Tokyo, 63% of the flameout reason was the suitable distribution of green spaces and the existence of rivers.

(2) Water and soil conservation

Vegetation dense leaf surface can prevent spate directly impacting the soil. The fallen leaves cover the soil and reduce the impact that flowing water exerts on the ground. Also, the root system can tightly complect in the soil and fix the sand, stone to prevent erosion. Thus green spaces have a good effect on adjusting flood and preventing soil being eroded. It has been measured that, when the slop is 30^0 and rainfall is 200 millimetres per hour, the erosion ability of soil is respectively 0%, 11%, 49% and 100%, according to the lawn's coverage rate of 100%, 91%, 60% and 31%. Therefore, urban green spaces can play a good function to the water and soil conservation, through holding back rain, slowing down the wind and fixing the soil by their root systems.

4. Eliminate noise

As one kind of the environmental pollution, noise will have a bad effect on residents' health when it is over 70-decibel. The most effective method to eliminate noise is to make a suitable green space system. The surface of tree's stem and leaf is very rough. Its numerous tiny pores and dense hairs can prevent the sound wave from transmitting, all of which can function as eliminating the noise. It has been proved that a 4.4-meter width green belt can eliminate 6-decibel noise. 40-meter width multiple hierarchical green spaces combined by arbors, shrubs and grasses can eliminate 10~15 decibel noise. Noise will be eliminated much better if green spaces are closer to the noise source. Likewise, the more flourishing the green spaces, the better the effect of eliminating noise. A denser and wider green belt of 19~30 meter integrated with a soft soil surface can eliminate 50% of the total noise. Actually it is impossible to construct very wide green belts in the city because of the limited spaces. If it is rationally designed, however, even a 6-meter width green belt can have some good effects on eliminating the noise. Furthermore, the barrier function of green spaces can give people a kind of psychological relief that they can eliminate noise.

2.3.2. Social benefits

1. Recreation

Recreation is one of the four urban basic functions in the Athens Charter. Active life itself is recreation and recreation is the essence of life (Wu 1998). Arousal-seeking theory says recreation is a kind of behaviour that can improve the individual arousal level. It is created by the interactive requirements between the individuality and environment, or between the individuality and society. The task of recreation is to provide people with opportunities to optimise the arousal level. When the urban planners and landscape designers regard green spaces as an important designing element and take it into application, they will virtually create the active open spaces where people can have a rest and play. With the improvement of material and culture, urban residents put their more emphasis on pursuing outdoor recreations. They are fond of carrying out all kinds of recreations in the green space system just because of its diverse representations, multiple functions and intimate characteristics. For example, the green space system in Guangzhou is an important resource and base for tour. Its greening rate (see section 4.2.3) in some sense determines the attractiveness for tourists, and this attractiveness is able to effectively promote the sale and production of urban tour products.

In order to make the residents have a good recreation in the green space system, it needs to ensure every one can have some suitable areas of green spaces. Thus a standard was made that green space per capita should be over 60 square metres. If 10% of the total urban residents spend the holiday in the green space system at the same time, then every one should have at least 6 square metres public green spaces. According to the research that Chinese Urban Planning and Designing Institute has made on the requirements for recreation green spaces, public green space per capita $F=P*f/e$. Where, P is the residents travelling rate (%) in the holiday. This rate was 8% in 1988 and it will increase 1% every four years. f represents the area that every traveller should have. It is 60 square metres per capita in the large park while 30 square metres per capita in the residential park. e is the turnover coefficient representing the percentage that current travellers divide by total travellers in the rush hour. The calculated result is public green space for planning is 7~11 square metres per capita applied from 2000 to 2010.

For the majority of the middle and low-income class people, a public green space serves as an essential meeting place, a place where they can go and spend their time while relaxing. It is true that green spaces are centres of recreation. This is more prevalent if the green space is within 10-minute walking distance. In many developing countries, not many amenities are offered by green spaces. Thus a proportion of people occupy themselves by playing games, others go walking and the rest simply take view of the green space surroundings from a distance. The urban poor generally have few affordable options for recreation, and thus place a high value on green areas (Mugenyi 2002).

2. Landscape aesthetics

From the view of architects, green space is the “soft component” that composes an integrated urban space with ‘hard space’ enclosed by entities. The landscape function of green spaces mainly reflects on space, time and location these three elements (Hesheng 1999). Green vegetation can enrich the urban architecture complex skyline and intenerate the hard space through their different forms, colours and styles. So green spaces can not only beautify the urban feature and set off architectures, but also improve aesthetic effects, which makes the urban environment more uniform and more diverse. Meanwhile, in order to embody the landscape value of symbolic aesthetics, it can combine different kinds of green spaces to enclose, plot out spaces and then to create a good urban space image.

In his bookmaking The Image of City, Lynch (1961) has proposed five kinds of image elements from the perspective of landscape sense: path, edges, district, nodes and landmarks. He pointed out that image is resulted from the interaction between environment and observer. Urban green space is the critical element for people to recognize and grasp the landscape structure. And it has a strong imageability because of its tuneful colours, integrated shape, intimate scale and obvious greenness. On the other hand, green space has become an important element to embody the urban culture and reconstruct the urban feature. This is because more and more people have felt city has its own characteristics, also called 'Local Spirit' (Shi 2002). It means that thinking and emotion, which are based on the local natural characteristics, can create a specific cultural landscape with those natural landscapes such as local terrain, soil, vegetation, water body, etc. as the urban green landscape line, green spaces generally occupy 25%~30% of the urban landuse, which will be the main element influencing on the urban feature. In addition, every green space has its specific form, colour and style. All of these characteristics will have a good expression of the 'Local Spirit'. A good example is Lincoln Park, Grand Park and Jackson Park connected by the green belts, have their own playground, botanic garden, gallery, museum and other facilities, which has endowed the city with more cultural meanings and creates a large-scale, impressive green space system in the world.

3. Adjust psychology

Green space can play a psychological role to people. M.J.Cohen (1993) has summarized the psychological effects on the nature. He concluded there are 97 kinds of human activities related to the nature, which can produce 49 kinds of satisfactions. From the view of chromatics, lakes' blueness and vegetation' greenness belong to impassive colours that can make people calm down. If there are not enough blueness and greenness but full of exciting redness in the city, there will be no peaceful environment for the residents (Shi 2002). Thus it can be showed that people must live together with the nature. In general, social benefits of green spaces originate from the potential influence that green spaces act on people's psychological behaviour model. This research tries to explicate it from the perspective of environmental behaviour.

People, as a single entity, have a mutual relationship with the existing environment. Kurt Lewin, a German psychologist, described such relationship as the following formula, which constitutes his basic frame of "Field Theory" (Shi 2002) :

$$\mathbf{B=f\ (P,\ E)}$$

B—behaviour **P**—personality **E**—environment

The above three parameters can transfer with each other. It means that people's behaviour is the mutual result of realistic nature and social environment. Based on the essential grasp to people's behaviour, here it adopts the explanation about the basic requirement and inner motivity in the hierarchic requirement theory (Figure 2.2), to analyse people's behaviour within the city. In contrast to the functions of green space system, it can be found that green spaces with a beautiful environment help to eliminate physical tiredness and mental oppression, and satisfy people's physiological requirements. Also, green spaces in a good layout condition can create some relatively private and private spaces, not only making people feel homelike and relaxed, but also satisfying people's safety requirement. Moreover, green spaces can maintain a beautiful, clean, comfortable environment for working and study, and provide spaces for rest and outdoor communication, which can satisfy people's requirement for going back to the nature and the need of ownership and love. In addition, recreation can satisfy the upper two requirements (in Figure 2.2).

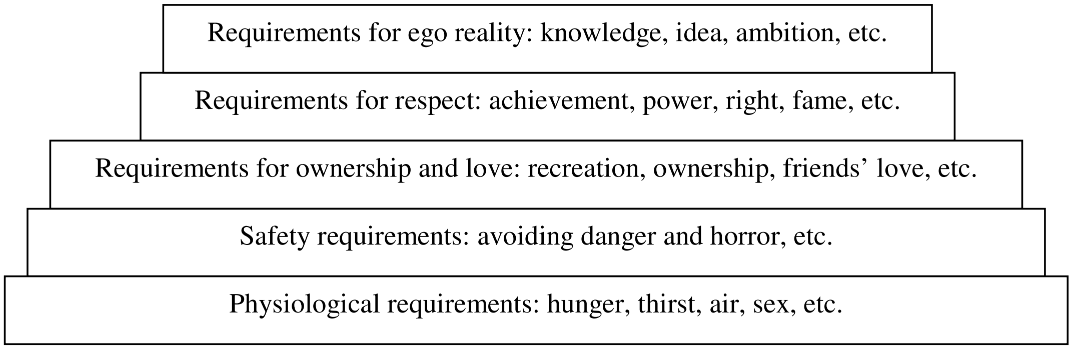


Figure 2.2 Hierarchical requirement theory (Abraham H. Maslow)

Note: The above five requirements are step-up in turn, namely the upper hierarchic requirement will be considered only after the lower hierarchic requirement is satisfied.
Source: Zhu Zhixian (1989), Psychology gradus, P_{808}, Figure a.

4. Education

Generally it is easy to ignore the education function in the social benefit of green spaces. Actually just because of the functions of recreation, landscape aesthetics and creating urban feature, green space has been a powerful media to potentially transmit all kinds of information and emotion in the city, which will influence on the residents' personality. Here it adopts the model of individual behaviour (Shi 2002) to explain the above process. The model is:

B=HELP

B—Behaviour, **H**—Heritage, **E**—Environment, **L**—Learning, **P**—Pursuit

Where, the element of **H** cannot be changed but other elements can be adjusted gradually. It is necessary to emphasize the active effects of green spaces exerting on **E** (environment), **L** (learning), and **P** (pursuit). As an external environment, green space itself is a nature museum and outdoor classroom. It is also a good place for disseminating and spreading the science. As such, people can have chances to directly approach the green spaces, learn more about them and consciously cherish them. In a fresh and quiet living environment, people's life style and behaviour will be potentially affected. A suitable green space system can arouse residents' environmental consciousness, make them produce pursuit, and desire for learning the green spaces environment. After the step-by-step learning and conscious observation about the nature's vicissitude, people will have more profound comprehensions on their own surroundings. Thus a good circular ring is formed (Figure 2.3).

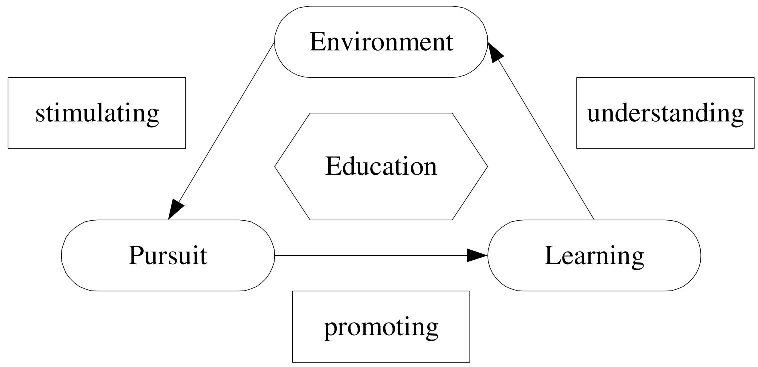


Figure 2.3 Circular ring for education function of green spaces

In order to stimulate the working of the above circular ring, it is critical to create an elegant environment and make a suitable green space system, which can provide people with more chances to approach the nature, particularly for the youth. It is impossible; otherwise, to appeal that people should care about their surrounding ecological environment and control their improper daily behaviours. Nowadays there are many foreign schools locating in the good green space system. They entitle students to manage the vegetative districts in parcels. This helps to improve the children's commonweal conception and make up for those disadvantages in the classroom. It is beneficial for children to learn more about the nature, and it can improve their consciousness, creativity, imagination, the spirit of loving life and go-ahead. Therefore, it is necessary to attach more importance to the social benefits of green spaces, and the more important is to stimulate the working of the above education circular ring.

2.3.3. Economic benefits

People often concern about the economic benefits of urban green spaces, but it is relatively difficult to be measured. The commercial value of urban green spaces includes shadow price and market price (Wu 1999). Shadow price is attached to some public products. For example, producing oxygen, absorbing toxic gases and trapping dusts can save energy. Those safety preventions such as earthquake and fire prevention, water and soil conservation can reduce some loss. In 1995, when the temperature was over 35 centigrade in Tokyo, the electricity consumption of air-conditions would be 1200 thousand kilowatt as long as the temperature rose 1 centigrade. It has been estimated that, 100 million adult trees can save 30 billion kilowatt electricity every year in American cities, which is equal to save 2 billion dollars energy consumption. Thus it can be showed that it is efficient to make use of green spaces to save energy through dropping down the temperature.

Market price is composed of three parts. One is some tangible products can directly generate the market price, such as the productions of lumbers, drugs, nurseries, fruit gardens, etc. The production value of flowers is 13 billion dollars every year in the Netherlands, German and many other countries. Another part is some intangible products can also generate the market price, such as the increase of surrounding land price, the increment of service, etc. In the new district of Pao Ya in Dalian city, the housing price rises from original 800~1000 RMB per square meters to 2000 RMB per square meters after the green spaces are suitably distributed. The last part of market price is also attached to some intangible products, which can generate the market price but are not realized by substance exchange.

For example, the ticket prices in some landscape areas and the prices of travelling service, constructing urban feature for improving the investing environment belong to this part. So it is very important to create an elegant environment to attract more investors, and then it will have good effects on the urban economy. In Dalian, China, the newly increased public green spaces are 6580 thousand square metres from 1994 to 1999, and the greening coverage rate reaches 40%. Meanwhile, the number of the joint, cooperative and single-foreign-invested enterprises has been developed from 1400 to 7000. This is the economic benefits resulted from the environmental benefits.

There are two conceptions of broad-sense and narrow-sense to calculate the economic benefits of urban green spaces. Broad-sense means it only calculates the substantial outputs represented by value and the benefits attained through management. Narrow-sense tries to convert the ecological, social and market value into currency unit, with the aim of reflecting the real value within the green spaces. At present, it is feasible to calculate the economic benefits but difficult to calculate the social benefits. Some scholars have used ecological benefits to reflect the social benefits, namely ecological benefits contain social meanings. In general, it is an arduous task for us to calculate the total benefits in the urban green spaces. How to calculate and which is the best method? It is a burning issue.

3. Methodology

3.1. Definition of suitability analysis

Land suitability analysis is the process of determining the fitness of a given tract of land for a defined use (Hopkins 1977; Steiner 1983). In other words, suitability analysis is the process to determine whether the land resource is suitable for some specific uses and to determine its suitability level. It is an important analytical method for ecological planning. Land suitability refers to the inherent suitability of the land for some specific, persistent uses. This land is determined by such characters as hydrology, geography, topography, geology, biology, sociology, etc. Land suitability will have no meanings unless it is relevant to some specific uses, and it is very important for making good use of land and promoting the land's social value.

3.2. Suitability analysis methods

There have been many analytical methods since suitability analysis came into being, which primarily include the method of sieve mapping, landscape unit method, grey tone method (map overlay) and computer method (GIS). The frontal three methods have been explained in section 1.1. Here it puts the emphasis on the GIS method, which can also be divided into three classes: direct overlay, weighted score, and ecological factors combination.

3.2.1. Direct overlay

The method of direct overlay includes map overlay and equal-weight summation. Map overlay can be traced back to the beginning of 20th century. According to McHarg (1969), this method can be successfully applied in land use suitability, which enables urban planning efficiently and comprehensively to allow for the social and environmental factors. The main steps of map overlay can be concluded as: (1) Defining the planning purpose and identifying the factors contributed to the planning. (2) Investigating each factor's situation and distribution (forming ecological purpose), making a classification according to the suitability for some specific land uses, and using some gradual colours to identify each factor's suitability class in a single factor map. (3) Overlaying two or more single factor maps to get a composite map. (4) Analysing the composite map and finally making the land use planning. In the planning of Staten Island, McHarg and his colleagues applied this method to analyse land use suitability of natural conservation, passive recreation, active recreation, housing development, commerce development and industry development, etc, which has made a great effect.

Map overlay is a kind of visual and intuitionistic method. It can integrate environmental factors with social-economic factors to make the suitability analysis. The disadvantage of this method is that it is essentially a kind of equal-weight additive method. Actually each factor's function is different and sometimes the same factor may be considered repeatedly. Another advantage is that while the factors increase, it is rather complicate to use the gradual colours to represent different suitability classes and to make the overlay. Moreover, it is difficult to identify the little difference from the gradual colours in the composite map. Anyway, map overlay plays an important historical role in the development of ecological suitability analysis. Afterwards, many new methods are developed primarily based on this method.

The method of equal-weight summation is first to quantify the factor's class, then to make a direct addition and finally to get a composite evaluation value. This method takes advantage of different numerical values (map overlay uses gradual colours) to represent the suitability class, which can overcome the inconvenient map overlay and the difficulty to identify the gradual colours. The formula of equal-weight summation is presented below (the premise of such direct overlay method is that each factor's influence on the specific land use is similar and independent):

$$V_{ij} = \sum_{k=1}^{n} B_{kij}$$

Formula 3.1 Equal-weight summation

Where, i represents the parcel number or gird number; j represents the land use number; k represents the number of the ecological factor influencing the j^{th} land use; n represents the total of the ecological factors; B_{kij} represents the suitability evaluation value of the k^{th} ecological factor in the in the i^{th} parcel of the j^{th} land use (single factor evaluation value); V_{ij} represents the composite evaluation value in the i^{th} parcel of the j^{th} land use (composite ecological suitability of the j^{th} land use).

3.2.2. Weighted score

When all kinds of ecological factors' influences on the specific land use are very obvious, it can't make a direct overlay to get the composite suitability. It must take advantage of the method of weighted score. The principle of this method is similar to that of the equal-weight summation. The difference is that it needs to identify each factor's relative importance (weight) in the weighted score. The more influence on the specific land use, the higher weight for the factor. On the basis of scoring each single factor class, it will carry out the weighted summation for the evaluation result of each single factor. Finally we will get the total scores of the corresponding parcels or grids of the specific land use. Generally a higher score represents the more suitability. The formula of weighted score is showed as follow. Where, W_k is the weight of the k^{th} factor for the j^{th} land use. Other symbols are the same as the above method of equal-weight summation.

$$V_{ij} = \sum_{k=1}^{n} B_{kij} W_k$$

Formula 3.2 Weighted score

The method of weighted score overcomes those disadvantages in the method of equal-weight summation. Another important advantage of this method is able to make a girding, classification and quantification in the map, which is suitable for the computer application. This is why this method is so widely applied in the past few years. Whether the method of direct overlay or the method of weighted score, however, the mathematics theory requires that each factor should be independent. Actually many factors have mutual relationships and mutual influences with each other. In order to overcome this disadvantage, ecological planning experts create a new method of 'ecological factors combination'.

3.2.3. Ecological factors combination

As mentioned above, direct overlay and weighted score require that each factor should be independent. Actually many factors depend on each other. For example, it is unsuitable to construct an expressway when the slope is over '30%', no matter how the drainage condition is. But according to the weighted score or direct overlay, when the slope is over '30%' and the drainage condition is very good, perhaps it will get the moderate suitability. The method of ecological factors combination acknowledges that different combinations of the dependent factors determine the suitability of the specific land use.

This method can be classified into hierarchical combination and non-hierarchical combination. The method of hierarchical combination is first to use a set of dependent factors to identify the suitability level, then to regard these dependent factors as a new factor and to combine it with other dependent factors to identify the final suitability level. The method of non-hierarchical combination is to combine all the dependent factors to identify the suitability level at the same time. Obviously, this method is suitable for the analysis with a few factors. And it is useful to apply the hierarchical combination in the analysis with large number of factors. Whether the method of hierarchical combination or non-hierarchical combination, first it is necessary for experts to establish a set of complicate and integrated dependent factors and an evaluation standard. This is the most critical and difficult step to apply the method of ecological factors combination in the suitability analysis. Allowing for the data available and the limited time for the fieldwork, the method of weighted score was selected to carry out the GIS-based suitability analysis in this research (see section 4.3.5).

3.3. GIS application in suitability analysis

GIS (Geographic Information System) is a computerised system that facilitates the phases of data entry, data analysis, and data presentation especially in cases when we are dealing with georeferenced data (By, Knippers et al. 2000). Generally it includes six parts: data source selection and standardization, data pre-processing, data entry, data management, data analysis and displaying, mapping. The core is the analysis function containing overlay processing, neighbourhood comparison, grid analysis, measurement statistics, etc. The geographic information can be collected from field investigation, map, remote sensing, environmental monitoring, and from social-economic data sources.

One of the burning issues in the GIS application is to establish the application and analysis models according to different requirements, such as land suitability evaluation, ecological sensitive areas analysis, ecological benefits analysis, and so on. In the suitability analysis, GIS offers spatial overlay capabilities and grid-cell processing methods that enable us to analyse spatial factors (Shuaib 1998).

Its development and capability to overlay digital maps has made suitability mapping easier and quicker. Its potential for being linked with the planning process through the development and application of relevant models, can be realised by its functionality. Since suitability analysis deals with the analysis of several data sets, GIS can effectively be used in looking at the characteristics of land from a number of layers for each location to solve a problem. GIS-based models can be used to create simplified representations of phenomena. This is done in GIS by combining different sets of map layers to analyse the relationships between them.

GIS-based suitability analysis models generally take advantage of the method of weighted score and the method of ecological factors combination (see section 3.2). IGIS (Intelligent Geographic Information System) is the latest development of GIS technology. It can integrate the expert knowledge with the immense functions in the computer system, which will have great potentials later on. Just because GIS can process enormous data and have the powerful functions of displaying and outputting maps, it will be the main tendency to apply GIS in the suitability analysis.

3.4. GIS-based traditional suitability analysis model (TSAM) and its improvement

Land suitability analysis is very important for the land planning and management. With the advent and rapid development of GIS, land suitability analysis has been more and more applied in the urban planning. One of the most important spatial analysis functions in GIS, overlay, is primarily designed for the multiple factors evaluation (e.g. land suitability analysis). Nowadays land suitability analysis has been developed into those evaluations such as agriculture suitability, graze suitability, forestry suitability, suitability for urban expansion, site selection for specific landuse, and so on. In contrast to the traditional pure-mathematics evaluation method, GIS-based suitability analysis can systematically integrate mathematical calculation with map processing. This method is so intuitionistic, easily operational and quick that it can greatly improve the evaluation efficiency. This research will expatiate on such GIS-based traditional suitability analysis model (TSAM), and will take advantage of the certainty factor to make an improvement and propose the improved traditional suitability analysis model (ITSAM).

3.4.1. Traditional suitability analysis model (TSAM)

1. TSAM procedure

Land suitability analysis is to determine the suitability for some specific landuses by scoring the land. In other words, the higher the score, the more suitable the land for some specific landuses. The traditional suitability analysis includes the following three steps:

(1) Selecting suitability factor. Each factor is represented by a thematic map in GIS. (2) Single factor analysis. Namely according to the single-factor evaluation standard, score is given to the map unit of each factor and then the single factor suitability map is generated. The score is normally grouped into '1', '2', '3' (ratio value) these three classes, which respectively represents 'no suitability', 'moderate suitability' and 'high suitability'. Sometimes the score can be grouped into five or six classes based on different requirements. (3) Multiple factors overlay. First weights are assigned to the suitability fac-

tors according to their relative importance. The weights are determined by statistic integration and hierarchic analysis in this research (see section 3.5). Then it takes advantage of Formula 3.2 to calculate the composite score (final score).

It should be noted that in the vector-based TSAM, the map unit after overlay is the most basic unit produced by multiple factors overlay. While in the raster-based TSAM, the map unit after overlay is the same as the original map unit in the single-factor map, which is composed of regular-arranged grids. Actually the principle of the vector-based TSAM is the same as that of the raster-based TSAM. The difference between them is the map processing. In this research, raster-based structure is used to carry out the GIS-based suitability analysis.

2. Example

The following is a simple example to select a suitable site for new green spaces. In order to explain the TSAM more clearly, here we only select two factors: existing land use, slope. We assume there are only two kinds of land uses in the single factor map of existing land use: existing green space, built up area. The existing green space includes an old park and a new park, and only residential land is in the built up area. Their codes are '26', '25', '24'. The single factor map of slope is grouped into three classes: 0%≤slope<1%, 1%≤slope<10%, 10%≤slope<20%. Here the slope is '0.1%', '9.99%', '10%', and their codes are '16', '15', '14'. Scores given to these two single factors are presented in Table 3.1. For simpleness we assume these two factors have the same weights, namely W_1=W_2=0.5. According to the single factor analysis and the multiple factors overlay, this TSAM procedure can be realized in Figure 3.1. The final overlay results show that, the higher the composite score, the more suitable the land use for the new green spaces.

Table 3.1 Factors and weights in the traditional suitability analysis

Factor	Suitability class	Code	Score	Weight
Existing land use	Existing green space (old park)	26	3	0.5
	Existing green space (new park)	25	3	
	Built up area (residential land)	24	1	
Slope	0%≤slope<1% (0.1%)	16	3	0.5
	1%≤slope<10% (9.99%)	15	2	
	10%≤slope<20% (10%)	14	1	

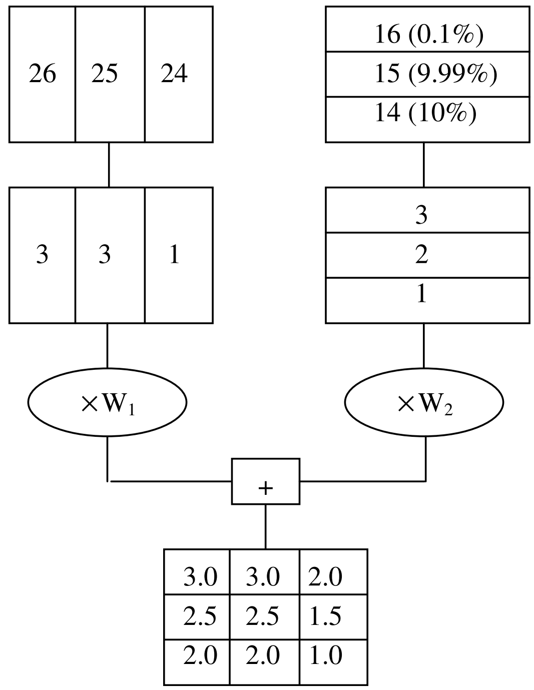


Figure 3.1 TSAM

3.4.2. Improved traditional suitability analysis model (ITSAM)

From the above TSAM, we can see that the single factor analysis has two disadvantages: (1) One is that no difference is identified among the different subclasses within the same suitability class. For example, an old park (subclass) and a new park (subclass) belong to the same suitability class of 'existing green space' and they get the same score of '3'. It is obvious that, however, the new park is less suitable for the site selection of new green spaces because its acquisition is more expensive than the old park. The slope of '1.01%' and '9.99%' are in the same suitability class of '1%≤slope<10% (9.99%)'. The suitability in these two subclasses is obviously different, because the expense for levelling off the ground of '9.99%' is much higher than that of '1.01%'. But these two subclasses get the same score of '2' in the TSAM that cannot identify their difference. (2) The other disadvantage is that the difference between the two different suitability classes is exaggerated around the division of scores. For example, there is very little difference between the slope of '9.99%' and '10%', but they are divided into 'moderate suitability' and 'no suitability' and they respectively get the score of '2' and '1'. Actually 'moderate suitability' and 'no suitability' are all fuzzy conceptions. One of the most efficient methods to solve this problem is to use the membership degree in the fuzzy set theory, but the membership degree is complicate to be integrated with GIS (Huang 1997). Thus in this research, certainty factor is used to solve this problem instead of the membership degree. The certainty factor obeys such a rule:

IF A THEN B

It means that if A holds then B holds. For example, if the land use belongs to the existing green space, then it gets a score of '3'. As mentioned above, the old park and the new park belong to this class of 'existing green space', but they are obviously different. In order to exactly identify the difference between them, the user has to give a certainty factor (CF) to this rule:

IF A THEN B (CF=0.8)

It means the certainty that the user is certain of the rule 'if A holds then B holds' is 80%. For example, we can give a certainty factor of '0.8' to the old park, which means the certainty of the rule 'if the land use is an old park then it gets the score of 3' is 80%. Likewise, we can give the new park a certainty factor of '0.3', to reflect the certainty that the new park gets the score of '3' is 30%. We also can give the certainty factor of '0.2', '0.4', or other values less than '0.8' to the new park. The value of the certainty factor should be based on the current situation and the practical requirements. Thus it can be showed that the certainty factor arranges from '0' to '1'. There are two methods to determine the certainty factor:

(1) The certainty factor is determined by the user. This method is suitable for the qualitative evaluation. For example, the suitability of the old park and the new park are difficult to be described by a mathematical formula. So it has to be determined by the user based on the real condition. As mentioned above, the certainty factor of the old park to get the score of '3' is '0.8', while that of the new park to get the score of '3' is '0.3'. As such, the suitability difference between the subclass of the old park and the new park is identified.

(2) The certainty factor is determined by establishing a certainty factor function. This method is suitable for the quantitative evaluation (e.g. the continuous variable). For example, the suitability class of '0%≤slope<1%' gets the score of '3' in the slope map. We assume the slope between '0%' and '1%' is linear. Thus a certainty factor function can be established to identify the difference between the slope of '0%' and '1%'. The other two certainty factor functions for the class of '1%≤slope<10%' and the class of '10%≤slope<20%' are established in the same way (Formula 3.3):

$$CF(x) = 1 - \frac{x-0}{1-0} = 1 - \frac{x-0}{1} \quad (0\% \le x\% < 1\%)$$

$$CF(x) = 1 - \frac{x-1}{10-1} = 1 - \frac{x-1}{9} \quad (1\% \le x\% < 10\%)$$

$$CF(x) = 1 - \frac{x-10}{20-10} = 1 - \frac{x-10}{10} \quad (10\% \le x\% < 20\%)$$

Formula 3.3 Certainty factor function

Where, x represents the slope value. If $x\% = 0.1\%$, its $CF = 1 - \frac{0.1-0}{1} = 0.9$, which means the certainty that the slope of '0.1%' can get the score of '3' is 90%. If $x\% = 9.99\%$, its $CF = 1 - \frac{9.99-1}{9} = 0.001$, which means the certainty that the slope of '9.99%' can get the score of

'2' is 0.1%. Likewise, if $x\% = 10\%$, its $CF = 1 - \frac{10-10}{10} = 1$. The original score and the certainty factors for each single factor have been determined, now we can use Formula 3.4 to calculate the composite certainty factor $CF^{'}(x)$ (composite single factor score).

$$CF^{'}(x) = S(x) - 1 + CF(x)$$

Formula 3.4 Composite certainty factor

Where, $S(x)$ represents the original single factor score, namely $S(x)$ = '1', '2', or '3'. According to the above principles and the multiple factors overly theory, the procedure of the improved traditional suitability analysis model (ITSAM) is realized in Figure 3.2. It is showed that this ITSAM encompasses more enriched and precise information than the TSAM (Figure 3.1). In other words, the difference among the different subclasses within the same suitability class is identified (e.g. the difference between the old park and the new park), and the difference between the two different suitability classes around the division of scores is not exaggerated but reduced (e.g. the difference between the slope of '9.99%' and '10%'). Therefore, the ITSAM can provide more options for the decision makers.

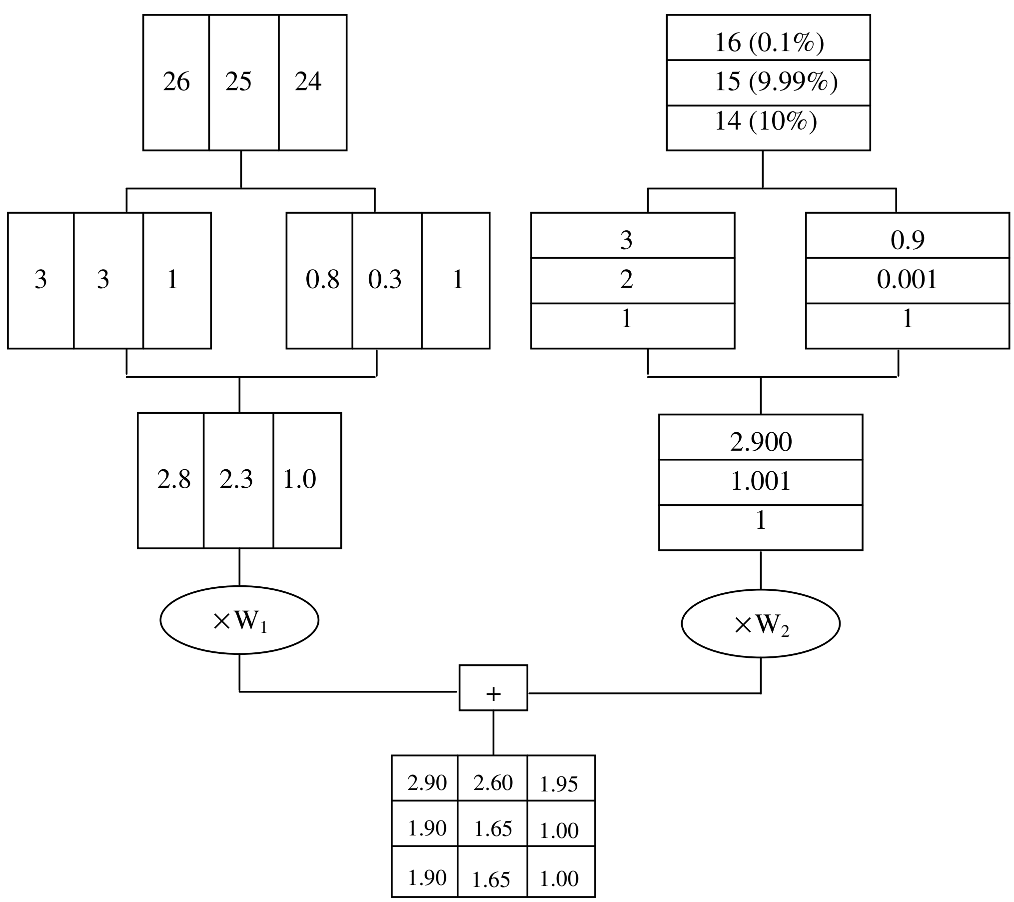


Figure 3.2 ITSAM

3.4.3. Summary

This research has proposed two land suitability analysis models including TSAM and ITSAM. They are all designed based on the multiple factors evaluation theory and the GIS technology. According to the different practical requirements, users can change the weights and the single factor score, and quickly get the final evaluation results. ITSAM, which takes advantage of the certainty factor, can greatly simplify the operation in GIS, and has a more powerful application than the membership degree in the fuzzy set theory. Determining the membership degree needs to consider the certainty that the evaluation object belongs to each suitability class. If the land suitability analysis involves multiple hierarchies, the evaluation procedure will be made rather complicate. The determination of the certainty factor, however, only needs to consider the certainty that the evaluation object belongs to one suitability class, and it doesn't need to assign the uncertainty to the other suitability classes. Therefore, the certainty factor is easier integrated with GIS than the membership degree. The major disadvantage of using the certainty factor is that it has some subjectivity to determine the certainty factor in the qualitative evaluation (e.g. the certainty factor ranges from '0' to '1', but it is somewhat subjective to give the certainty factor of '0.8' and '0.3' to the old park and the new park). And if the values in the single factor map are not linear, the certainty factor function is not very suitable for this quantitative evaluation.

3.5. Weighting methods

"Weighted suitability is more complex, because we do not only consider the binary suitable/unsuitable for each aspect but we compare suitability scales for all aspects and we give them a weighting factor that should reflect their relatively importance. " (Bruijn 1991) "Weighting should be applied when not all aspects have an equal importance. It should be realized that the choice of a weight is most important, as it has a great effect through multiplication of the scores." (Hofstee and Brussel 1999) Assigning the weights to factors is a critical element in suitability analysis. Weighting factors are often based on a mixture of implicit knowledge, personal experience and individual opinions. In order to reduce the subjective bias as much as possible, this research will use three weighting methods based on three different considerations in the study area.

3.5.1. Statistic integration

The method of statistic integration is a kind of special 'expert-assess' method. It is based on a large number of investigations with many experts. Then it carries out the statistic induction and uses the method of integration to get the final weighting values. The following is an example using statistic integration to calculate the factors weights in the environmental quality evaluation. Four factors including air pollution, surface water pollution, groundwater pollution, and noise pollution are selected out for this evaluation. First an investigating table is sent to some experts for comparing the factors importance (Table 3.2). Secondly according to the feedbacks and investigation information, it will carry out the statistic induction and represent the information with percent style (Table 3.3).

Table 3.2 Investigating table of importance order

Importance order	Air pollution	Surface water pollution	Groundwater pollution	Noise pollution
First	√			
Second				√
Third		√		
Last			√	

Table 3.3 Information table of statistic induction (%)

Factor	First importance	Second importance	Third importance	Last importance
Air pollution	71%	22%	7%	0
Surface water pollution	3%	78%	19%	0
Groundwater pollution	13%	20%	19%	48%
Noise pollution	2%	31%	45%	22%

Table 3.2 is an example for one expert to compare the importance the importance among the evaluation factors. The table shows that in this expert's opinion, air pollution is the most important for evaluating the environmental quality, followed by noise pollution, surface water pollution and groundwater pollution. Other experts will also be asked to show their opinions by filling in the same kind of investigating table. All the experts' opinions about the factors importance order have been showed in Table 3.3 by statistic induction. For example, as to the factor of air pollution, 71% of the experts acknowledge it is the most important, second importance with 22%, third importance with 7%, and none of the experts think air pollution is the least important.

Table 3.3 is a statistic induction matrix and is represented by matrix D. Then we can create a weighting order vector. This vector is represented by natural number order, namely $C = (4,3,2,1)$. Actually it uses numerical number to identify the difference among the first importance, second importance, third importance and last importance. Finally matrix D and vector C are integrated and each factor weight is calculated according to Formula 3.5:

$$\overline{W} = [D \bullet C^T]^T = \left[\begin{bmatrix} 0.71 & 0.22 & 0.07 & 0 \\ 0.03 & 0.78 & 0.19 & 0 \\ 0.13 & 0.20 & 0.19 & 0.48 \\ 0.02 & 0.31 & 0.45 & 0.22 \end{bmatrix} \bullet \begin{bmatrix} 4 \\ 3 \\ 2 \\ 1 \end{bmatrix} \right]^T = (3.64,2.84,1.98,2.13)$$

Formula 3.5 Statistic integration

After the normalization, the original weighting vector, $\overline{W} = (3.64,2.84,1.98,2.13)$, is converted into the final weighting vector, $\overline{W} = (0.344,0.268,0.187,0.201)$. As such, each factor weight is showed in Table 3.4.

Table 3.4 Factors weights by statistic integration

Factor	Air pollution	Surface water pollution	Groundwater pollution	Noise pollution
Weight	0.344	0.268	0.187	0.201

There are some advantages in applying the method of statistic integration. First this method is based on inquiring many experts with different contexts. Each weight is calculated by statistic induction and integration, and the calculated values are relatively precise. It is suitable for the evaluation that needs to allow for large number of factors. The most disadvantage of statistic integration is that it has some subjectivity to create the weighting order vector (vector C). This weighting order vector has an important effect on the relationship among the final values, namely different weighting order vectors will generate different weights according to Formula 3.5, and the ratio among the weights will be different. To some extent, the final weights calculated by the method of statistic integration are relatively precise and scientific, but it can't completely get away from the man-made interference after all.

3.5.2. Hierarchic analysis of nine-degree

Nowadays it is prevalent to apply the method of hierarchic analysis of nine-degree in the multicriteria weighting system (Xu 1999; R.Ramanathan 2001; Sharifi and Herwijnen 2003). First this method needs to compare evaluation factors with each other (pairwise comparison), including comparing the factor with itself. Secondly it will use a nine-degree scale to transform the comparison judgements into numerical values. The nine-degree scale is explained in Table 3.5. Then a structural judgment matrix (Table 3.6) is generated by every factor's numerical value. After the normalization, the eigenvector of the largest eigenvalue derived from the structural judgment matrix is the corresponding factors' weighting vector.

Table 3.5 Importance comparison of nine-degree

Degree	Description of pairwise comparison judgements
1	Factor i is equally important as factor j, or comparing i with i, or j with j.
3	Factor i is moderately more important than factor j.
5	Factor i is strongly more important than factor j.
7	Factor i is very strongly more important than factor j.
9	Factor i is extremely more important than factor j.
2,4,6,8	The importance is between the upper degree and lower degree.
Reciprocals	It is contrary to the above importance, namely factor j is more important than factor i.

Table 3.6 Structural judgment matrix of nine-degree

Factor	Air pollution	Surface water pollution	Groundwater pollution	Noise pollution
Air pollution	1	3	8	4
Surface water pollution	1/3	1	5	2
Groundwater pollution	1/8	1/5	1	1/4
Noise pollution	1/4	1/2	4	1

Here it also uses the example of environmental quality evaluation to explain the method of hierarchic analysis of nine-degree. The example includes four factors: air pollution, surface water pollution, groundwater pollution, and noise pollution. First it needs to make the pairwise comparison based on the stakeholder analysis. For example, when air pollution (factor i) is compared with surface water pollution (factor j), if four experts acknowledge that factor i is moderately more important than factor j in the urban environment (the value should be '3' according to the nine-degree scale), while three experts accept that factor i is strongly more important than factor j (the value should be '5'). So the final numerical value will be '3' in the structural judgment matrix. As such, the structural judgment matrix (Table 3.6) will be generated by the numerical values based on Table 3.5 and the stakeholder analysis.

It should be noted that in Table 3.6, all the values are '1' in the main diagonal of the structural judgement matrix (self comparison). The corresponding values between the upper triangle and the lower triangle are reciprocals (the upper triangle represents comparing factor i with factor j while the lower triangle represents comparing factor j with factor i). After the normalization, the eigenvector of the largest eigenvalue is $\overline{W} = (0.56, 0.24, 0.05, 0.15)$, and those four factors weights are determined by this eigenvector (Table 3.7).

Table 3.7 Factors weights by hierarchic analysis of nine-degree

Factor	Air pollution	Surface water pollution	Groundwater pollution	Noise pollution
Weight	0.56	0.24	0.05	0.15

The method of hierarchic analysis of nine-degree can be potentially useful for determining factors weighs in many ways. The powerful mathematics is the main reason why this method is so prevalent. It helps to elicit the complex judgements of different experts in a common platform. It also ensures accuracy in the sense that it has an inbuilt method to check the inconsistency of judgements (see: Saaty and Vargas, 1984). This ensures that the judgements are provided only with sufficient care and the error due to negligence is thus minimised. However, due to the fast growing number of pairwise comparisons, it is not sensible to use the method of hierarchic analysis of nine-degree for a large set of factors. In other words, it is difficult to determine the numerical value from the nine-degree scale when too many factors need to be considered. For example, air pollution is more important than surface water pollution for evaluating the environmental quality. But it is not easy to determine the value of '3', '4', or '5' to identify the importance scale. Hence, the final eigenvector of the largest eigenvalue derived from the structural judgement matrix also has some subjectivity.

3.5.3. Hierarchic analysis of three-degree

The analysis above shows one of the disadvantages of hierarchic analysis of nine-degree, which is relatively difficult to convert the comparison judgements into numerical values according to the nine-degree scale. It is easier to only judge the more important, same important and less important these three classes in the pairwise comparison. Thus the method of hierarchic analysis of three-degree is developed. The first step of hierarchic analysis of three-degree is to make a comparison matrix based on the three-degree pairwise comparison. Then a structural judgment matrix is generated by the above comparison matrix and mathematical formula. After the normalization, all the factors weights will be represented by the eigenvector of the largest eigenvalue derived from the structural judgment matrix. The example of this method is explained below:

(1) Comparing all the factors with each other and quantitating by Formula 3.6, and using the quantitative values to generate the comparison matrix (Table 3.8).

$$K_{ij} = \begin{cases} 0 \ \text{(factor } i \text{ is less important than factor } j\text{)} \\ 1 \ \text{(factor } i \text{ is as important as factor } j\text{, or the factor is compared with itself)} \\ 2 \ \text{(factor } i \text{ is more important than factor } j\text{)} \end{cases}$$

Formula 3.6 Quantitative comparison of three-degree

In the above formula, K_{ij} is the comparing quantitative value between factor i and factor j. It is the corresponding element in the comparison matrix. If $i = j$, namely $K_{11}, K_{22}, K_{33}, K_{44}$, it means factors are compared with themselves, the value will be '1' in the main diagonal of the comparison matrix (Table 3.8). Just like the structural judgment matrix of nine-degree (Table 3.6), the values in this comparison matrix of three-degree are determined based on Formula 3.6 and the stakeholder analysis.

Table 3.8 Comparison matrix of three-degree

Factor	K_1	K_2	K_3	K_4	$\sum_{i=1}^{4} K_i$
Air pollution K_1	1	2	2	2	7
Surface water pollution K_2	0	1	2	2	5
Groundwater pollution K_3	0	0	1	0	1
Noise pollution K_4	0	0	2	1	3

Table 3.9 Structural judgment matrix of three-degree

r_i	r_j			
	r_1	r_2	r_3	r_4
Air pollution r_1	1	10/3	8	17/3
Surface water pollution r_2	3/10	1	17/3	10/3
Groundwater pollution r_3	1/8	3/17	1	3/10
Noise pollution r_4	3/17	3/10	10/3	1

(2) Using the cumulant ($\sum_{i=1}^{4} K_i$) from the comparison matrix to make the structural judgment matrix by Formula 3.7.

$$r_{ij} = \begin{cases} \dfrac{K_i - K_j}{K_{\max} - K_{\min}} \bullet (b_m - 1) + 1 (K_i \geq K_j) \\ 1/[\dfrac{K_i - K_j}{K_{\max} - K_{\min}} \bullet (1 - b_m) + 1](K_i < K_j) \end{cases}$$

Formula 3.7 Hierarchic analysis of three-degree

In the above formula, r_{ij} represents the elements in the structural judgment matrix. K_i, K_j respectively represents the rows cumulant ($\sum_{i=1}^{4} K_i$) of the corresponding factor in the comparison matrix. For example, $K_1 = 7, K_2 = 5, K_3 = 1, K_4 = 3$ in Table 3.8. $K_{\max}, K_{\min}$ are the maximum value and minimum value in $\sum_{i=1}^{4} K_i$. b_m is equal to $K_{\max} + K_{\min}$, which is the sum of the corresponding values between the most important factor and the lest important factor. Here $b_m = 8$. Thus the structural judgment matrix (Table 3.9) is made.

(3) Just like the hierarchic analysis of nine-degree, after the normalization the eigenvector of the largest eigenvalue derived from the structural judgment matrix is $\overline{W} = (0.588, 0.256, 0.048, 0.108)$. Note that the eigenvector is showed as a vector, and the values in this vector represent the corresponding factors weights. Unlike the integration matrix in the method of statistic integration, hierarchic analysis of three-degree needn't create a weighting order vector to generate the structural judgement matrix. These two different matrixes contain two different kinds of information. The factors weights are showed in Table 3.10.

Table 3.10 Factors weights by hierarchic analysis of three-degree

Factor	Air pollution	Surface water pollution	Groundwater pollution	Noise pollution
Weight	0.588	0.256	0.048	0.108

Comparing with hierarchic analysis of nine-degree, the method of hierarchic analysis of three-degree is easier for decision makers to understand and take into application. It is more explicit and has better certainty. Particularly when a large number of evaluation factors need to be considered, it is easier to make the pairwise comparison and transform the comparison judgements into numerical values, only allowing for the three-degree scale. Xu (1999) has proved that this advantage will be showed completely when it needs to evaluate more than ten factors. Here the example only allow for four factors, so this advantage cannot be showed obviously. However, the discernment in hierarchic analysis of three-degree is not very good. For example, one expert acknowledges that air pollution is very strongly more important than groundwater pollution and it gets the value of '2' in the three-degree scale. Another expert thinks air pollution is weakly more important than groundwater pollution, but it also gets the same value of '2' according the three-degree scale. As such, two different opinions will generate the same weighting system, which can be showed that the discernment in hierarchic analysis of three-degree is not very powerful.

3.6. Evaluation methods for ranking

The aim of evaluation method for ranking is to reject "bad" alternatives or identify good ones, to better understand the potentials and limitations of different alternatives, to identify the best alternative and make a ordering of alternatives. In the opinion of Janssen (1994),"An evaluation method is any procedure that supports the ranking of alternatives using one or more decision rules. An evaluation method can generate:

(1) a complete ranking : A>B>C>D
(2) the best alternative : A>(B,C,D)
(3) a set of acceptable alternatives : (A,B,C)>D
(4) an incomplete ranking of alternatives : A>(B,C,D) or (A,B)>(C,D)
(5) a presentation of alternatives"

He thinks any criterion (factor) can be converted to a measurable quantity. The style is a kind of numeric value that reflects the degree to which a particular objective is achieved. And "an objective is a statement about the desired state of the system."

Evaluation methods differ in the type of decision rule applied, the characteristics of the set of alternatives they can handle and the type of rules used to value the attributes (Jankowski and Richard 1994). As to the set of alternatives, this research is a kind of discrete decision problems comprising a finite set of alternatives (six suitability scenarios in this research), while continuous decision problems are characterized by an infinite number of feasible alternatives. The problem in discrete evaluation is to identify the attractiveness of alternatives, based on two elements: 1) the consequences of the alternatives in terms of the decision criteria; 2) the weights assigned to the criteria.

There are many methods to evaluate the ranking of alternatives till now. Most of them are designed to process quantitative information on attributes (e.g. weighted summation, ideal point method). In order to process qualitative or mixed information, some evaluation methods such as regime method, evamix method or permutation method have been developed. According to the aggregation method, the DM-analyst relationship and to the way of elucidation of the preferences, evaluation methods can be grouped in three classes: compensatory approach, outranking approach and non-compensatory approach. Compensatory approach assumes that there is an absolute compensation in the evaluation, which means high performance in one criterion of one alternative can compensate its weak performance in another criterion. Outranking approach is partially compensatory. It is based on the pairwise comparisons of all alternatives and their outranking relations. Non-compensatory approach accepts the hypothesis that there is no compensation among the criteria al all. (Table 3.11)

Table 3.11 Overview of evaluation methods for ranking

Classes	Methods	Processing information
Compensatory	Weighted summation	Quantitative
	Ideal point method	Quantitative
	Multiattribute utility model	Quantitative
	Regime method	Qualitative or mixed
	Permutation method	Qualitative or mixed
	Evamix method	Qualitative or mixed
Outranking	Electre method	Quantitative
Non-compensatory	Dominance method	Qualitative or mixed

All methods mentioned in the above table will be evaluated according to their information requirements, the efficiency of using information and the effectiveness of the method in terms of the results.

Allowing for the quantitative information in this research, it will use two methods including weighted summation and electre method to make the ranking of alternatives (six suitability scenarios).

3.6.1. Weighted summation

Weighted summation is a simple and often used evaluation method. First all criteria scores need to be standardized. Then an appraisal score is calculated for each alternative by multiplying each standardized score by its corresponding weight, followed by summing of the weighted scores for all criteria. The final ranking of alternatives can be formulated as follow:

$$S = \sum_{i=1}^{i} (x_{ij} w_i) \qquad (i = 1,......i;\ j = 1,......j)$$

Formula 3.8 Weighted summation

Where S represents the final score of alternatives. The higher the S, the better the ranking of alternative. x_{ij} is the score of alternative j according to criterion i. w_i is the weight assigned to the evaluation criterion. Thus it can be showed that the final scores and ranking depend on the standardization method and weights assigned. Weighted summation can only be applied if the attributes are additive (Sharifi and Herwijnen 2003). It requires quantitative information on scores and weights. Only the relative values of this information are used in the evaluation. Weighted summation can provide a complete ranking and information on the relative differences between alternatives.

3.6.2. Electre method

Electre method, also known as concordance analysis, which is the most common technique based on pairwise comparison, determines the ranking of alternatives by means of pairwise comparison. The comparison is based on calculations of the concordance measure, which represents the degree of dominance of alternative i over alternative k, and the discordance measure, which represents the degree of dominance of alternative k over alternative i (Voogd 1983). According to these measures, the differences between alternatives are quantified and a final score is calculated for every alternative. From this score the alternatives can be ranked from best to worst.

Thus it can be showed the basic idea of this method is to measure the degree to which scores and their associated weights confirm or contradict the dominant pairwise relationships among alternatives. This dominance relationship for every pair of alternatives can be derived by a concordance index and a discordance index. The concordance index for the alternatives j and k, conc (j,k), which represents the degree to which alternative j is better than alternative k, can be defined by summing the weights associated with criteria contained in the concordance set (Formula 3.9). The discordance index, disc (j,k), representing the degree to which alternative j is worse than alternative k, can be defined as the largest of those differences between the scores of both alternatives from the discordance set (Formula 3.10). This reflects that beyond a certain level, bad performance on one criterion cannot be compensated for by good performance on the other criterion (Janssen 1994).

$$conc(j,k) = \sum_{i:x_{ij} \geq x_{ik}} w_i \qquad (\sum_{i=1}^{n} w_i = 1,\ x_{ij} \text{ and } x_{ik} \text{ are the original scores})$$

Formula 3.9 Concordance index

$$disc(j,k) = \max_{i:x_{ij} \geq x_{ik}} (\bar{x}_{ik} - \bar{x}_{ij}) \qquad (\bar{x}_{ik} \text{ and } \bar{x}_{ij} \text{ are the standardised scores})$$

Formula 3.10 Discordance index

Then two concordance threshold values and two discordance threshold values have to be defined by decision maker. These threshold values, in combination with the concordance and discordance indices are used to establish a weak and a strong outranking relationship between each pair of alternatives. Finally an iterative procedure of step-by-step elimination is used to convert the weak and the strong graph representing these outranking relationships into an overall ranking of the alternatives.

3.6.3. Summary

The assumptions behind weighted summation are that weights are quantitative, the criteria scores are determined on a ratio scale, and value is aggregated by addition. The most frequently violated assumption is the second one. It is sometimes impossible to measure all the relevant criteria on a ratio scale. Another potential disadvantage is that if the criteria weights are not linear, it will make the linear aggregation of value not very precise. The advantage of this method is its simplicity. However, this simplicity not only limits the ranking of alternatives but also limits sensitivity analysis.

There are also some advantages and disadvantages in electre method. First, the pairwise comparison between alternatives can provide a much more elegant evaluation of the relative performance of a given alternative. Second, this method is relatively thorough because every alternative is compared with every other alternative instead of the performance of the alternatives being stated by an average achievement. Third, the threshold values give the user some control over what minimum standards are to be enforced. However, this method is somewhat complex that only users familiar with this technique can understand the mechanics, which will make the control of threshold values meaningless. In some sense, this analysis is a 'black box' approach that miraculously decides which alternative is the best. Therefore, electre method makes better use of available information than the weighted summation, but it may not necessarily be better for decision support.

3.7. Sensitivity analysis

Sensitivity analysis is a technique that enables decision makers to test the validity of scores, weights used and the ranking of alternatives. It can measure the impact on evaluation results of changing one or more key input values about which there is uncertainty. In problems where the criterion scores and weights can be estimated with complete certainty and where all evaluation methods yield the same ranking of alternatives, this ranking is certain. In the majority of problems, however, scores and weights are uncertain and evaluation methods involve different assumptions. According to Colson

(1989), uncertainty arises from lack of information or knowledge of some aspects of a decision problem. Sometimes uncertainty can be avoided by collecting more information, and sometimes it must be accepted because it is due to unforeseen occurrences. The main factors of uncertainty are the role of chance, the ambiguity and insufficient understanding of a problem and in making an abstraction of the actual problem.

Multicriteria evaluation (MCE) consists of four main components: criteria, criteria scores, weights (priorities) and the choice of an evaluation method. Generally there are some ambiguities existing in one or all of these components, so the MCE results will always be associated with some uncertainties. Since the aim of evaluation is to provide the decision maker with the best alternative or with a ranking of alternatives, these uncertainties are only relevant to their impacts on the ranking. In this research, therefore, procedures are introduced to analyse the sensitivity of the ranking to criteria scores and weights.

3.7.1. Uncertainty on scores

Sensitivity of the ranking to the criteria scores can be tested from two aspects. One is to look at the overall uncertainty of the scores. The other is to look at the influence on the ranking when only changing one score.

1. Overall uncertainty of the scores

Sensitivity of the ranking of alternatives to overall uncertainty in scores is analysed by using a Monte Carlo approach (Janssen 1994). The decision maker has to estimate the maximum percentage that the actual criteria values may differ from the estimated values included in the scores table. A random generator is used to convert this information into a large number of scores tables around the original scores table. Rankings are then determined for all scores tables and aggregated into a final ranking. This method can be applied for every evaluation method resulting in a complete ranking. But it should be noted that the user must pay more attention to the interdependences among the criteria when applying the random generator. Otherwise, they may greatly distort the results of sensitivity analysis on the rankings of alternatives.

2. Uncertainty of one score

The second type of uncertainty is to look at the influence of changing one criterion score on the ranking of two selected alternatives. This method generates a certain interval in which the ranking of the two selected alternatives is not sensitive to changes in value of the selected criterion. If much debate exists on the value of a certain criterion score and the certainty graph of this score shows that small changes in the score result in a different ranking of the alternatives, then more research will be needed to remove or decrease the uncertainty (Sharifi and Herwijnen 2003).

3.7.2. Sensitivity on weights

Weights or priorities, reflecting the relative importance among the criteria, also have a great effect on the final ranking of alternatives. This is because there are some uncertainties existing in determining the weights, particularly when the weights need to be quantitatively assessed. According to Sharifi and Herwijnen (2003), sensitivity of the ranking to the weights can be tested by: (1) looking at the overall uncertainty of the weights; (2) looking at the influence on the ranking when changing one criterion weight; (3) looking at changes in all weights; (4) using different sets of weights. The first two methods can be analysed in a similar manner as the above methods concerning the sensitivity of the ranking to the criteria scores. Here it only emphasizes on the latter two methods.

1. Changes in all weights

This method determines which combination, most similar to the original combination of weights, changes the ranking order of a selected alternative. The following three ways can carry out this operation (Sharifi and Herwijnen 2003). (1) Rank reversal of two alternatives: This procedure determines a most similar weight combination for which the ranking of two selected alternatives changes. (2) First position of an alternative: This procedure determines a most similar weight combination for which one selected alternative becomes the best. (3) Loss of first position of an alternative: This procedure determines a most similar weight combination for which the (selected) best alternative will be displaced by another alternative.

2. Different sets of weights

This method aims to test the sensitivity of the ranking of alternatives to the weights by using different sets of weights, which acknowledges the existence of more than one viewpoint and represents different strategic viewpoints. For example, as to an environmental problem, different relevant departments may have different viewpoints from their own purposes. So they will pay different attentions to the same criteria of such an environmental problem. In other words, there will be different sets of weights corresponding to the same criteria. Too many viewpoints may make things unclear and make it difficult to select a desired alternative. Therefore, it is important to have a few clear viewpoints and pay more attention to the valuable one.

3.7.3. Summary

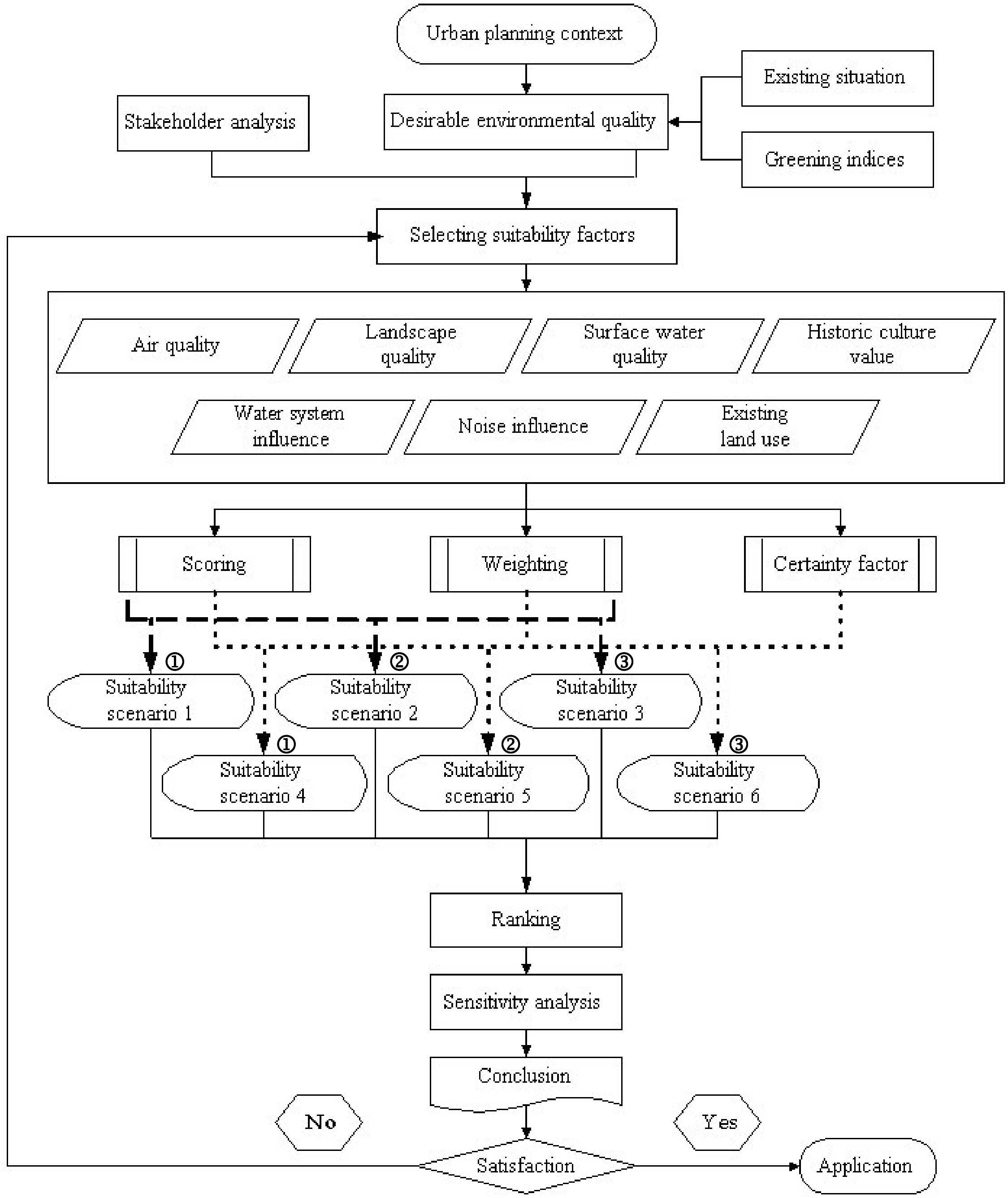
There are several advantages of using sensitivity analysis on the ranking of alternatives. First, sensitivity analysis recognizes the uncertainty associated with the input and gives information about the range of output variability. Second, it identifies evaluation criteria that may have the greatest potential impact on the ranking. This can allow analyst to focus on those criteria that are most important. Third, the process provides more information upon which to base a decision. In particular, it provides a notion of where the impacts of uncertainty are important for the analysis and where they are not. This will cause the analyst to gather additional information. Fourth, it is relatively easy to compute the necessary information required for either approach. In fact, the analyst can assume a range of values around the most likely case, without undertaking a great deal of work. Fifth, because the process requires a careful examination of the criteria and weights most likely to influence ranking of alternatives, the analyst is better informed as to what the results of the analysis truly represent. Finally sensitivity analysis can be used on any measure of alternatives and can be used when there are little information, resources, and time for more sophisticated techniques.

Several disadvantages are also prevalent. First, there is no explicit probabilistic measure of risk exposure. That is, although the analyst might be sure that one of several outcomes might happen, the analysis contains no explicit measure of their respective likelihood. So it does not reflect the effects of diversification and does not incorporate any information about the possible magnitudes of the forecast errors. Second, while the method fails to account for criteria interaction, the scenario approach usually only includes a small number of potential scenarios. Finally, the lack of a systematic method for determining the appropriate combination of criteria and weights used to define given scenarios limits the reliability of sensitivity analysis.

3.8. Methodology flow chart

In the research methodology, first it pays attention to the urban planning context, such as location, physical characteristics and social-economic characteristics in the study area. Secondly it needs to propose the desirable environmental quality from two aspects: existing situation and greening indices. And after the stakeholder analysis for suitability, seven suitability factors including air quality, landscape quality, surface water quality, historic culture value, water system influence, noise influence, and existing land use, will be selected to carry out the GIS-based suitability analysis of the urban green space system, by taking advantage of the method of weighted score.

As such, six suitability scenarios will come out according to different sets of scores and weights, and certainty factors. Here, it uses statistic integration to calculate the weights for ‘suitability scenario 1’ and ‘suitability scenario 4’. Hierarchic analysis of nine-degree is applied in generating ‘suitability scenario 2’ and ‘suitability scenario 5’. Weights calculated by hierarchic analysis of three-degree are used to generate ‘suitability scenario 3’and ‘suitability scenario 6’. The first three suitability scenarios are based on the traditional suitability analysis model (TSAM). Certainty factor is another important element applied in generating ‘suitability scenario 4’, ‘scenario 5’ and ‘scenario 6’. These three suitability scenarios are based on the improved traditional suitability analysis model (ITSAM). Afterwards, it wants to use MCA (multicriteria analysis) to carry out the ranking among the above six suitability scenarios (alternatives). Sensitivity analysis is then used to test the validity of scores, weights and the ranking of alternatives. Thus, we can make a conclusion based on all the above analyses. If the conclusion is satisfied, we can take the final best suitability scenario into application. Otherwise, we have to turn back to select another set of suitability factors, repeat all the above steps and try to get a satisfied conclusion. The methodology flow chart is presented below:



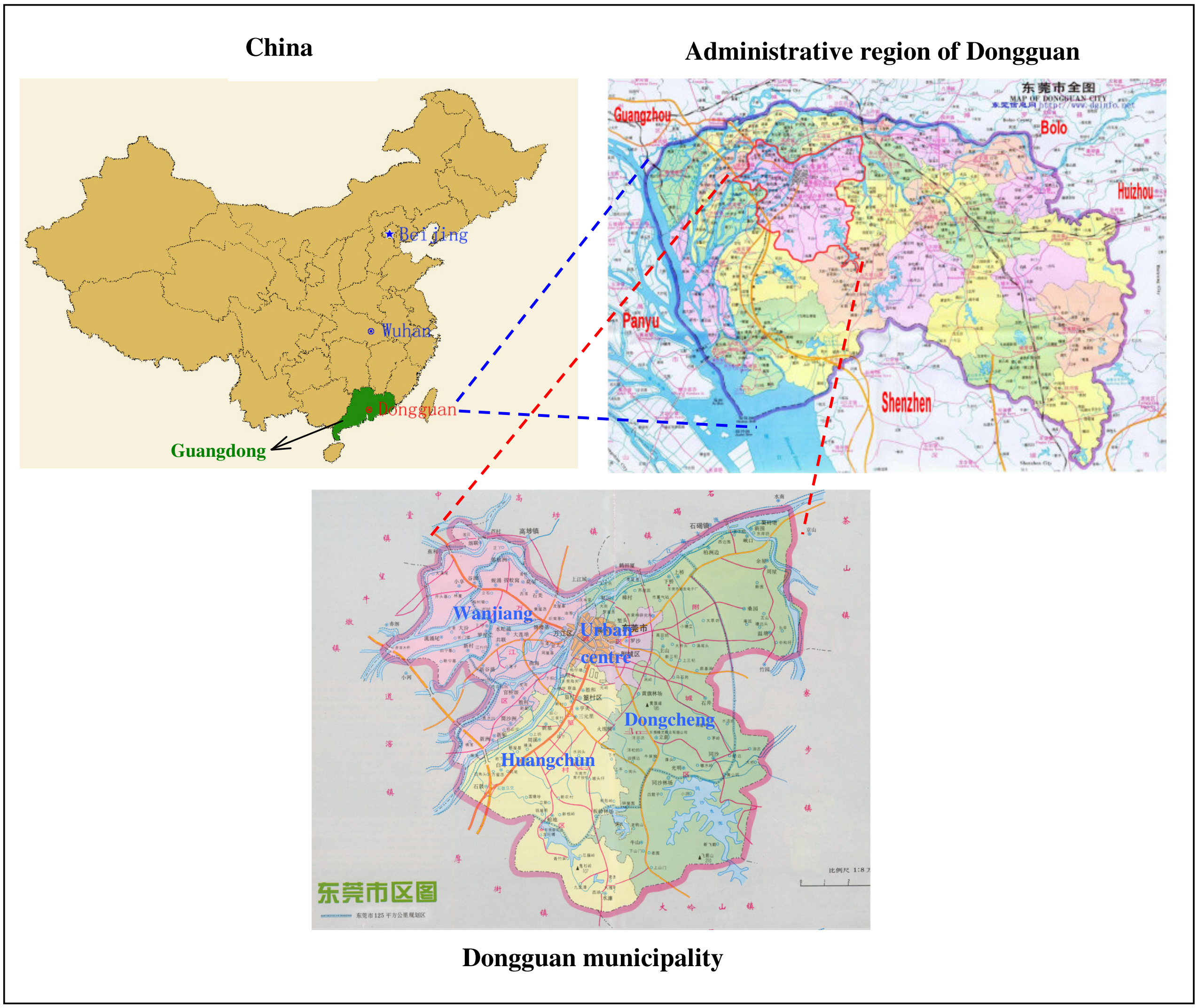
Note: ① Calculating weights by statistic integration. ② Calculating weights by hierarchic analysis of nine-degree. ③ Calculating weights by hierarchic analysis of three-degree.

Figure 3.3 Methodology flow chart

4. Case study in Dongguan

4.1. Study area: Dongguan municipality

4.1.1. Location



Map 4.1 The location of Dongguan municipality (study area)

Administrative region of Dongguan lies in the central-south of Guangdong province, and by the lower passage of Dong River in the Pearl River Delta centre. To its north is Guangzhou and Shenzhen lies south; to its east is Huizhou and Bolo while Panyu is parted by Pearl River on its west. It is situated in the Guangzhou-Shenzhen-Hongkong economic corridor, which is renowned as a prosperous, high-valued region.

This research only focuses on studying Dongguan municipality, which is located in the west north of administrative region of Dongguan. Dongguan municipality is 50 kilometres far away from Guangzhou, 84 kilometres far away from Guangzhou and 80 kilometres far away from Guangzhou. It includes four districts: Urban centre, Huangchun district, Dongcheng district and Wanjiang district. Actually this study area is also a planning area validated from 2000 to 2015. It includes the existing urban area and some surrounding reserved areas for the urban future development. The location of this study area (Gongguan municipality) is showed in Map 4.1.

4.1.2. Physical characteristics

The east south and centre of Dongguan municipality are mountains. Its north is a plain of Dong drainage area, while west and west north are close to Pear River port. So the terrain inclines from east south to west north. Wanjiang River, Dongguan Channel and Dongguan Canal go through Dongguan municipality from east north to west south. There are 3 big reservoirs in the south and one of them has the water reserves of over 500 thousand. All of which form an abundant water network composed of rivers, lakes and reservoirs. The average ground evaluation is only 2~3 metres in some areas (e.g. the areas near Guangzhou-Shenzhen expressway in Huangchun district) while a century flood line is over 6 metres. So these areas are not suitable for urban construction and it is necessary to make green belts to prevent the flood.

The climate of Dongguan municipality is characterized by very hot in summer and warm in winter. It is very sunny and rainy. The annual average temperature is 22 centigrade and the absolute highest temperature reaches 41.2 centigrade. Particularly in July and in August, the temperature usually ranges from 26 centigrade to 40 centigrade. The annual average rainfall is 1788.6 millimetres, the highest rainfall reaches 367.8 millimetres, and the annual average relative humidity is 79%. Thus it can be showed that the climate in Dongguan municipality is not very suitable for a good human settlement. With the aim of making a better adjustment and improvement to the urban climate, one of the most efficient methods is to make a suitable urban green space system.

4.1.3. Social-economic characteristics

The total area of Dongguan municipality is 227.58 square kilometres, with a population of 826.7 thousand including 316.4 thousand Hukou (Household registration) residents and 510.3 thousand temporary residents (1999). The built up area in Dongguan municipality is 54.12 square kilometres and its total population is 668 thousand, which includes 240 thousand Hukou residents and 428 thousand temporary residents. There are 158 thousand non-agriculture residents in the Hukou residents and the landuse per capita in the built up area is 81.02 square metres. Thus we can see that the built up area is relatively small and it is only 23.78% of the total area of Gongguan municipality, but the population in the built up area is 80.8% of the total area. This is because the environment, public facilities, economy, etc. in the built up are much better than that in other areas. It is an arduous task for decision makes to improve the urban environment by making a suitable green space system, in order to attract those numerous population in the built up area to other developing areas, and finally to lead the urban development into the right direction.

The economy of Dongguan is mainly export-oriented, most capitals coming from abroad; meanwhile, raw materials also coming from overseas, and the product distribution are carried out by international market. Dongguan's foreign capitals originated from 'San Lai Yi Bu' enterprises. But these enterprises have been developed into the joint, cooperative and single-foreign-invested enterprises. The gross domestic product (GDP) of Dongguan was 41.284 billion RMB in 1999, which was 17.9% more than that in 1998. The average GDP has been improved from 3961 RMB in 1989 to 27561 RMB in 1999. Using overseas capital and the total imports-exports are respectively 1.457 billion dollars and 28.463 billion dollars in 1999, which are 8.91% and 22.3% more than that in 1998. Dongguan has become an international processing and manufacturing base, and the industry of electronic communication and electric machine develop very quickly. As such, much pollution has been generated with the fast economy development, particularly the industry development. Then how to eliminate this pollution and improve the urban environment, to keep the existing economy development and attract more investors, it is a burning issue for the economists, urban planners and local decision makers.

4.2. Current green space system analysis in Dongguan

4.2.1. Existing situation of the green space system

The built up area in Dongguan municipality is 54.12 square kilometres (1999). There are nine public green spaces existing in the study area, which include People's Park, Qifeng Park, Keyuan Garden, Wanjiang Park, Cultural Square, Huying Suburban Park, Fengjing Golf Course and Dongcheng Cultural Square. The total areas of these public green spaces are 363.70 hectare (not including those natural reservations and green belts such as Qifeng Mountain, etc.). Public green space per capita (see section 4.2.3) is 5.44 square metres, and greening coverage rate (see section 4.2.3) in the built up area is 35.1%. Compared with the national greening indices that green space per capita must be more than 9.0 square meters, and public green space per capita must be more than 7.0 square meters, the current greening indices in Dongguan municipality are obviously not enough. So it is an important task for the government to improve these greening indices and then to improve the environmental quality.

4.2.2. Problems existing in the green space system

1. Public green space and suburban forestry

(1) Public green spaces are not distributed uniformly. Public green space per capita is 5.44 square metres, but most public green spaces are located in the east south. There are some green spaces in the urban centre such as People's Park, Keyuan Garden and Cultural Square. However, their areas are only 25.7 hectare. Greening rate (see section 4.2.3) is relatively low in contrast to the numerous population in the urban centre. The area of Qifeng Park is 90 hectare and it is more than 80% of the total parks areas. It is situated in the urban fringe; the area is large enough but the using rate is very low. There is only one park of 2.3 hectare in Wanjiang district and even no parks in Huangchun district. Middle-scale parks and small-scale parks are extremely not enough in Dongguan municipality, so it can't satisfy the residents' needs and play a good ecological role.

(2) It can't use the predominant conditions of abundant mountains and water to construct a horticultural city. Originally there were many mountains, lakes and rivers in the study area, and the natural

mountain-water skeleton was very good. But in the previous urban construction, some mountains were destroyed and some lakes were used for other landuses. Moreover, the buildings were very close to the rivers and lakes. Thus it can be showed that the favourable natural conditions can make Dongguan be an elegant mountain-water horticultural city, but it cannot be well realized in the urban planning and construction. Now the current suburban forestry can be regarded as the urban pulse, however, only several types of trees existing in the forestry result in the bad ecological function.

(3) It cannot form a uniform-distributed park system integrated with large-scale parks, middle-scale parks, and small-scale parks. The ecological diversity is poor and it lacks science and rationality to distribute to the parks. The worst is that more and more parks are continuously replaced by other commercial landuses.

2. Residential green space and departmental (work unit) affiliated green space

In Dongguan, one of the urban construction emphasises is to improve the environmental quality in the residential areas and the work units. However, now it only focuses on the housing construction, regardless of the residential green spaces. Particularly residential greening (afforestation) is the weakness in the urban centre. In the residential districts, building density and floor area rate are high while the road is narrow and there is a lack of green trees. The planning fieldwork has showed that there are no formal parks in the residential districts except Bu Bu Gao residential quarter. So greening rate of residential districts and work units is relatively low in the study area. Moreover, the quality and management of residential green spaces are not very good. Some high-class residential quarters can succeed in managing their green spaces, but most residential quarters are the exception, which has results in the low environmental quality and poor ecological benefits (see section 2.3.1). The government doesn't attach enough importance to the balcony and roof greening. The problems existing in the green spaces of work units are similar to that of residential districts. Namely greening rate is relatively low and green spaces can't play a good ecological role to the work units.

3. Road green space

The areas of road green spaces are 148.5 hectare in Dongguan municipality. Most roads are relatively narrow with one board in the urban centre. Greening rate of roads is low and only one row of tree is situated in the roadside. The new major roads are composed of three green belts: car-separated green belt, street tree and roadside green belt. Most of them have been planted with certain amount of trees. The current road greening has been finished quite well in the study area. Generally the trees can be planted where the roads are constructed. The problems existing in the road green spaces are: (1) Except that some roads have a good landscape, street trees in most roads are so young that they cannot play a good function of beautifying roads, supplying passengers with umbrage and improving the environmental quality in the roadside. (2) As to the new three-board roads, the width of car-separated green belt in some sections is less than 1.5 metres, which will influence on the arbors growth and the landscape effects. (3) The breeds of street trees are not enough to form a kind of Dongguan-style road green spaces.

4. Productive and defensive green space

There are productive green spaces of 78.5 hectare (nursery, flower garden, grass garden) in the study area. Productive green space is a productive base to supply the city with seedlings. The deficiency of productive green spaces will have a bad effect on the annual greening quality and quantity. Depending on buying seedlings outside is difficult to ensure the breeds of required seedlings and their standards. It will also influence on the surviving rate of new-planted trees. Thus the government has to plant what it can buy. It is impossible to form a Dongguan-style urban landscape. In the suburb, farmlands and forestry network have suffered certain destructions. So far, defensive green spaces are only 1.67 hectare.

5. Landscape forestry land

It is incompletely reported that the areas of landscape forestry lands are 6.1 hectare. They are mainly located in Dongcheng district and Wanjiang district. The forestry lands inside the study area are very different from those outside the study area. The inside section lacks in forestry while the outside section is abundant of forestry.

4.2.3. Greening indices

1. Definitions of three greening indices

From the view of ecological balance, environmental protection and environmental improvement, there must be some green spaces and a certain greening coverage rate in the city, which can play an active role of ecological benefits (see section 2.3.1). Greening index is one of the important measures used to plan the green space system and assess the environmental quality. It is a development expectation for a certain period, which should be determined by the practical requirements, national situation and urban situation. So far, there are three greening indices used to assess the environmental quality in China:

(1) Public green space per capita. It refers to the number of public green spaces that every resident can own in the city. This index shows urban residents can directly share certain amount of green spaces. To some extent, it also shows the condition with which green spaces can supply people's recreation. **(2) Greening coverage rate**. It refers to the percentage that the vertical projective areas of all vegetation (arbour, shrub, grass, etc) share the total urban areas. **(3) Greening rate**. It refers to the percentage that all kinds of green spaces share the total urban areas.

The detailed calculations of the above three greening indices are:

Total urban green spaces (m^2) = Park areas + Public green space areas + Productive green space areas + Defensive green space areas + Ecological landscape green space areas + Specific green space areas + Road green space areas

Public green space per capita (m^2/Person) = (Park areas + Public green space areas) / (Total urban population)

Greening coverage rate (%) = (Park areas + Coverage areas of street tree + Coverage areas of other green spaces) / (Total urban areas) *100%

Greening rate (%) = Total urban green spaces / (Total urban areas) *100%

2. Functions of three greening indices

Different countries have different urban greening indices according to their different situations, and they use many types of indices to assess the environmental quality. In china, it primarily concerns about the greening coverage rate and public green space per capita before 1990. These two indices have played certain roles in history, however, they cannot exactly reflect the overall situation of the environmental quality.

Greening coverage rate can reflect the coverage level within the city. It is one of the efficient standards used to assess the environmental quality. Except those massive grass lands, most greening coverage rates are figured out by the stem size and by assuming different coverage areas. In China, urban population is large and landuse per capita is relatively low. So in the urban afforestation, it should try to develop the road greening and to plant trees in those vacant areas as much as possible. Some trees ‘occupying sky not occupying earth’ can efficiently improve the environmental quality. Thus it can be showed that calculating greening coverage rate can accelerate the urban afforestation.

Now greening rate has been integrated with the greening coverage rate to act as the assessing index in a district or a work unit. Thus it can be more exactly to reflect the environmental quality. But after eliciting the greening rate, two problems should be analysed more critically. One is that it should not use the unit of tree quantity in the planning and assessment of urban green space system, but use the unit of green space area. The other is there should be a quantitative rule to identify to which extent vegetation can be converted into green spaces, in order to ensure the green space system quality and function as ecological benefits (see section 2.3.1). These two problems should be integrated with the urban affroestation characteristics to make a further rule.

Public green space per capita is mainly to reflect the exoteric quality, namely it is an index to assess the green space system for supplying people with recreation. From the view of ecological horticulture, those public green spaces for recreation is one part of the urban green space system, and the function of supplying people with recreation is only one aspect in the diverse social benefits (see section 2.3.2). According to Min (1999), recreation is the most important in the social benefits and it is feasible to regard public green space per capita as the most important index. However, only reflecting the function of recreation is not enough. It should also reflect the total of all kinds of green spaces. The index of greening rate that has been used since 1991 can make up this disadvantage. In summary, greening rate integrated with public green space per capita and greening coverage rate can be used to reflect the urban afforestation level and to assess the environmental quality in the round.

4.2.4. Desirable environmental quality in Dongguan

Some national indices have been proposed to assess the environmental quality in China (e.g. green space per capita must be more than '9.0' square meters and public green space per capita must be more than '7.0' square meters). Actually these indices can be regarded as the basic requirements that the country exerts on the cities. Different city has different urban property, geographic environment, historic condition and economic development level. So it is impossible to apply the same indices in each city. It is not difficult to realize these indices and even have realized them in some cities. While in other cities, it is difficult to do that and cannot realize these requirements. Guided by the national policies, therefore, every city should take the existing situation into account to make some local-style greening indices.

Based on the urban planning context, the existing situation of green space system and the national greening indices, Dongguan planning bureau has proposed the desirable environmental quality: Greening coverage rate in the planning area should be more than '50%' until 2015, greening rate should range from '30%~40%', and public green space per capita in the built up area should be '10' square metres (not including the Qingfeng mountain reservation and other landscape green belts). As such, the government wants to import the forestry into the city and make the city approach the nature. It will carry out the overall afforestation in the planning areas to reduce the loss of water and soil. Taking advantage of the favourable climate condition and the good soil condition, Dongguan government tries to construct an ecological city, realize sustainable development and create an optimal human settlement.

4.3. Suitability analysis of green space system based on GIS

4.3.1. Stakeholder analysis for suitability

Stakeholders are those whose interests are affected by the issue or those whose activities strongly affect the issue. Stakeholder Analysis is a vital tool for identifying those people, groups and organisations who have significant and legitimate interests in specific urban issues. Clear understanding of the potential roles and contributions of the many different stakeholders is a fundamental prerequisite for a successful participatory urban governance process, and stakeholder analysis is a basic tool for achieving this understanding (Hemmati 2002). As such, four group stakeholders are involved in the analysis.

1. Urban planners

Six urban planners were invited to the group discussion. This group provided the most vivid discussion, mostly about the potential for the development of tourism and the problems existing in the green space system. Four urban planners acknowledged that a suitable green space system could not only play an ecological role, but also attract more tourists just because of its rational layout and high landscape quality. But two planners only concerned about the ecological benefits of urban green spaces. They felt the most important was that green spaces can effectively clean air, improve urban climate and eliminate noise, and social benefits such as improving landscape quality, historic culture value and economic benefits were not very important. Overall, the group accepted the comment that the problems existing in the green space system were because it was not systematically planned and the number of green spaces was not enough. So the urban planners had responsibility to solve these problems by planning a suitable green space system. They later acknowledged that in previous years they had seen those land uses unsuitable for building because high water levels may threaten the buildings, but now beginning to see the potential of those lands for attracting tourists, as they can be converted into recreation green spaces.

2. Environmentalists

The group of environmentalists comprised five individuals. They were mostly concerned about the pollution being generated by development and degrading the urban environment, and the existing green spaces were not enough with the fast increase of urban population. Hence, a new suitable green space system should be able to effectively deal with the pollution (e.g. toxic gas, dust, polluted water, noise). On the other hand, the suitable sites for green spaces development should approach the water source, and be located with appropriate slope and good surface water quality. If possible green spaces can be expanded at the expense of other land uses, as long as they can play an ecological role to the urban environment. Concern was expressed about the conflicts between 'eco-tourism' and mass tourists activities. The group was against the building of large hotels and favoured the development of small units, and a mixture of activities for tourists, such as building of a landscape corridor. Some environmentalists thought it was a good idea to build a new big park in the centre of built up area, as tourists would arrive in greater numbers and gain easier assess to the area. However, other environmentalists pointed out this new park could degrade the landscape quality and historic culture value, and occupy many important land uses, having negative consequences for tourism in the longer term. Thus it can be showed that the group was in favour of further development. They were concerned that both economic benefits and ecological benefits should be considered in future plans, and there were trade-offs to be made between the two.

3. Local residents

The group of local residents was composed of ten families, five with children and five with no children. They felt that green space system played an important role to the human settlement but the existing green spaces were not enough with the development of living standard, and there was a responsibility to preserve the existing green spaces rather than to destroy them. They were mostly concerned about the problem of pollution resulted from the industry and traffic. The local residents acknowledged that the fast growing industry and traffic had led to the degradation of air quality and the increase of noise. However, they felt it was not their responsibility to talk to the industry employers, but that of local government officials. So the government should pass laws to make the environment sustainable. In addition, some families with children stated that there should be more green spaces for their children's recreation near their residential areas, while other families with no children hoped there would be more parking grounds for them instead of the recreation green spaces.

4. Local government officials

This group comprised three individuals. Two officials provided a number of interests and ideas concerning about the future development of Dongguan municipality, particularly insisted that the new green space system should be first to consider the existing land use. In other words, new green spaces should be restricted to certain areas such as those vacant areas and government reserved areas instead of built up areas. Green spaces could be enjoyed but not interfere with future building developments. Hence, the green spaces were perceived as one of a number of important land uses, which should have defined boundaries, and should certainly not be expanded at the expense of other important land uses. However, one official only focused on the local function that green space system can play. He stated that as long as green spaces can play an active role in improving air quality, preventing flood and eliminating noise, it was possible to convert some existing land uses of built up area into green spaces. Overall, the group favoured the development of green space system to move some urban population out of the built up area. They all regarded green spaces as an important local resource and accepted that they had a responsibility for preserving the green spaces as a natural asset, and framed this in terms of future ecological development.

4.3.2. Selecting suitability factors

One of the main concerns of physical planning is the proper designation of suitable sites for appropriate land uses. The selection of suitable sites for specific land uses must be based upon a set of local criteria to ensure that the maximum cost-benefit ratio for a community is attained (Hofstee and Brussel 1999). In suitability analysis, the most important is the determination of how relative values, or weights, are to be given to two or more combined factors. Factors are simple characteristics of land that are grouped as attributes (Pease, Coughlin et al. 1996). Slope, soil type, surface water quality, vegetative cover, existing land use, etc. are examples of such factors. Actually the meaning of 'factor' is the same as that of 'criterion'. This research decides to use the name of 'factor' instead of 'criterion' because 'factor' is more often used in suitability analysis.

In this case study, several sources of information are used to identify the ecological benefits of green space system, factors and suitability classes are needed to perform the suitability analysis. The primary source for the identification of ecological benefits is the desirable environmental quality (see section 4.2.4) set forth in the Dongguan Master Plan. The desirable environmental quality and its associated elements have been further supplemented by advice from community officials and the general public. Factors within the ecological benefits are selected by using the stakeholder analysis for suitability in the above section and the literature review (section 2.3.1). Information on the attributes associated with each factor is derived from a combination of published literatures, expert opinions and fieldwork. Here the attribute is defined as the categories, or classes, used to describe a factor, such as air quality classes, landscape quality classes, etc. In this case study, the following seven factors in selecting suitable sites for green space system development are considered: **air quality**, **landscape quality**, **surface water quality**, **historic culture value**, **water system influence**, **noise influence** and **existing land use**.

1. Available data

Suitability analysis of green space system requires many different types of data. Generally it should allow for ecological, social and economic these three types of data. Due to the limited time for the fieldwork and the difficulty to collect the spatial data, this research primarily emphasizes on the ecological benefits. The nature of the spatial data is collected to represent this type of ecological benefits. Factor and suitability are dependent on the nature of the component. Based on the above opinions, what it should be first to do is to set up a GIS to deal with the site selection problem of green space system. The following data set become available for analysis:

Air a CAD map of air quality distribution, derived from the air evaluation map.
Lscape a CAD map of landscape quality distribution, derived from the landscape planning map and fieldwork.
Swater a CAD map of surface water quality, derived from the water evaluation map.
History a CAD map of historic culture value, derived from the planning map of historic culture protection and fieldwork.
Wsystem a CAD map containing the major rivers, reservoirs and lakes in the study area, derived from the water system distribution map.
Noise a CAD map of noise pollution distribution, derived from the noise evaluation map.
Luse a CAD map of urban land uses in 1999, derived from the existing land use map and fieldwork.

2. Data pre-processing

As it has been mentioned above that, all the available data are AutoCAD maps (Dwgfiles). Some of the data are in a format compatible for importing to the GIS. However, others have to need additional processing before they can be incorporated. Since suitability analysis involves determination of the suitability of an area, and the identification of those areas meeting specific factors, the primary entity-type for this analysis (especially in the overlay operation) is polygon data. Where the spatial data are not represented by polygons (vector or line data), they have to be converted into polygons by using a buffering technique. Buffer widths should be assigned according to the suitability identifications (e.g. distance to water system at 250m and 750m intervals). The basic procedure of data pre-processing has been shown in Figure 4.1. First, it needs to create a new personal geodatabase by ArcCatalog in the ArcGIS software. Secondly, it imports the original CAD map to geodatabase to generate polygons. After that, the shapefile is coming out by exporting the geodatabase to shapfile. This study wants to take advantage of ILWIS software to carry out the suitability. So the next step is to import the shape-file to generate the polygon format compatible for the ILWIS analysis. Finally all the polygon maps should be transferred into the raster maps through the operation of polygon to raster. As such, the data pre-processing has been finished before it can use the slicing, distance calculation, overlay and other GIS techniques.

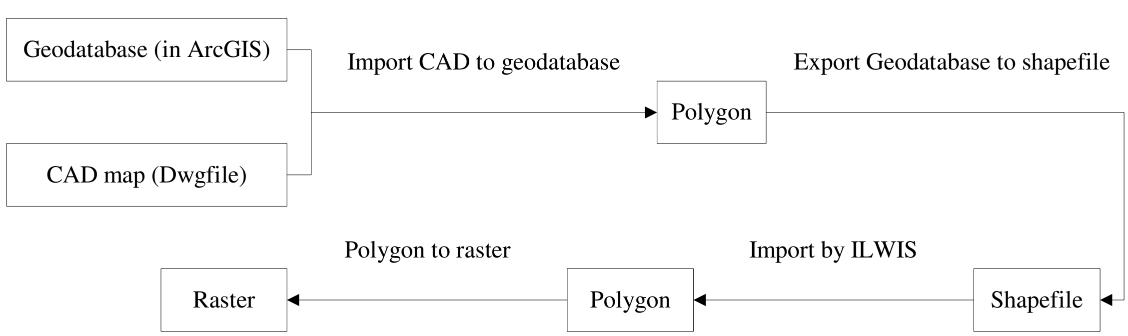


Figure 4.1 Data pre-processing

4.3.3. Scoring

1. Scores of suitability factors

Scoring factors used in suitability analysis can be measured using interval or ratio values (scores) or ordinal values (score classes). The choice of either scores or score classes can markedly influence the efficiency of scoring factors. There is little consistency in the use of terminology in the suitability analysis literature, and frequently the term ‘score’ is used to refer to both interval /ratio and ordinal values. Interval or ratio values are referred to this research as ‘scores’ while ordinal values are termed ‘score classes’.

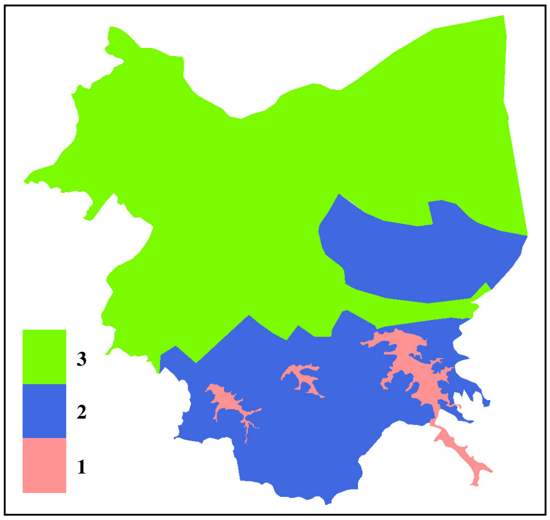
Ordinal values, as the name suggests, implies an order or ranking among factors. The order may be either ascending or descending according to the application. And a ranking implies on an ordering among factors but nothing more. Ordinal value is a kind of qualitative measurement scales that are often used, especially in environmental decision problems. However, it should be noted that ordinal values couldn’t be added or multiplied. Errors often arise from the addition of ordinal values. Interval values have ordinal properties and they have the meaning about the intervals between objects. Corresponding intervals on different parts of an interval scale have the same meaning (Sharifi and Herwijnen 2003). For example, the interval between two objects with values of ‘20’ and ‘10’ (an interval of 10) is equal to the interval between two objects with values of ‘40’ and ‘30’. Interval values can also be used in arithmetic operations such as addition and multiplication. But after adding or multiplying interval values, it cannot be identified that a total of ‘60’ is twice as good as a total of ‘30’.

Ratio values are the highest level, which have ordinal and interval properties, as well as the property of ratios. Just like the interval values, corresponding ratios on different parts of a ratio scale have the same meaning. For example, the ratio between two objects with values of ‘10’ and ‘5’ is equivalent to the ratio between two objects with values of ‘200’ and ‘100’. In this research, first it wants to give scores and weights to the suitability factors, and then it will use multiplication and addition to get the composite scores. Finally the composite suitability can be classified by mathematical rules based on the composite scores. From the above opinions it can be showed that ratio values are more compatible for scoring suitability factors in this suitability analysis. The description of suitability classes within factors and corresponding scores are listed in Table 4.1. The scores of ‘3, 2,1’ are used to identify the differences among high suitability, moderate suitability and no suitability. The maps of suitability classes and scores in every factor (single factor map) are presented from Map 4.2 to Map 4.8. They have been converted into raster format compatible for the operation in ILWIS.

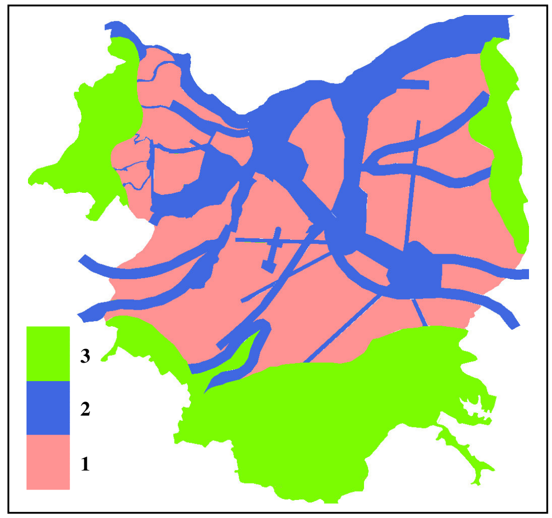
Table 4.1 Suitability classes and scores

Factor	Suitability class	Class description	Score
Air quality			
	High	Areas with low air quality	3
	Moderate	Areas with moderate air quality	2
	No	Areas with high air quality	1
Landscape quality			
	High	Landscape area, garden scene area, reservoir scene area	3
	Moderate	Cuneal ecological green space, main road avenue, riverside green space, urban square, landscape corridor, urban landscape axis	2
	No	Other areas with potential of good biodiversity	1
Surface water quality			
	High	Some areas showing indications of bad erosion, little or no vegetation present, presence of toxic chemical products	3
	Moderate	Low levels of human activity, some bank stabilization needed, few erosion factors present	2
	No	Banks are well vegetated, capable of trapping sediment and slowing erosion, with potential for active nutrient cycling by aquatic plants	1
Historic culture value			
	High	Tour area, reservoir conservation, old city relic, cultural relic and historic site conservation	3
	Moderate	Landscape corridor with mountains and water, historic site, normal green space	2
	No	Other areas with potential of high historic culture value	1
Water system influence			
	High	Distance to main rivers, reservoirs, or lakes is < 250m	3
	Moderate	Distance to main rivers, reservoirs, or lakes is ≥ 250m, but < 750m	2
	No	Distance to main rivers, reservoirs, or lakes is ≥ 750m	1
Noise influence			
	High	Areas with much noise pollution	3
	Moderate	Areas with not much noise pollution	2
	No	Areas with little noise pollution	1
Existing land use			
	High	Existing green spaces	3
	Moderate	Vacant areas and government reserved areas	2
	No	Other important land uses	1

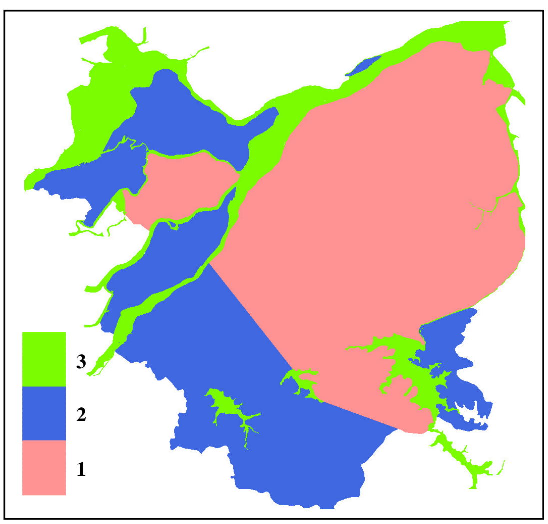
From the above table we can see that this suitability analysis of green space system is primarily based on the point of ecological benefits, because the goal of this green space system is to improve the air quality and surface water quality, prevent flood (water system influence), and eliminate noise (noise influence). As such, green spaces should be best located in the areas with low air quality, low surface water quality and with much noise pollution, and the distance to water system should be best within 250 metres to prevent the flood. This analysis also considers social factors including landscape quality, historic culture value and existing land use. In order to improve the urban landscape quality, green spaces can be used to plan some areas of high landscape quality in the urban environment, such as Landscape area, garden scene area or reservoir scene area. Likewise, tour area, reservoir conservation, old city relic, cultural relic and historic site conservation will be planned to improve the historic culture value by using the green spaces. Note that green spaces cannot be expanded at the expense of other important land uses (e.g. commercial areas, municipal utilities areas, or public facilities areas). Besides the existing green spaces, the new green spaces should be best located in those vacant areas and government reserved areas.



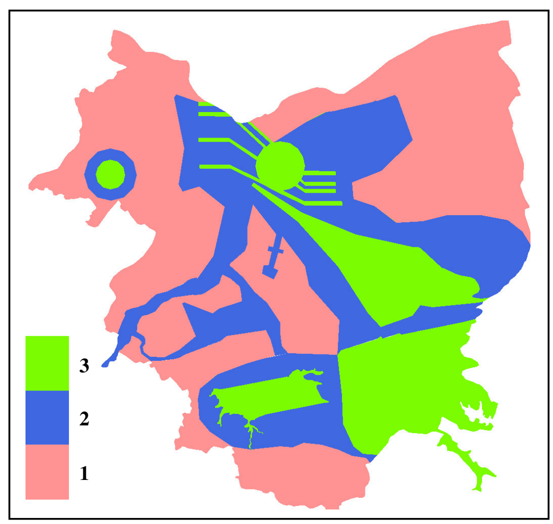
Map 4.2 Air (air quality)



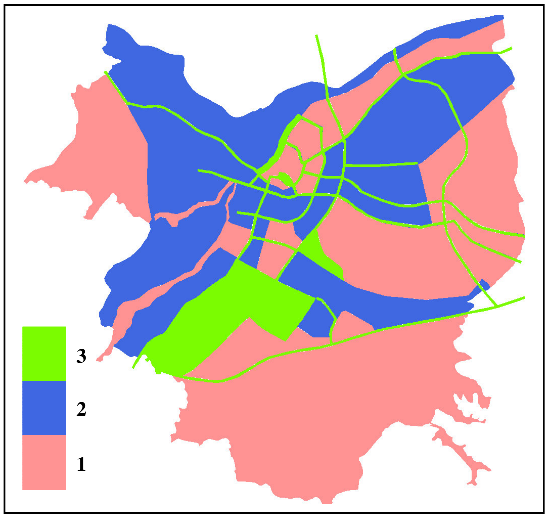
Map 4.3 Lscape (landscape quality)



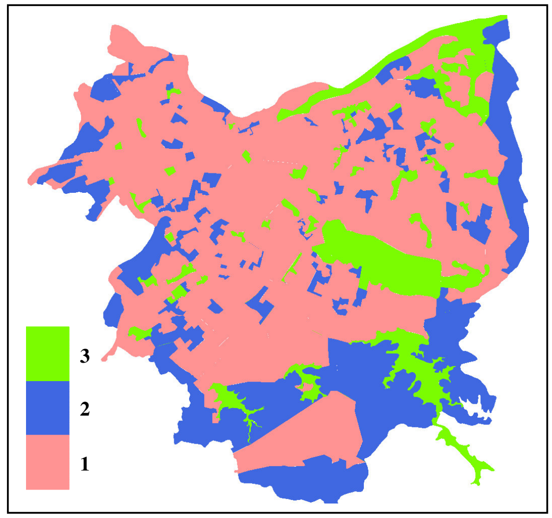
Map 4.4 Swater (surface water quality)



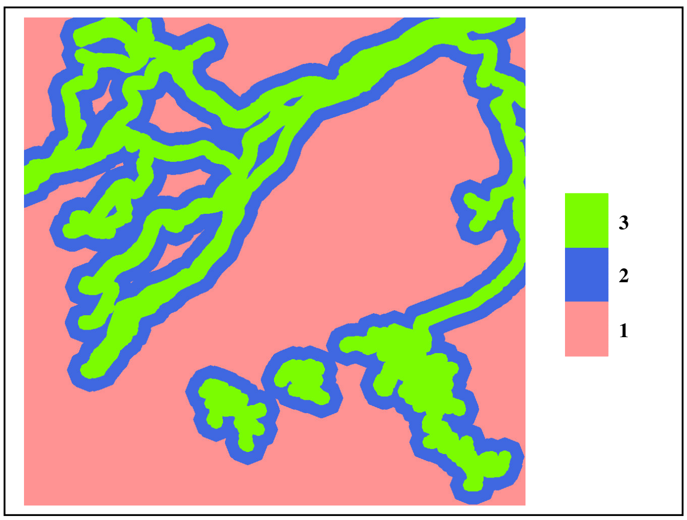
Map 4.5 History (historic culture value)



Map 4.6 Noise (noise influence)



Map 4.7 Luse (existing land use)



Map 4.8 Wsystem (water system influence)

2. Certainty factor

As mentioned in section 3.4.2, certainty factor is used to improve the GIS-based traditional suitability analysis model. In order to make the following explanation more clear, here we want to give a name to each single factor map: Air (air quality), Lscape (landscape quality), Swater (surface water quality), History (historic culture value), Wsystem (water system influence), Noise (noise influence), Luse (existing land use). Air, Swater and Noise these three factors are raw data (measured in practice), which won't be changed with any man-made elements. So it is not necessary to give them the certainty factors. Lscape, History and Luse are qualitative data, which can get the certainty factor arranging from '0.2' to '0.8'. For example, as to the landscape quality, cuneal ecological green space and urban square belong to moderate suitability class and get the same score of '2'. But the cuneal ecological green space is more suitable for the green space development than the urban square, then we can give a certainty factor of '0.8' to the cuneal ecological green space and '0.6' to the urban square, in order to identify the difference between them. Thus the certainty factors for Lscape are coming out (Map

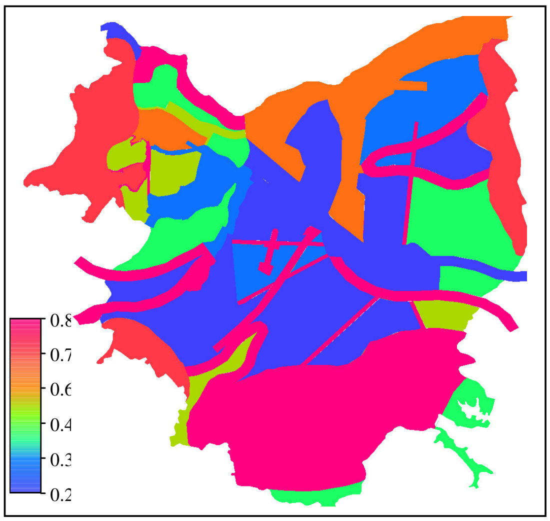
4.9). The certainty factors for History and Luse are determined in the same way (Map 4.10 and Map 4.11). Wsystem is quantitative data and its certainty factors (Map 4.12) can be determined by the following certainty factor function (like Formula 3.3):

$$CF(x) = 1 - \frac{x-0}{250} \quad (0m \le x < 250m)$$

$$CF(x) = 1 - \frac{x-250}{500} \quad (250m \le x < 750m)$$

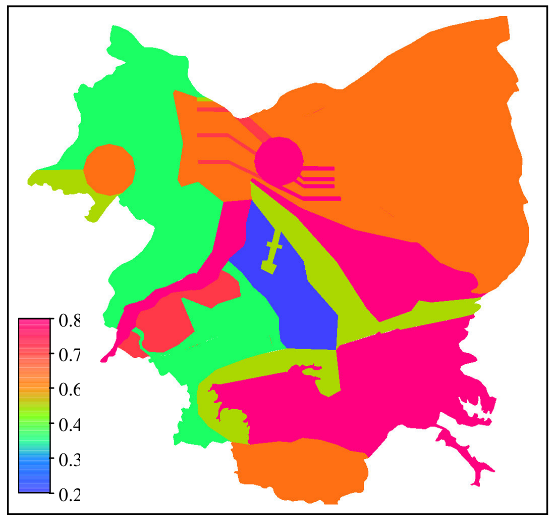
$$CF(x) = 1 - \frac{x-750}{5360} \quad (750m < x \le 6110m)$$

(x is the distance to main rivers, reservoirs, or lakes)



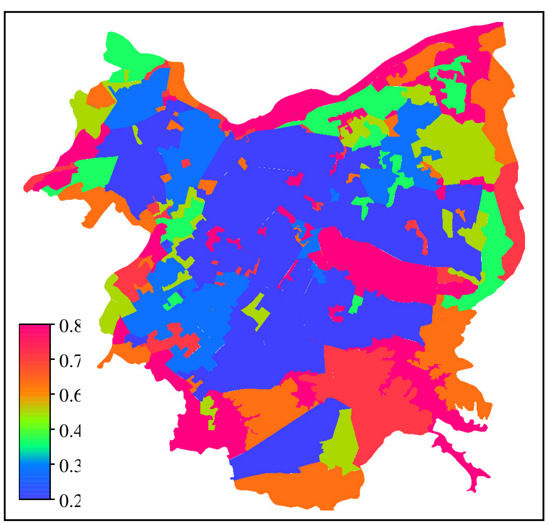
Map 4.9 Cerlscape

(certainty factors for landscape quality)



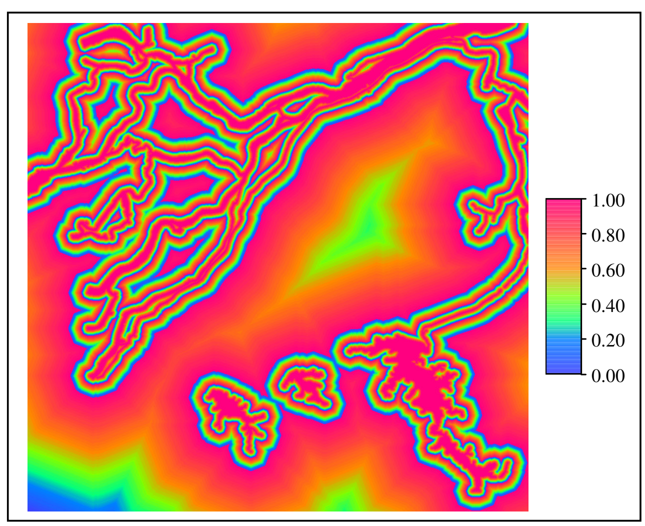
Map 4.10 Cerhistory

(certainty factors for historic culture value)



Map 4.11 Cerluse

(certainty factors for existing land use)

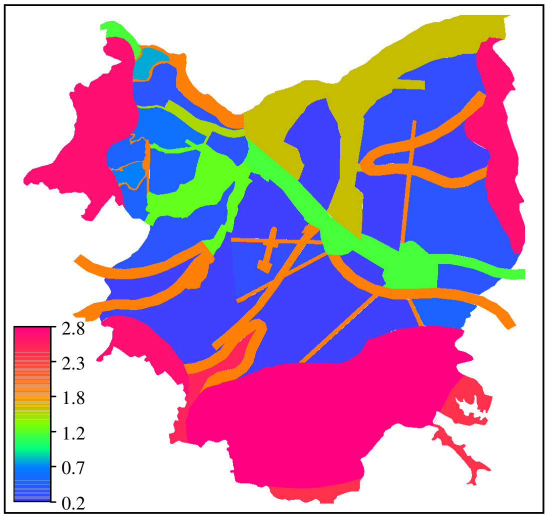


Map 4.12 Cerwsystem

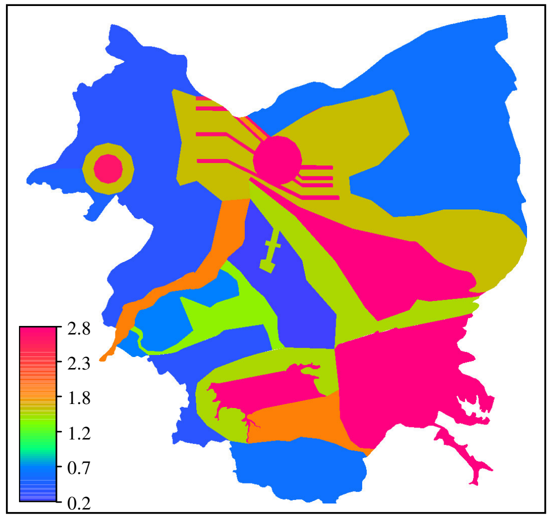
(certainty factors for water system influence)

Now we can get the composite certainty factors (Map 4.13 to Map 4.16) for the above four factors according to Formula 3.4. The detailed formulas used are presented below:

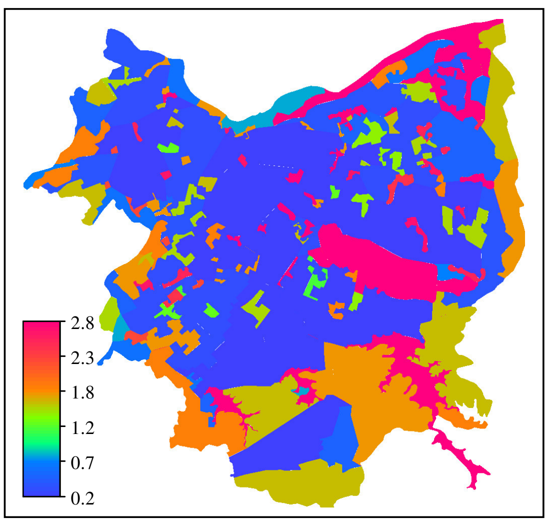
$$Clscape = Lscape - 1 + Cerlscape$$
$$Chistory = History - 1 + Cerhistory$$
$$Cluse = Luse - 1 + Cerluse$$
$$Cwsystem = Wsystem - 1 + Cerwsystem$$



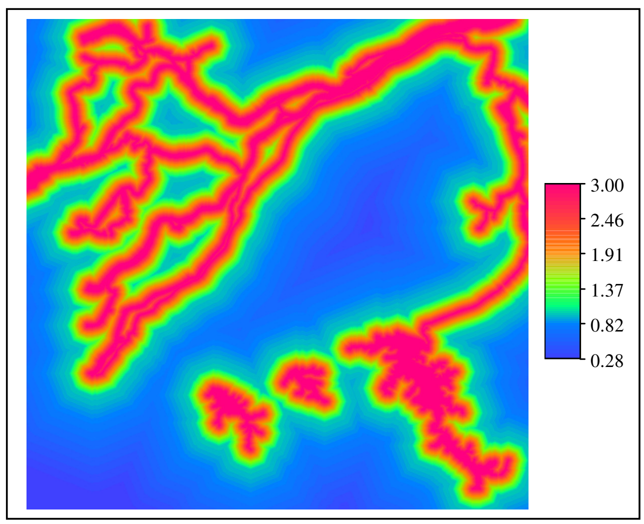
Map 4.13 Clscape (composite certainty factors for Landscape quality)



Map 4.14 Chistory (composite certainty factors for historic culture value)



Map 4.15 Cluse (composite certainty factors for existing land use



Map 4.16 Cwsystem (composite certainty factors for water system influence)

As such, Lscape, History, Luse and Wsystem have got their respective certainty factors and have been transferred into Clscape, Chistory, Cluse and Cwsystem. Integrated with other three suitability factors including Air, Swater and Noise, the above four factors will be used to generate 'final suitability scenario 4', 'final suitability scenario 5' and 'final suitability scenario 6' (see section 4.3.5), based on the improved traditional suitability analysis model (ITSAM) (see section 3.4.2).

4.3.4. Weighting

Weighting in suitability analysis refers to assigning a weight to each factor in order to recognize its relative importance (Pease, Coughlin et al. 1996). Just like the scores, weights also have a major impact effect on the final results (composite scores). As it has mentioned in section 3.8, this research wants to make use of three methods to calculate the weights for suitability analysis. Weights for generating 'suitability scenario 1' and 'suitability scenario 2' are calculated by the method of statistic integration (see section 3.5.1). Hierarchic analysis of nine-degree (see section 3.5.2) is used to calculate the weights for 'suitability scenario 2'and 'suitability scenario 5'. And the weights for 'suitability scenario 3' and 'suitability scenario 6' are calculated by hierarchic analysis of three-degree (see section 3.5.3).

1. Calculating weights by statistic integration

As mentioned in section 3.5.1, the method of statistic integration is a kind of special 'expert-assess' method. Here the 'expert-assess' is based on the stakeholder analysis. Stakeholder analysis is an important element to select the suitability factors (see section 4.3.1). Also, it is the foundation for calculating the weights of the suitability factors. In order to use the method of statistic integration to calculate the factors weights, twenty-four stakeholders including six urban planners, five environmentalists, ten local residents and three local government officials were invited to determine the importance order among the seven suitability factors. As such, twenty-four investigating tables (like Table 3.2) were sent to these stakeholders to show their opinions about the importance order. The investigating information of the stakeholders has been aggregated by statistic induction in Table 4.2.

Table 4.2 Investigating information by statistic induction

Factor	First importance	Second importance	Third importance	Fourth importance	Fifth importance	Sixth importance	Last importance
Air quality	25%	25%	0	8.3%	16.7%	16.7%	8.3%
Landscape quality	33.3%	8.3%	25%	8.3%	8.3%	16.7%	0
Surface water quality	8.3%	25%	25%	16.7%	8.3%	16.7%	0
Historic culture value	0	0	8.3%	16.7%	16.7%	25%	33.3%
Water system influence	8.3%	8.3%	33.3%	16.7%	16.7%	8.3%	8.3%
Noise influence	0	16.7%	0	0	33.3%	8.3%	41.7%
Existing land use	25%	8.3%	16.7%	33.3%	0	8.3%	8.3%

From Table 4.2 we can see that, as to the factor of air quality, six stakeholders acknowledged that it was the first importance for the suitability analysis of the urban green space system, namely 25% of the twenty-four stakeholders showed this opinion. Second importance with 25%, fourth importance with 8.3%, fifth importance with 16.7%, sixth importance also with 16.7%, last importance with 8.3%, while none of the stakeholders thought air quality was the third importance for this suitability analysis. Likewise, other factors importance has been aggregated in Table 4.2 in the same way. Then according to the following formula (like formula 3.5), the preliminary weights of the above seven suitability factors are presented below:

$$\overline{W} = [D \bullet C^T]^T = \left[\begin{bmatrix} 0.250 & 0250 & 0 & 0.083 & 0.167 & 0.167 & 0.083 \\ 0.333 & 0.083 & 0.250 & 0.083 & 0.083 & 0.167 & 0 \\ 0.083 & 0.250 & 0.250 & 0.167 & 0.083 & 0.167 & 0 \\ 0 & 0 & 0.083 & 0.167 & 0.167 & 0.250 & 0.333 \\ 0.083 & 0.083 & 0.333 & 0.167 & 0.167 & 0.083 & 0.083 \\ 0 & 0.167 & 0 & 0 & 0.333 & 0.083 & 0.417 \\ 0.250 & 0.083 & 0.167 & 0.333 & 0 & 0.083 & 0.083 \end{bmatrix} \bullet \begin{bmatrix} 7 \\ 6 \\ 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{bmatrix}\right]^T = (4.500, 4.994, 4.582, 2.417, 2.830, 2.584, 4.664)$$

After the normalization, the final weights $\overline{W} = (0.169, 0.188, 0.172, 0.091, 0.107, 0.097, 0.176)$ calculated by statistic integration will be presented in Table 4.6.

2. Calculating weights by hierarchic analysis of nine-degree

The method of hierarchic analysis of nine-degree is a kind of analytic hierarchy process (AHP). It is based on factors that are measured on a ratio scale. By using this hierarchic analysis of nine-degree, the user first has to make a comparison for every pair of factors: first qualitative and then quantitative on a degree from '1' to '9' to make the method operational (see Table 3.5). As such, the original fourteen stakeholders including six urban planners, five environmentalists and three local government officials were invited to make the pairwise comparison according to the nine-degree scale. Those ten local residents were excluded in this invitation just because of their weak sense, which would make it difficult for them to use the nine-degree scale to make the pairwise comparison among the seven suitability factors. The method then creates a structural judgment matrix based on the pairwise comparison judgments of these fourteen stakeholders (Table 4.3).

Table 4.3 Structural judgment matrix of suitability factors by nine-degree

Factor	K_1	K_2	K_3	K_4	K_5	K_6	K_7
Air quality K_1	1	1/4	1/2	1/3	2	1/5	1/6
Landscape quality K_2	4	1	3	2	5	1/2	1/3
Surface water quality K_3	2	1/3	1	1/2	3	1/4	1/5
Historic culture value K_4	3	1/2	2	1	4	1/3	1/4
Water system influence K_5	1/2	1/5	1/3	1/4	1	1/6	1/7
Noise influence K_6	5	2	4	3	6	1	1/2
Existing land use K_7	6	3	5	4	7	2	1

The values in the above matrix were determined by using the rule of 'the minority should obey the majority'. For example, there were three different opinions when comparing the factor of historic culture value with the factor of air quality in this suitability analysis. Six urban planners stated that historic culture value was moderately more important than air quality (the value should be '3' in the judgment matrix according to the nine-degree scale), one environmentalist and three local government officials acknowledged that historic culture value was strongly more important than air quality (the value should be '5'), and four environmentalists accepted that air quality was moderately more important historic culture value (the value should be '1/3'). Therefore, the value comparing historic culture value with air quality was '3' in the judgment matrix according to the above rule, because most of the stakeholders (six urban planners) supported the first opinion. Likewise, other values in the judgment matrix were determined in the same way.

Based on this judgment matrix, we can use MATLAB (a mathematical software) to calculate its eigenvector ($\overline{W}$) of the largest eigenvalue. Here, the original eigenvector $\overline{W} = (0.094, 0.333, 0.1420, 0.2177, 0.0655, 0.5041, 0.7444)$. After the normalization, this original eigenvector is converted to the final vector, $\overline{W} = (0.045, 0.159, 0.068, 0.104, 0.031, 0.240, 0.354)$. The values in this final vector represent the weights of those seven suitability factors, which will be presented in Table 4.6.

3. Calculating weights by hierarchic analysis of three-degree

Hierarchic analysis of nine-degree is particularly designed to calculate weights within a hierarchic structure of the factors. Due to the fast growing number of pairwise comparisons, however, it is not sensible to use this method for a large number of factors. Within hierarchic analysis of nine-degree, the number of comparisons increases with the number of effects (n*(n-1)/2). For example, in order to calculate the weights of those seven suitability factors, it needs to make twenty-one comparisons in the structural judgement matrix. Moreover, it needs to make a judgement among those nine degrees (see Table 3.5), which will often make the user rather puzzled.

Hierarchic analysis of three-degree is also a kind of analytic hierarchy process (AHP). But in this method, it involves no more than three degrees when making a pairwise comparison: less important, same important and more important (see Formula 3.6). Thus it can be showed that three-degree is easier for the user to make a judgement than nine-degree. In order to determine the final values in the comparison matrix (Table 4.4) based on the three-degree scale, only the original six urban planners were invited to make the pairwise comparisons among the seven suitability factors, from their profession perspective of urban planning. Just like hierarchic analysis of nine-degree, this method also adopts the rule of 'the minority should obey the majority'. As such, when comparing the factor of air quality with the factor of landscape quality, four urban planners stated that air quality is less important than landscape quality for this suitability analysis (the value should be '0' in the comparison matrix). While other two planners thought it was the other way around (the value should be '2'). According to the above rule, the value between air quality and landscape quality was '0' in the comparison matrix. Likewise, other comparisons' values were determined in the same way (Table 4.4).

Table 4.4 Comparison matrix of suitability factors by three-degree

Factor	K_1	K_2	K_3	K_4	K_5	K_6	K_7	$\sum_{i=1}^{7} K_i$
Air quality K_1	1	0	1	0	2	0	0	4
Landscape quality K_2	2	1	2	2	2	0	0	9
Surface water quality K_3	1	0	1	0	2	0	0	4
Historic culture value K_4	2	0	2	1	2	0	0	7
Water system influence K_5	0	0	0	0	1	0	0	1
Noise influence K_6	2	2	2	2	2	1	0	11
Existing land use K_7	2	2	2	2	2	2	1	13

Based on the above comparison matrix, the structural judgment matrix is generated below according to Formula 3.7 (see section 3.5.3).

Table 4.5 Structural judgment matrix of suitability factors by three-degree

r_i	r_j						
	r_1	r_2	r_3	r_4	r_5	r_6	r_7
Air quality r_1	1	12/77	1	4/17	17/4	12/103	12/259
Landscape quality r_2	77/12	1	77/12	19/6	29/3	6/19	3/16
Surface water quality r_3	1	12/77	1	4/17	17/4	12/103	4/43
Historic culture value r_4	17/4	6/19	17/4	1	15/2	3/16	2/15
Water system influence r_5	4/17	3/29	4/17	2/15	1	6/71	1/14
Noise influence r_6	103/12	19/6	103/12	16/3	71/6	1	6/19
Existing land use r_7	259/12	16/3	43/4	15/2	14	19/6	1

According to the above structural judgment matrix, this method also uses MATLAB to calculate its eigenvector ($\overline{W}$) of the largest eigenvalue. Here, $\overline{W} = (0.0480, 0.2429, 0.0532, 0.1340, 0.0248, 0.4393, 0.8511)$. After the normalization, this eigenvector can represent the weights of the corresponding suitability factors, namely $\overline{W} = (0.027, 0.135, 0.030, 0.075, 0.014, 0.245, 0.474)$, which will be presented in Table 4.6.

4. Weighting results for suitability scenarios

As mentioned in section 3.8, weights calculated by statistic integration are used to generate 'suitability scenario 1' and 'suitability scenario 4'. Hierarchic analysis of nine-degree is used to calculate the weights for 'suitability scenario 2'and 'suitability scenario 5'. And the weights for 'suitability scenario 3'and 'suitability scenario 6' are calculated by hierarchic analysis of three-degree. Hu (1994) and Xu (1999) suggested that the ranking weights as calculated should be normalized for each function under analysis. The normalized weighting results for the suitability scenarios of the urban green space system are presented in Table 4.6. These results indicate that landscape quality has the highest priority among the seven suitability factors according to statistic integration, followed by existing land use. This result also shows that historic culture value, water system influence and noise influence are much less important factors. But that is not the case according to the other two weighting methods: hierarchic analysis of nine-degree and three-degree. Therefore, weight is a very important element in the suitability analysis. Different scores and different weights will generate different suitability scenarios.

Table 4.6 Weighting results for suitability scenarios

Factor		Air quality	Landscape quality	Surface water quality	Historic culture value	Water system influence	Noise influence	Existing land use
Weight	Scenario 1, Scenario 4 ①	0.169	0.188	0.172	0.091	0.107	0.097	0.176
	Scenario 2, Scenario 5 ②	0.045	0.159	0.068	0.104	0.031	0.240	0.354
	Scenario 3, Scenario 6 ③	0.027	0.135	0.030	0.075	0.014	0.245	0.474

Note: ① Weights calculated by statistic integration. ② Weights calculated by hierarchic analysis of nine-degree. ③ Weights calculated by hierarchic analysis of three-degree.

4.3.5. Suitability scenario

According to the ratio values (scores) for all suitability classes, a total of seven GIS data coverages are created, one for each of the suitability factors identified above (Map 4.2 to Map 4.8). These coverages are based on the individual suitability values for each factor. In addition, weights for the seven factors and certainty factors have been determined, so these seven single factor maps can be combined into a composite suitability map by addition of the suitability scores with a weighting system. That means we can use a GIS overlay procedure to get a suitability evaluation of all the seven factors according to Formula 3.2.

As mentioned in section 3.8, six suitability scenarios will be generated according to different scores, weights and certainty factors. Here we give the names of ‘Scenario 1’, ‘Scenario 2’, ‘Scenario 3’, ‘Scenario 4’, ‘Scenario 5’ and ‘Scenario 6’ to these six suitability scenarios. The frontal three scenarios are generated based on the traditional suitability analysis model (TSAM), while the latter three scenarios are based on the improved traditional suitability analysis model (ITSAM) that they need to take advantage of the certainty factors from section 4.3.3. The detailed calculation formulas are presented below (W_{ai} represents the weight calculated by statistic integration; W_{bi} represents the weight calculated by hierarchic analysis of nine-degree; W_{ci} represents the weight calculated by hierarchic analysis of three- degree):

$$\text{Scenario 1}=Air*W_{a1}+Lsapce*W_{a2}+History*W_{a3}+Swater*W_{a4}+Wsystem*W_{a5}+Noise*W_{a6}+Luse*W_{a7}$$

$$\text{Scenario 2}=Air*W_{b1}+Lsapce*W_{b2}+History*W_{b3}+Swater*W_{b4}+Wsystem*W_{b5}+Noise*W_{b6}+Luse*W_{b7}$$

$$\text{Scenario 3}=Air*W_{c1}+Lsapce*W_{c2}+History*W_{c3}+Swater*W_{c4}+Wsystem*W_{c5}+Noise*W_{c6}+Luse*W_{c7}$$

Scenario 4=Air $*W_{a1}$+Clsapce$*W_{a2}$+Chistory$*W_{a3}$+Swater$*W_{a4}$+Cwsystem$*W_{a5}$+Noise$*W_{a6}$+Cluse$*W_{a7}$

Scenario 5=Air $*W_{b1}$+Clsapce$*W_{b2}$+Chistory$*W_{b3}$+Swater$*W_{b4}$+Cwsystem$*W_{b5}$+Noise$*W_{b6}$+Cluse$*W_{b7}$

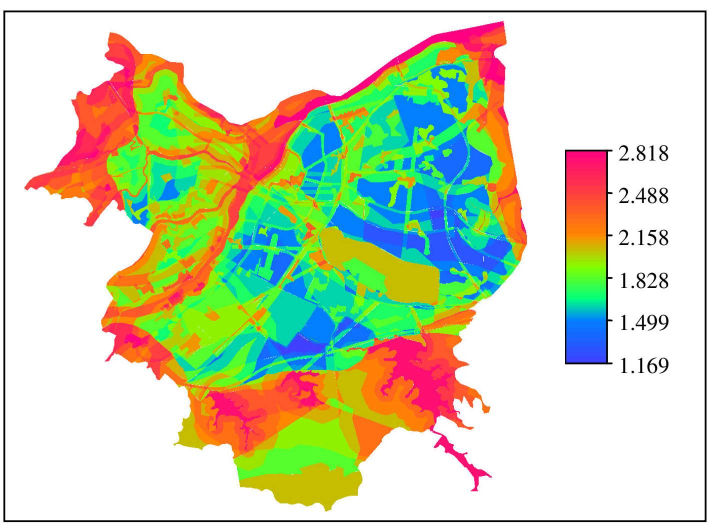
Scenario 6=Air $*W_{c1}$+Clsapce$*W_{c2}$+Chistory$*W_{c3}$+Swater$*W_{c4}$+Cwsystem$*W_{c5}$+Noise$*W_{c6}$+Cluse$*W_{c7}$

As such, the composite suitability score for each scenario can be derived based on the above formulas. Ideally, this composite suitability score ranges from '1' to '3'. But that is not the case in these six suitability scenarios (e.g. the composite suitability score of 'Draft suitability scenario 1' ranges from '1.169' to '2.818'). The distribution of these composite scores seems not very regular in the draft suitability scenarios (e.g. Map 4.17). It is recommended the composite suitability score should be grouped in classes to help clarify the data and to make the resulting scenarios more decipherable and easier to interpret. Thus the final suitability scenarios (Map 4.18 to Map 4.23) can be grouped in three levels according to the following suitability intervals (V_s represents the composite suitability score), by using the histogram of the composite suitability score in ILWIS:

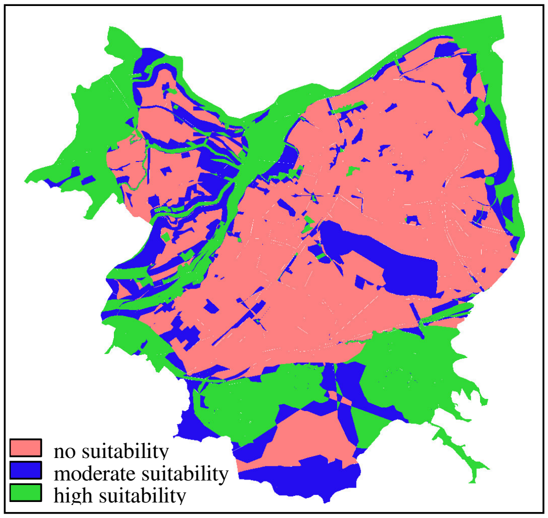
$$Scenario1\begin{cases} High-suitability: 2 \le V_s \le 2.818 \\ Moderate-suitability: 1.812 \le V_s < 2 \\ No-suitability: 1.169 \le V_s < 1.812 \end{cases} \quad Scenario2\begin{cases} High-suitability: 2 \le V_s \le 2.795 \\ Moderate-suitability: 1.646 \le V_s < 2 \\ No-suitability: 1.046 \le V_s < 1.646 \end{cases}$$

$$Scenario3\begin{cases} High-suitability: 2 \le V_s \le 2.850 \\ Moderate-suitability: 1.526 \le V_s < 2 \\ No-suitability: 1.027 \le V_s < 1.526 \end{cases} \quad Scenario4\begin{cases} High-suitability: 2 \le V_s \le 2.690 \\ Moderate-suitability: 1.612 \le V_s < 2 \\ No-suitability: 0.791 \le V_s < 1.612 \end{cases}$$

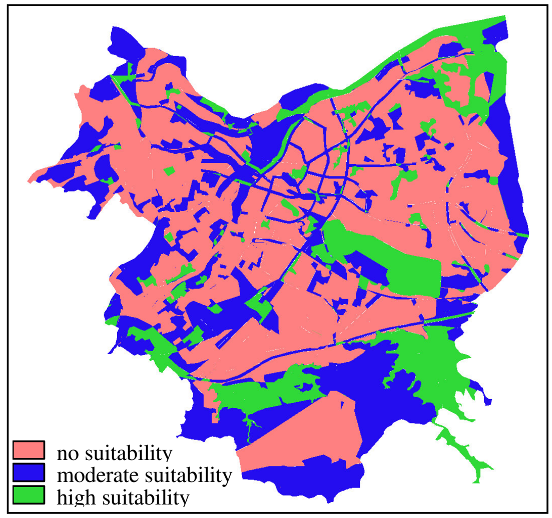
$$Scenario5\begin{cases} High-suitability: 2 \le V_s \le 2.635 \\ Moderate-suitability: 1.464 \le V_s < 2 \\ No-suitability: 0.548 \le V_s < 1.464 \end{cases} \quad Scenario6\begin{cases} High-suitability: 2 \le V_s \le 2.685 \\ Moderate-suitability: 1.326 \le V_s < 2 \\ No-suitability: 0.478 \le V_s < 1.326 \end{cases}$$



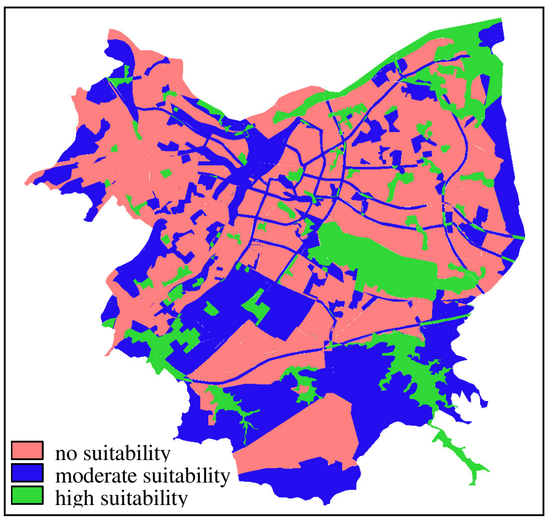
Map 4.17 Draft suitability scenario 1



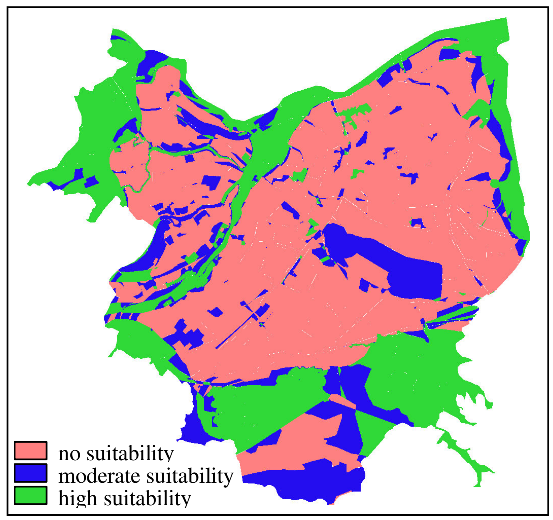
Map 4.18 Final suitability scenario 1



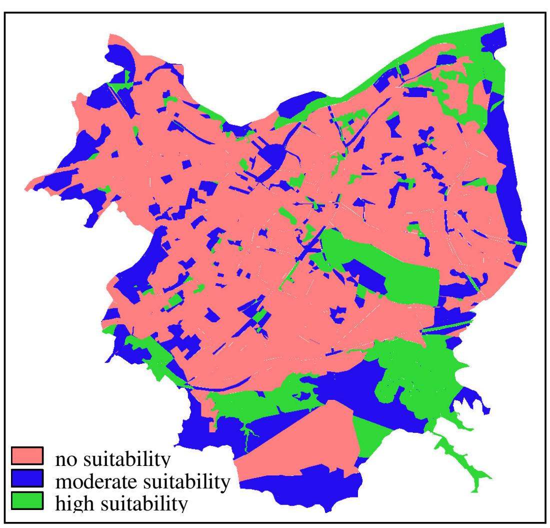
Map 4.19 Final suitability scenario 2



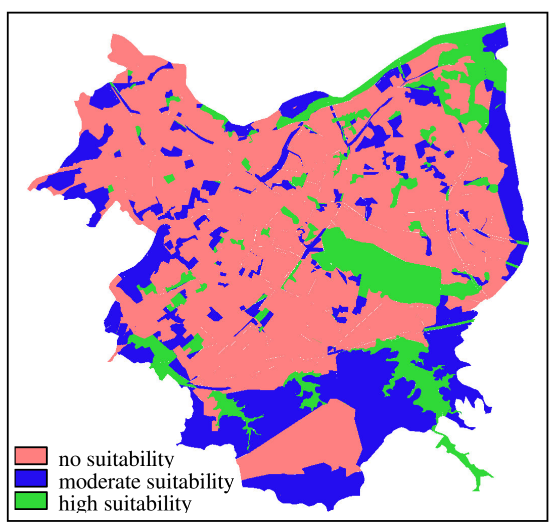
Map 4.20 Final suitability scenario 3



Map 4.21 Final suitability scenario 4



Map 4.22 Final suitability scenario 5



Map 4.23 Final suitability scenario 6

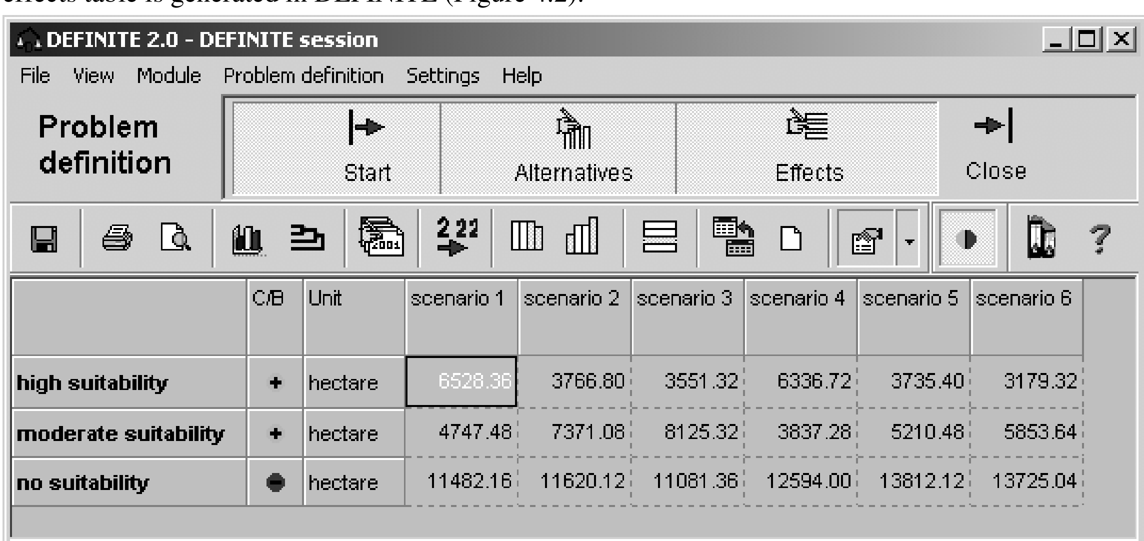
4.4. Multi-criteria analysis for ranking

In order to help in the development of more accurate and reliable resource management plans, many software systems have been developed. This will allow an easier planning of the resources at hand by using automated tools. It will also give some flexibility to the plan in a way that it may be easily modified and improved. Meanwhile it will look for the optimal solution for the use of a conflicting resource. The flexibility of the programs is a must in today's world because of the changing characteristics of the conflicts.

In this research, DEFINITE, a decision support system (DSS) software, will be used to make a ranking of the above six suitability scenarios and sensitivity analysis. DEFINITE is designed to support decision making on a finite set of alternatives. Actually it is a whole toolbox of methods that can be used on a wide variety of problems. If you have a problem to solve, and you can identify alternative solutions, then DEFINITE can weigh up the alternatives for you and assess the most reasonable. The program contains a number of methods for supporting problem definition as well as graphical methods to support representation. To be able to deal with all types of information, DEFINITE includes multicriteria methods, cost-benefit analysis and graphical evaluation methods. Related procedures such as weight assessment, standardization, discounting and a large variety of methods for sensitivity analysis are also available. A unique feature of DEFINITE is a procedure that systematically leads an expert through a number of rounds of an interactive assessment session and uses an optimisation approach to integrate all information provided by the experts to a full set of value functions (Janssen, Herwijnen et al. 2001).

4.4.1. Effects table

In section 4.3.5, each suitability scenario has been grouped in three classes: 'high suitability', 'moderate suitability' and 'no suitability'. Actually these three classes can be regarded as three effects (in DEFINITE, effects are equivalent to criteria) to make a ranking among the six suitability scenarios. And the areas of these three classes can be regarded as the effects scores (criteria scores). Thus an effects table is generated in DEFINITE (Figure 4.2).



	C/B	Unit	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6
high suitability	+	hectare	6528.36	3766.80	3551.32	6336.72	3735.40	3179.32
moderate suitability	+	hectare	4747.48	7371.08	8125.32	3837.28	5210.48	5853.64
no suitability	●	hectare	11482.16	11620.12	11081.36	12594.00	13812.12	13725.04

Figure 4.2 Effects table

The effects table above includes six alternatives (from ‘suitability scenario 1’ to ‘suitability scenario 6’), three effects (‘high suitability’, ‘moderate suitability’, ‘no suitability’) and the effects scores (suitability areas). These three effects are measured by the same unit, ‘hectare’. The areas of ‘high suitability’ and ‘moderate suitability’ are what we need in the green space system, which mean the larger the areas, the higher the suitability. So the effects of ‘high suitability’ and ‘moderate suitability’ belong to the benefit effect. The areas of ‘no suitability’ are the least important in the green space system, so it is a cost effect that means the larger the areas, the lower the suitability.

4.4.2. Standardization

Making the criteria scores comparable is often called standardization or normalization. Through a standardization procedure the measurement units can be made uniform, and the scores lose their dimension along with their measurement units (Sharifi and Herwijnen 2003). There are many methods available to standardize the criteria scores till now. The method to use should depend on the problem character and the attributes character. In this research, three methods are used to standardize the three suitability criteria (effects).

1. Goal standardization for ‘high suitability’

Goal standardization scales the scores for each criterion according to the relative distance between a goal value and a minimum value (Formula 4.1). These two values should be determined by decision makers based on the practical requirements. The total area of Dongguan municipality is ‘22758’ hectare. In order to make a good environmental quality, the greening rate should range from ‘30%~40%’ (see section 4.2.4). So the goal value of green spaces areas for ‘high suitability’ is ‘22758*40%=9103.2’ hectare, and the minimum value is ‘22758*30%=6827.4’ hectare. Figure 4.3 shows the original scores and the matching standardized values. The result of this standardization is positive scores for the benefits effects. The advantage is that the standardized values have a clear, real meaning independent of the evaluation alternatives.

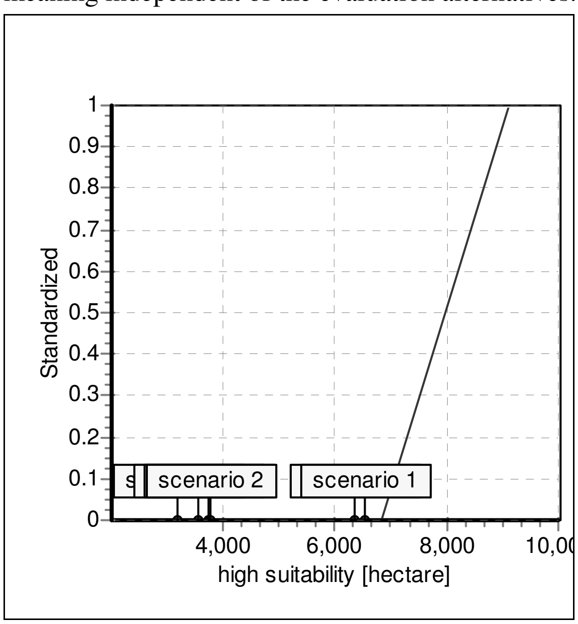


Figure 4.3 Standardization for ‘high suitability’

$$\bar{x}_{ij} = \frac{x_{ij} - v_{\min}}{v_g - v_{\min}}$$

Formula 4.1 Goal standardization

(Where $\bar{x}_{ij}$ is the standardized score, x_{ij} is the original score, $v_{\min}$ is the minimal value, v_g is the goal value.)

2. Interval standardization for 'moderate suitability'

Interval standardization is somewhat similar to the goal standardization, yet instead of the goal and minimum values the highest score and the lowest score are specified (Formula 4.2). It scales the criterion scores according to their relative position on the interval between the lowest and highest scores. Figure 4.4 shows the graph representing the conversion of the original scores to the standardized scores. In this benefit effect, the absolute highest score of 'scenario 3' is indicated with a '1', and the lowest one of 'scenario 4' with a '0'. The scores of other scenarios in between are scaled proportionally. For this benefit effect the graph goes from low to high, in other words a low score gets a low-standardized value.

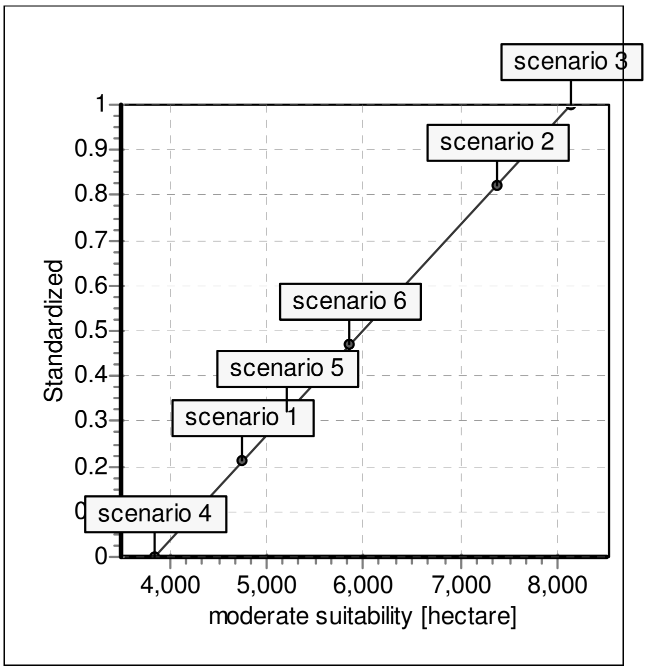


Figure 4.4 Standardization for 'moderate suitability'

$$\bar{x}_{ij} = \frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}}$$

Formula 4.2 Interval standardization

(Where $\bar{x}_{ij}$ is the standardized score, x_{ij} is the original score, $\min_j x_{ij}$ is the lowest score, $\max_j x_{ij}$ is the highest score.)

3. Maximum standardization for 'no suitability'

Maximum standardization scales the scores for each criterion according to the relative distance between the original and the highest score (Formula 4.3). Figure 4.5 shows the scores are standardized with a linear function. 'no suitability' is a cost effect, so the absolute highest score is indicated with a '0'. Other standardized values are determined proportionally. On the X-axis are the original scores, from the lowest score of 'scenario 3' to the highest score of 'scenario 5'. On the Y-axis are the standardized scores. For this cost effect the graph grows from high to low, namely a low score gets a high-standardized value.

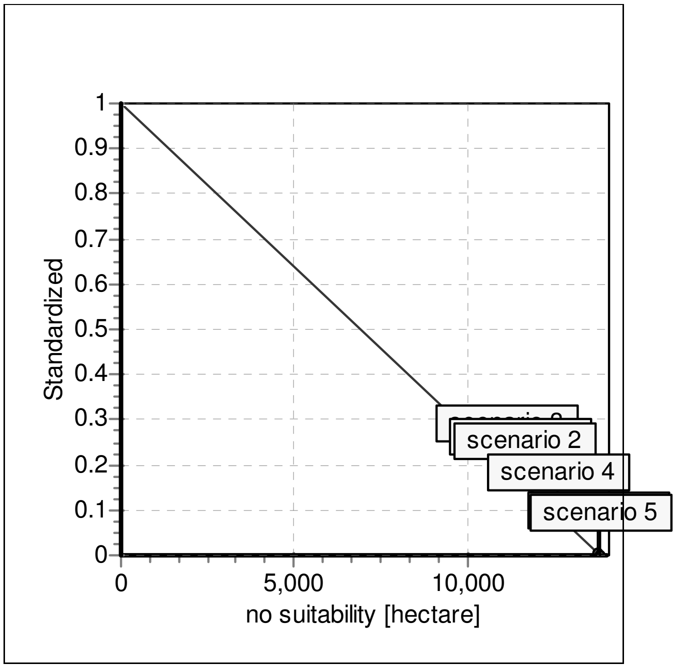


Figure 4.5 Standardization for 'no suitability'

$$\bar{x}_{ij} = 1 - \frac{x_{ij}}{\max_j x_{ij}}$$

Formula 4.3 Maximum standardization

(Where $\bar{x}_{ij}$ is the standardized score, x_{ij} is the original score, $\max_j x_{ij}$ is the highest score.)

4.4.3. Weight

Assigning weights to effects (criteria) is often a complicate task (Janssen, Herwijnen et al. 2001). DEFINITE includes various methods to support this task: Direct assessment, Pairwise comparison, Expected value method, Random weights, Extreme weights. From the effects table (Figure 4.2) we can easily rank the effects according to their relative importance: 'high suitability' > 'moderate suitability' > 'no suitability'. So Expected value method is used to determine the ranking of the effects. Expected value method assumes each set of weights that fits the ranking order of effects has equal probability. The weight vector is calculated as the expected value of the feasible set. Therefore, it can simulate the average idea of a group (Sharifi and Herwijnen 2003). Expected value method calculates the weight, w_i, for effect i according to Formula 4.4. Where n is the number of effects. The weights fit the ranking order of effects, meaning that $w_1 \geq w_2 \geq \ldots \geq w_n \geq 0$.

$$w_i = \sum_{k=1}^{n+1-i} \frac{1}{n(n+1-k)}$$

Formula 4.4 Expected value method

The final weights for those three effects including 'high suitability', 'moderate suitability' and 'no suitability' are presented in Figure 4.6.

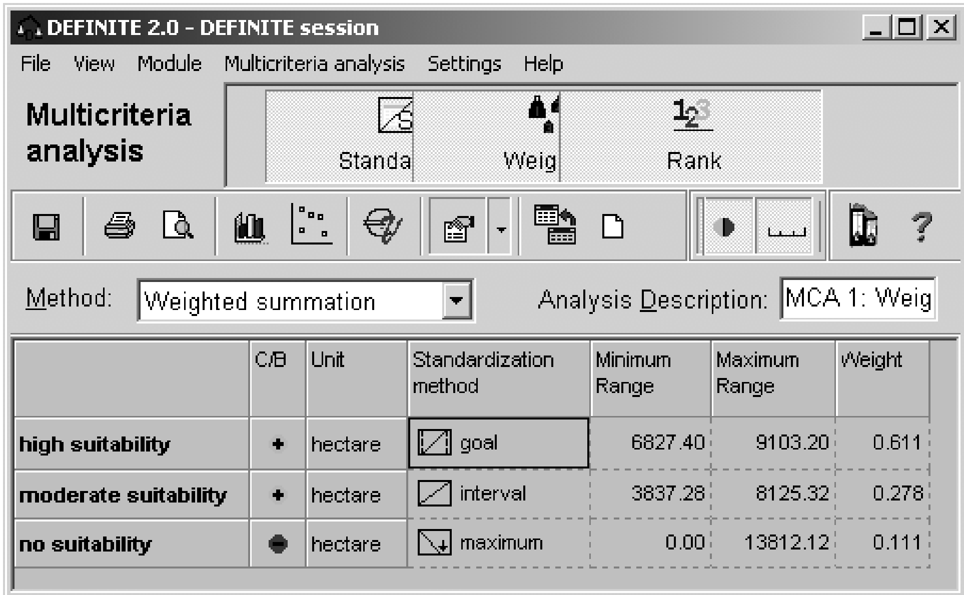


Figure 4.6 Standardizations and weights

4.4.4. Ranking

1. Weighted summation

The standardized scores and weights have been determined, now we can use weighted summation to make a ranking of alternatives (from scenarios 1 to scenario 6) according to Formula 3.8.

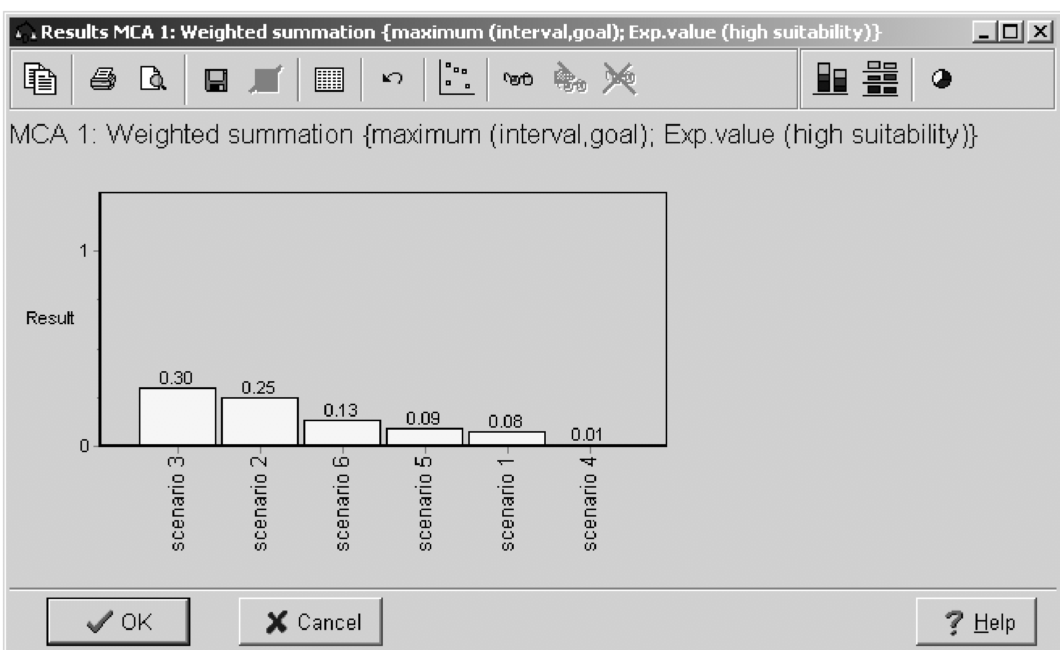


Figure 4.7 Ranking results I by weighted summation

Above we can see the ranking results represented graphically. Note that 'scenario 3' is the best alternative, followed by 'scenario 2', 'scenario 6', 'scenario 5', 'scenario 1', and 'scenario 4'. In order to explain the results with more details, we can display the weight as a pie graph next to this bar graph. And a stacked bar graph can be used to view the contributions of the effects scores to the total scores. The stacked bar divides the bar of every alternative into the relative contributions of the effects. Those contributions depend on the size of the effect and its weight (Figure 4.8).

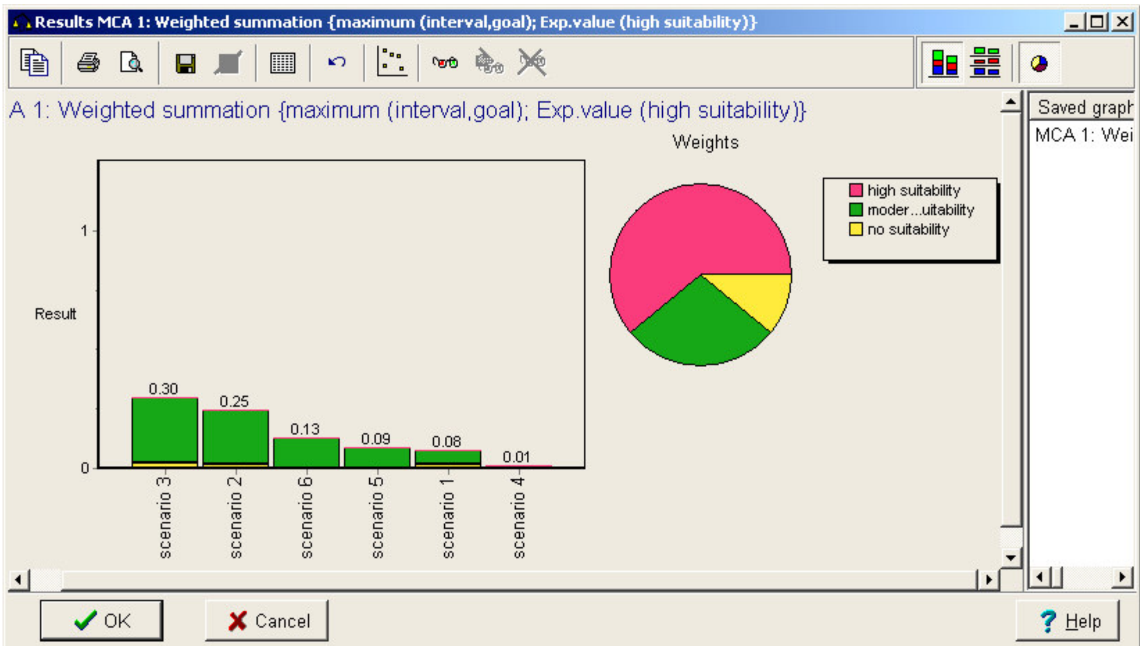


Figure 4.8 Ranking results II by weighted summation

The stacked bar above clearly shows that the effect of 'moderate suitability' is the main cause for 'scenario 3' to be the best alternative. Over half of the final score of 'scenario 3' derives from the contribution of 'moderate suitability'. The next contribution originates from the effect of 'no suitability', while the effect of 'high suitability' only makes a few contributions. Furthermore, the pie graph shows that the influence of 'moderate suitability' on the ranking of alternatives is limited because of the low weight assigned to this effect. After that, a scatter diagram can be used to have a closer look at the two effects that contribute most to the total scores (Figure 4.9).

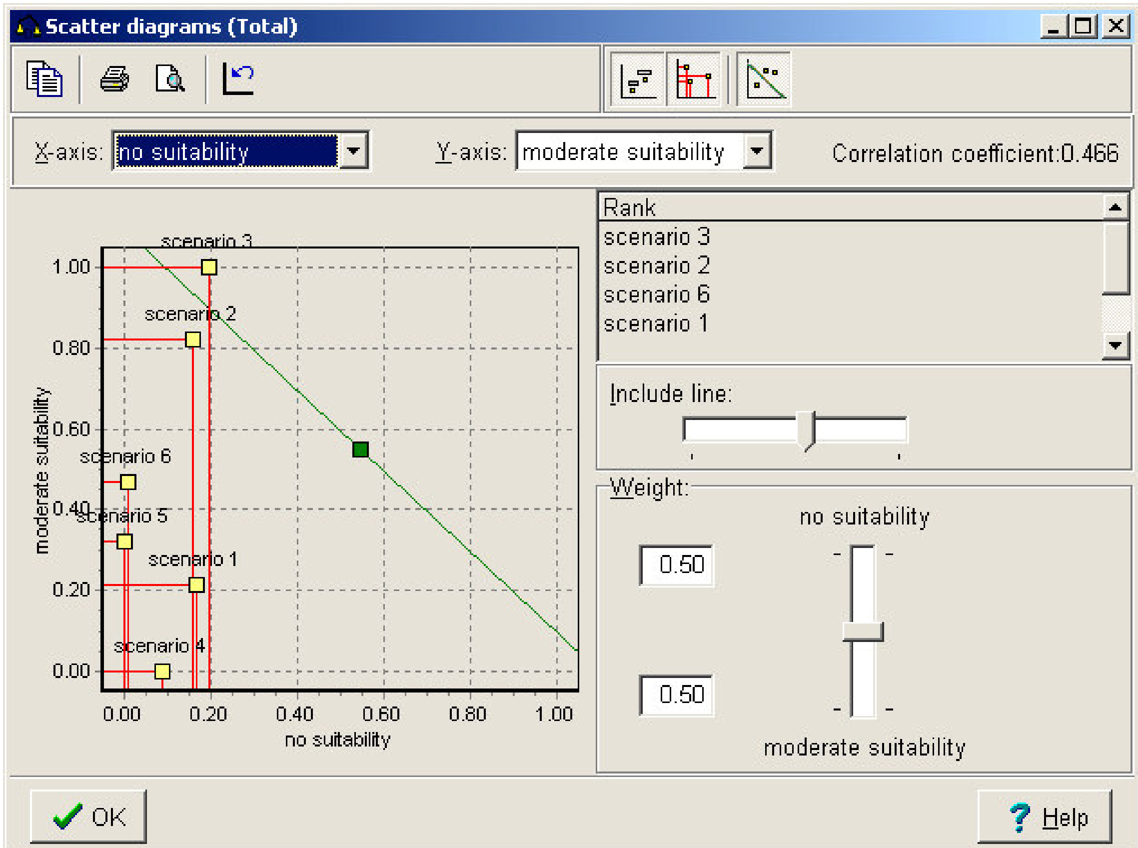


Figure 4.9 Ranking results III by weighted summation (Scatter diagram)

The diagram above shows the standardized scores of the alternatives for the effects ‘no suitability’ and ‘moderate suitability’. The best ideal alternative would have a score of ‘1’ for both effects and would be found in the top right corner of the diagram. The alternative located closest to this ideal is the best. And we can find the best alternative by moving the green line from the upper right corner to the lower left. The first alternative crossing this line is the best. Thus it can be showed that ‘scenario 3’ is the best alternative, followed by ‘scenario 2’ and ‘scenario 6’. The assumption made here is that the ranking of the alternative with equal weights for ‘no suitability’ and ‘moderate suitability’. Changing the weights of the two effects may move a different alternative to the first or other positions. For example, if the weight of ‘no suitability’ is increased to ‘0.8’, ‘scenario3’ and ‘scenario 2’ are also the two better alternatives, but they are followed by ‘scenario 1’ instead of ‘scenario 6’. This proves that ‘scenario 3’ is still the best one although the weights of effects have been changed.

2. Electre method

Based on the effects table (Figure 4.2) and the standardized effects table (Table 4.7), electre method can generate a ranking of alternatives through a large number of intermediate results, which include concordance table, discordance table, the strong and the weak results.

Table 4.7 Standardized effects table

	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	weight
high suitability	0	0	0	0	0	0	0.611
moderate suitability	0.21	0.81	1	0	0.32	0.47	0.278
no suitability	0.17	0.16	0.20	0.09	0	0.01	0.111

(1) Concordance table

The first intermediate result is the concordance table showed in Figure 4.10. According to Formula 3.9, the value '0.72' in the concordance table for the alternatives 'scenario 1' and 'scenario 2' is calculated as the sum of the weights of the effects for which 'scenario 1' is not worse than 'scenario 2'. Here it means that, the original score of '6528.36' of 'high suitability' in 'scenario 1' is higher than the score of '3766.80' in 'scenario 2', and original score of '11482.16' of 'no suitability' in 'scenario 1' is higher than the score of '11620.18' in 'scenario 2', so this concordance index $conc(j,k) = 0.611 + 0.111 = 0.722$. Other concordance indices in the concordance table are generated in the same way. In this case the effect 'high suitability' with weight '0.611', the effect 'moderate suitability' with weight '0.278' and the effect 'no suitability' with weight '0.111' (Table 4.7).

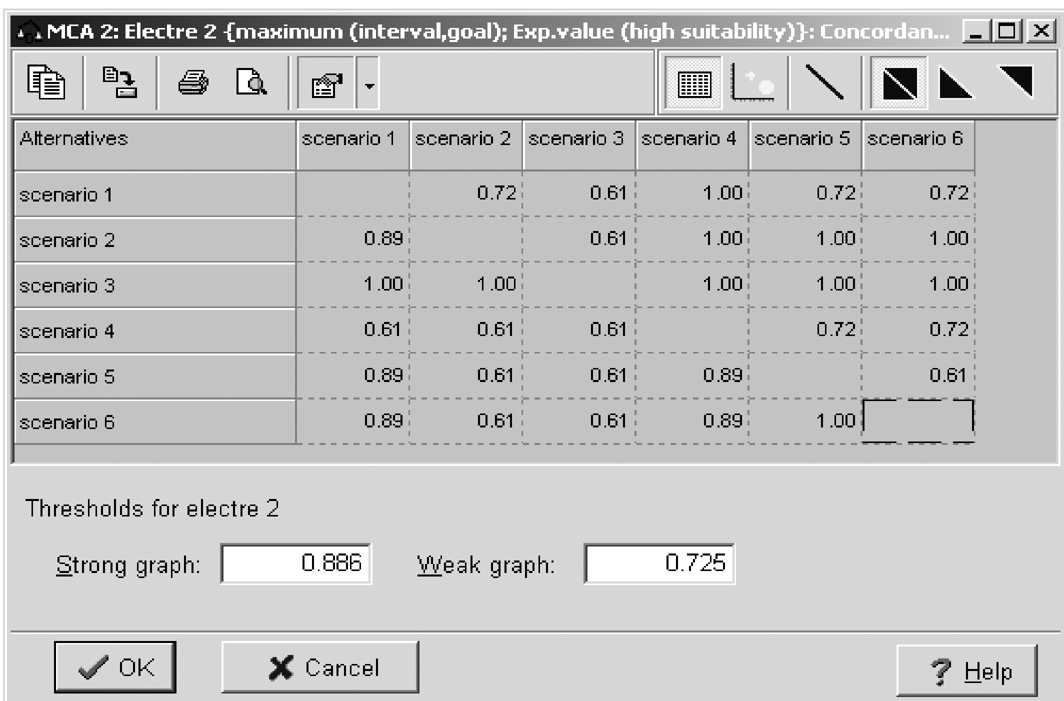
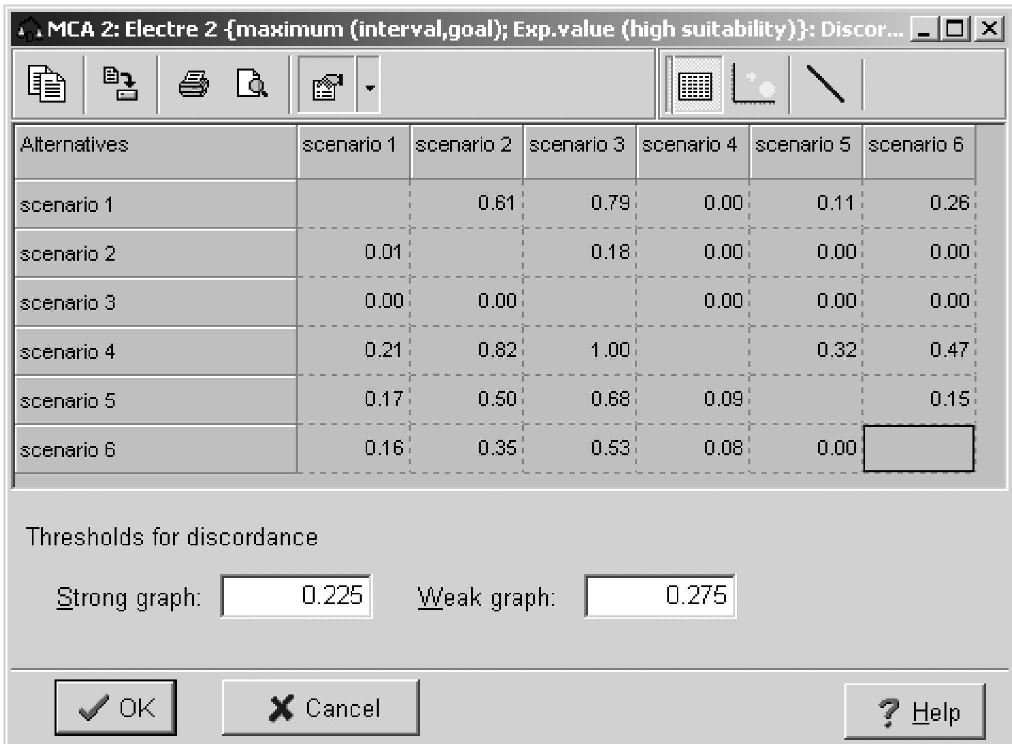


Figure 4.10 Concordance table

Based on the above concordance table, the decision maker has to determine a strong threshold P_s and a weak threshold P_w for this table. Here the strong concordance threshold value is specified as '0.886' and the weak concordance threshold value is specified as '0.725'.

(2) Discordance table

The second intermediate result is the discordance table showed in Figure 4.11. According to Formula 3.10, the value of '0.61' for both alternatives, 'scenario 1' and 'scenario 2', is defined as the largest deference of all effects in which 'scenario 1' performs worse than 'scenario 2'. In this example it means that, only the original score of '4747.48' of 'moderate suitability' in 'scenario 1' is lower than the score of '7371.08' in 'scenario 2', so the discordance index $disc(j,k)=0.81-0.21=0.60$. Other discordance indices are generated in the discordance table in the same way.



Alternatives	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6
scenario 1		0.61	0.79	0.00	0.11	0.26
scenario 2	0.01		0.18	0.00	0.00	0.00
scenario 3	0.00	0.00		0.00	0.00	0.00
scenario 4	0.21	0.82	1.00		0.32	0.47
scenario 5	0.17	0.50	0.68	0.09		0.15
scenario 6	0.16	0.35	0.53	0.08	0.00	

Figure 4.11 Discordance table

Based on the above discordance table, the decision maker also has to specify a strong threshold Q_s and a weak threshold Q_w for this discordance table. Here the strong discordance threshold value is set at '0.225' and the weak discordance threshold value is set at '0.275'.

(3) Strong and weak graph

Two concordance thresholds (P_s, P_w) and two discordance thresholds (Q_s, Q_w) have been determined above. Using these thresholds, a strong graph and a weak graph can be made according to the following strong and weak rules:

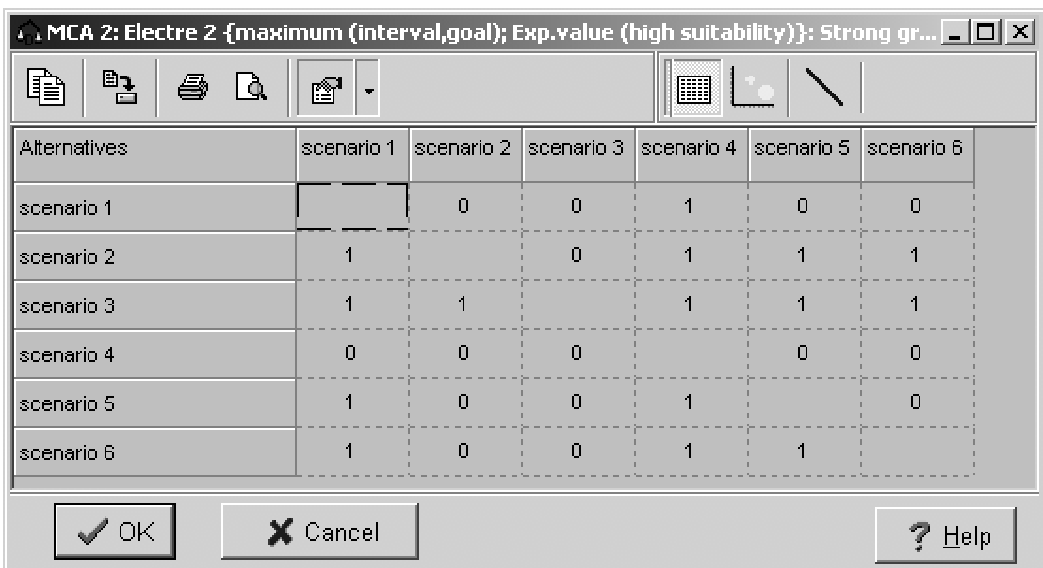
Strong graph:

j is strongly preferred to k $\Leftrightarrow$ $(con(j,k) > P_s)$ and $(disc(j,k) < Q_s)$

Weak graph:

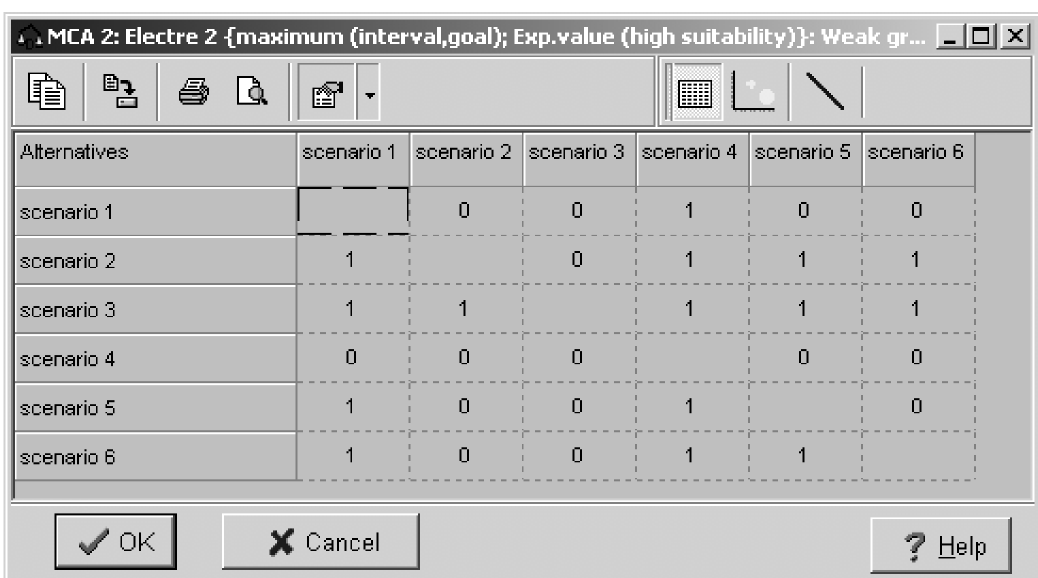
j is weakly preferred to k $\Leftrightarrow$ $(con(j,k) > P_w)$ and $(disc(j,k) < Q_w)$

Here the strong threshold P_s for the concordance index is specified as ‘0.886’ and the strong threshold Q_s for the discordance index is specified as ‘0.225’. This means the alternative ‘scenario 1’ is better than ‘scenario 4’, due to the value of ‘1.00’ comparing ‘scenario 1’ with ‘scenario 4’ in concordance table is higher than the strong threshold P_s of ‘0.886’, and the value of ‘0.00’ in discordance table is lower than the strong threshold Q_s of ‘0.225’. This is shown with a ‘1’ in the strong graph (Figure 4.12). The strong graph is generated composed of the value of ‘1’ (representing a ranking) and ‘0’ (representing no ranking). The weak graph showed in Figure 4.13 can be made in the same way according to the above weak rule. Here the weak threshold values for the concordance index and discordance index (P_w and Q_w) are respectively set at ‘0.725’ and ‘0.275’.



Alternatives	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6
scenario 1		0	0	1	0	0
scenario 2	1		0	1	1	1
scenario 3	1	1		1	1	1
scenario 4	0	0	0		0	0
scenario 5	1	0	0	1		0
scenario 6	1	0	0	1	1	

Figure 4.12 Strong graph (0: no ranking, 1: a ranking)



Alternatives	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6
scenario 1		0	0	1	0	0
scenario 2	1		0	1	1	1
scenario 3	1	1		1	1	1
scenario 4	0	0	0		0	0
scenario 5	1	0	0	1		0
scenario 6	1	0	0	1	1	

Figure 4.13 Weak graph (0: no ranking, 1: a ranking)

(4) Ranking results

In the final step, the circuits of the strong and weak graph are reduced. Then those alternatives of the strong graph that are strongly preferred to other alternatives are selected. From these selected alternatives a second selection is carried out based on the weak graph: the alternatives that are weakly preferred to other alternatives. These alternatives are given rank number one. The alternatives already ranked are then deleted from the two graphs and the selection of alternatives starts again until the two graphs are examined totally. Finally a complete ranking showed in Figure 4.14 is generated by combining two different complete pre-orders: one obtained by first selecting the alternatives that are not outranked by any other alternative and then going down the graph; the other obtained by first selecting the alternatives that are outranked by other alternatives and then going up the graph.

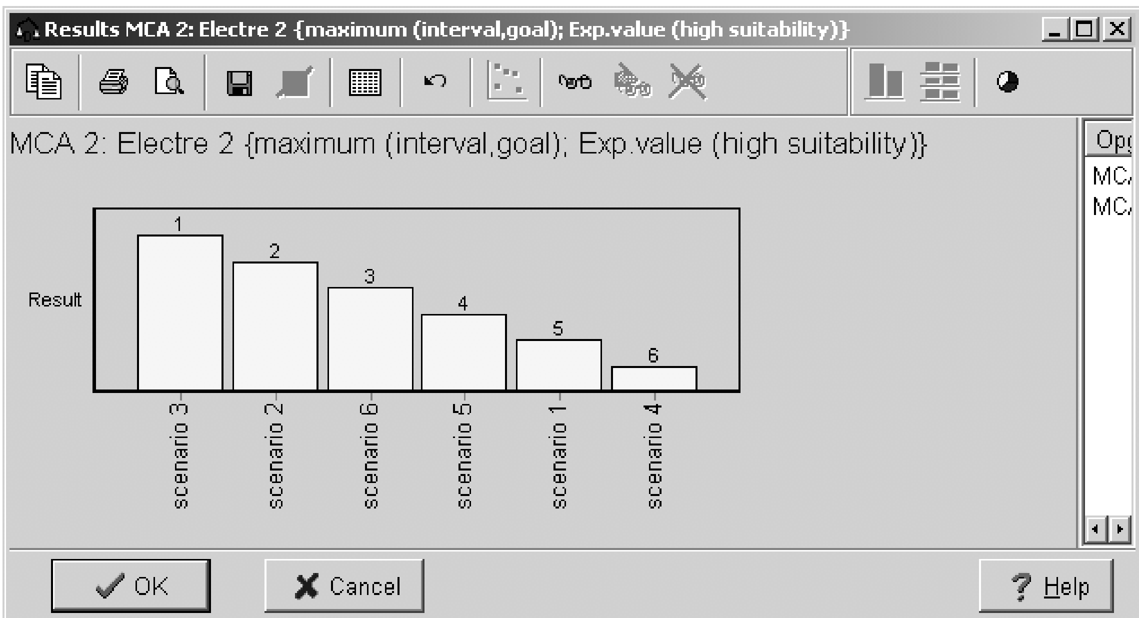


Figure 4.14 Ranking results by electre method

The ranking results by electre method above show the same order of alternatives as that by weighted summation (Figure 4.7). This means ‘scenario 3’ is the best alternative, followed by ‘scenario 2’, ‘scenario 6’, ‘scenario 5’, ‘scenario 1’, and ‘scenario 4’. Thus the alternatives have been ranked. Of course not all information is completely certain. The sensitivity of the ranking for uncertainties in scores and weights can be analysed in the next section ‘Sensitivity analysis’.

4.5. Sensitivity analysis

Multicriteria analysis (MCA) is mainly composed of four uncertainty components: criteria, criteria scores, weights and the choice of an evaluation method (see section 3.7). This section systematically focuses on the sensitivity of the ranking to uncertainties in scores and weights.

4.5.1. Uncertainty of one score

In this section a procedure is described to estimate certainty intervals for criterion scores. Within a certainty interval the ranking of two alternatives is not sensitive to changes in criterion scores. Figure 4.15 shows the sensitivity of the ranking for 'moderate suitability' of 'scenario 1'. The 'moderate suitability' areas of 'scenario 1' are estimated at '4747.48' hectares (see Figure 4.2). If this estimate is correct 'scenario 3' is the best alternative. The question whether 'scenario 3' is still the best if 'moderate suitability' areas of 'scenario 1' prove to be higher can be answered using this figure. The original estimate, a 'moderate suitability' of '4747.48' hectares, is marked with a vertical line. At '4747.48' hectares the total score of 'scenario 3' is above the total score of 'scenario 2', 'scenario 6' and other scenarios. It is clear that the difference between 'scenario 3' and 'scenario 1' is somewhat large but that a certain increase in the 'moderate suitability' areas of 'scenario 1' will make 'scenario 1' the better alternative. Reversal occurs at a 'moderate suitability' by 'scenario 1' of about '8200' hectares. This ranking is shown to be not very sensitive to changes in this score. The sensitivity of the ranking to changes in one weight can be analysed in the same way. But in calculating certainty intervals for one weight it is assumed that all weights add up to '1' and that the ratios between all other weights remain unaltered.

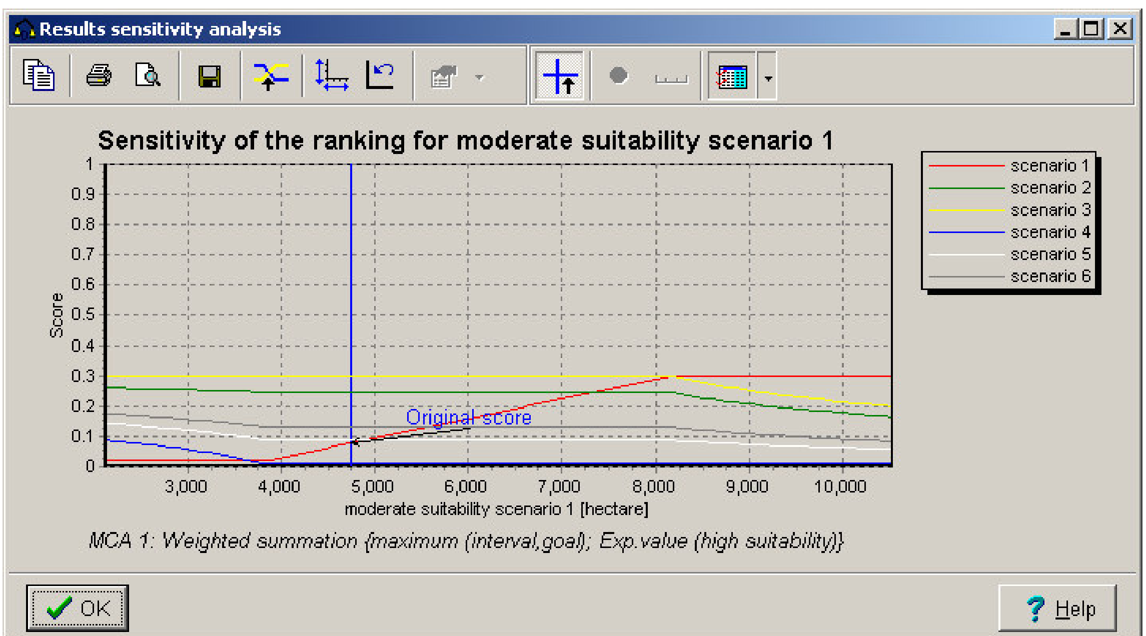


Figure 4.15 Sensitivity of the ranking for changes in one score

4.5.2. Overall uncertainty of the weights

As mentioned in section 3.7.1, the sensitivities of rankings of alternatives to overall uncertainty in scores and weights are analysed by using a Monte Carlo approach. The decision maker is asked to estimate the maximum percentage that actual values may differ from the values included in the elements of the effects table or set of weights. Figure 4.16 shows a result of sensitivity analysis on the ranking of alternatives by looking at the overall uncertainty of the weights. It is the probability that an alternative is ranked first, second, etc. Here it assumes that the weights can be '50%' higher or lower than the assigned weights and that this deviation is normally distributed. The figure shows that the alternatives ‘scenario 3’, ‘scenario 2’ and ‘scenario 6’ are always ranked on the first three positions, while ‘scenario 5’, ‘scenario 1’ and ‘scenario 4’ almost rank the last three positions. Numbers associated with this figure can also be derived. For example, ‘scenario 3’ and ‘scenario 2’ are found ‘100%’ on first and second positions, while ‘scenario 4’ ‘100%’ on last position. It can be seen that ‘scenario 6’ has the highest probability of being ranked third, but that ‘scenario 5’ even ‘scenario 1’ can rank third. The large-sized circles on the main diagonal indicate that the ranking of the alternatives under ‘50%’ weight uncertainty is relatively stable. Therefore it is quite certain that ‘scenario 3’ is the best alternative, followed by ‘scenario 2’ and other scenarios.

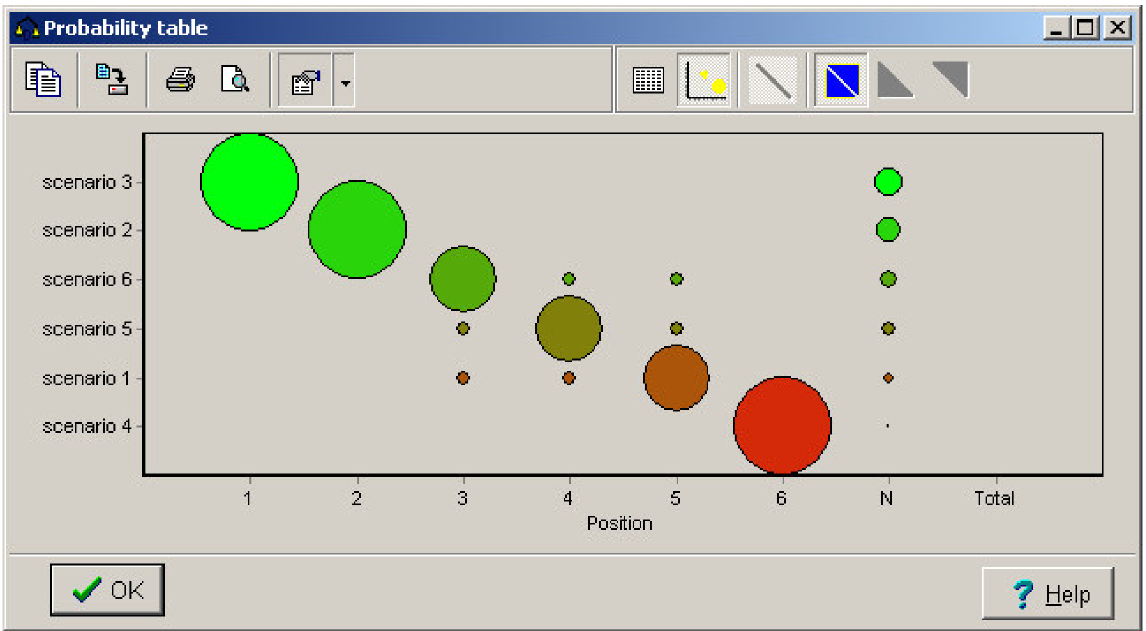


Figure 4.16 Uncertainty analysis on the weights (50%)

4.5.3. Changes in all weights (rank reversal of two alternatives)

As mentioned in section 3.7.2, three methods can be used to test the sensitivity of ranking to changes in all weights. The method of rank reversal of two alternatives is described in this section. Figure 4.17 shows the result of a rank reversal of two alternatives ‘scenario 1’ and ‘scenario 2’, the second position. In the upper part of this window, the column on the left shows the original weights. The column on the right shows the weight combination most similar to the original weights for which the alternatives ‘scenario 1’ and ‘scenario 2’ change the rank order. The ranking of the alternatives belonging to this weight combination is found in the lower part of this window in the column on the right, while the original ranking results using weighted summation are presented in the column on the left. It is obvious that the largest changes in weights decreasing the weight of ‘moderate suitability’ and increasing the weight of ‘no suitability’ may result in a better result of alternative ‘scenario 3’ (Note that the order of importance of the criteria has been changed). From all above sensitivity analyses of ranking for uncertainties in scores and weights, it can be concluded that ‘scenario 3’ is the best alternative although there are some uncertainties existing in the multicriteria analysis.

Weights:

	Total	Reversal point scenario 1 / scenario 2
	Weight	Weight
high suitability	0.611	0.745
moderate suitability	0.278	0.004
no suitability	0.111	0.251

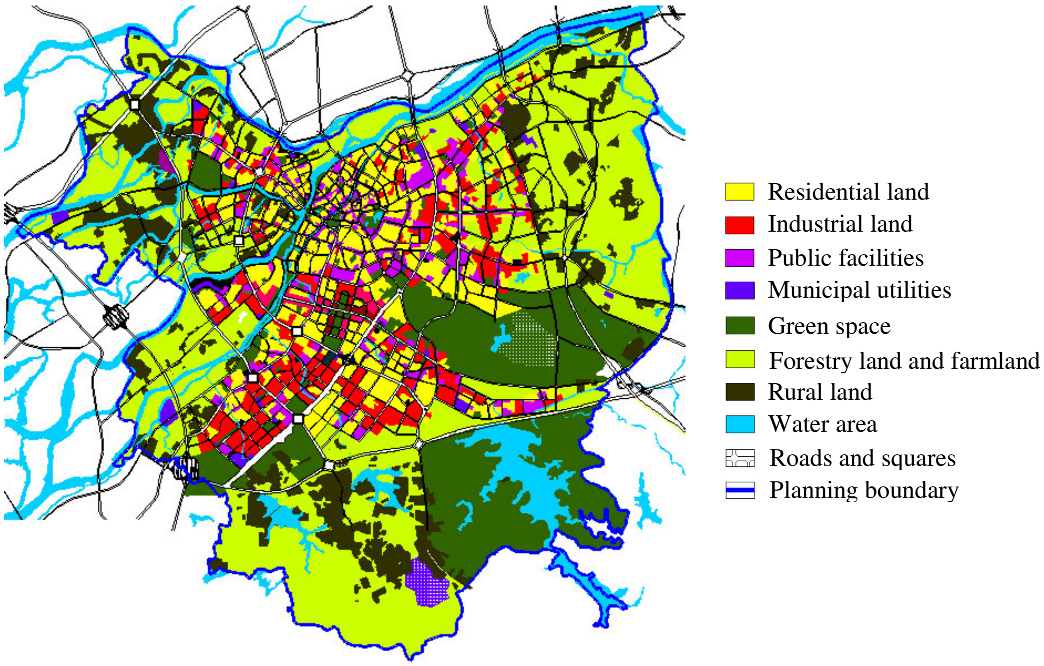
Results:

Alternatives	Total	Reversal point scenario 1 / scenario 2
scenario 3	0.30	0.05
scenario 1	0.08	0.04
scenario 2	0.25	0.04
scenario 4	0.01	0.02
scenario 6	0.13	0.00
scenario 5	0.09	0.00

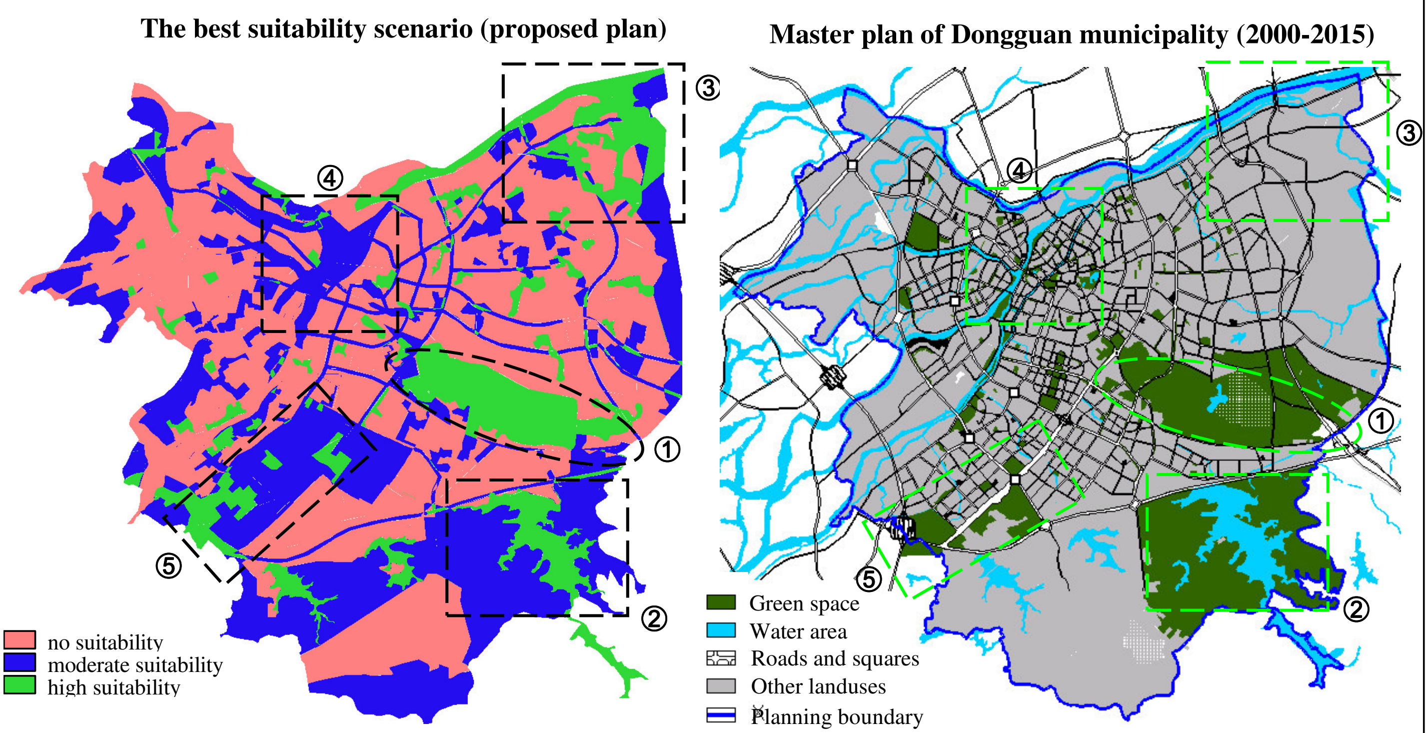
Figure 4.17 Weight combination by rank reversal between 'scenario 1' and 'scenario 2'

4.6. Comparison

The best suitability scenario has come out through the ranking and sensitivity analysis, now we can compare it with the urban master plan to find the commons and differences between them, and to find the reasons behind them. Map 4.24 is a master plan of Dongguan municipality (2000-2015) made by Chinese Academy of Sciences and Dongguan Institute of Urban Planning and Design. Map 4.25 is the comparison between the best suitability scenario and the master plan. In order to make a better explanation for the comparison, here we give a name of '**proposed plan**' to the best suitability scenario.



Map 4.24 Master plan of Dongguan municipality (2000-2015)



Note: ① Qifeng mountain area ② Tongsha reservoir area ③ Baima area

④ Rivers intersection area ⑤ Industrial area

Map 4.25 Comparison map

4.6.1. Commons

(1) Seen from the holistic distribution of the green space system, green spaces are mainly located in the east and the south in both plans (Map 4.25). There are some famous historic relics existing in these areas, but so little importance was attached to them that they were not protected well in the past. The government wants to plan a cultural relic and a historic site conservation to improve the historic culture value. Moreover, the landscape quality and surface water quality are rather low in the south, which needs to use green spaces to improve these two kinds of quality. The most important is that the built up area is primarily situated in the middle part, while most of the vacant areas and government reserved areas lie in the east and the south. Hence, the green spaces won't interfere with the future buildings development and certainly not be expanded at the expense of other important landuses.

(2) Idea of applying large-scale and small-scale green spaces in the green space system is the same in both plans. The proposed plan and the master plan consider the suitable sites for green space system should be not only in the built up area but also in the rural area. Large-scale green spaces in the rural area are the main parts of the green space system. They can play a good ecological role in cleaning air, preventing and reducing hazard. Also, both plans create more places with high landscape quality and supply better places for the residents' recreation to move the large number of urban population out of the built up area, with the aim of solving this kind of over-urbanization problem. Some small-scale green spaces decentralize in the built up are, which to some extent can adjust and improve urban climate, adjust the residents' psychology, and eliminate the noise caused by the fast growing industry and traffic. The green space system composed of large-scale and small-scale green spaces is consistent with the existing urban structure. Many buildings are located in the built up area that make the urban landuses be less potential. Thus the urban structure of Dongguan municipality has developed into a radiated style, and the direction for urban development is primarily showed on the development sequence.

(3) The green space system in both plans is developed centring around the mountains and water areas. In the built up area, Wanjiang River, Dongguan Channel and Dongguan Canal are the centres for the green spaces development, while Qifeng Mountain is the development centre of green spaces in the east and the three reservoirs are the other centres in the south (Map 4.25). The location of Qifeng Mountain area (see ① in Map 4.25) is almost the same. In the proposed plan, this area is almost equal to the existing green space area. Master plan states that Qifeng Mountain area is not enough for the fast increasing population any more. It should be expanded at the expense of its surrounding forestry lands and farmlands. Both plans acknowledge that the slide in this area is potentially dangerous and the soil is very sensitive to the neighbouring residents' activities. Some natural resources and historic relics exist in the Qifeng Mountain area but have been partially destroyed. All of which need to be improved by planning a suitable green space system. On the other hand, green spaces can play a good education function (see section 2.3.2) to the residents that they can enjoy in this area but have a responsibility for preserving the local resources. In summary, the green space system in both plans is characterised by that urban landuses are tightly integrated with the elegant mountains and water area, which will finally play an ecological role to the urban environment. The whole city seems to be enclosed by the green spaces, mountains and water areas, and the urban structure has a development tendency of cross-axis.

4.6.2. Differences

(1) In the proposed plan, the green space system is planned primarily allowing for the ecological factor (air quality, surface water quality, water system influence, noise influence), while the master plan mainly takes the social factor into account, particularly the factor of existing land use and historic culture value. As the research has mentioned the definition of urban green space system in section 2.1, in the proposed plan, those water areas enabling people to contact the nature and those greenways that can play a good ecological function are included in this urban green space system. For example, in Tongsha reservoir area (see ② in Map 4.25), Tongsha reservoir showing good ecological benefits is one of the important green spaces in the south. In the east south, Baima area (see ③ in Map 4.25) is the other ecological green space including some forestry lands and water areas. This is very different from the opinions in the master plan, which states that the existing water areas, forestry lands and other important natural resources should be strictly preserved. They cannot be occupied by other landuses but green spaces can be planned around them to play the ecological function. These opinions are obviously showed in Tongsha reservoir area and Baima area in both plans. As such, the green space system in the proposed plan is more systematic and decentralized than that in the master plan.

(2) In the rivers intersection area (see ④ in Map 4.25), green spaces in the master plan are mainly close to Wanjiang River, Dongguan Channel and Dongguan canal, with the aim of improving the surface water quality and acting as a green buffer to prevent the flood. In the proposed plan, only some small-scale green spaces decentralise around the rivers. The factor of surface water quality and the factor of water system influence for identifying the suitability are less important than other ecological and social factors (see the weighting results in Table 4.6). The proposed plan accepts that in the past few years, many industries of electronic communication and electric machine near the rivers before have been moved to the areas surrounding the built up area. Thus the water quality in Wanjiang River, Dongguan Channel anf Dongguan canal has been relatively improved. In addition, the water line of these three rivers is much lower than the 10-year flood line, so more green spaces should be planned in other areas that have higher flood potential, show more indications of advance erosion and high level of human activities (e.g. the three reservoir areas in the south). In summary, both plans acknowledge that the flood should be prevented by green buffers in the future. In the proposed plan, this can be showed from the areas around the rivers in the north of the built up area not with ‘high suitability’, but with ‘moderate suitability’.

(3) In the south of the built up area, green spaces in the master plan are mainly on the margin of the industrial area (see ⑤ in Map 4.25), as a green belt of absorbing toxic gas, trapping dust and eliminating noise. In the proposed plan, some green spaces are on the margin of the industrial area, others are planned at the expense of some industrial areas, in order to play a better ecological role, improve the landscape quality and adjust the workers psychology. Residents working in the industrial area not only need to eliminate the industrial pollution as much as possible, but also need an elegant environment with high landscape quality to adjust their oppressive psychology. This can be realized by planning the green spaces situated in the industrial area and on its margin. However, the master plan states that industry is the base of the urban economy. The existing industrial lands are so important that they cannot be occupied by other landuses. As long as the green spaces are suitably located on the margin of the industrial area, they can also play a good role in improving the working environment. In addition, with the fast growing of the urban traffic, noise has become a serious pollution that has a bad

effect on the residents' health. The proposed plan accepts that planning a suitable green space system is the most effective method to eliminate the noise. This can be showed from the areas with 'moderate suitability' beside the main roads in the proposed plan, while it is neglected in the master plan.

5. Conclusion and recommendation

5.1. Conclusion

This research involves two themes, which are urban green space system and suitability analysis. Urban green space system in this research means that there are some good green areas in the urban spatial environment, which are mainly covered with natural or man-made vegetation and can function as ecological balance, playing an active role to urban environment, landscape, and residents recreation. Suitability analysis is the process to determine whether the land resource is suitable for some specific uses and to determine the suitability level. Combing these two themes to one is the research purpose to develop an approach of GIS-based suitability analysis to identify suitable sites for urban green space system development. The conclusions can be addressed as follow:

Suitability analysis can be regarded as a relatively difficult task partially due to large number of factors and large volume of data that may be required for the determination. Seven suitability factors are selected in this research, but they are not the optimal ecological factors combination and not enough to carry out the GIS-based suitability analysis. The research approach for such suitability analysis depends heavily on the data available. Comprehensive information needs to be available for each of the suitability factors applied in the analysis. This information includes accurate suitability mapping, delineated city boundary, urban planning context, existing situation assessments, greening indices and future development restrictions. Stakeholder analysis becomes important as a means of selecting the suitability factors and evaluating the relative importance among them. Qualitative and quantitative factors information for the certainty factor is also necessary.

Integrating the certainty factor with GIS is an efficient method to improve the traditional suitability analysis model (TSAM). The improved traditional suitability analysis model (ITSAM) using the certainty factor can efficiently identify the difference among the different subclasses within the same suitability class, and can easily reduce the difference between the two different suitability classes around the division of scores. So ITSAM encompasses more enriched and precise information than TSAM. Six suitability scenarios based on TSAM and ITSAM are generated in this research. ‘Final suitability scenario 3’ (Map 4.20) based on TSAM is found to be the best alternative after the ranking. This is because only four suitability factors (landscape quality, historic culture value, water system influence, existing land use) can take advantage of the certainty factor. The certainty factor is not suitable for the other three factors (air quality, surface water quality, noise influence) due to their deficient numerical values (observation data). Also, it has some subjectivity to determine the certainty factor when making the subclasses in the suitability class. Further, it is somewhat subjective to determine the final suitability levels (‘no suitability’, ‘moderate suitability’, ‘high suitability’) by using the histogram of the composite suitability score in ILWIS.

Suitability analysis can be used to help direct the future growth of the green spaces and protect the other important landuses at the same time. The result of implementing the proposed approach is a map that categorises and illustrates the different levels of green space suitability throughout the study area. As can be seen on Map 4.25 of the best suitability scenario (proposed plan), large portions of the study area are found not to be suitable for the green space system development. This is a direct result of the growing conflict between the ecological environment and development restriction. Areas that receive high and moderate suitability levels are revealed to be the predominant areas of the existing green spaces, vacant areas and government reserved areas. This is suitable for the future growth of the green spaces. After comparing the proposed plan with the urban master plan (2000-2015), it can be showed that their ideas and part of the results are similar. The result in the proposed plan is reasonable and consistent with the local master plan, but it still needs to improve.

In order to advance the art of land suitability analysis, it is important that not only the result is replicable within a study area, but also the approach is transferable, or at least adaptable in other places. By applying the proposed approach in Dongguan municipality, this research provides an example of such transferability. The suitability results of the urban green space system are mathematically achieved, so they can be applied as valid factors into the generation of other approaches to achieve alternative landuse or design strategies. Revaluation of initial conceptions or updated information also can easily regenerate landuse or design strategies. The evaluation process is so explicit that alternative scenarios can be modelled without reconstructing the entire procedure. From the view of the technical level, this GIS-based suitability analysis approach is quite able to integrate ecological and social geographic data with human knowledge in an objective and manageable nature. It allows for all kinds of information from experts and general public to be used in the weighting process. From the view of the organizational level, the use of GIS technology brings people together, including the urban planners, environmentalists, local residents and local government officials. The high level of cooperation and involvement generates a broad-based approach to multiobjective suitability analysis for the green space system. From this work we are able to suggest that, the approach applied in this study area can be adapted in other areas of Guangdong province.

In summary, the suitability results can provide helpful knowledge on the factors interactions and their relation to the urban environment within the study area. It can be used to help people make better, more informed decisions, thus providing a more healthy quality of life for the community and the surrounding ecological environment. Suitability analysis is a powerful tool for green space system planning. Continued development and refinement of suitability analysis, particularly with GIS technology, can enable urban planners to help local government officials and local residents to create a suitable green space system in the urban environment.

5.2. Recommendation

Nowadays many methods can be used to make the suitability analysis, such as sieve mapping, landscape unit method, grey tone method (map overlay) and computer method (GIS). In this research, GIS is used to carry out the suitability analysis just because it can handle large number of data, powerfully visualize current and old information, produce new maps, etc. By applying GIS in the suitability analysis, what we should do first is to establish a set of suitability factors and weighting system. This is the most important and difficult step in the suitability analysis.

This search selects seven factors to make the suitability analysis, including air quality, landscape quality, surface water quality, historic culture value, water system influence, noise influence and existing land use. It is a relatively new attempt to select these factors to analyse the suitability in the urban planning. In some sense these factors may be not enough for showing the influence on the urban environment by the green space system. However, there are no many useful data (maps) available for this case study. As to the green space system, we should also consider the other ecological factors such as soil fertility, groundwater recharge, vegetation cover, erosion control, potential damage and some other social-economic factors (e.g. development pressure, extending public parcels), which are only presented in the books rather than in the maps. Hence, it is difficult to integrate these data with GIS, which will finally result in the relative shortage of urban foundational data. It shows that the scientists can' t have a good cooperation with the urban planners. So it is recommended that the scientists and the planners should keep in more touch with each other, work together to carry out some researches of the relevant speciality and make up the urban foundational data.

This research is a preliminary attempt applying GIS-based suitability analysis in the urban green space system development. The GIS software (ILWIS) used in the case study is of a raster-based design. The major advantages of raster-based design are their capability of individual pixel analysis and map algebra inherent in the raster systems, which make this suitability analysis much easier. However, depending on the scale of the individual cell values, the analysis may have been less precise than the vector-based design. Allowing for the limited time and the deficient data, the pixel precision may be not very appropriate for this suitability analysis. Further, the original maps' scales are different that sometimes there are some errors in transforming the data. But this suitability result is enough for the regional control, which can be showed from comparing the proposed plan with the master plan (Map 4.25). Therefore, if a detailed planning needs to be made in a region, it is better to use vector-based and raster-based GIS software (e.g. ArcView, MapGIS) to carry out the suitability analysis, not only making the suitability analysis free from the manual way, but also making the suitability results more precise and suitable for the planning.

It is widely accepted that GIS is a toolbox capable of providing support for spatial problem-solving and decision-making. However, current GIS analysis is based on simple spatial geometric processing operations such as overlay comparison, slicing, and distance calculation. It does not provide optimisation, iterative equation solving, and simulation capabilities necessary in the suitability analysis. Also, GIS does not integrate nonspatial data or decision makers' preference into the decision analysis. Given the current set of suitability factors, GIS land suitability mapping generates a set of suitability scenarios, rather than presenting the decision maker with an optimum scenario. Six suitability scenarios are generated in this research by using GIS software (ILWIS). After that, a decision support system (DSS) software (DEFINITE) is used to make the ranking and sensitivity analysis to find the best suitability scenario. These two softwares cannot easily exchange the data and only can allow for one set of weighting system at one time. Therefore, GIS should be integrated with the DSS software to make the suitability analysis in a systematic way, taking into account spatial and nonspatial information and allowing the decision maker to analyse the information based on one or more sets of weighting systems.

GIS-DSS is an advancement in decision-making for the suitability analysis, but there is still a clear need for further research in this field. One is about the extension of links between GIS and DSS software, in order to increase the exchange of data in the reverse direction from DSS software to GIS. Another topic for further research is the development of new approaches of generating alternatives within the GIS. Development of such approaches should be able to increase the usefulness of GIS-DSS, because a major disadvantage of any decision analysis is the generation of a feasible, complete set of alternatives.

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