CASA
WORKING PAPER SERIES
78
03 | 04
http://www.casa.ucl.ac.uk/working_papers/paper78.pdf

ISSN: 1467-1298

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Determining Sustainable Development Density using the Urban Carrying Capacity Assessment System

Kyushik Oh[*], **Yeunwoo Jeong**[**], **Dongkun Lee**[***], **Wangkey Lee**[****]

Abstract

Diverse urban problems in the capital region of Korea occur due to over-development and over-concentration which exceed the region's carrying capacity. Particularly, environmental problems such as air and water pollution have become more evident and become central issues for urban planners and decision-makers. In achieving sustainable environment through resolving such problems, practical approaches to incorporate the concept of environmental sustainability into managing urban development are needed.

This research aims at developing an integrated framework for assessing urban carrying capacity which can determine sustainable development density, and has yielded the following. First, seven determining factors for urban carrying capacity including energy, green areas, roads, subway systems, water supply, sewage treatment, and waste treatment were identified, and the assessment framework was developed by integrating such factors. Second, the UCCAS, a GIS-based carrying capacity assessment system was developed based upon the framework. Finally, through a case study of determining carrying capacity of an urban area, it was revealed that decision support with the UCCAS demonstrated in this research could play a pivotal role in planning and managing urban development more effectively.

Keywords: Sustainable development, Urban management, Development density, Urban Carrying Capacity Assessment System, GIS

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1. Introduction

Seoul, the capital region in Korea, is a high density, high development area with a disproportionately large concentration of residents; approximately 1/4 of total population of South Korea live here, due to the fact that it is the nation's administrative, business, and commercial center. Consequently, massive and high-rise development has been an ongoing problem resulting in increases in land and housing prices and continuing urban sprawl. Moreover, environmental problems such as air and water pollution have become more evident due to increases in urban land uses and human activities.

The primary concern for administrators in the city, particularly during the major economic growth period in the '60s – '70s, has been the establishment of an appropriate infrastructure for the number of people targeted. Their efforts initially focused on satisfying the public demands quantitatively. In the process of meeting these demands however, harmful environmental side effects have emerged, namely pollutants, which have created great concern from the public for the possible harmful effects and deterioration to the urban environment.

Under these circumstances, establishing new ways of urban management to achieve sustainable environment has been, a challenge for urban planners and policy-makers. Traditional approaches which mainly focused on supplying physical facilities should be shifted towards more practical methods of incorporating the concept of environmental sustainability into managing urban development. In addition, recent advancements in innovative theories and technologies on urban management along with the development of digital tools such as GIS, are now more readily available and thus should be utilized to provide opportunities for planners and decision-makers to understand complicated urban systems and thus formulate more effective urban policies and strategies.

This research is designed first to identify various determining factors of urban carrying capacity and to develop ways to assess carrying capacity by integrating such factors. A GIS-based assessment system is then developed based upon the theoretical and methodological framework. Finally, carrying capacity of a case urban area is determined using the system, and its utility is examined.

2. Sustainable development and carrying capacity

2.1. Sustainable development and its strategic objectives

Environmentally sound and sustainable development (ESSD) is a concept which aims at harmony between economy and environment, maintaining environmental quality while economic growth is pursued. Within this scheme, Agenda 21 seeks to look beyond conventional ways of addressing economics which has been responsible for many of the changes, or lack of, in society. The concept of ESSD suggests that the environment has a limit after which human activities, such as urban development, cannot be sustained. Such activities therefore, should be controlled within the carrying capacity of the environment. In other words, ESSD emphasizes the need for the environmental carrying capacity to be fundamentally maintained while economic growth progresses.

To accomplish sustainable urban environment and maintain its quality, strategic goals and objectives are needed. In this regard, a number of efforts for establishing sustainable development indicators have been conducted. In 1996, the United Nations Commission on Sustainable Development (UNCSD) announced the formulation of a draft for sustainable development indicators to evaluate and compare the degree of sustainable development of each country. Since then, sustainable development indicators have been developed and applied in many countries in European Union (EU). International organizations such as the Organization for Economic Cooperation and Development (OECD) and the World Trade Organization (WTO) have also developed diverse indicator sets for assessing the results of their research.

The indicators developed in these countries and organizations generally include social, economic, environmental, and institutional dimensions. Among these, the environmental dimension is a primary concern in pursuing ESSD in Korea. Environmental indicators suggested by UNCSD, OECD, EU, the United States, and the United Kingdom have mainly focused on air, forest, ocean, fresh water, bio-diversity, etc. In this research, air and water quality among the environmental indicators are employed as strategic objectives which are of importance in urban planning and management in Seoul.

2.2. Carrying capacity

Ecologists generally consider carrying capacity to be the maximum number of individuals that can be supported in an environment without the area experiencing decreases in the ability to support future generations within that area (Chung, 1988). Planners usually define carrying capacity as the ability of the natural or artificial system that can absorb the population growth or physical development without considerable degradation or damage (Schneider et al., 1978). Carrying capacity is also said to be the ability of natural and man-made systems to support the demands of various uses, and subsequently it refers to inherent limits in the systems beyond which instability, degradation, or irreversible damage occurs (Godschalk and Parker, 1975). As a social science concept focusing on humans, carrying capacity can be defined as a scale of economy that the natural system of an area can sustain (Seoul Development Institute, 1999).

The urban carrying capacity concept in this research is defined as the maximum level of human activities—e.g. population growth, land use, physical development, etc.—which can be sustained by the urban environment without causing serious degradation and irreversible damage. This concept is based upon the assumption (Kozlowski, 1990) that there is certain environmental thresholds which when exceeded can cause serious and irreversible damage to the natural environment. This carrying capacity approach can be useful when the thresholds are identified ahead of time. The determination of the capacity of a system is fairly straightforward when managing such urban facilities as water supply, sewage treatment, and transportation (Oh, 1998).

2.3. Determining factors of urban carrying capacity

Urban carrying capacity types can be classified based upon the purpose of application and spatial setting to which the concept is applied. Previous studies identified different types of carrying capacity (Penfold et al., 1972; Godschalk and Parker, 1975; Godschalk and Axler; and Daily and Ehrlich, 1992). Despite some differences in classification, urban carrying capacity can be understood in relation to four dimensions; environmental and ecological; urban facilities, public perception, and institutional dimensions (Table 1).

Types	Definitions
Environmental and ecological	The degree of human activity that environments and ecosystems within an area can support without causing serious degradation or damage on maintenance of quality of life
Urban facilities	The degree of human activity that facilities and services within an area can support without causing serious degradation of or damage to the maintenance of quality of life
Public perception	The amount of activity or degree of change that can appear before recognizing the visual or psychological quality of environment differently than previously perceived
Institutional	The administrative/financial condition of a city for maintaining the optimal scale of urban development toward public goals

Table 1. Types of urban carrying capacity

Specific factors determining urban carrying capacity can be further developed from the aforementioned four types. Godschalk and Axler (1977) suggest soils, slope, vegetation, wetlands, scenic resources, natural hazards, air and water quality, and energy availability as determining factors for environmental carrying capacity. For measuring facility carrying capacity, Onishi (1994) utilized such factors as water supply, sewage, waste treatment, railway, road, and housing. Other factors such as recreational, educational, and administrative services are also employed. Factors for determining perceptual carrying capacity generally include human attitudes, values, behavior, and expressed anticipation toward controlling other carrying capacity types (Godschalk and Axler, 1977). Godschalk and Parker (1975) suggest land use regulations such as performance standards and density controls, economic and cultural limits on environmental decision-making, governmental structure, and financial stability as determinant factors for institutional carrying capacity.

In this research, determining factors for assessing urban carrying capacity specifically focus on the quality of air and water. Seven factors were primarily selected: energy and green areas as determining factors for environmental and ecological carrying capacity; and roads, subway systems, water supply, sewage treatment, waste treatment for urban facilities carrying capacity. Such selection was mainly based upon the actual operability of this type of assessment in local government settings. Currently, there are not many successful cases although a number of strategies and tools have been developed and provided for the urban planning and management in local governments in Korea. One reason is the lack of supporting data and the need for constant updating. The operability in local government settings often heavily depends upon data availability. A set of determining factors in this research was therefore, made in consideration to the data availability in the Urban Information Systems (UIS) database framework of the City of Seoul. Other factors for public perception and institutional carrying capacity are excluded in this research due to the reason.

3. Assessment methods

3.1. Integrated urban carrying capacity assessment

The framework for urban carrying capacity assessment in this research can be overviewed by integrating urban management goal, strategic objectives, assessment methods for diverse determining factors, and urban management indicators (Figure 1).

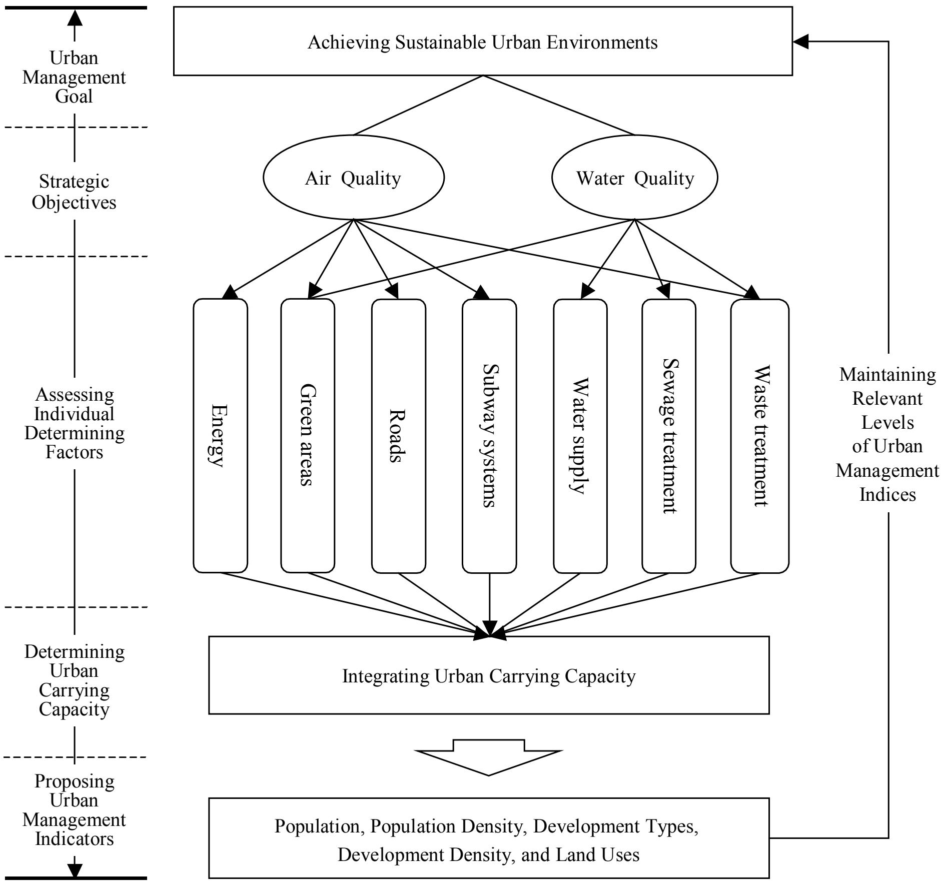


Figure 1.

Integrated Urban Carrying Capacity Assessment System

First of all, in order to achieve sustainable urban environment which is a goal of urban management, air and water quality are set as strategic objectives. The relationship between seven determining factors and the quality of air and water are identified. Carrying capacity assessment is then performed for each determining factor. By integrating the results from a series of assessments, an urban carrying capacity is determined. Finally, indexes for urban management is then developed in terms of population, population density, development type, development density, and land use. Such indexes can important key roles for urban planning and management processes.

3.2. Carrying capacity assessment for determining factors

The carrying capacity assessment for seven determining factors can be further understood with the following three steps in mind (Figure 2). First, for the determining factors, environmental standards and targeting service levels for maintaining air and water quality are established (Table 2). Second, the energy consumption and the operational loads of urban facilities/infrastructure (green areas, roads, subway systems, water supply, sewage treatment, waste treatment) to provide the targeting levels of service for sustaining human activities are measured. Third, environmental impacts resulting from the energy consumption and operations of urban facilities are analyzed. The impacts are compared with environmental standards and allowable development density is then determined.

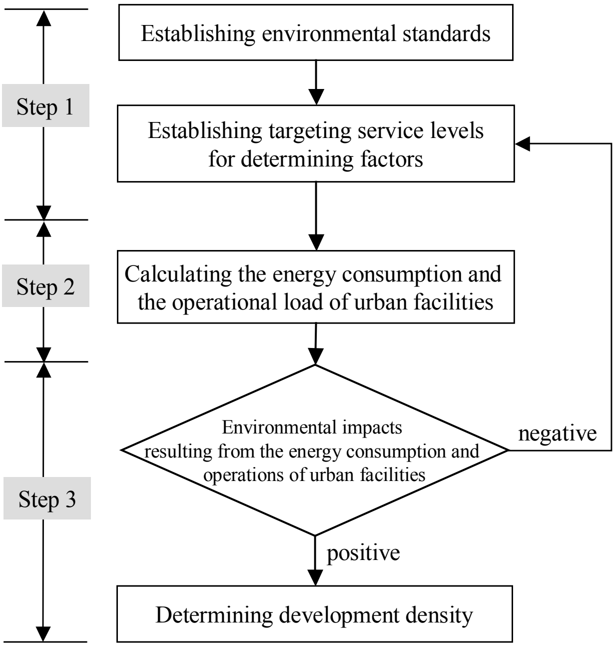


Figure 2. Three-step assessment process

Determining factors	Environmental quality standards	Targeting service levels
Energy	NO$_2$ concentration: 0.04ppm/year	Level of energy consumption (substituted with air quality)
Green areas	-	Green area per capita: 6□
Roads	NO$_2$ concentration: 0.14ppm/hour	Level of service: E
Subway systems	-	Crowding ratio: 150%
Water supply	-	Water supply per capita: 310ℓ
Sewage treatment	BOD concentration: 3 - 6□/ℓ	Sewage treatment ratio: 100%
Waste treatment	Dioxin concentration: 0.0006ng/□	Waste treatment ratio: 100%

Table 2. Environmental quality standards and targeting service levels

3.3. Development of the Urban Carrying Capacity Assessment System (UCCAS)

The UCCAS includes five main functional modules: File, Input/Edit, Urban Information, Assessment, and Scenario Analysis (Figure 3). The Input/Edit module creates a new field, which is needed for creating and updating the database for determining factors' graphic and attribute data. The Urban Information module displays diverse thematic maps, graphs, tables, and texts for urban areas of interest. The Assessment module consists of carrying capacity assessment for each factor and integration of results from individual assessments. Finally, the Scenario Analysis module allows the performance of carrying capacity assessments under diverse scenarios.

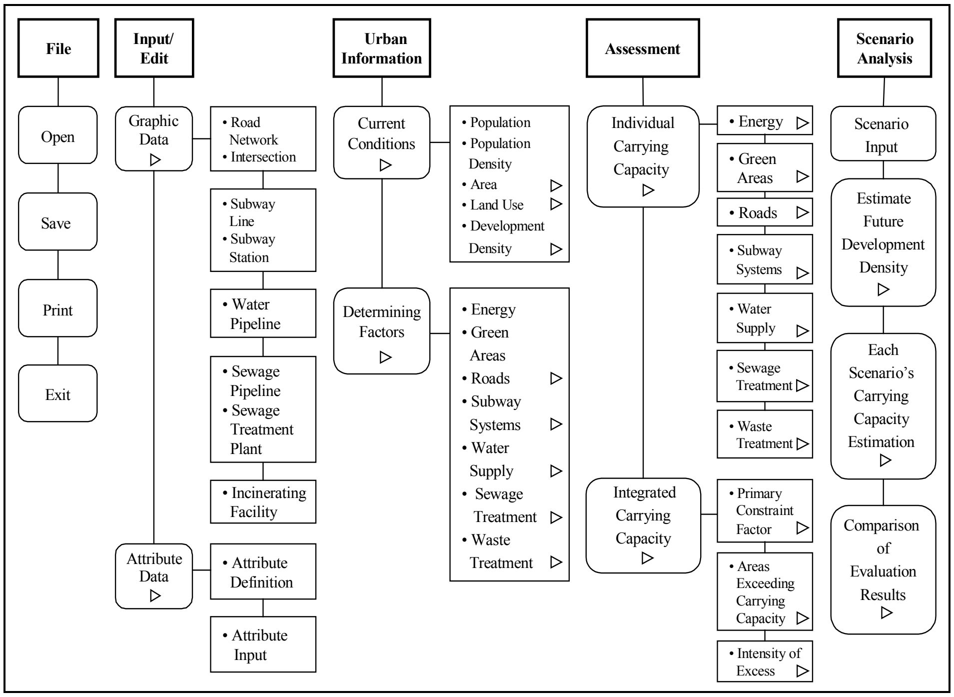
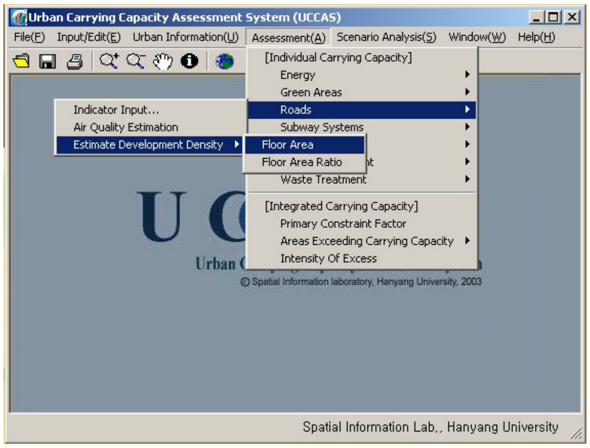


Figure 3. Main functions of the UCCAS

The UCCAS was programmed with Visual Basic 6.0, Excel VBA, and MapObjects 2.1[1].

Figure 4 shows a sample assessment of the case study area's carrying capacity.



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[1] 'Visual Basic 6.0' and 'Excel VBA' are Miscrosoft software for programming. 'VBA' means Visual Basic for Application. 'MapObjects 2.1' is a GIS application development tool of ESRI.

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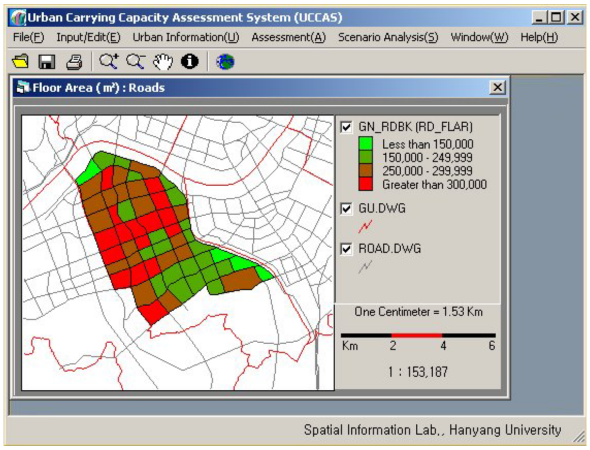

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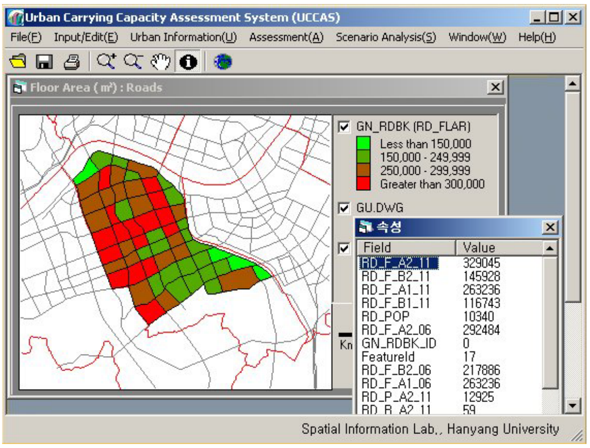

Field	Value
RD_F_A2_11	329045
RD_F_B2_11	145928
RD_F_A1_11	263236
RD_F_B1_11	116743
RD_POP	10340
RD_F_A2_06	292484
GN_RDBK_ID	0
FeatureId	17
RD_F_B2_06	217886
RD_F_A1_06	263236
RD_P_A2_11	12925
RD_B_A2_11	59

Figure 4. Example of operating the UCCAS

4. Case Study: the application of the UCCAS

4.1. Case study area

The study area, the Gangnam District (Figure 5) is one of the most densely developed in Seoul. The area is about 39.55□ and has 550,000 residents (in 2000). The total residential, commercial, and business areas combined is 27,873,327□, and floor area ratio (FAR) of the study area is 152%. Figure 6 displays FAR of each *dong*[2]. Yeoksam-dong, a typical commercial area, and Daechi-dong, a representative residential area, show an especially high FAR. The greenbelt and urban natural parks in the Gangnam District are mostly located in the southern area which do not possess urban facilities. Therefore, in this research, the spatial extent of assessment for each determining factor was restricted to the northern part of the Gangnam District where urban development has been concentrated.

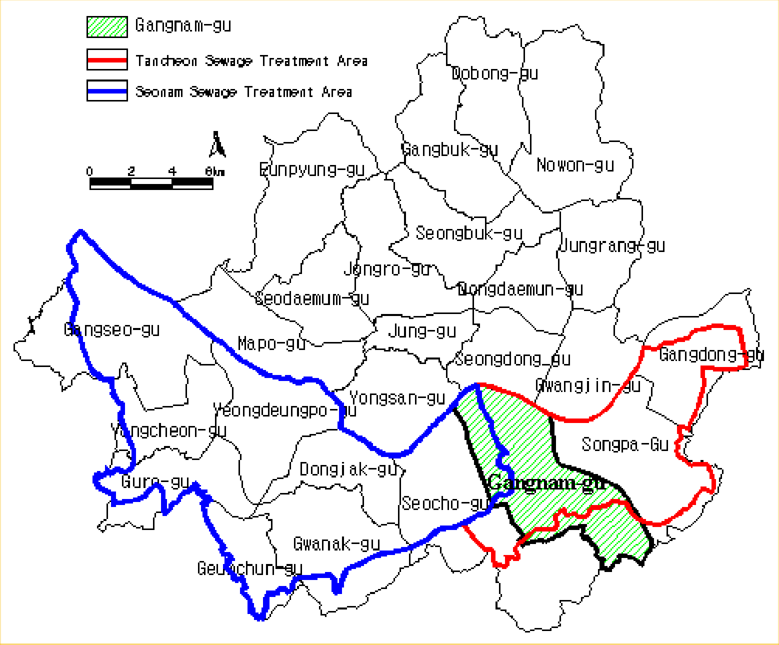

Figure 5. Case study area

For SO_2, the degree of air pollution in Seoul by energy consumption is 0.0006ppm (in 2000). This is within the limit of 0.019ppm suggested level by WHO. Air pollution in terms of level of NO_2 however, is 0.035ppm which exceeds WHO's standard of 0.021ppm. The concentration of SO_2 and NO_2 in the air at measuring points in the case study area is 0.0044ppm and 0.036ppm, respectively. They are similar to the annual air

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[2] "*dong*" is an administrative spatial unit representing a local area in Korea.

pollution levels in Seoul.

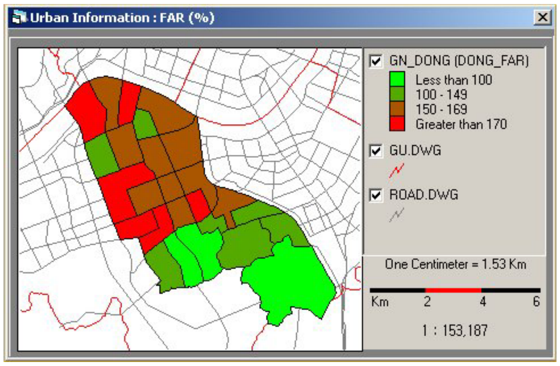

Figure 6. Current development density in the Gangnam District

Although the green areas in Seoul measure 155.85km^2 total and 15m^2 per capita (in 2001), green areas with which citizens can actually utilize on a daily level is quite insufficient because 78% of the areas compose forests in the outer ring of the city. In the Gangnam District, green area per capita is 8.8m^2, which is even lower than the average of the city.

Signaled intersections on major roads are total 63 places in the Gangnam District. Only two intersections show 'D' level of service (LOS), 13 intersections have 'E' LOS, and other 48 intersections show 'F' LOS where traffic jams usually occur during rush hour.

The water supply in the Gangnam District meets 100% of its demand. The capacity of the sewage treatment plant in the study area is 1,100,000tons/day. Currently the sewage treatment plant is operated by a standard activated sludge process method and treated water from the plant is released into streams. The water quality of the streams has been measured at the worst level (the 5th grade).

The amount of solid waste has consistently decreased. The metropolitan landfill site accommodates waste from 56 cities in the metropolitan area including the study area. Only one incineration plant is being operated in the study area, and its capacity is 900tons/day. The concentration of dioxin generated by burning solid waste is less than 0.1ng/□ which meets current emission control standards.

4.2. Carrying capacity assessment for determining factors

4.2.1. Energy

In order to assess the carrying capacity in terms of energy, how much energy needs to be consumed for supporting urban activities should be understood. Currently however, such a standard is not available due to the difficulty in generalization. As a substitute for the energy consumption level therefore, the level of air pollution resulting from energy consumption is used in this research. The relationship between emission and NO_2 concentration can be derived from the BOX model (Seinfeld and Pandis, 1998), a simple air dispersion model. The amount of air pollutant emission is calculated with a pollutant emission coefficient from the BOX model. Sustainable development density in the study area is determined by calculating relevant population to the amount of air pollutant emission.

As a result of applying the BOX model, the amount of NO_2 emission was calculated as 2,953,210tons which is under the 0.04ppm/year standard of air quality in Seoul. The population that could be supported was then calculated as 690,013 people based upon the emission and population relationship. This figure is equal to 17,566,535□ of the total floor area of development, and is 100% FAR (Figure 7).

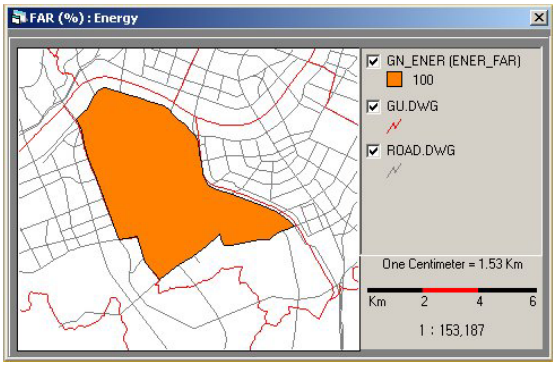

Figure 7. Carrying capacity for energy (FAR)

4.2.2. Green areas

Currently, it is suggested that 6㎡ per capita be provided under urban planning guidelines in Korea. Green areas including urban parks, green open spaces, and urban forests are identified from satellite images of the city. The total area of green is then divided by the suggested level of provision, 6㎡ per capita, and desirable development density in terms of green areas is determined.

Green areas in the Gangnam District is 3,994,200㎡. For supplying and maintaining a minimum 6㎡ per capita, the sustainable population for the Gangnam District was estimated to be 665,700 people. It can be converted as 16,947,556㎡ of floor area, equal to 97% FAR. FAR in each *dong* ranges from 10% to 480% (Figure 8).

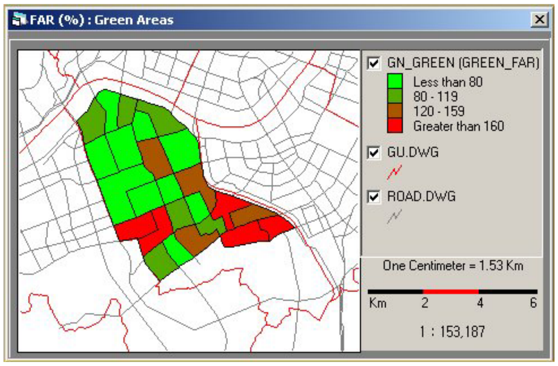

Figure 8. Carrying capacity for green areas (FAR)

4.2.3. Roads

For assessing the carrying capacity for roads, a minimum LOS of roads should be determined. LOS ranges from A, the best condition of traffic flow, to F, the worst condition. In general, the difference between E and F is considered to be critical. In this research therefore, level E is employed as the minimum LOS. The traffic volume which roads can accommodate with level E is then calculated using TSIS[3]. Environmental impacts of air pollutants caused by the traffic are analyzed. As the minimum standard of air quality for the analysis, 0.14ppm/hour of NO_2 concentration (the standard of air quality in Seoul) is employed. If the NO_2 concentration caused by traffic exceeds the standard, traffic volume is adjusted in order to comply with the environmental standard, and development density is determined accordingly.

The results of analysis using the TSIS program revealed that the total traffic volume at peak hour (08:00□09:00) was 468,740 vehicles with LOS E. NO_2 emission by the traffic volume was 28,624g/hour, and the concentration of NO_2 was predicted as high as 0.094ppm/hour using ISCST3[4] model (Figure 9). This value was less than 0.14ppm/hour which meets the air quality standard of NO_2 concentration. The environmental impact by current traffic volume was considered to be insignificant.

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[3] Traffic Software Integrated System, ITT Industries, Inc.

[4] Industrial Source Complex - Short Term, EPA

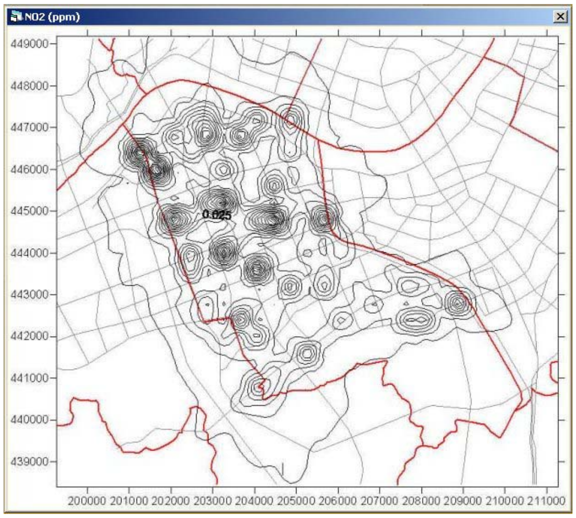

Figure 9. Air quality in the Gangnam District (NO_2)

Applying the total traffic volume above, it was revealed that the total floor area and FAR sustained by roads in the Gangnam District were 15,571,770□ and 89% respectively, and the population for this floor area of development was 611,659 people. The blocks in the study area can accommodate FAR ranging from 40% up to 550% (Figure 10).

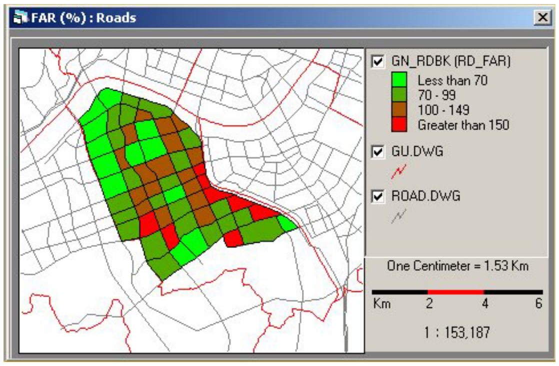

Figure 10. Carrying capacity for roads (FAR)

4.2.4. Subway systems

The level of crowding can be used as a reference for the service level for subway systems. The maximum level of crowding in this research is set at 150%, which is a figure that has been adopted in many developed countries. With this crowding ratio and the planned capacity of each station and related subway line sections, the number of passengers at each station and subway section occupied per hour can be calculated. Affected areas of each subway station then can be delineated with Reilly's law[5]. Accordingly, the floor area supported by each station and is calculated, and the development density in the study area can be determined.

Under the 150% crowding ratio, the number of passengers supported by entire subway systems in the study area at peak hour (08:00□09:00) was calculated as 747,814 people. The total floor area and FAR supported were 42,997,924□ and 213%, respectively. The population for this floor area was equal to 1,688,958 people. It was also estimated that each station and nearby area could accommodate FAR ranging from 70% up to 1,700% (Figure 11).

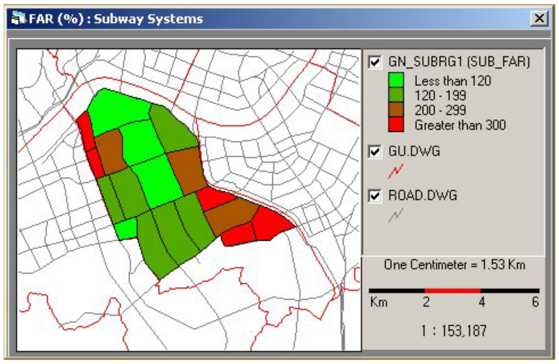

Figure 11. Carrying capacity for subway systems (FAR)

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[5] $$d_{ix} = \frac{d_{ij}}{1+\sqrt{P_j / P_i}}$$

d_{ix} : The distance from 'i' to 'x' the break point at which passengers will be drawn to one or another of two competing subway stations

d_{ij} : The total distance between two subway stations 'i' and 'j'

P_i : The number of passengers on subway station 'i'

P_j : The number of passengers on subway station 'j'

4.2.5. Water supply

The minimum level of water supply to assess the carrying capacity is set at 310ℓ per capita per day, which was the average consumption level in Seoul in 2002. The amount of water produced by current water supply facilities is determined by the primary constraint factor[6] among pipeline networks, water purification plants, distribution reservoirs, and intake stations. Sustainable development density in the study area based on the amount of water supply is then determined.

The available amount of water is 291,440□/day, which is determined by the capacity of a water purification plant, the primary constraint factor. With the minimum level of water supply (310ℓ per capita per day) and considering water loss due to leakage, the population supported by the current water supply system in the study area was estimated at 626,753 people. This can be converted into total floor area of 15,956,027□. It also equals 91% FAR (Figure 12).

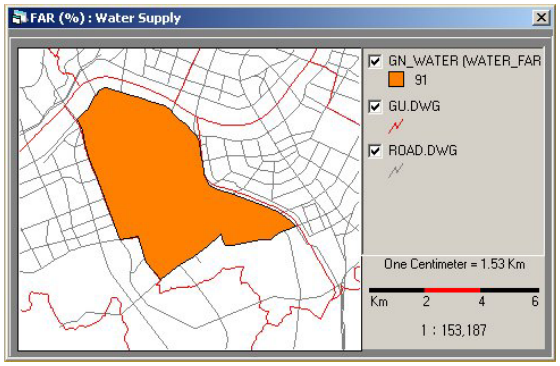

Figure 12. Carrying capacity for water supply (FAR)

4.2.6. Sewage treatment

The target level of sewage treatment is set to 100%. The allowable volume of sewage

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[6] "Primary constraint factor" is the facility that has the minimum capacity.

is identified under the capacity of current sewage facilities. Environmental impacts on water quality from treated sewage and untreated runoff are then assessed. In this research, the minimum level of water quality for the Tancheon sewage treatment area is BOD 3□/ℓ, which represents the level of drinkable water processed by normal purifying methods. The minimum level of water quality for the Seonam sewage treatment area is BOD 6□/ℓ, which is the level for marginal potable water quality. If the total amount of pollutants discharged in the water is more than the minimum level of water quality, the allowable volume of sewage is adjusted in order to comply with environmental standards, and development density is determined accordingly.

The amount of sewage which can be treated in the study area was 428,758□/day. On the other hand, the total volume of pollutant discharge in the Tancheon sewage treatment area and Seonam sewage treatment area was 100,027,251g/day and 261,385,546g/day, respectively. The resulting water quality was BOD 2.88□/ℓ and 4.28□/ℓ, respectively. This BOD level meets the minimum level of water quality. With 100% sewage treatment, the population which can be accommodated in terms of sewer capacity in the study area is 668,160 people, which can be converted into total floor area of 17,520,689□. This is equal to 100% FAR (Figure 13).

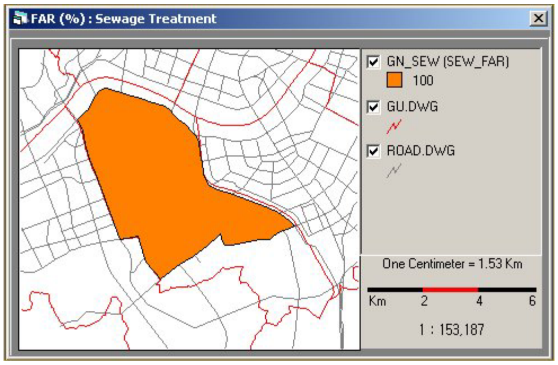


Figure 13. Carrying capacity for sewage treatment (FAR)

4.2.7. Waste treatment

The target level of waste treatment is 100%. The capacity of current waste treatment facilities includes landfill, waste incinerators, composting facilities, and recycling facilities. Dioxin produced by waste incinerators is particularly harmful. Dioxin concentration of 0.0006ng/□ (Seoul Development Institute, 2000) is employed as the standard of air quality. If dioxin concentration by waste treatment does not satisfy the environmental standard, development density is calculated after adjusting the amount of waste for achieving the standard.

Currently there is a waste incinerator within the study area. With 100% waste treatment, the amount of waste processed by current incinerator was 1,181,300kg/day. On the other hand, the highest level of dioxin concentration at landing points caused by waste incineration was 0.000002ng/□ (Figure 14). This level was below the environmental standard of 0.0006ng/□. The environmental impact of incineration was therefore, considered insignificant. The population accommodated by current waste facilities in the study area is 1,158,259 people, which can be converted into total floor area 29,487,257□. This equals to 169% FAR (Figure 15).

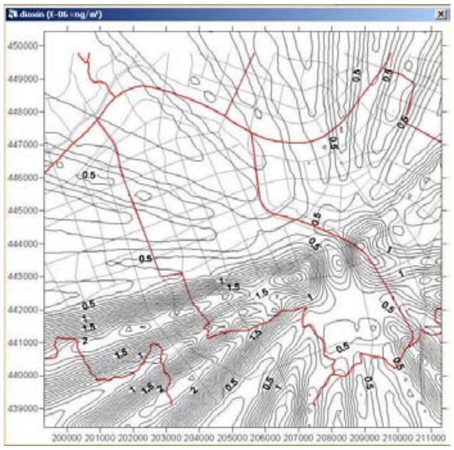


Figure 14. Air quality in the Gangnam District (dioxin)

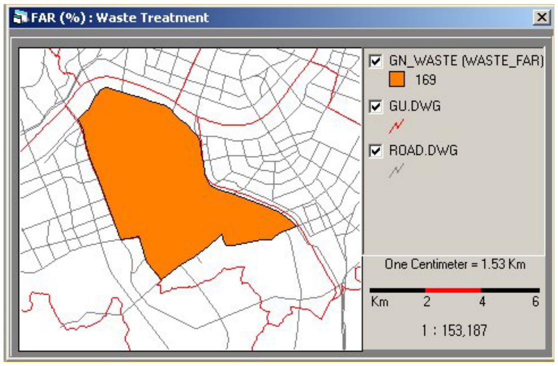
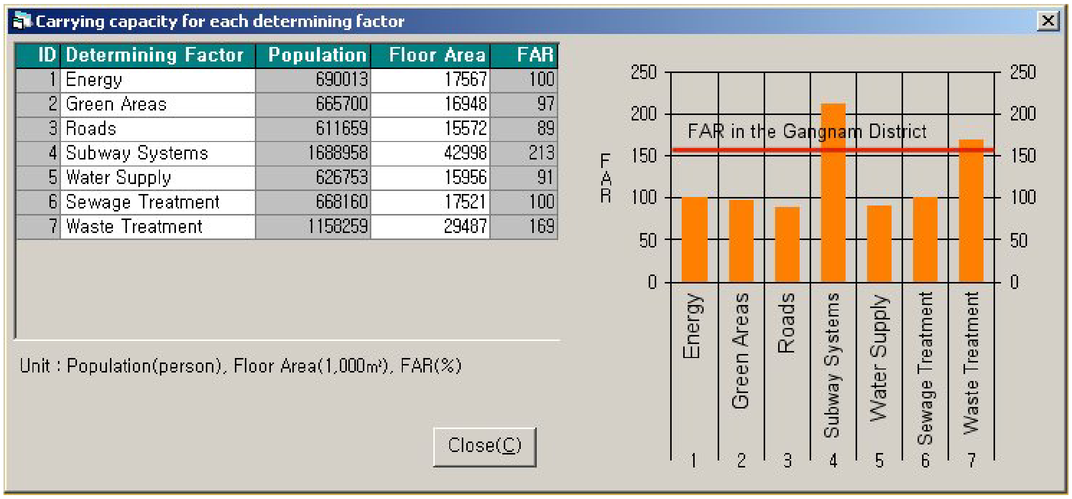


Figure 15. Carrying capacity for waste treatment (FAR)

4.2.8. Integrated assessment

Based upon the results from analyses for the seven determining factors, it was revealed that urban carrying capacity of the study area was determined mainly by roads, water supply, green areas, sewage treatment, and energy factors. The sustainable development density for the entire study area as revealed by the primary determining factor of roads, was estimated as 15,571,770□ of the floor area (89% FAR) (Figure 16) which was approximately 56% of those of the Gangnam District in 2000. It was also found that determining factors that could sustain current development density (152% FAR) were subway systems and waste treatment facilities.

In order to assess the carrying capacity of the case study area in further detail, the assessment result for each determining factor and existing density were superimposed. Figure 17 shows areas (*dong*s) where current development density exceeds the carrying capacities for the seven determining factors.



Carrying capacity for each determining factor

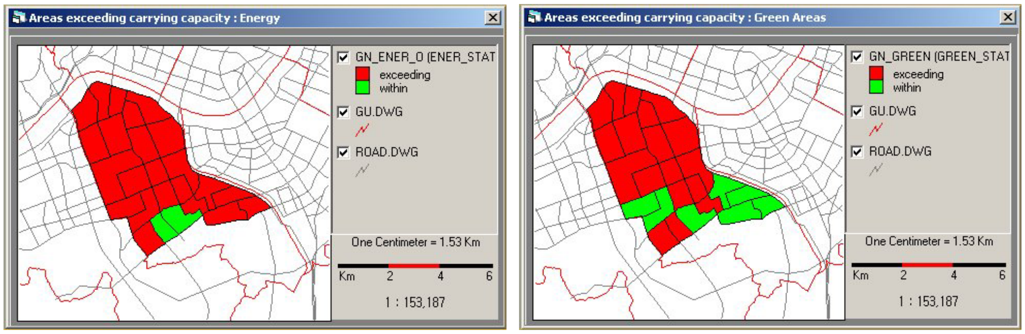
ID	Determining Factor	Population	Floor Area	FAR
1	Energy	690013	17567	100
2	Green Areas	665700	16948	97
3	Roads	611659	15572	89
4	Subway Systems	1688958	42998	213
5	Water Supply	626753	15956	91
6	Sewage Treatment	668160	17521	100
7	Waste Treatment	1158259	29487	169

Unit : Population(person), Floor Area(1,000m²), FAR(%)

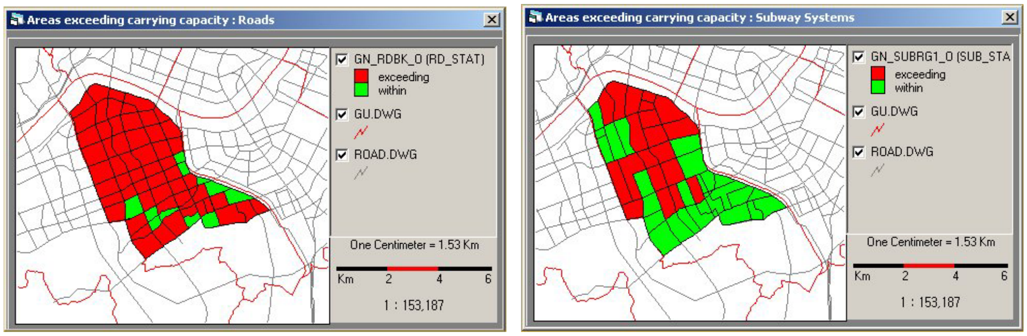
Figure 16. Evaluation results of determining factors

Finally, the intensity of carrying capacity exceeded can be analyzed by overlaying the results from the assessment for areas exceeding carrying capacity (Figure 18). In general, the carrying capacity in the northwestern part of the study area where commercial and business developments were mostly concentrated was exceeded in almost every aspect—i.e. six or seven out of seven determining factors. Areas where carrying capacity was exceeded in all factors were Shinsa-dong, Apgujeong-dong, Yeoksam-dong, and Daechi-dong where FAR was over 170%.

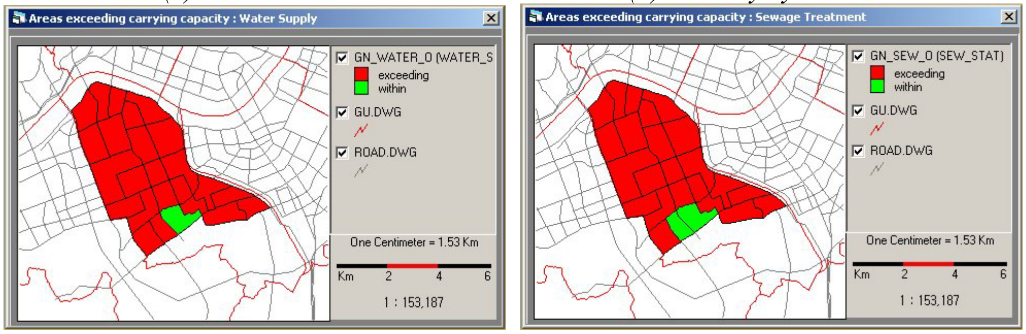
On the other hand, the southeastern part of the study area which is mainly comprised of residential areas showed less excess in carrying capacity. In particular, Gaepo-dong, in the southern part was determined to be the most sound, as the development density of the area was found to be within its carrying capacity in all factors. It was however, revealed that the energy consumption and operational loads in roads, water supply, and sewage treatment still needed to be reduced. Specific strategies for managing the area can further be developed from these results.



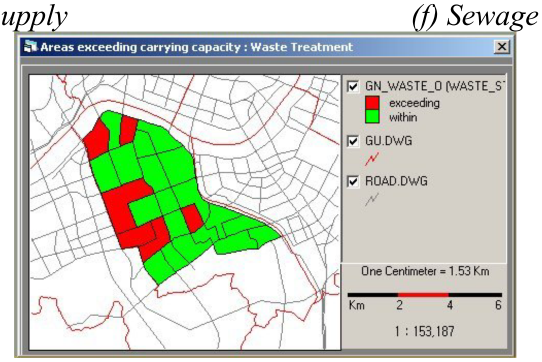
(a) Energy *(b) Green areas*



(c) Roads *(d) Subway systems*



(e) Water supply *(f) Sewage treatment*



(g) Waste treatment

Figure 17. Areas exceeding carrying capacity

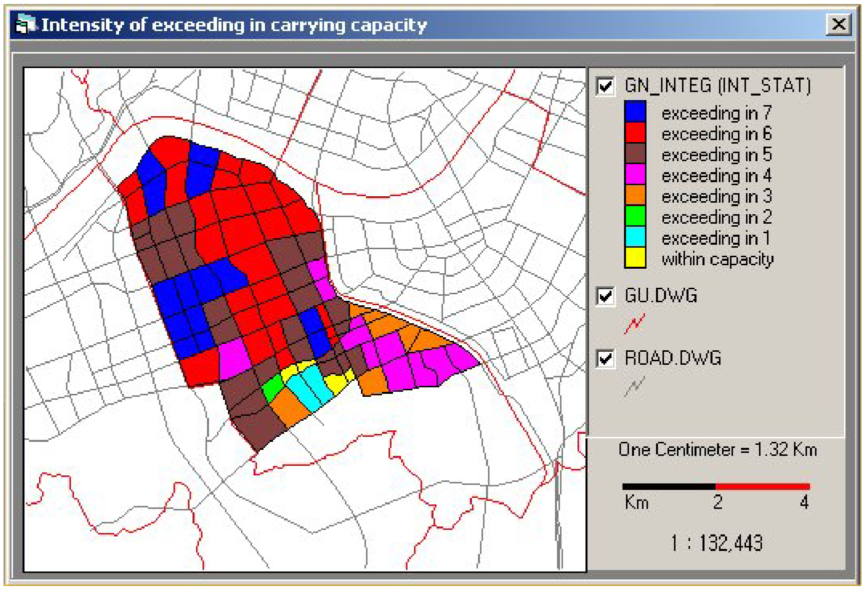


Figure 18. Intensity of carrying capacity exceeded

5. Conclusion

If developments already exceed carrying capacity of an area, strategies for improving its capacity such as developing or adopting better technologies for environmental treatment and pollution prevention/control in conjunction with supplying additional public facilities should be considered. On the other hand, if the area is not yet overly developed and more facilities cannot be provided in the near future, it is vital to prepare ways to control possible future developments. Decision support with a GIS-based carrying capacity assessment system demonstrated in this research can play a pivotal role in planning and managing urban developments more effectively.

Such an approach is meaningful because it is integrated and proactive. Specifically, it is useful because it can identify which factor(s) is most influential for determining the carrying capacity of an area. Also, problematic area(s) can be delineated and the nature of such problems can be analyzed through a systematic and transparent process. Moreover, a specific development density level, which is critical for maintaining sustainability of the urban environment, can be suggested.

Further research should be conducted to assess not only with the dimensions of carrying capacity employed in this research, but also with other dimensions related to public perception and institutions. The use of data with finer unit of analysis should yield more accurate assessment results. Sensitivity analyses can also be conducted for future scenarios with different levels of environmental standards and targeting service levels to establish more effective urban management strategies.

Acknowledgements

This work was supported by grant No.(R01-2001-000-00459-0) from the Basic Research Program of the Korea Science & Engineering Foundation.

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