Integration of Climate Information into Spatial Planning in Seoul, South Korea

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Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig verfasst und nur unter Verwendung der in der Dissertation angegebenen Hilfsmittel und Quellen angefertigt habe.

Berlin, den 5. März 2008

Jeong-Hee Eum

Meinen Eltern gewidmet

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ABSTRACT

In recent years, demands on urban climate information for various planning purposes have increased in South Korea. However, spatial and environmental planners are still not in possession of comprehensive and spatially distributed information covering large areas. This dissertation explores ways to integrate urban climate information in spatial planning of Seoul by focusing on the following main research questions: how to generate comprehensive and spatially distributed information on urban climate for planning usages in Seoul, and how to apply this information to spatial planning.

In order to examine these questions, an already existing methodology is applied to Seoul, which was developed for generating maps of climate analysis/evaluation and planning recommendations in European cities. The application of this methodology to Seoul is called CAMPUS (Climate Analysis Maps for Planning Usage in Seoul) in this study.

By performing CAMPUS, spatially distributed and qualitatively evaluated information on climate and air quality is generated: function-related Areal Types, wind and temperature fields simulated by a mesoscale meteorological model 'MetPhoMod', and simulations of local atmospheric/thermal loads. In addition, spatial information on the ventilation situation, such as local cold air production, transport, and stagnation, local surface influence, local wind exposition, and mesoscale wind circumstances, is also generated. Based on this climate analysis and evaluation information, spatial information on planning recommendations is further produced for the three targets 'ventilation, air quality and thermal situation'. Finally, this information provided by CAMPUS is applied to suggest what new planning strategies can be recommended in relation to climate and air quality situations at the three levels of spatial planning in Seoul: the comprehensive urban plan (regional level), the urban master plan (urban level), and the urban management plan (district level).

This study comes to the following conclusions:

- It is important to generate land cover classes ('pixel classes' in this study) suitable for Seoul and to estimate their structural and ground parameters. They permit a more exact representation of the urban structure and surface characteristics of Seoul.
- The existing biotope dataset is useful as supplementary data to generate pixel classes and to estimate parameters. The Digital Elevation Model with high

resolution in flat areas is needed to reduce misrepresentations of ground surface in flat areas.

- The modification of evaluation formulas for establishing maps with planning recommendations enhances spatial differentiation in maps representing the densely built-up area of Seoul.
- The potential to integrate information generated by CAMPUS varies according to the level of planning. The information is most suitable for the two levels of the comprehensive urban plan and the urban master plan. For the urban management plan, the information can offer only general overviews of the climate situation. More detailed climate analysis and measurements will enhance the usefulness of the information at the district level of spatial planning.

ZUSAMMENFASSUNG

Integration klimatischer Informationen in die räumliche Planung in Seoul, Südkorea

In der dicht bebauten Stadt Seoul mit ihren typischen klimatischen Problemen einer Megacity sind Klima und Lufthygiene heutzutage von großer Bedeutung für ihre Bewohner. Die bisher getroffenen Maßnahmen, z.B. Nutzungsbeschränkungen für den Verkehr, reichen nicht aus, die Belüftungsprobleme zu lösen, die aus der Landnutzungssituation (dichte Bebauung) und den ungünstigen topographischen Verhältnissen resultieren. Der planerischen Steuerung der Raumentwicklung kommt in Seoul also eine besondere Bedeutung für die Unterstützung einer für den Menschen günstigen Klimasituation zu.

Das allgemeine Ziel der vorliegenden Arbeit besteht darin, klimatische und lufthygienische Information in die räumliche Planung Seouls zu integrieren, mit den folgenden Hauptforschungsfragen: wie die räumlich differenzierte und zur räumlichen Planung verwendbare Information der relevanten klimatischen und lufthygienischen Sachverhalte in Seoul erstellt werden, und wie die Information in die räumliche Planungen umgesetzt wird.

Um die benötige flächendeckende Information zu Seoul bereit zu stellen, wird das „Regelbasierte Klimaanalyse- und Bewertungsmodell“ auf Seoul angewandt. Die Anwendung des Modells auf Seoul, das ursprünglich für mitteleuropäische Städte entwickelt wurde, wird als CAMPUS (Climate Analysis Maps for Planning Usage in Seoul) bezeichnet.

Die Ergebnisse von CAMPUS liegen als räumlich und zeitlich homogene, flächendeckende Informationen vor. Bezüglich der Klimaanalyse und -bewertung liegen die folgende Informationen vor: Arealtypen, mesoskalige Wind- und Temperaturfeldmodellierung, lokale Luft- und Wärmebelastungsrisiken und Durchlüftungssituationen (darunter lokale Kaltluftproduktion, -stau und -transport, lokaler Oberflächeneinfluss und lokale Windexposition, mesoskalige Windverhältnisse). Auf diesen räumlich differenzierten Grundlagen werden drei weitere flächendeckende Datensätze erstellt, die jeweils Planungsziele und -maßnahmen beinhalten: Durchlüftung, Lufthygiene und thermische Situation. Anschließend wird überprüft, wie die mit CAMPUS erstellten Informationen auf den drei Planungsebenen (Regionalebene, Stadtebene und Stadtteilebene) von Seoul umgesetzt werden können.

Im Ergebnis der Arbeit zeigt sich die folgendes:

- Es ist wichtig, für Seoul passende Landbedeckungsklassen (Pixelklassen in dieser Arbeit) zu erstellen, und ihre Strukturparameter und Parameter zu den Oberflächeneigenschaften zu berechnen. Sie erlauben eine genauere Wiedergabe der städtischen Struktur und der Oberflächeneigenschaften von Seoul.
- Der bestehende Biotop-Datensatz bietet zusätzliche Informationen für Pixelklassen zu generieren und ihre Parameter zu berechnen. Das digitale Höhenmodell mit hoher Auflösung in flachen Gebieten wird benötigt, um Fehldarstellungen der Oberfläche in flachen Gebieten zu reduzieren.
- Die Modifizierung der Bewertungsformeln zur Herstellung von Planungshinweiskarten verbessert die räumliche Differenzierung in Karten, die dicht bebaute Gebiete von Seoul wiedergeben.
- Das Integrationspotential der Informationen, die von CAMPUS erstellt wurde, variiert je nach Planungsebene. Die erstellen Klima- und Lufthygieneinformationen eignen sich am besten für die regionale und gesamtstädtische Ebene. Auf der Stadtteilebene geben die Ergebnisse nur einen allgemeinen Überblick zur klimatischen und lufthygienischen Situation. Zur Verstärkung der Anwendbarkeit auf die Stadtteilebene bedarf es weiterer Ansätze inkl. detaillierte Klimaanalyse und Klimamessungen.

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AWS	Automatic Weather Station
BauGB	Baugesetzbuch (German Federal Building Code)
BNatSchG	Bundesnaturschutzgesetz (German Federal Nature Conservation Act)
CACA	Clean Air Conservation Act
CAMPUS	Climate Analysis Maps for Planning Usage in Seoul
CAMPAS-CH	Climate Analysis Maps for Planning Aspects of Solothurn/CH
CCNL	Act on Comprehensive plans for Construction in the National Land
CNG	Compressed Natural Gas
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DWM	Diagnostic Wind Model
FAEP	Framework Act on Environmental Policy
FANL	Framework Act on the National Land
FITNAH	Flow over Irregular Terrain with Natural and Anthropogenic Heat Sources
GCP	Ground Control Point
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
KABA	Klimaanalyse der Region Basel
KAMM	Karlsruhe Atmospheric Mesoscale Model
Landsat-7 ETM+	Landsat-7 Enhanced Thematic Mapper Plus
MetPhoMod	Meteorology and Photochemistry Model
MDC	Mahalanobis-Distance Classifier
MLC	Maximum-Likelihood Classifier
MM5	Penn State/NCAR Mesoscale Meteorological Model
MOA	Memorandum of Agreement

MOCT	Ministry of Construction and Transportation
MUKLIMO	Mikroskaliges Urbanes Klima-Modell
NASA	National Aeronautics and Space Administration
NECA	Natural Environment Conservation Act
NLPU	National Land Planning and Utilization Act
PVC	Polyvinyl Chloride
RDZ	Restricted Development Zone
REKLISO	Regionale Klimaanalyse Südlicher Oberrhein (Regional Climate Analysis Southern Upper-Rhine)
SRTM	Shuttle Radar Topography Mission
TIN	Triangulated Irregular Network
TM	Transverse Mercator
UHI	Urban Heat Island
UMNL	Act on the Utilization and Management of the National Land
UPA	Urban Planning Act
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
WRS	Worldwide Reference System

Abbreviations used for CAMPUS

AP	Air pollution risks
AT	Areal Type
CP	Local cold air production
CS	Local cold air stagnation
CT	Local cold air transport
HD	High density areas (pixel class as well as areal type)
HS	Heat stress risks
LD	Low density areas (pixel class as well as areal type)

MD	Medium density areas (pixel class as well as areal type)
ME	Mesoscale wind conditions
PC	Pixel Class
SI	Local surface influence
SwoB	Sealed areas without buildings (pixel class as well as areal type)
SwVB	Sealed areas with variable buildings (pixel class as well as areal type)
TR	Trees (pixel class as well as areal type)
unS	Unsealed areas (pixel class as well as areal type)
WA	Water surfaces (pixel class as well as areal type)
WE	Local wind exposition

1 Introduction

1.1 Climate information and spatial planning

For many years, changes in climate have been observed all over the world. According to the climate change reports of IPCC (Intergovernmental Panel on Climate Change) in 2007, over the next century the climate will change more quickly that it ever has in the recent history of the earth.

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the earth's climate system (U.S. Environmental Protection Agency 2002). These changes in climate result in temperature rise, precipitation change, sea-level rise, droughts and floods. Besides, they also impact on human and natural systems, for example, human health, ecosystem, biodiversity and water resources.

And vice versa, there are effects of human activities leading to emission of greenhouse gases and thus causing climate change. These activities create a significant increase in the average surface temperature of the planet. In analogy to this warming on a global scale, urban warming is occurring on an urban scale and is known as Urban Heat Islands (UHIs).

Urbanized regions physically alter their climate in the form of elevated temperatures, decreased wind speed and reduced air exchange in comparison to rural areas at their peripheries (Landsberg 1981). These climatic characteristics in urban areas influence other urban environmental factors. Increased temperature affects changes in distribution and physiological changes in tree and shrub species (Sukopp & Wurzel 2003). Decreased wind speed may facilitate the accumulation of air pollutants emitted from human activities like vehicles.

Many studies have provided the scientific basis to understand the causes of these special climate characteristics in urban areas: Many studies show that land use patterns have influence on the urban climate pattern (Horbert 2000; Marquez & Smith 1999; Romero et al. 1999; Svensson 2002). The U.S. National Aeronautics and Space Administration (NASA) sought to derive a better scientific understanding of how land use changes associated with urbanization have affected and continue to affect local and regional climate, surface energy flux, and air quality characteristics (Project ATLANTA; Quattrochi et al. 1998). Stone & Rodgers (2001) studied residential development patterns and urban heat island formation in the Atlanta, Georgia

Metropolitan region. Other studies show the effects of component parts for urban design, such as street geometry (Eliasson 1996), pavement (Pomerantz et al. 1997) and roof materials (Akbari et al. 2000).

Many policies and strategies have been discussed to improve urban climatic conditions. Rosenfeld et al. (1996) and Emmanuel (1997) proposed policies on the reduction of heat islands and strategies on land use control to mitigate the disadvantageous effects of urban heat islands during the summer, respectively. Other strategies are to cool cities e.g. by planting trees or switching dark surfaces of roofs and pavements to light reflective surfaces (Konopacki et al. 1997; Akbari et al. 1999; Akbari et al. 2001).

In recent years, urban climatologists have tried to improve environmental conditions by inducing urban planners to integrate climatic aspects (Matzarakis et al. 1998). For instance, climate and air quality were dealt with as planning factors (Barlag & Kuttler 1991; Reuter et al. 1991; Schirmer et al. 1993; Mayer et al. 1994; Barlag 1999). In particular, climatic conditions were analyzed for various kinds of planning purposes, e.g. landscape planning (Mosimann et al. 1999; Horbert 2000) and environmental impact assessment (Trenkle 1998). In addition, guidelines are provided to enable climate experts and regional and urban planners to consider climate issues like cold air and human bio-meteorological topics in spatial and environmental planning (Verein Deutscher Ingenieure 1998, 2003 and 2004).

Based on the above-mentioned research by urban climatologists, two types of maps related to urban climate have commonly been used for the purpose of urban planning in Europe, particularly in German-speaking countries: the so-called 'synthetic climate function maps' containing analyzed and evaluated climate information, and the 'maps with planning recommendations' (Verein Deutscher Ingenieure 1997). The cities or regions that have established such maps for planning purposes are Stuttgart (Nachbarschaftsverband Stuttgart 1992), Ruhr District (Kommunalverband Ruhrgebiet 1992), Berlin (Senate Department for Urban Development 1993 and 2004), Aachen (Havlik & Ketzler 2000), the Southern Upper Rhine Region (Parlow et al. 2006) in Germany, the city of Basel (Beha et al. 1996) and the Canton Solothurn (Scherer et al. 2000) in Switzerland, and the city of Graz (Lazar et al. 1994) in Austria. These maps present the spatial distribution of climate and air quality information. Hence, they acquire great significance for the purpose of environmental protection and improvement as well as in the area of nature protection and landscape conservation (Verein Deutscher Ingenieure 1997). Guidelines are provided to generate these two kinds of maps (see Verein Deutscher Ingenieure 1997), and improved methods for analyzing and evaluating urban climate have been introduced (e.g. Scherer et al. 1999; Fehrenbach et al. 2001).

In recent years, Japanese cities have begun to analyze urban climate for planning purposes and to establish spatially distributed information with planning recommendations like in the city of Osaka (Tanaka & Moriyama 2004), Tokyo (Ashie et al 1998), and Sendai (Watanabe & Jyunimura 2003).

1.2 Urban climate and spatial planning in Korea

The issue of urban climate is also of great importance in the Republic of Korea. In particular, Seoul that has achieved a rapid growth as the capital city of South Korea has suffered from disadvantageous climate conditions like urban heat islands and air pollution problems. In Korea, environmental planning is not oriented towards spatial planning but strongly focuses on comprehensive strategic planning that includes all important policy sectors in Korea (International Institute for Sustainable Development 2004). Thus, strategies have been introduced to improve unfavorable climate situations in large cities with serious air pollution and thermal problems, for example promoting the use of CNG (Compressed Natural Gas) fueled buses to reduce traffic emissions in Seoul (Jeon 2007) and planting trees to cool the city of Daegu (Kim et al. 2000).

Biotope maps have been produced for Korean cities since 2000, which have increased the interest in considering environmental issues in spatial planning. By now, biotope (fauna and flora) considerations have generally been integrated into planning processes, such as reviews on environmental aspects in urban management planning (see the guidelines of this review system for Seoul Metropolitan City in Kim & Jeong 2006).

However, there are no climate maps yet, as the environmental issue ‘climate’ has not been integrated into spatial and environmental planning in Korea until now. The reasons are as follows (Eum & Köppel 2007; Park et al. 2004):

- Comprehensive and spatially distributed information on urban climate is still not available.
- The methods of analysis for planning-related climate issues have not yet been developed.

- The evaluation criteria on climate are not available for the purpose of spatial and environmental planning.

There have been research activities in Korea which focus on urban climate issues for planning purposes. Some studies have discussed residential types or layouts of residential buildings in relation with climate conditions. Hwang & Kim (2003) compared Urban Heat Island (UHI) phenomena of three different residential types in Jeonju city to show which residential types are beneficial to mitigating UHI effects. Kwon & Lee (2004) discussed suitable layouts of high-rise residential buildings (i.e. apartment buildings) that contribute to minimizing the barriers to fresh air flow from the hillside. In addition, Cho & Lee (2004) compared the wind velocity ratio for different directional layouts of high-rise residential buildings. Cho & Lee (2006) further analyzed the characteristics of wind movement and air flow according to the blockage ratio and the building coverage ratio of apartment blocks.

More detailed analysis on urban ventilation has relied on empirical-statistical and numerical-mathematical models for planning purposes. Eum (2000) and Eum et al. (2001) studied open space planning that integrates urban ventilation paths to improve urban atmospheric conditions. She analyzed three-dimensional wind fields in Yongin city using the DWM (Diagnostic Wind Model). Based on the model results, she examined both present and future open space planning and proposed alternative plans. Kim & Kim (2001) analyzed the effects of high-rise residential buildings of Seoul city on urban micro climate by using the three-dimensional microclimate model ENVI-met in their second research project on an experimental study about climate as a factor in urban design. Hwang & Song (2003) presented strategies on urban ventilation planning (in other words, air corridor planning), based on simulation by the three-dimensional prognostic model MUKLIMO 3 (Microscale Urban Climate Model) in a new town development area of Pangyo city.

Some studies have evaluated climate conditions to generate spatially distributed information about cold air. Kim & Jung (2005) evaluated cold air functions in Daegu city according to the qualitative grading system and criteria proposed by Marks et al. (1992). They applied three of the six classification and evaluation criteria: ratio of agricultural areas and grasslands, mean gradient, and roughness of valley bottom. Such a qualitative evaluation and grading method enables a simple estimation on urban climatic phenomena by empirical and climate-related information linked to certain land use and topographical information (von Haaren 2004).

Regarding the generation of spatially distributed information on urban climate, Song (2002) defined 'climatopes[1]' and conducted mapping of urban climate for a district in Seoul. In this study, he classified nine types of climatopes on the basis of biotope maps and land use types of Seoul. Finally, he presented an urban climate map of a district, which contains classified climatopes, air flow corridors and isothermal lines.

A review of research activities concerning climate information and planning reveals that general climate analysis is being undertaken, but this analysis does not contain the evaluation criteria needed for planning proceedings. Hence, the established information on climate is not appropriate for planners. The methods that have so far been used for generating ventilation maps or urban climate maps are so simple that various kinds of climate conditions cannot be represented. In addition, maps with planning recommendations have not yet been established, which are useful tools for planners. Hence, spatial and environmental planners in Korea are still not in possession of comprehensive and spatially distributed information covering large areas.

1.3 Research objective and Questions

The fundamental aim of this study is to show a way to integrate urban climate information in spatial planning of Seoul in order to improve urban climate conditions. In order to accomplish this aim, the study focuses on answering the following main research questions:

- *how to generate comprehensive and spatially distributed information on urban climate for planning usages in Seoul; and*
- *how to apply this information to spatial planning in Seoul.*

These two research questions are being pursued by focusing on the following four aspects:

- What type of datasets should be newly established for Seoul, and which methods should be used to establish them?
- To what extent are the existing datasets useful as input data for climate analysis to be applied in spatial planning in Seoul?

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[1] Climatopes describe geographic areas with similar microclimatic characteristics (Ministry of the Interior Baden-Württemberg 2004).

- In evaluating results from climate analysis for Seoul, how should the present criteria and formulas be modified?

The first three aspects are concerned with finding a suitable method to provide spatially distributed information for planning usages in Seoul. For this, an already existing methodology is applied to Seoul, which is being used for generating maps of climate analysis/evaluation and planning recommendations in Europe.

- Is the information provided by the methodology applicable to the three levels of spatial planning in Seoul like the urban comprehensive plan, urban master plan, and urban management plan?

The answer to the fourth aspect is explored on the basis of the information generated from the applied methodology. After understanding the current spatial plans of Seoul, it is suggested what new planning strategies can be recommended in relation to climate and air quality situations. This is conducted at every level (regional, urban, district) of spatial plans in Seoul.

1.4 Dissertation structure

This study is divided into six chapters, as illustrated in Figure 1.1. The first chapter provides the introduction to the topic, beginning with an analysis of the literature of various studies concerned with urban climate and land use. It goes on to present an overview of international research activity concerning climate and air quality in spatial planning. The next section of the chapter discusses how the issues ‘climate and air quality’ have been dealt with in Korea, and what kind of research has been conducted. After this, the objective of the new contribution and the corresponding research questions are defined.

Chapter 2 focuses on the description of the climate situation in Korea generally, as well as Seoul on which this study is centered. Due to the influence of large-scale atmospheric conditions on local climate, the chapter begins with general climatic conditions of the Korean Peninsula. Subsequently, the climatic characteristics of Seoul are analyzed in detail according to three topics related to spatial planning: ventilation, air quality and thermal situation. This gives an overview on how the climatic characteristics at local and regional scales are modified by climate factors like topographic conditions or human activities. At the end of this chapter a framework is presented for generating spatially distributed climate information for planning usages in Seoul, both climate analysis/evaluation maps and maps for planning recommendations.

The third chapter covers the preprocessing of satellite imagery to generate the land cover dataset required for further performances. Then the existing dataset is compared with the generated land cover dataset to determine the usefulness and the limitations of the existing dataset in climate analysis/evaluation for planning purposes. This is followed by two postprocessing tasks: computation of fractional coverage and estimation of structural parameters for the urban structure of Seoul. At the end of this chapter, the topography dataset is analyzed in order to simulate local ventilation conditions, which are the topic of the next chapter. This chapter elaborates on the answers to the first two aspects of research, namely how to establish new datasets for Seoul and based on what methodology, and if/how to integrate existing data sets.

Chapter 4 provides the spatially distributed information for climate analysis/evaluation maps and maps for planning recommendations (based on the data generated in Chapter 3). This is done in three sub-chapters: It begins with the generation of the function-related land use dataset, followed by the performing of a mesoscale meteorological model. The purpose of this is to simulate wind and temperature fields of the study area and its surroundings. Then the environmental loads for atmospheric and thermal pollution are analyzed. In a next step, various types of ventilation situations are analyzed and evaluated. The results are used in the final process, the numerical evaluations that generate maps for planning recommendations. These latter maps concern the three topics handled in Chapter 2, ventilation, air quality and thermal situation. Chapter 4 includes elaboration of the answers to the second (partly) and third research aspects.

Chapter 5 applies climate information to spatial planning, based on the spatially distributed information generated in Chapter 4. This application is conducted at the three levels of spatial plans in Seoul, regional, urban and district level. The comprehensive plan, which concerns the long-term framework for future development of Seoul and its neighboring cities, is first analyzed. This is followed by examining the urban master plan, which describes the overall concept for Seoul and coordinates land use at the city level. Subsequently, the urban management plan is examined, which regulates construction and the general shape of the urban physical development at the urban district level. This chapter elaborates on the answers to the fourth research aspects.

This study is concluded in Chapter 6. This final part of this dissertation includes a discussion of the findings from this study. This is done by offering answers to the four research aspects at the beginning of the study. Finally, further research needs in this area of study are discussed.

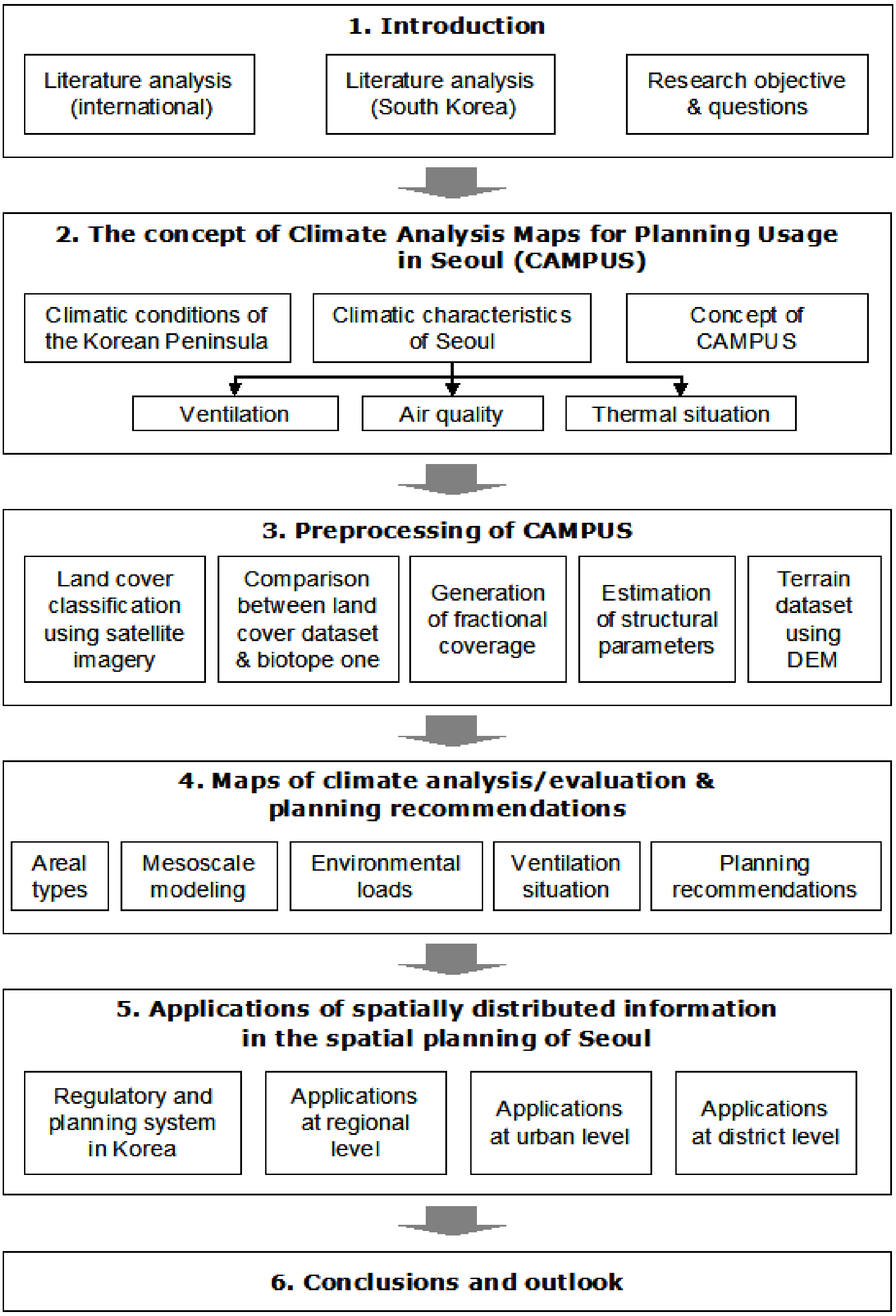


Figure 1.1 Structure of the dissertation

2 The Concept of Climate Analysis Maps for Planning Usage in Seoul (CAMPUS)

2.1 The climate situation in the Republic of Korea

Climate is studied at three ranges of altitude: the microscale of up to 2 km, the mesoscale which reaches up to 2000 km of altitude, and the synoptic scale beyond 2000 km (Orlanski 1975). Generally, the climate in a region is influenced by global atmospheric conditions as well as conditions covered by the micro- and mesoscale. In the Northern hemisphere, where the Korean Peninsula is located, the tropical air masses moving towards the poles and the polar air masses moving towards the equator are colliding in the medium latitude. Therefore, continents in this latitude can be influenced by tropical air masses during summer and by polar and arctic masses moving to the South in winter. Besides large seasonal changes in temperature, the daily variations can also be significant.

The Korean Peninsula, situated in the Northeast of the Asian continent, falls within the temperate climate zone and has four distinct seasons. In winter, the climate is bitterly cold and dry, due to the high atmospheric pressure developed over the continental landmass. During the summer, air masses moving in from the Pacific Ocean cause hot and humid weather. The transitional seasons of spring and fall are characterized by mostly clear and dry days.

Except for the mountainous central parts of the peninsula, the yearly mean temperatures over 30 years (1971-2000) across South Korea range from 10 to 16 degrees Celsius (℃) (Korea Meteorological Administration 2001). The hottest month is August, with temperatures between 23 and 27℃. In January, the coldest month, temperatures range from -6 to 7℃. The temperatures during May and October, the core months of the spring and fall seasons, are in the range between 16 to 19℃ and 11 to 19℃ respectively.

At the center of the Korean Peninsula, where the Seoul Metropolitan region is located, annual precipitation ranges between 1100 and 1400mm. In the Southern region of the peninsula, annual precipitation amounts to between 1000 and 1800mm. About 50 to 60 percent of the annual rainfall occurs during the summer months, nearly half of it during the monsoon (heavy rain) season, which usually comprises the whole month of June. Relative humidity remains high throughout July and August, reaching about 80 percent.

Typhoons are formed over the Northwestern Pacific Ocean. The Korean Peninsula is less vulnerable to them than neighboring countries like Japan and the East coast of China. Yet on average, two or three typhoons annually affect South Korea, either directly or indirectly. They usually pass over the peninsula in late summer, bringing heavy rains.

2.2 The climate in the Seoul Metropolitan area

The climate of a region is modified by climate factors like topographic conditions and land use. Seoul is encircled by inner and outer mountains ranging from 111m to 836m above sea level (a.s.l.). In addition, an overall population of more than ten million has made Seoul a densely built-up area, which covers approximately 605 square kilometers. In the following section the climatic characteristics of Seoul are explained, divided into three parts: ventilation, air quality, and thermal situation.

2.2.1 Ventilation

Ventilation refers to an air exchange process that transports fresh and cold air into settlements. Ventilation is of central importance to the urban climate because it exerts major influence on air quality and thermal situation (Fehrenbach 1999).

Advantageous ventilation is usually associated with higher wind speeds. However, topographical conditions and land use characteristics deeply affect the ventilation situation. As mentioned above, Seoul has unfavorable topographical conditions for ventilation. In addition, the high building-to-land ratio (ratio of the area covered by buildings to the area of the plot) and the high floor area ratio (ratio of the total building square footage to the area of the plot) result in high aerodynamic surface roughness in Seoul.

Consequently, the mountainous topography and the intensive land use in Seoul cause a weak wind speed. The annual mean wind speed in Seoul from 1971 to 2000 was 2.4m/s, which was measured in a weather station at 85.5m a.s.l. (Korea Meteorological Administration 2001).

The low wind speed induces disadvantageous ventilation conditions in Seoul. Further, it facilitates the development of temperature inversions which in turn reduce the vertical air exchange (Ministry of the Interior Baden-Württemberg 2004).

During weather conditions with low wind speed, however, the mountainous relief of Seoul can create thermally induced local wind systems such as mountain and valley breezes. These wind systems can facilitate ventilation in the city and therefore improve unfavorable air quality as well as the thermal situation.

2.2.2 Air quality

Air quality is one of the most pressing environmental issues in cities, because dirty air endangers public health and can significantly harm ecosystems. Five central pollutants are commonly used to describe air quality conditions of Seoul: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM10, particles measuring 10 micrometers or less in diameter), and sulfur dioxide (SO_2). Table 2.1 shows emissions of these five air pollutants for the last 10 years from 1996 to 2005, together with various standards for them. Whereas sulfur dioxide and carbon monoxide have steadily and significantly decreased since 1996, there are year-to-year variations in the concentration of nitrogen dioxide, particulate matter and ozone.

Table 2.1 Emissions of the five critical pollutants in Seoul (1996-2005)

	SO_2	PM10	O_3	NO_2	CO
National environmental standard (2005)	0.02ppm/y	70μg/m^3*y	0.06ppm/8h	0.05ppm/y	9ppm/8h
Seoul environmental standard (2005)	0.01ppm/y	60μg/m^3*y	0.06ppm/8h	0.04ppm/y	9ppm/8h
WHO-recommended standard (2005)	0.019 ppm/y	50 μg/m^3*y	0.06 ppm/8h	0.021ppm/y	8.6ppm/8h
1996	0.013	72	0.015	0.033	1.2
1997	0.011	68	0.016	0.032	1.2
1998	0.008	59	0.017	0.030	1.1
1999	0.007	66	0.016	0.032	1.1
2000	0.006	65	0.017	0.035	1.0
2001	0.005	71	0.015	0.037	0.9
2002	0.005	76	0.014	0.036	0.7
2003	0.005	69	0.014	0.038	0.6
2004	0.005	61	0.014	0.037	0.6
2005	0.005	58	0.017	0.034	0.6

* Source: National Institute of Environmental Research (2006) & Seoul statistical yearbook (1997-2006)

Air pollutants come from a variety of emission sources. In 2005 transport was the main source with 76.1 percent of total emissions, followed by industry (15.2 percent), heating (8.2 percent) and energy industries (0.5 percent) (Seoul Metropolitan Government 2006A). Emissions from the transport sector are particularly significant, not only because they constitute the highest percentage of all emission sources but also because of the still increasing number of vehicles in Seoul. There were 2,168,182 registered vehicles in 1996, and the number has gradually increased since then (Figure 2.1). In 2005 the total number of vehicles registered in Seoul reached approximately 2.8 million, an increase of nearly 29.5 percent over the number recorded in 1996.

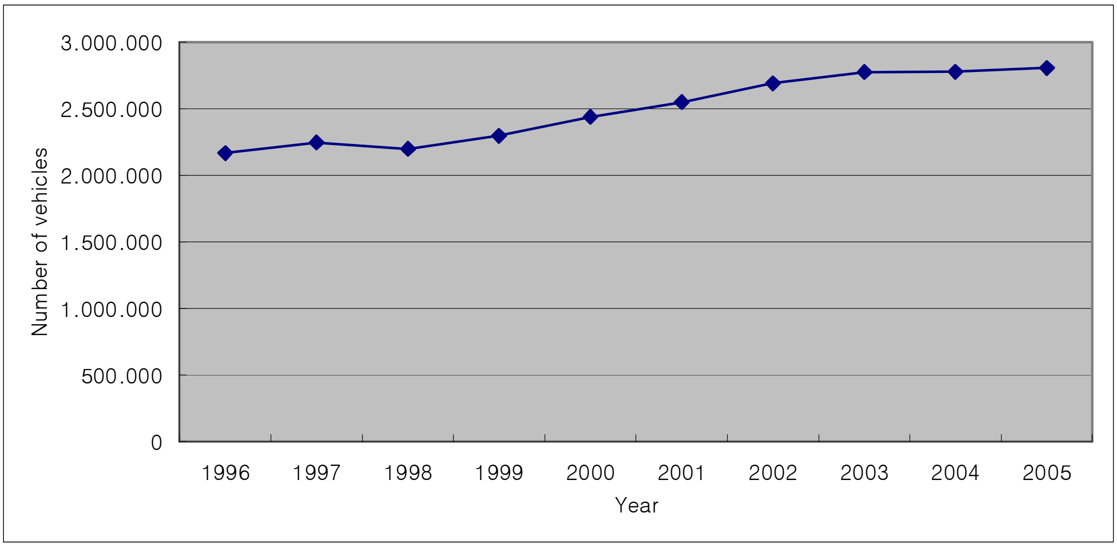


Figure 2.1 Total number of registered vehicles from 1996-2005 (Source: Seoul statistical yearbook 1997-2006)

In 2003, the main emissions caused by vehicles in Seoul were carbon monoxide, nitrogen oxide, and particle matter, accounting for 90.1 percent, 60.0 percent and 71.0 percent, respectively, of all emissions (Seoul Metropolitan Government 2006A).

Of the three emissions, nitrogen oxide is an especially big contributor to the excessive formation of ozone and other health-endangering oxidants during the summer heat periods (Senate Department for Urban Development 1996 and 1997). Therefore, the increasing motor vehicles are the primary emissions responsible for ozone formation.

In cities, the ozone level can rise to a point where it becomes hazardous to public health. Because of high temperatures, unfavorable wind conditions, and increasing emissions of nitrogen dioxide, the first ozone alert program was initiated in Seoul in 1995. In this program the alert is activated when the concentration of ozone reaches 0.12ppm/h. The fact that as much as 90 percent of the national ozone warnings occur in Seoul and the surrounding areas indicates the unfavorable air quality conditions in Seoul.

2.2.3 Thermal situation

The thermal environment is influenced by various factors. Among them, human activities are one of main sources of changes in the urban thermal environment. Urbanization causes changes in land surface, from natural ground cover into impervious materials like asphalt roads, concrete pavements and buildings. Such changes lead to changes in the energy partitioning of the surface net radiation between sensible heat and latent heat (Geiger et al. 1995). Consequently, they cause an unfavorable thermal environment due to increasing heat storage and decreasing surface evaporation in settlements and built-up areas.

The thermal environment in Seoul corresponds to the general characteristics of urban areas. Table 2.2 shows average values of temperature, relative humidity and wind speed from 1971-2000 and 1996-2005 for Seoul. The annual mean temperature in Seoul over 30 years is 12.2℃. In the same period the annual maximum mean temperature is 16.9℃ and the minimum mean temperature is 8.2℃. For the last ten years from 1996 to 2005, the temperature has increased, showing higher annual mean, maximum and minimum temperatures with 12.9℃, 17.3° C and 9.0℃, respectively, than those averaged over 30 years. In contrast, the relative humidity has decreased over the last 10 years. The relative humidity in Seoul, averaged from 1971 to 2000, is 66.9 percent, whereas for the last 10 years it is 63.4 percent. The wind speed over the last 10 years has decreased by 0.2m/s from that measured over 30 years.

Table 2.2 Average values of temperature, relative humidity and wind speed from 1971-2000 and 1996-2005 of Seoul

Average values	Temperature (°C)			Relative humidity (%)	Wind speed (m/s)
	Mean	Maximum	Minimum		
1971-2000	12.2	16.9	8.2	66.9	2.4
1996-2005	12.9	17.3	9.0	63.4	2.2

* Source: Korea Meteorological Administration (2001) & Seoul statistical yearbook (1997-2006)

Some studies show that urbanization in Seoul since the 1970s contributes to rapidly increasing temperature and consequently causes intense urban heat islands (UHIs; here, canopy layer heat island) in Seoul (e.g. Chung et al. 2004; Kim & Baik 2002 and 2004). Compared to other large cities of Korea, Seoul has the strongest daily maximum UHI intensity with 3.34℃ over the 29 year period from 1973-2001 (Kim & Baik 2004).

According to temperature data measured at 27 automatic weather stations (AWSs) at various altitudes ranging from 5m a.s.l. to 460m a.s.l. across Seoul, the urban heat island of Seoul deviated considerably from an idealized, concentric heat island structure, mainly because of the location of the main commercial and industrial sectors and the local topography (Kim & Baik 2005). A relatively warm region extends in the east-west direction where industrial and commercial areas with tall buildings and heavy traffic are prevailing, while a relatively cold region is observed in mountains and near the Seoul city limits, except near the southwestern and southeastern areas where the sprawling expansion of urbanization has already occurred (Kim 2005).

Vegetation can be used to mitigate some of the anthropogenic effects generated by the development of urban areas (Avissar 1996). Kim et al. (2001) confirmed that green spaces play an important role for mitigating urban heat islands. Strictly speaking, Seoul has a high percentage of green and open space areas, about 42 percent of the entire area. However, approximately 75 percent of these green areas of Seoul are located on the outskirts (Seoul Development Institute 2000). Hence, settlements have a low ratio of green spaces, which means a high ratio of impervious surfaces in built-up areas.

With mitigating urban heat island (UHI) effects, Kim & Baik (2002) suggest that the critical wind speed, above which the UHI is not noticeable, is 6.9m/s in Seoul if a daily maximum UHI intensity of less than 0.3℃ is considered as the near-absence of UHIs. According to this suggestion, the wind situation of Seoul, with a mean value of 2.4m/s over 30 years (1971-2000), is not sufficient for mitigating the urban heat islands in Seoul.

2.3 The concept of CAMPUS

In order to integrate the three topics ‘ventilation, air quality and thermal situation’ into urban land use planning, we need spatially distributed and qualitatively evaluated information on these topics. CAMPUS (Climate Analysis Maps for Planning Usage in Seoul) is a framework of climate analysis and evaluation, which generates analyzed and evaluated climate information for planning purposes. In the next sections, the concept of CAMPUS is described.

2.3.1 Land use and land cover as input data to CAMPUS

Land use and land cover are often used synonymously, but they have different meanings. ‘Land use’ describes human activity on the surface, for example, recreation, settlement or agriculture. In contrast, 'land cover' refers to the surface cover of the ground, e.g. vegetation, bodies of water or bare soil.

Atmospheric and climatic processes are mostly related to land surface, e.g. the exchange of water vapor and sensible heat between the land surface and the atmosphere, and the radiation balance of the land surface (Climate Change Science Program 2003). Therefore, the classification of land cover is an important work for climate analysis and modeling. By land use classification, such atmospheric processes might not be represented; although a football field is a kind of sport area in the meaning of land use, it has a different effect on climatic processes than another kind of sport area like a swimming pool.

Land cover information can be derived from remote sensing data by analyzing the spectral signatures. Remotely sensed data have been widely used in the research fields of environmental planning because they offer the possibility of a fast and area-wide assessment of urban changes and developments. Furthermore, land surface information for inaccessible areas, which cannot be gathered on the ground, can be collected in a cost-effective manner by remotely sensed images. And besides, land surface information can be easily updated by this dataset.

2.3.2 Concept and process of CAMPUS

The conceptual framework for generating spatially distributed and qualitatively evaluated information on the three topics mentioned above is a set of rule-based climate analysis and evaluation tools. The results, including spatial information on planning recommendations, are generated by the use of numeric analysis and evaluation models without manual intervention. This automated procedure guarantees the reproducibility of consistent non-biased results. Another important part of the concept is the exclusive usage of spatially distributed information. Hence, land cover information derived from satellite imagery and terrain information derived from the digital elevation model (DEM) are used as main input data. These tools were developed and applied for central European regions: the city of Basel (KABA; Beha et al. 1996, Fehrenbach 1999, Fehrenbach et al. 2001, Parlow et al. 2001, Scherer et al. 1996 and 1999), the Canton Solothurn (CAMPAS-CH; Scherer et al. 2000) in Switzerland and the Southern Upper Rhine Region in Germany (REKLISO; Parlow et al. 2006).

Based on the above-mentioned climate analysis and evaluation tools from Europe, an application is conducted for Seoul by altering and adapting these tools, which are called the CAMPUS framework. Spatial classification of land cover information, which is one of the main stages of the whole process, is gained from satellite imagery to establish ‘Pixel Classes (PCs)’ that are introduced as land cover classes. The already existing biotope maps of Seoul represent another source of spatial information, which are based on the Geographic Information System (GIS). The biotope dataset is, therefore, compared with satellite-derived land cover classification and discussed as the dataset supplementary to satellite-derived pixel classes (Chapter 3).

Fractional coverage data from pixel classes and the digital terrain model (DTM) derived from DEM as well as attribute data of biotope maps are used for calculating structural parameters (Chapter 3). Structural parameters involve attribute data (e.g. terrain data or building height) as well as climatic and air quality information (e.g. line and area emission sources). The factional coverage data are also used for producing ‘Areal Types (ATs)’ which describe function-related land use types (Chapter 4.1). The structural parameters are the intermediate data for calculating environmental loads e.g. local atmospheric and thermal loads (Chapter 4.1), and spatially distributed ventilation situations (Chapter 4.2). Ventilation situations are extracted not only from the structural parameters, but also from the mesoscale meteorological model ‘MetPhoMod’ (Perego 1999) which calculates wind and temperature fields. Finally, spatially distributed and qualitatively evaluated information on ventilation, air quality and the thermal situation are combined with areal types, environmental loads and ventilation situations (Chapter 4.3). They are subsequently used to produce spatial information on recommendations for spatial planning. Figure 2.2 shows the whole process of the CAMPUS framework.

All results of CAMPUS can be directly integrated into the GIS database because they are offered as raster format. In addition, they can be presented in maps on various scales. Individual sections may be interpreted on larger scales for regional planning, e.g. in a map scale of 1:50,000 corresponding to that of the general planning database in Seoul.

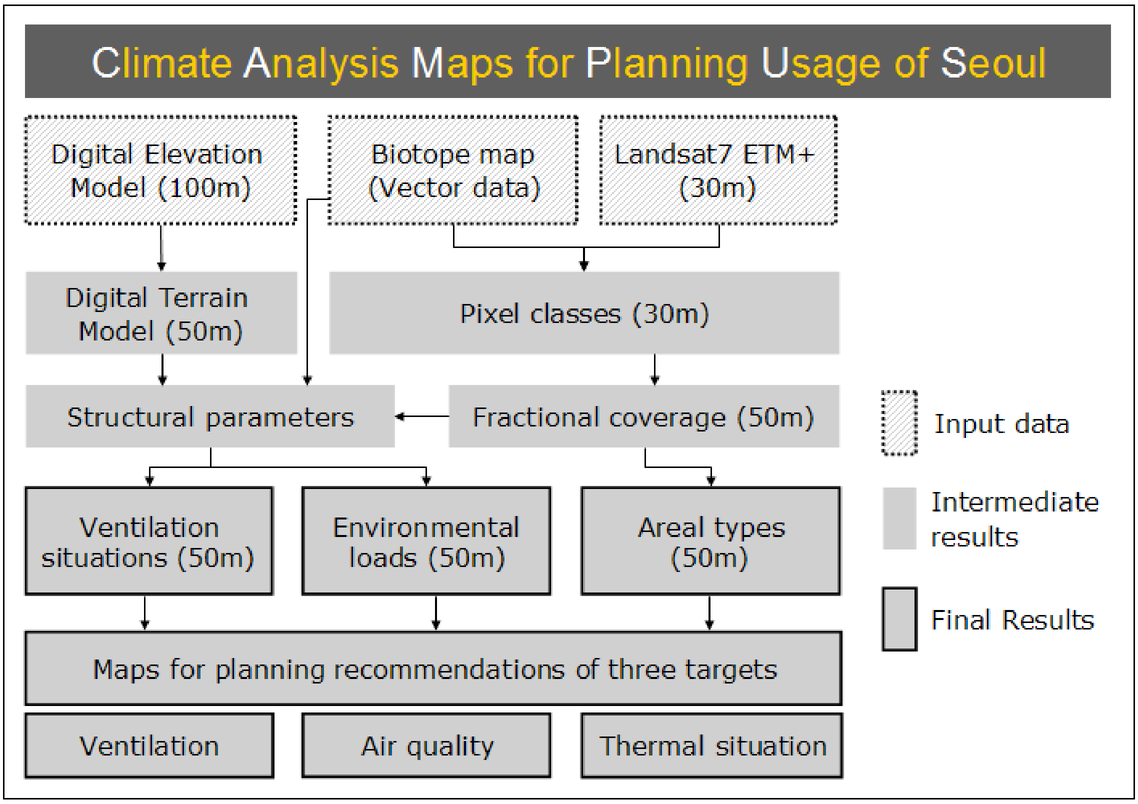


Figure 2.2 The design of climate analysis and evaluation for Seoul based on a data flow from input data via intermediate results to final results

3 Preprocessing of CAMPUS

As explained in chapter 2.1, CAMPUS is based on comprehensive spatial information on land cover and topographical properties. This information is gathered by using satellite imagery and the Digital Elevation Model (DEM) as main input data.

Land cover information is derived from remote sensing data by analyzing the spectral signatures. However, the extraction of land surface properties from remote sensing data is not straightforward in heterogeneous urban environments due to the spectral complexity of urban land cover (e.g. Jürgens 2001). Furthermore, urban land cover classification based on medium spatial resolution data, like Landsat-7 ETM+, is difficult due to the large number of mixed pixels and the spectral confusions among different land cover types (Lu & Weng 2006).

Advances in remote sensing techniques make it easier to obtain land cover data from highly resolved imagery, such as IKONOS or QuickBird (Pauleit et al. 2005). High resolution remote sensing data offer the potential for more accurate and detailed mapping of urban land cover (Herold et al. 2003), e.g. for the extraction of streets (Couloigner & Ranchin 2000). However, they are not considered in CAMPUS because of some disadvantages: The detailed mapping of land cover from high-resolution data is not needed for the purpose of planning-oriented climate analysis at the regional scale, on which CAMPUS is focussing. Besides, the higher spatial resolution or the improved radiometry of high-resolution data causes problems with classification, cloud contamination being one of the more obvious ones (Goward et al. 2003). In addition, from the practical standpoint that costs are often the most important factor in a remote sensing application (Phinn 1998), high resolution data are not attractive for use in large areas because they are significantly more expensive to obtain than medium-resolution data (Rogan & Chen 2004). For these reasons, Landsat-7 ETM+ is used to obtain the input data for CAMPUS, which is satellite imagery with medium spatial resolution,.

Table 3.1 shows in detail the input data required for CAMPUS.

3.1 Preprocessing of satellite imagery

One segment of the Landsat-7 ETM+ (Enhanced Thematic Mapper Plus) imagery covers Seoul and its surroundings; this segment is defined by WRS path 116 and WRS row 34 (Figure 3.1).

Table 3.1 Input data used for climate analysis in CAMPUS

Dataset	Description	Character	Source	Application
Landsat-7 ETM+	One set of images of Landsat-7 Enhanced Thermal Mapper Plus (ETM+) from Sep. 4, 2000. WRS path 116 and WRS row 34	Six multispectral bands with 30m spatial resolution, one thermal infra-red band* (60m spatial resolution) and one panchromatic band with 15m spatial resolution	U.S. Geological Survey (USGS)	Land cover classification represented by 8 pixel classes (PCs)
DEM_100m	Digital Elevation Model with 100m spatial resolution	Elevation data above sea level with 100m spatial resolution. Raster data	U.S. Geological Survey	Topographic correction of Landsat-7 imagery
DEM_30m	Cartographically-derived Digital Elevation Model	Elevation data on the basis of digital topographic map in the scale of 1:25,000 with 30m spatial resolution	Korean Ministry of Environment	Creation of Digital Terrain Model (DTM) for calculating ventilation situations
SRTM DEM	Shuttle Radar Topography Mission (SRTM) digital topographic data	Near-global digital elevation model, 3 arc-second resolution (approximately 90m)	U.S. National Aeronautics and Space Administration	Comparison with DEM_30m
Biotope map	Biotope dataset of Seoul containing land use information	Georeferenced vector data with attribute information of Seoul	Seoul Metropolitan Government	Reference data for geometric correction / Comparison with Pixel Classes / Usage of attribute data. e.g. building height
Aerial photograph	Aerial photos from Nov. to Dec. 2001	Actual information about Seoul with 1m spatial resolution	Blue map (www.rtouch.com)	Visual interpretation for validation of land cover classification and comparison with the classification
Google Earth	Images taken by satellites and aircraft	Information about Seoul and the surrounding areas covered with medium resolution imagery and terrain data	Google earth (earth.google.com)	Visual interpretation for validation of land cover classification and comparison with the classification

* The data for the thermal band 6 is collected at both low (nn61) and high (nn62) gain settings.

From this segment the image taken on September 4, 2000 was selected because it has been acquired at roughly the same time period that the biotope maps of Seoul were also established. Those biotope maps are used to compare the land cover classification derived from the Landsat-7 ETM+. In addition, air photographs taken during roughly the same time period are used for validation and comparison.

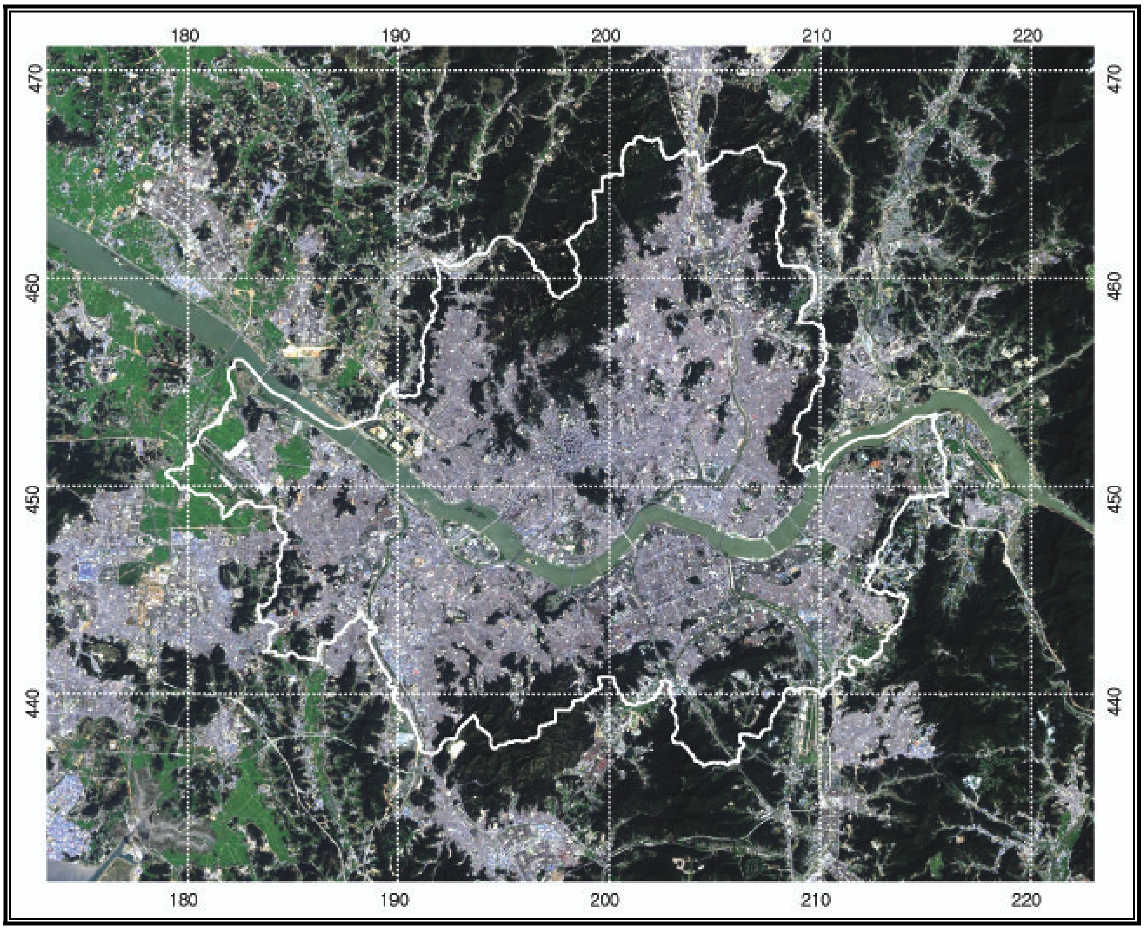


Figure 3.1 Landsat 7 ETM+ imagery of Seoul and its surroundings from 04 September 2000 with the administrative boundary of Seoul metropolitan area. Bands 3, 2 and 1 are displayed as true-color composite.

Other criteria for selecting appropriate acquisition data were the climatic characteristics of different seasons of the year. Remotely sensed imageries taken in Korea during the summer season are usually not suitable for land cover classification because the monsoon season brings with it extended cloud coverage. Furthermore, those from early spring are often not feasible due to some atmospheric problems arising from haze. Winter is not a suitable season for land cover classification either, because of the lack of vegetation information. For these reasons the Landsat-7 imagery of September 2000 was selected for this study.

The area around Seoul chosen for classification extends about 50 km in W-E direction and 40 km in N-S direction, of which Seoul covers 36.78 km in W-E direction and 30.3 km in N-S direction. The larger area was chosen for this study because land cover and topographic situation of the surroundings deeply influence the climatic situation of Seoul. In particular, the ventilation of Seoul is directly influenced by the mountainous environment.

At the outset of this work, a georeference of the Landsat-7 image was conducted, using the biotope maps as reference data. For it, thirty ground control points (GCPs) were selected, which are clearly identifiable in both the satellite image and biotope maps. Additionally, a 100 m resolution digital elevation model (DEM) provided by U.S. Geological Survey was used as an elevation source for orthorectification because of the mountainous terrain. The Transverse Mercator (TM) coordinate system, which is used in the Republic of Korea since the 1970's, was employed in this study. Because the biotope maps were also coordinated by TM, no errors were caused by coordinate system transformations.

3.2 Pixel classes derived from satellite imagery

'Pixel class (PC)' is a term for a land cover class generated by classifying satellite imagery, which was introduced in studies focused on European cities (Fehrenbach 1999; Fehrenbach et al. 2001; Scherer et al. 1999). PCs are recognized by distinctive electromagnetic surface properties in the reflection spectrum. Strictly speaking, PCs are not spectrally pure; rather, mixed surface types give a distinctive property to each PC. For example, the distinguishable characteristics for the PC 'low density areas' consist of artificial materials used for building construction or streets as well as vegetation.

For this study, various land cover classes were categorized into eight pixel classes (Table 3.2). Water surfaces, coded as WA, comprise all kinds of water bodies. They include the main river in Seoul (Han River), its tributary streams and lakes as well as part of the Yellow Sea of Korea. The pixel class 'Trees (TR)' represents all kinds of trees, e.g. forests, parks, orchards, while grasslands belong to the PC 'Unsealed areas (unS)'. Areas used for agriculture and bare soils, which are not covered with artificial materials, are also interpreted as ‘unS’, whereas areas covered with asphalt and concrete materials refer to the PC ‘Sealed areas without buildings (SwoB)’.

Table 3.2 Pixel classes used in CAMPUS

No.	Code	Pixel class (PC)	Remark
1	WA	Water surfaces	Water surfaces, e.g. Han river and its tributary streams, lakes
2	TR	Trees	Surfaces covered by trees, e.g. forests
3	unS	Unsealed areas	Open and natural surfaces, e.g. grass, soil, stone
4	SwoB	Sealed areas without buildings	Surfaces covered by impermeable materials, e.g. asphalt and concrete; no building structure
5	SwVB	Sealed areas with variable buildings	Heterogeneous sealing rate and building structures
6	LD	Low density areas	Areas comprised of detached building structures and high ratio of green surfaces
7	MD	Medium density areas	Areas comprised of building structures in a line with green surfaces; normally apartment buildings in CAMPUS
8	HD	High density areas	Areas mostly comprised of attached building structure and low ratio of green surfaces

The following three PCs differ by the degree of their built-up densities. The PC ‘Low density areas (LD)’ represents areas of detached building structures with a high rate of natural surfaces like greens and soils, whereas the PC ‘High density areas (HD)’ addresses areas mostly consisting of attached building structures with a high rate of artificial materials like asphalts and concretes. The PC ‘Medium density areas (MD)’ is introduced for residential housing blocks (i.e. apartment areas) with more buildings than LD but more vegetation than HD. It is a very popular type of residential construction in Seoul, occupying 25.82 percent of the entire area of Seoul (Seoul Development Institute 2000). The last PC ‘Sealed areas with variable buildings (SwVB)’ represents areas with heterogeneous rates of sealing and variable types of building structures. Shadows emerging from high buildings belong to the PC ‘Unclassified (unC)’, because no information on surface properties can be acquired in shadow areas.

PCs differ according to climatic and air quality characteristics as well as surface properties. For example, sealed areas with concrete and asphalt (like the PC ‘SwoB’ or ‘HD’) have a much higher thermal storage capacity than unsealed areas covered with natural surfaces (like the PC ‘unS’ or ‘WA’). Therefore, sealed areas store larger amounts of thermal energy during the day and release them in the night. In relation to the ventilation in cities, areas without buildings (like the PC 'unS' or 'SwoB') have more favorable conditions, due to lower surface roughness, than those with buildings (like the PC 'SwVB' or 'HD').

In this work the surface and climatic properties peculiar to each PC are distinguished by the three aspects of 'ventilation, air quality and thermal situation' in Table 3.3.

Table 3.3 Characteristics of PCs in relation to ventilation, air quality and thermal situation

Pixel Classes	Ventilation	Air quality	Thermal situation
Water surfaces	Few flow barriers	No appreciable emission	Balanced daily range, dampened yearly range
Trees	Few flow barriers, but effective as flow resistance	High Volatile Organic Compounds (VOCs)	Balanced daily range, high cold air production
Unsealed areas	Few flow barriers	Variable VOCs, no anthropogenic emission, fresh air production	Balanced daily range, cold air production
Sealed areas without buildings	Isolated flow barriers	No VOCs, medium or high anthropogenic emissions (Traffic)	Strongly pronounced daily range
Sealed areas with variable buildings	Big variability of flow barriers	No VOCs, high variability of anthropogenic emissions (Traffic, Industry)	Variable, with little cooling at night and possible high heat emission from buildings; partly urban heat island (UHI)
Low density areas	Medium flow barriers	Low VOCs, low or medium anthropogenic emissions	Medium cooling effect at night
Medium density areas	Partly massive flow barriers	No VOCs, medium anthropogenic emission	Low cooling effect at night, low or medium heat emission, partly UHI
High density areas	Massive flow barriers	No VOCs, medium or high anthropogenic emissions	Very low cooling at night, medium or high heat emission, UHI

Water surfaces

Areas of this PC are dominated by water bodies, meaning both flowing water and stagnant water. There are few, if any, isolated flow barriers in these areas, resulting in very low surface roughness. No air pollution and thermal emission occurs. The water areas have a compensating effect on the thermal situation of the surroundings, because their temperature has lower daily variations than land surface.

Trees

The PC ‘Trees’ is characterized by high surface roughness and high cold air production (big volume and moderate cooling effect) due to a large tree cover. Although few barriers to ventilation exist, dense forest areas pose partial barriers to ventilation. No anthropogenic emission exists.

Unsealed areas

The predominant property in this PC is an intensive production of cold air (small volume, but strong cooling effect) through extreme daily variations in temperature and humidity. Furthermore, areas are of low or medium surface roughness and scarcely obstruct ventilation. No anthropogenic emission is expected. This PC comprises meadows and arable areas as well as open spaces with few trees.

Sealed areas without buildings

This PC is dominated by sealed areas, with only a few single structures. Therefore, low surface roughness and few barriers to ventilation are to be expected. The predominant land use is transportation, like highway and roads, with high air pollution from vehicles and thermal emission of heat stored in asphalt and concrete materials over the day-time.

Sealed areas with variable buildings

Various building structures and densities of this PC, from big structures like warehouses to PVC-covered green houses, present a high variability of surface roughness and emission. As building structures and densities vary, middle to high surface roughness and anthropogenic emission are expected.

Low density areas

The PC ‘low density areas’ is characterized by less densely built-up areas with mostly detached buildings and rich green spaces (e.g. private gardens, roadside trees) as well as some sealed roads. Buildings are barriers to ventilation, but ventilation can flow through low density buildings, resulting in medium surface roughness. Low to medium anthropogenic emissions by vehicles and heating emissions from buildings are expected.

Medium density areas

This PC 'Medium density areas' has similar properties like the PC 'Low density areas', but it is distinguished by apartment buildings in a line, which are normally higher than buildings in low density areas. Higher buildings cause stronger barriers to ventilation. However, ventilation is not completely blocked, due to the detached apartment buildings in certain areas. For this reason, middle to high surface roughness is expected. Medium anthropogenic emissions are present.

High density areas

Areas of this PC are dominated by densely built-up areas with mostly attached buildings and few green spaces, which lead to a strong heat island effect with low humidity. Ventilation cannot flow through the attached building structures, indicating high surface roughness. High levels of air pollution and thermal emission are present.

3.2.1 Definition of training areas

A significant part of generating pixel classes is to create a set of training areas as input data for land cover classification. Training areas refer to homogeneous and representative samples of the different land cover types of interest. To identify suitable training areas, aerial photographs and images provided by 'Google Earth' were used as ground truth data. Additionally, different band combinations were employed to distinguish surface properties of various land cover types and to choose the best enhancement of features in the image.

The spectral separability for training areas of classes was employed to examine how well the classes can statistically be separated, calculating values ranging from 0 to 2.0. Values greater than 1.9 indicate a good separability, whereas values less than 1 refer to very low separability.

Each pixel class is composed of sub-classes. For instance, the PC 'TR' includes trees which are located in the shade or in the sun, conifers or broadleaf trees. Additionally, the PC 'unS' covers soils which can be sandy or organic (subdivided as bare soils), vegetated or covered with sparse vegetation (subdivided as grassland and agricultural areas). Finally, 39 sub-classes were selected for eight pixel classes. Each sub-class is defined by a minimum of five training areas.

The land coverage of Seoul was classified by supervised classification, using the Maximum-Likelihood Classifier which is one of the most used methods of classification in remote sensing. To evaluate the performance of the classifier or a processor, a confusion matrix was used, which contains data about actual classes (ground truth values) and predicted classes (classified dataset).

3.2.2 Land cover classification of Seoul

The classification accuracy of the study area, which was measured by kappa coefficients calculated from a confusion matrix, was 94.3 percent. The PC with the highest accuracy was 'WA' with 99 percent, followed by 'unS' and 'TR' with 97.5 percent and 96.8 percent, respectively (Table 3.4).

Table 3.4 Percentage and classification accuracy of PCs for CAMPUS area, derived from Landsat-7 ETM+

No.	Code	Pixel Class (PC)	Area (m^2)		Classification Accuracy (%)
			Km^2	%	
0	unC	Unclassified areas	6.9	0.33	-
1	WA	Water surfaces	62.8	3.02	99.0
2	TR	Trees	803.4	38.61	96.8
3	unS	Unsealed areas	469.6	22.57	97.5
4	SwoB	Sealed areas without buildings	90.7	4.36	89.4
5	SwVB	Sealed areas with variable buildings	179.2	8.61	70.4
6	LD	Low density areas	177.2	8.52	73.2
7	MD	Medium density areas	89.0	4.28	75.5
8	HD	High density areas	202.0	9.71	85.6
Total			2,080.8	100.00	94.3

Figure 3.2 shows the result of spatial distribution of pixel classes. 'TR' and 'unS' are the predominant PC types in the outskirts of Seoul. Most parts of Seoul were classified as 'HD' occupying 22.3 percent. The PC 'LD' occurs all across the outskirts of Seoul and between densely built-up areas and green areas, whereas 'MD' is centered on a few parts of Seoul. 'SwVB' is common in densely built-up areas or industrial areas. 'WA' is least common, with only 4.8 percent. The percentages of all PCs are shown in Table 3.5.

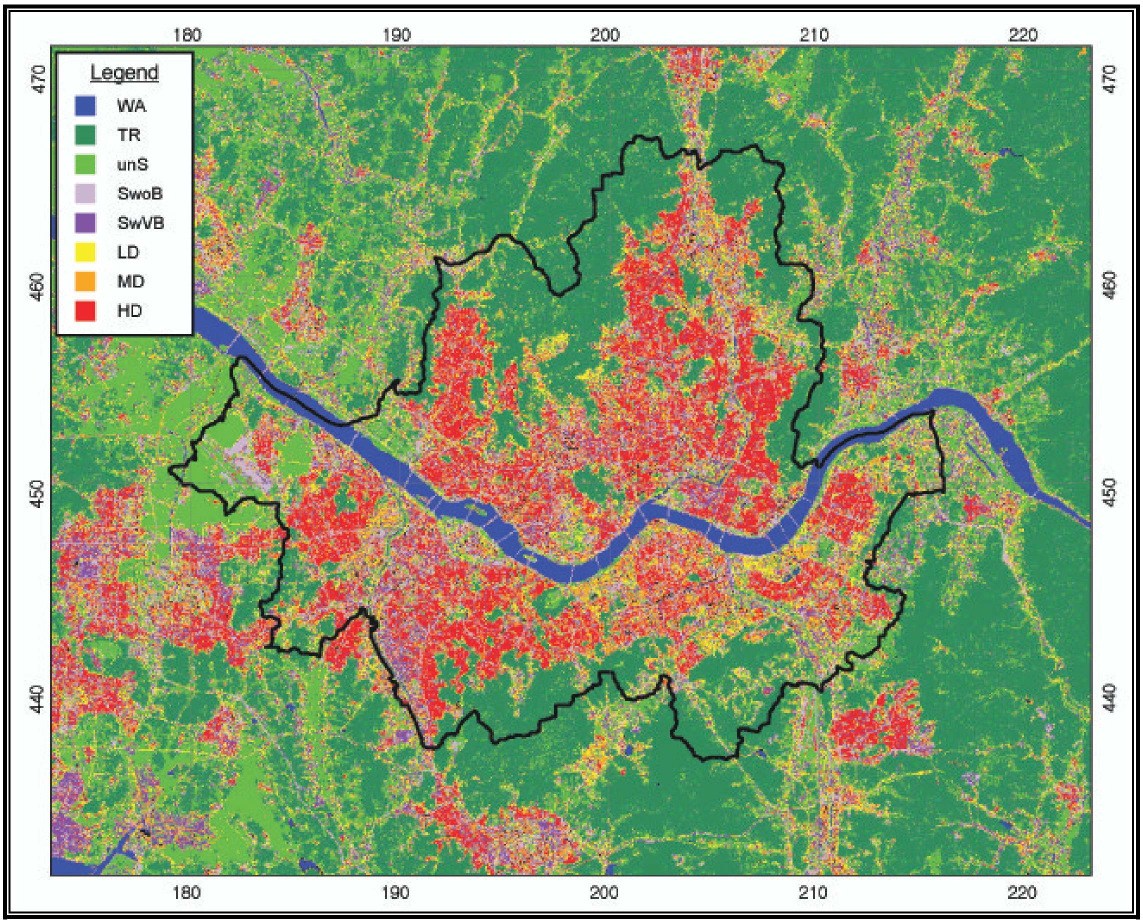


Figure 3.2 Land cover classification of Seoul using Maximal Likelihood Classification (Combined result of 36 sub-classes into eight pixel classes)

Table 3.5 Percentage of PCs for Seoul area, derived from Landsat-7 ETM+

No.	Code	Pixel Class (PC)	Area (km^2)	
			Km^2	%
0	unC	Unclassified areas	3.6	0.6
1	WA	Water surfaces	29.1	4.8
2	TR	Trees	141.1	23.3
3	unS	Unsealed areas	67.2	11.1
4	SwoB	Sealed areas without buildings	67.8	11.2
5	SwVB	Sealed areas with variable buildings	53.9	8.9
6	LD	Low density areas	59.9	9.9
7	MD	Medium density areas	47.8	7.9
8	HD	High density areas	135.0	22.3
Total			605.4	100.0

The results of land cover classification in Seoul using Landsat-7 ETM+ were compared with aerial photographs in Figure 3.3. The comparisons of two southeastern parts of Seoul indicate that HD is clearly distinguishable from LD (separability value with HD: 1.7; see Chapter 3.2.1. for the separability value in detail) and MD (separability value with HD: 1.5). Furthermore, trees (TR) are easily distinguishable from built-up areas and clearly visible in the Pixel Classes LD, MD and HD, showing high separability values of 1.8, 1.97 and 1.99 respectively.

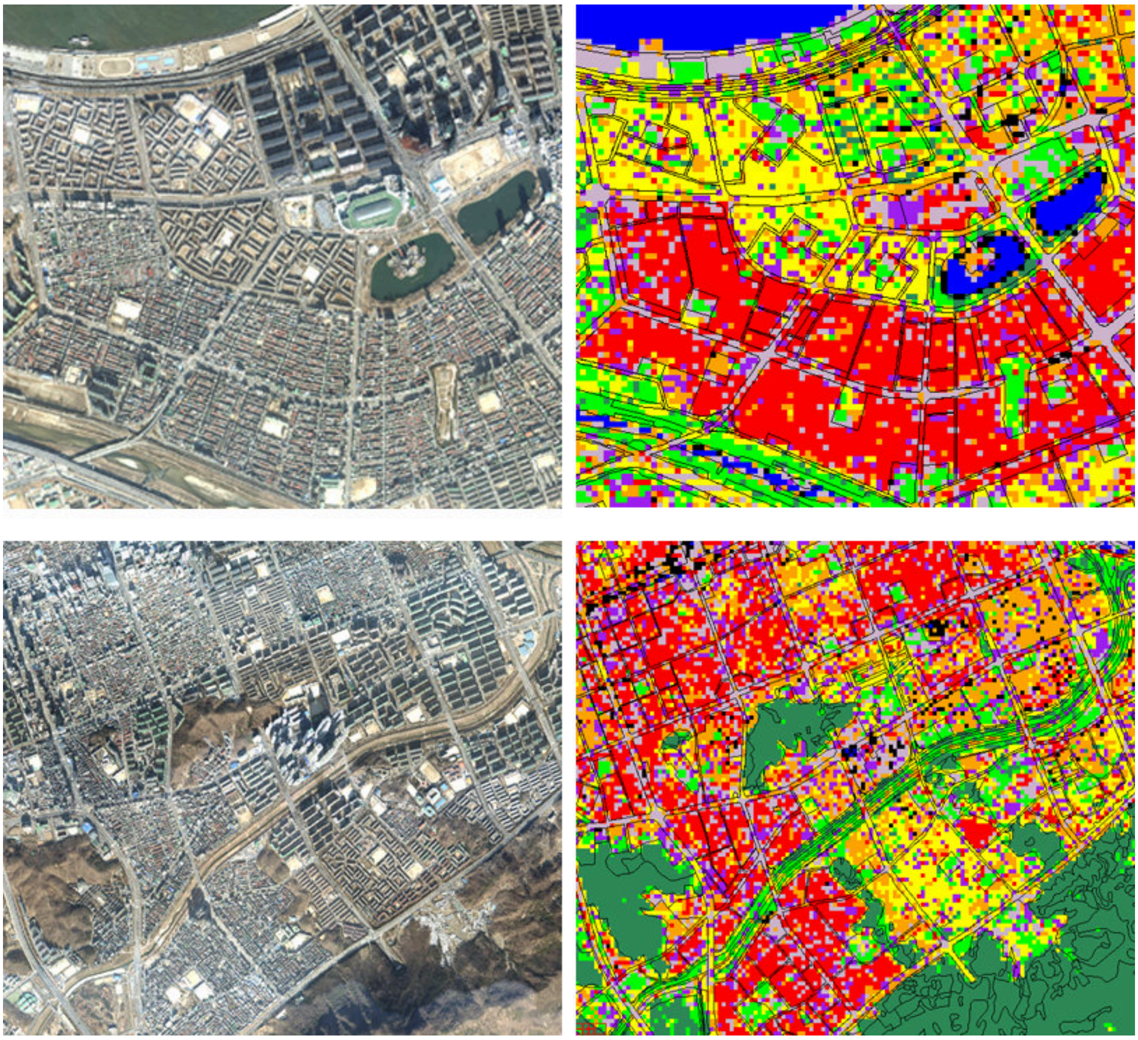


Figure 3.3 Comparison between aerial photos (left) and land cover classification overlaid with vector files of the biotope dataset (right) of two southeastern parts of Seoul. See Figure 3.2 for defining colors of land cover classification. (Source of aerial photos: Blue map - www.rtouch.com)

3.2.3 Misclassifications of land cover using Landsat-7 ETM+

Several misclassifications occurred during satellite-based land cover classifications that were using the Maximum-Likelihood Classifier. They mostly occurred among similar spectral signatures of land surface types. Three cases of misclassifications and their corrections are discussed in this section.

Apartment areas and agricultural areas covered with Polyvinyl Chloride

In Seoul and its surroundings, vegetables and flowers are mostly grown in agricultural areas covered with Polyvinyl Chloride (PVC), which are called vinyl houses or greenhouses. Although they are agricultural areas in terms of land use, they don't have the same climatic characteristics as other agricultural areas like rice fields, due to different land surface properties. During the land cover classification, these PVC-covered areas (SwVB) were often misclassified as apartment areas (MD). Spectral separabilities of training areas for LD, MD, HD and SwVB were calculated by using the Jaffries-Matusita method (Table 3.6). The PVC-covered areas, coded as SwVB4, have low separability values with LD and, in particular, with a subclass of apartment areas coded as MD1.

Table 3.6 Separability values of training areas (Jaffries-Matusita method). See Table 4.2 for definitions of codes.

	LD2	MD1	MD2	MD3	HD1	HD2	HD3	SwVB1	SwVB2	SwVB3	SwVB4*
LD1	1.69	1.52	1.94	1.99	1.87	1.87	1.64	1.96	1.99	2.00	1.39
LD2		1.80	1.89	2.00	1.97	1.88	1.84	1.90	1.97	1.99	1.33
MD1*			1.91	2.00	1.92	1.79	1.94	1.95	1.97	2.00	**1.05**
MD2				2.00	1.48	1.37	1.92	1.54	1.69	1.96	1.89
MD3					2.00	2.00	2.00	2.00	2.00	2.00	2.00
HD1						0.54	1.91	1.57	1.94	2.00	1.85
HD2							1.95	1.36	1.85	2.00	1.70
HD3								1.91	2.00	1.99	1.70
SwVB1									1.75	1.96	1.90
SwVB2										1.98	1.98
SwVB3											2.00

* 'SwVB4' indicates the PVC-covered agricultural areas; 'MD1' is a subclass for apartment areas

Although PVC-covered agricultural areas occupy only 1.37 percent of Seoul, discerning them from apartment areas is important for analyzing climatic characteristics of Seoul. They are usually located on the outskirts of Seoul, whose mountainous topography affects the ventilation of the city through the mountain and valley wind systems. Their misclassification can be corrected by using a biotope type 'Equipped farm land (G5)' in the biotope maps of Seoul.

Flat roofs consisting of concrete materials and concrete-sealed surfaces

In Seoul, building structures with flat roofs make up approximately 70 percent of the entire area (Seoul Development Institute 2000) with roofs mostly consisting of concrete. Because land cover classification using satellite imagery is based on spectral signatures of surface types, there are specific limitations in the separation of these flat roofs with concrete-sealed surfaces. Therefore, buildings with a flat concrete roof were sometimes misclassified as the PC 'SwoB'. The Youido district near the Han River, a commercial area with many big buildings, is an excellent example for this case. For the same reason, areas with concrete pavements and vegetation such as roads with roadside vegetation were sometimes misclassified as the PC 'LD' that typically consists of individual houses with flat concrete roof and green areas.

The misclassifications occurring in roads with roadside vegetation can be corrected by replacing them with a biotope type 'Road (D3)' of biotope maps of Seoul. However, the misclassifications caused by flat roofs cannot be excluded, although individual pixels of them can be partly removed by a filter using the spatial pixel connectivity. And since roads have a low surface roughness and buildings have a high one, these misclassifications may lead to wrong results for the ventilation situations as one part of climate modeling.

Water surfaces and building shadows

In land cover classification using Landsat data, building shadows are often misclassified as water surfaces, and vice versa, due to their spectral similarities. In this study the misclassification of water surfaces occurred mostly in shallow waters like water retention ponds or at water's edge. This is confirmed by separability values of shadows. The separability of shadows and the shallow waters is 1.4, whereas that of shadows and the Han River is 2.0.

In order to find a better way of classification, the Mahalanobis-Distance Classifier (MDC) was also used, which has been used for better classification of water surfaces in a previous study focused on an European city (Scherer et al. 2000), to compare the findings with the results that were obtained previously by using the Maximum-Likelihood Classifier (MLC). In this second study, however, the misclassification increased when MDC was used. The confusion matrix generated for the two classifiers shows that the number of shadow pixels (ground truth) representing shallow waters (classified dataset) increases from 6.3 percent (MLC) to 13.8 percent (MDC) and the number of shallow water pixels (ground truth) representing building shadows (classified dataset) also increases from 17.7 percent (MLC) to 22.9 percent (MDC). Therefore, the Mahalanobis-Distance Classifier was not suitable for the classification of water surfaces. Therefore, it was not used in the final classification.

However, this misclassification can sometimes be tolerated, because less than one percent of the entire area of Seoul is affected, and because unconnected individual pixels of shadows can be removed by the filter processing mentioned above.

3.3 Comparison of Landsat-derived PCs and Biotope-based PCs

A multitude of methods for analyzing and evaluating climate data has been developed and used for planning purposes, particularly in Germany (e.g. Verein Deutscher Ingenieure 1997 and 2002). Spatially distributed data on land use or biotopes have been used as basic input for this kind of planning application (e.g. Lazar et al. 1994; Mosimann et al. 1999).

Actually, 'biotope' refers to the habitat of a community of plants and animals. But in cities, the habitat correlates with land use patterns. For this reason, land use structures are used as the main information for establishing biotope maps of Seoul (Hong et al. 2005). Biotope maps have been widely used for planning purposes in Seoul since they provide comprehensive data e.g. on building height and surface sealing ratio from ground-based data collection.

Hence, this already existing and widely used dataset may offer a useful and convenient way to establish input data used for planning-oriented climate analysis and evaluation. Actually, in a study of generating climate analysis maps of Seoul (Seoul Development Institute 2007), biotope types of Seoul were used to generate climatopes, which describe geographic areas with similar microclimatic characteristics (Ministry of the Interior Baden-Württemberg 2004). Hence, it is necessary to examine if the already existing biotope maps of Seoul are suitable for climate analysis and evaluation in CAMPUS and how they could contribute to the process of CAMPUS.

The primary purpose is to elaborate on the advantages and drawbacks of both the satellite-derived PCs and biotope-based PCs. Hence, the satellite-based approach is compared to land cover classification (chapter 3.2) with the existing biotope map of Seoul. Further, it is discussed whether land cover information gained from Landsat-7

ETM+ can be sufficient as basic input data for climate analysis, whether its drawbacks can be remedied, and how land use information of biotope maps of Seoul can contribute to the process.

3.3.1 Biotope maps of Seoul

Biotope maps of Seoul were set up in 2000 by Seoul Development Institute under contract with Seoul Metropolitan Government (Seoul Development Institute 2000). At this time public interest in ecology within urban areas was increasing but the available data for ecological analysis and evaluation related to urban planning were limited. In this context the biotope maps of Seoul at the scale of 1:1000 were constructed based on citywide ground survey with comprehensive attribute data, e.g. building type, number of floors, surface sealing ratio. All data were compiled into a GIS database to store and analyze them and they shall be renewed and supplemented with up-to-date information every five years.

Biotope maps of Seoul have 65 biotope types by the three criteria: land use, impermeable pavement ratio and vegetation type (Seoul Development Institute 2000). Above all, land use was the main criterion for the categorization. For instance, all kinds of residential areas were categorized into three biotope types ‘detached house’, ‘apartment house’ and ‘traditional house’ areas. The type ‘detached house areas’ was subcategorized into two biotope types of A1 and A2 which indicate high (more than 70 percent, inclusive) and low (less than 70 percent) impermeable pavement ratio respectively. The biotope type ‘apartment house areas’ was subcategorized into six types not only by the impermeable pavement ratio but also by the number of building floors. Table 3.7 shows the 65 biotope types and their percentages of the entire area of Seoul, which were arranged into nine categories (A to I) according to their functions: residential area biotope, commercial or business area biotope, industrial or urban infrastructural facilities area biotope, transportation facilities biotope, landscape or green area biotope, stream or wetland biotope, farmland biotope, forest biotope.

Table 3.7 Biotope types used in the biotope maps of Seoul (Seoul Development Institute 2000)

Code	Biotope type	%
	Residential Area Biotope	**17.96**
A1	Detached houses with high impermeable pavement ratio (over 70 percent)	9.15
A2	Detached houses with low impermeable pavement ratio (under 70 percent)	0.33
A3	1~4 story apartment houses with high impermeable pavement ratio (over 70 percent)	1.67
A4	1~4 story apartment houses with low impermeable pavement ratio (under 70 percent)	0.09
A5	5~10 story apartment houses with high impermeable pavement ratio (over 70 percent)	1.40
A6	5~10 story apartment houses with low impermeable pavement ratio (under 70 percent)	0.53
A7	Over 10 story apartment houses with high impermeable pavement ratio (over 70 percent)	4.17
A8	Over 10 story apartment houses with high impermeable pavement ratio (under 70 percent)	0.56
A9	Traditional houses built with natural construction materials	0.06
	Commercial or Business Area Biotope	**19.35**
B1	1~5 story high commercial or business area with high impermeable pavement ratio (over 70 percent)	4.34
B2	1~5 story high commercial or business area with low impermeable pavement ratio (under 70 percent)	0.16
B3	6~10 story high commercial or business area with high impermeable pavement ratio (over 70 percent)	0.69
B4	6~10 story high commercial or business area with low impermeable pavement ratio (under 70 percent)	0.01
B5	Over 10 story high commercial or business area with high impermeable pavement ratio (over 70 percent)	0.44
B6	Over 10 story high commercial or business area with low impermeable pavement ratio (under 70 percent)	0.01
B7	Mixed landuse area with high impermeable pavement ratio (over 70 percent)	13.47
B8	Mixed landuse area with low impermeable pavement ratio (under 70 percent)	0.23
	Industrial or Urban Infrastructure Facilities Area Biotope	**11.55**
C1	Industrial area with high impermeable pavement ratio (over 70 percent)	1.26
C2	Industrial area with low impermeable pavement ratio (under 70 percent)	0.09
C3	Sewage treatment facility	0.28
C4	Storm water retention pond	0.23
C5	Water supply reservoir	0.02
C6	Waste landfill area	0.13
C7	Water purification plant	0.07
C8	Power plant	0.09
C9	Waste incineration facility	0.01
C10	Agricultural and fishery products market	0.16
C11	Waste transfer station	0.07

C12	Public facilities larger than 1ha	4.63
C13	Public facilities smaller than 1ha	0.31
C14	Construction site	2.28
C15	Inaccessible area	1.92
	Transportation Facilities Biotope	**10.44**
D1	Railroad and related facilities area with high impermeable pavement ratio (over 70 percent)	0.24
D2	Railroad and related facilities area with low impermeable pavement ratio (under 70 percent)	0.71
D3	Road	7.91
D4	Large parking area	0.57
D5	Airport area	1.01
	Landscape or Green Area Biotope	**3.09**
E1	Planted area smaller than 1ha	0.59
E2	Planted area larger than 1ha	1.70
E3	Cemetery	0.36
E4	Golf course	0.24
E5	Botanical garden	0.02
E6	Ancient palace	0.18
	Stream or Wetland Biotope	**6.99**
F1	Water body	5.54
F2	Waterfront constructed with artificial materials	0.22
F3	Waterfront constructed in natural form	1.09
F4	Dry stream	0.02
F5	Wetland	0.12
	Farmland Biotope	**5.34**
G1	Paddy field	1.30
G2	Field	2.15
G3	Grazing field	0.00
G4	Orchard	0.24
G5	Equipped farm land	1.37
G6	Nursery garden	0.28
	Forest Biotope	**25.28**
H1	Forest afforested with foreign deciduous and broad-leaved trees	8.32
H2	Forest afforested with foreign coniferous trees	0.13
H3	Natural forest dominated by native fine trees	2.63
H4	Natural forest dominated by native oak trees	3.46
H5	Natural forest dominated by drought-tolerant deciduous and broad-leaved trees	8.97
H6	Natural forest dominated by water-tolerant deciduous and broad-leaved trees	0.42
H7	Grassland dominated by foreign species	0.09
H8	Dry grassland dominated by native species	1.00
H9	Deforested or denuded area	0.09
H10	Rocky area (part of forest with naked rock)	0.17
	Etc	**0.05**
I1	Etc (e.g. unused bare ground)	0.05

3.3.2 Re-categorization of biotope types into pixel classes

In order to compare the biotope-based land use information with the satellite-derived land cover classification, the 65 biotope types were re-categorized into eight pixel classes. The biotope type of water body (F1) was assigned to the PC 'WA', while dry streams (F4) and wetlands (F5) belong to 'unS'. All types of forest (H) as well as the biotope types dominated by trees like a botanical garden (E5) or orchards (G4) were classified into 'TR'. The types dominated by natural surfaces like grass and soil, e.g. agricultural fields (G1, G2, G3), cemeteries (E3) and golf courses (E4), were also assigned to 'unS'. In contrast, the biotope types of roads (D3) and parking places (D4) covered mostly with artificial materials were classified into 'SwoB'.

Biotope types containing heterogeneous land surface types were assigned to 'SwVB'. The following types belong to this case: industrial areas (C1, C2), railroads and related facilities (D1, D2), other urban infrastructural facilities like power plants (C8), public facilities like universities and hospitals (C12, C13), ancient palaces (E6), the airport (D5), construction sites (C14) and inaccessible areas like military facilities (C15).

All biotope types for residential areas (A) and commercial or business areas (B) were re-categorized into the PCs 'LD', 'MD' and 'HD'. The types of 'detached house areas' and '1-4 story-apartment house areas' with low impermeable pavement ratio (less than 70 percent; A2, A4) as well as 'traditional house areas' built with natural construction materials (A9) appertain to 'LD'. But the same areas with high impermeable pavement ratio (70 percent and above; A1, A3) belong to 'HD'.

The 'commercial or business (B1 to B6)' and 'mixed land use (B7, B8)' areas were divided into 'MD' and 'HD' by low or high impermeable pavement ratio respectively. However, all kinds of apartment house areas with five stories or more (A5 to A8) were assigned to 'MD', because apartment house areas are residential areas which are not as densely built-up as commercial or business areas.

The 65 biotope types re-categorized by the eight pixel classes and their distribution across Seoul are shown in Table 3.8. The PC 'HD' including biotope types of residential and commercial areas occupies the largest space with 29.7 percent, followed by 'TR' with 27.2 percent. The PCs 'MD' and 'LD' consisting of the remaining biotope types for residence and commerce has low percentages. In particular, 'LD' with only three residential types occupies 0.5 percent. Most biotope types concerning industry and infrastructure facilities were re-categorized into 'SwVB', which occupies the third largest share of Seoul's area.

Table 3.8 Categorization of biotope types into pixel classes

No.	PC	Biotope type	Remark	%
0	unC	-	-	-
1	WA	F1	Water body	5.5
2	TR	E1, E2, E5, G4, G6, H1, H2, H3, H4, H5, H6	Planted area, botanical garden, orchard, nursery garden and forest	27.2
3	unS	C6, E3, E4, F3, F4, F5, G1, G2, G3, H7, H8, H9, H10, I1	Cemetery, golf course, grassland, waterfront constructed in natural form, dry stream, agricultural field, deforested area, rocky area	7.3
4	SwoB	D3, D4, F2	Road, large parking place	7.7
5	SwVB	C1, C2, C3, C4, C5, C7, C8, C9, C10, C11, C12, C13, C14, C15, D1, D2, D5, E6, G5	Industrial area, public facility (e.g. school, hospital, university, institute), urban infrastructural facility (e.g. power plant, sewage treatment facility), construction site, inaccessible area (e.g. army), railroad and related facilities, airport, ancient palace, PVC-covered agricultural area	15.0
6	LD	A2, A4, A9	Detached house and 1-4 story apartment house area with low impermeable pavement ratio (under 70 percent), traditional house area built with natural construction materials	0.5
7	MD	A5, A6, A7, A8, B2, B4, B6, B8	Apartment house area with over 5 stories, commercial or business and mixed land use area with low impermeable pavement ratio (under 70 percent)	7.1
8	HD	A1, A3, B1, B3, B5, B7	Detached house and 1-4 story apartment house area with high impermeable pavement ratio (over 70 percent), commercial or business and mixed land use area with low impermeable pavement ratio (over 70 percent)	29.7
Total				100.0

3.3.3 Comparing pixel classes from satellite imagery with those from biotope types

In order to compare the two datasets, the area of Seoul was masked from the PCs retrieved from satellite imagery.

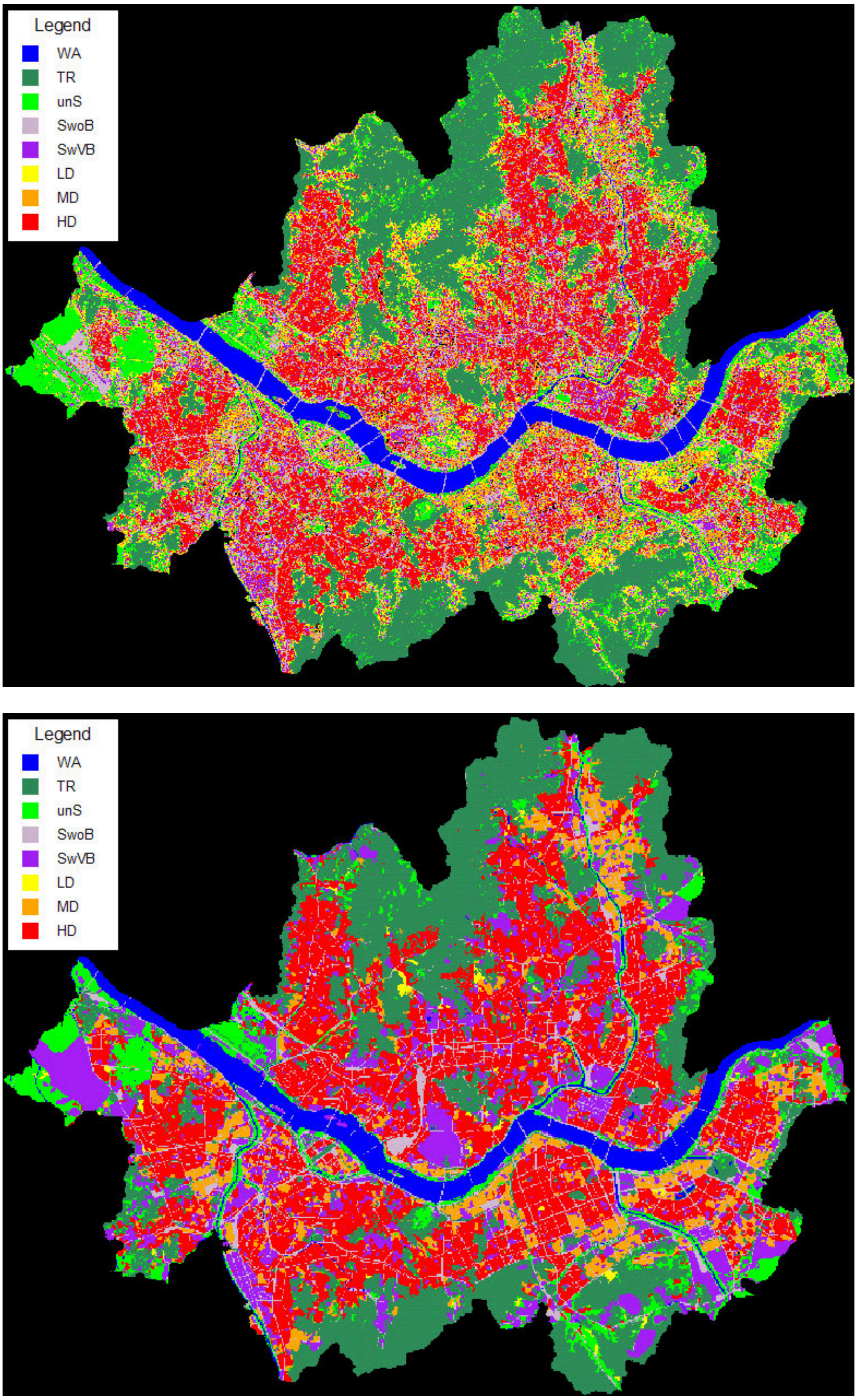


Figure 3.4 Distribution of pixel classes based on land cover classification of satellite imagery (upper) and biotope types of Seoul's biotope map (lower).

This was done because the biotope dataset is available only for Seoul, not its surroundings. The re-categorized biotope types, which are in vector format, were transformed into raster images to compare them with the PCs derived from Landsat-7 ETM+ images. Figure 3.4 shows spatial distribution of the pixel classes based on both datasets. The upper figure corresponds to the PCs of Seoul derived from land cover classification, the lower one is based on biotope types of Seoul's biotope map.

Figure 3.5 compares both datasets by showing percentages of each PC. Although the PCs 'TR' and 'HD' occupy the largest percentages of area in both datasets, 'TR' and 'HD' based on the biotope map had higher percentages than those derived from Landsat-7 ETM+. The percentages of 'HD' and 'SwVB' increased in the biotope-based PCs, but 'unS' and 'SwoB' increased in the satellite-based ones. While some bare grounds or roads were subsumed under the biotope types categorized as 'HD' and 'SwVB' in the biotope-based PCs, these bare grounds and roads were extracted from those biotope types and arranged as 'unS' or 'SwoB' in land cover classification.

The percentage of 'LD' shows the greatest variation of all PCs between the satellite-derived PCs and the biotope-based ones. The PCs 'WA' and 'MD' had low variations. The small variation for WA was due to their high consistency between the biotope-based PCs and Landsat-derived PCs.

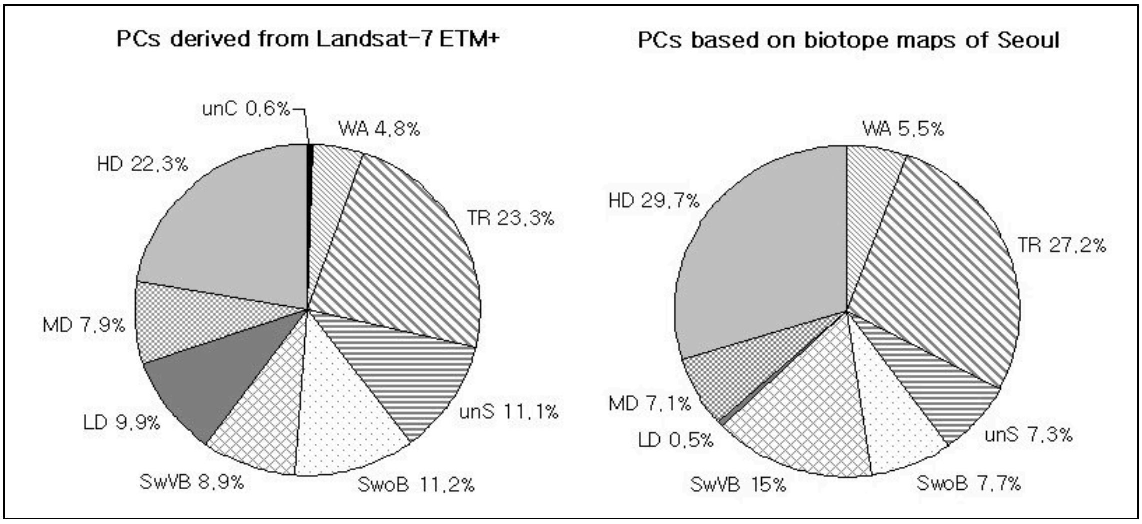


Figure 3.5 Comparison between PCs derived from Landsat-7 ETM+ and PCs based on the biotope map of Seoul. See Table 3.2 for definitions of codes.

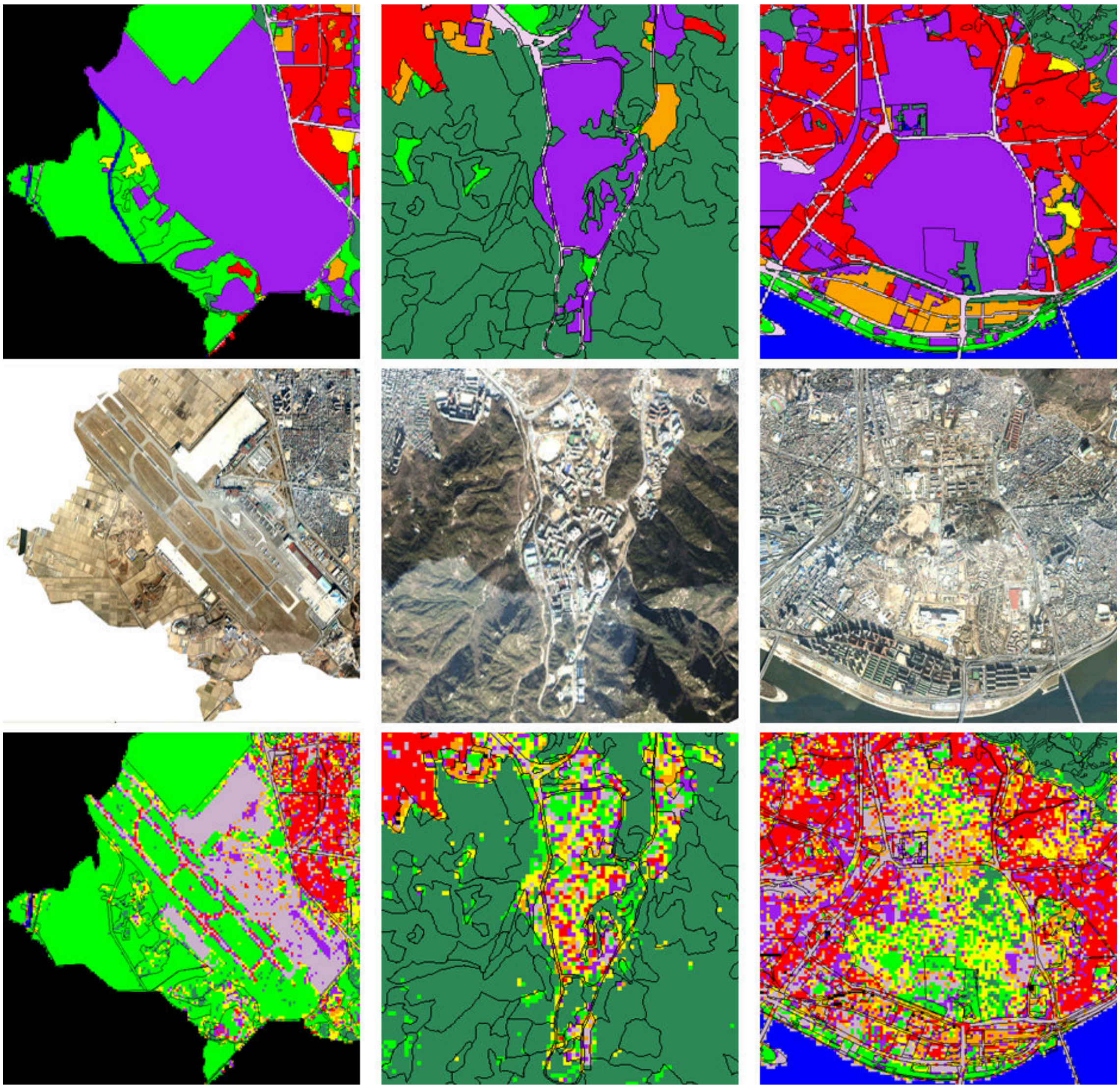
A confusion matrix was produced from the both datasets, as listed in Table 3.9, to calculate the consistency for all PCs. The overall consistency was 54.5 percent. Out of all PCs, ‘WA’ and ‘TR’ showed the highest consistency between the two datasets with 85.4 percent and 76.3 percent respectively, whereas ‘SwVB’ had the lowest one with 17.4 percent. The low consistency of ‘SwVB’ indicates that most areas categorized as ‘SwVB’ in the biotope dataset were classified as other PCs in the Landsat-7 ETM+ dataset. 82.6 percent of entire areas categorized as ‘SwVB’ from the biotope map were classified from Landsat-7 ETM+ imagery as follows: 21.1 percent as ‘unS’, 20.6 percent as ‘SwoB’, 15.1 percent as ‘LD’, 10.4 percent as ‘HD’, 9.9 percent as ‘MD’, 4.6 percent as ‘TR’, 0.8 percent as ‘unC’ and 0.1 percent as ‘WA’.

Table 3.9 Confusion matrix of pixel classes. The rows of the confusion matrix represent the PCs derived from satellite data (classified pixel), whereas the columns indicate the PCs based on biotope data (ground truth), showing the degree of agreement between the classified pixels and the ground truth. See Table 3.2 for definitions of codes.

		Ground truth								
Classified pixels	**PC**	WA	TR	unS	SwoB	SwVB	LD	MD	HD	Total
	unC	252	140	113	579	758	5	1529	912	4288
	WA	**31657**	29	259	212	135	0	31	52	32375
	TR	85	**142253**	8019	707	4642	340	661	899	157606
	unS	809	17685	**25899**	2568	21424	634	2940	2934	74893
	SwoB	2032	2059	2257	**17293**	20938	214	5076	25680	75549
	SwVB	456	3933	2964	5787	**17715**	392	6391	22633	60271
	LD	424	12875	6801	7925	15290	**1099**	8813	14074	67301
	MD	1197	2963	1990	7282	10057	269	**14362**	15303	53423
	HD	172	1704	809	10030	10599	242	8499	**118398**	150453
	Total	37084	183641	49111	52383	101558	3195	48302	200885	**676159**
Accuracy (%)		**85,4**	**76,3**	**52,7**	**33,0**	**17,4**	**34,4**	**29,7**	**58,9**	**100**

Three areas of ‘SwVB’ with a low concurrence are exemplified in Figure 3.6. Of the nine images, the top three show the areas of ‘SwVB’ from the biotope map, which are the airport (D5), a university as public facility (C12, C13) and a military area as an inaccessible area (C15) respectively.

However, in the three images at the bottom the same areas are comprised of various kinds of PCs gained from Landsat-7 ETM+. For instance, various land surfaces in the airport, e.g. concrete-covered areas in runway and parking areas for cars and aircrafts, grass, bare grounds as well as buildings, are subsumed under the biotope type ‘airport (D5)’ in the biotope map. Further, that military area which is inaccessible to ground surveyors comprises various kinds of land cover. Consequently, it is not possible to comprehensively describe and interpret various climatic phenomena by using the biotope dataset of Seoul, which is the sum of various land cover types and represents land use types.



(A) Airport **(B) University** **(C) Inaccessible area**

Figure 3.6 The PC 'SwVB' based on biotope types (upper) and satellite imagery (lower) overlaid with vector files of the biotope dataset in comparison with aerial photos (middle). The images indicate the airport (A), a university (B) and an inaccessible area (C, a military area), respectively. See Figure 3.4 for defining colors of land cover classification. (Source of aerial photos: Blue map - www.rtouch.com)

3.3.4 Conclusion of comparing both datasets

Table 3.10 shows the advantages and drawbacks of the two datasets together with their general information.

Table 3.10 Comparison of Landsat-7 ETM+ and biotope maps of Seoul

	Landsat-7 ETM+	**Biotope maps of Seoul**
Information type	Land cover	Land use
Available area	Seoul and the surrounding areas	Only Seoul
Renewal	Any time, if satellite images would be provided	Every 5 years
Advantages	- Easy renewal or supplementing of up-to-date land cover change - Available for various kinds of land surface properties - Available for land cover information in inaccessible areas - Acquisition in a fast and cost-effective manner	- Detailed land use information based on field survey in the map on scale 1:1,000 - Comprehensive attribute data included
Drawbacks	- Misclassification resulting from similar spectral properties of surface materials - Difficulty of getting information in areas smaller than 30 meters using Landsat-7 ETM+, e.g. roads, railways	- Insufficient for getting various kinds of surface characteristics, e.g. airport, university, hospital - Time-consuming and costly during field survey for renewing or supplementing land use change - Incapable of getting information in inaccessible areas by field survey, e.g. US army, conservation areas

The already existing biotope maps of Seoul were not suitable as main input in climate analysis for planning usage in Seoul, although this dataset offered detailed land use information and comprehensive attribute data: The biotope dataset of Seoul is available only for the administrative area of Seoul, which implies insufficient information about effects of the surroundings on climate and air quality in Seoul. Besides, the 65 biotope types were not designed to represent detailed information on land surface properties appropriate for climate analysis. Some of the biotope types include several types of land cover showing different climatic characteristics. Furthermore, land use information for inaccessible areas, e.g. military areas, could not be acquired by ground survey.

Thus, no detailed land cover data are available for these areas. Finally, due to an interval of five years for its renewal and supplement, the biotope dataset does not reflect the rapid changes in land use taking place in Seoul over short time periods. A shorter interval would, however, cause time-consuming and expensive ground-based data collection.

In contrast, the satellite dataset of Landsat-7 ETM+ shows a lot of potential as a basis for planning-oriented climate analysis in Seoul. First of all, land cover information on the surroundings as well as the administrative area of Seoul can be acquired by Landsat-7 ETM+ imagery. Second, these satellite data also allow to identify various kinds of land cover characteristics of otherwise inaccessible areas. Third, land cover change can be easily updated and supplemented if satellite images are provided. Thus it is possible to quickly respond to changes in land cover and their effects on climate.

Misclassifications resulting from similar spectral signatures of surface materials are a drawback of Landsat-7 ETM+ in the case of Seoul. Because of its spatial resolution of 30 m, smaller areas like roads and railways could not be fully retrieved from Landsat-7 ETM+ in this study. However, some misclassifications were remedied by replacing them with corresponding datasets of biotope maps.

3.4 Postprocessing for pixel classes used in CAMPUS

The final spatial distribution of the pixel classes used in CAMPUS was determined by combining the satellite-based land cover classification and roads and railways with the PVC-covered agricultural areas taken from biotope dataset. The roads from the biotope dataset were fused to the PC ‘SwoB’, and the railways to the PC ‘SwVB’. This is because the biotope types of railways (D1 and D2) include not only railways but also related facilities, e.g. railway stations. The PVC-covered agricultural areas were replaced by the biotope type ‘G5’, merging to the ‘SwVB’.

In order to use the pixel classes for further analysis in CAMPUS, two processes were followed; computation of fractional coverage of each individual pixel class (3.4.1) and attributation of pixel classes (3.4.2).

3.4.1 Fractional coverage

The fractional coverage was computed based on the final pixel classes that have a 30m resolution grid. A 50m resolution grid was used as a target grid of arbitrary spatial resolution for storing the computed fractional coverage within a square area surrounding the center of each target grid cell, for which the fractional coverage of each PC in a grid cell is computed. The computation of fractional coverage at a 50m scale was set for 1000 pixels in W-E direction and 800 pixels in N-S direction.

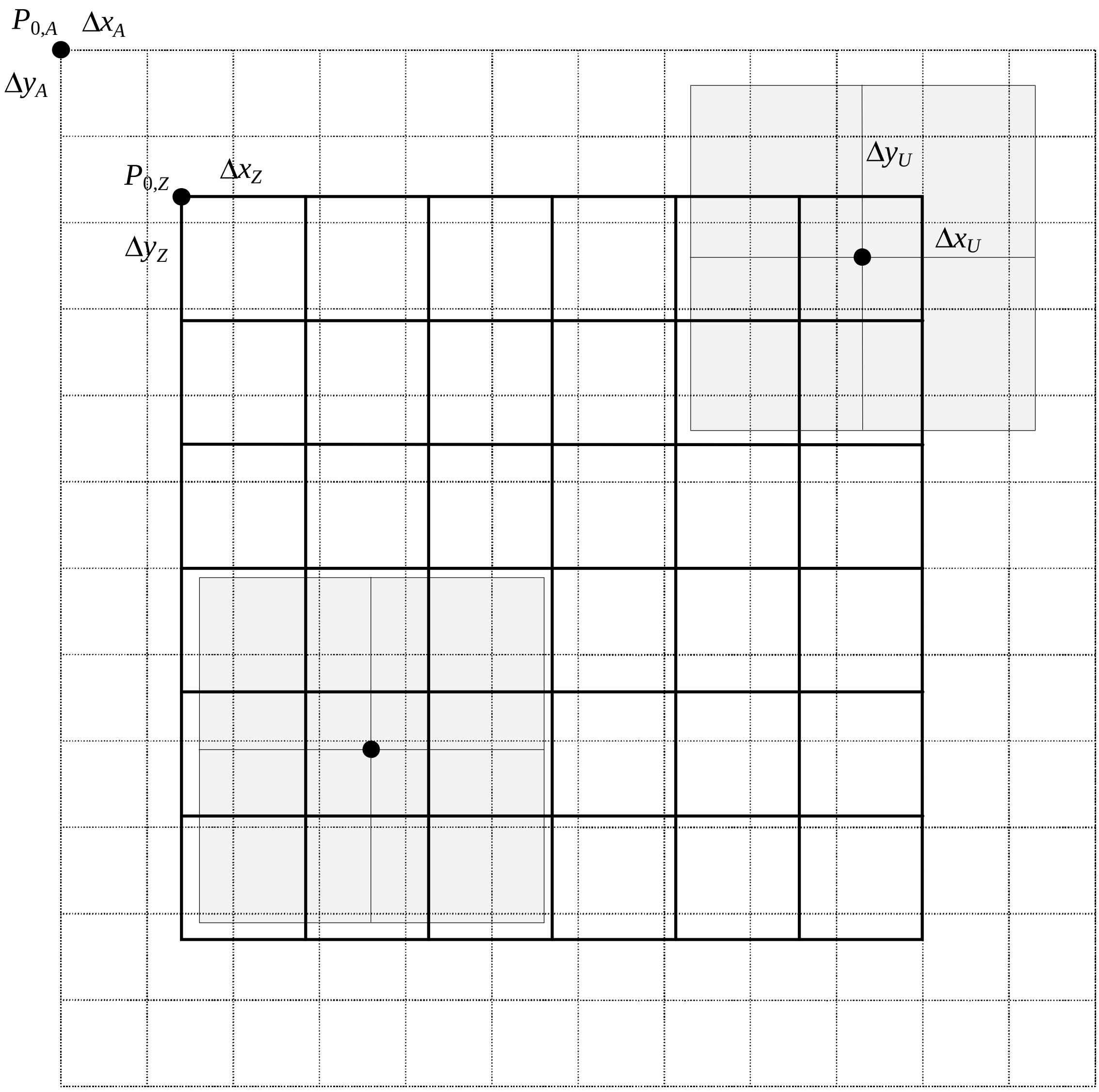


Figure 3.7 Scheme of the computation of fractional coverage (solid grid as output; $\Delta x_Z = \Delta y_Z = 50m$) of pixel classes (dotted grid as input; $\Delta x_A = \Delta y_A = 30m$) for a square area (gray window; $2\Delta x_U = 2\Delta y_U = 100m$) centered on each target grid cell. The spatial resolutions of both grids as well as the size of the square can be chosen arbitrarily. The grid resolutions in brackets were used in CAMPUS (Source: Parlow et al. 2006).

The size of the square is usually chosen equal to or larger than the size of a target grid cell. In CAMPUS, the fixed size of a square is 100m, i.e. the fractional coverage of each pixel class is computed to the order of 1ha. Figure 3.7 shows the scheme of the computation of fractional coverage

$$ {}^{j}f_{i,k} = \frac{1}{\Delta A_U} \cdot \sum_{m} \sum_{n} {}^{i,k}\Delta A_{m,n} \cdot \delta\left(c_{m,n}, j\right) \tag{3.1} $$

where j is the pixel class and ΔA_U is the neighborhood area. The indices (m,n) and (i,k) indicate coordinates on input grid and output grid, respectively.

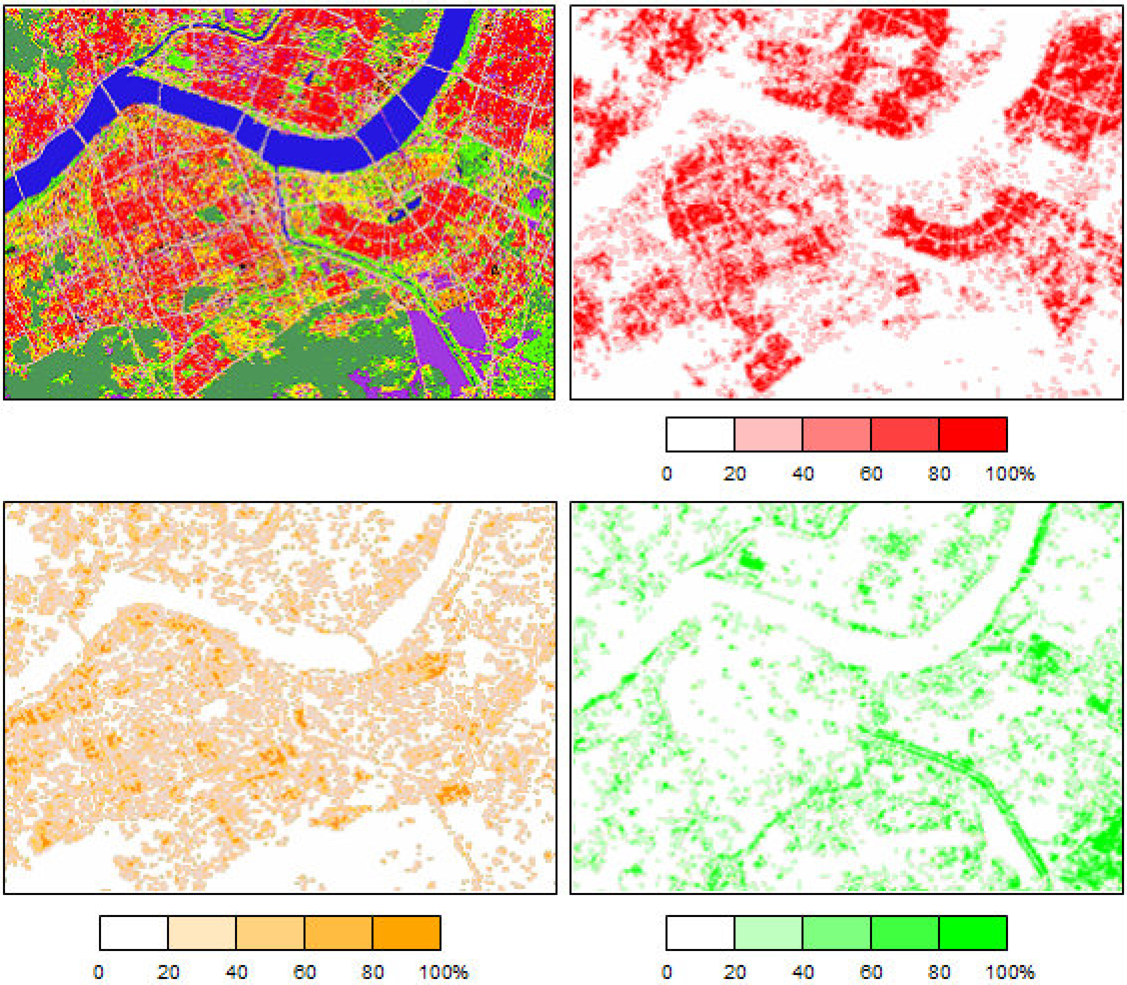


Figure 3.8 Distribution of original PCs in a southern part of Seoul (upper left) and their fractional coverage of HD (upper right), MD (lower left) and unS (lower right). Grading color scales indicate graduating percentages of coverage, ranging from 0 percent (white color) to 100 percent (high color saturation).

According to this formula, the fractional coverage of each pixel class was computed, which shows the space that each PC occupies within 1ha. Figure 3.8 shows the distribution of original PCs in a southern part of Seoul and its fractional coverage of HD, MD and unS in the same area.

Grading color scales of white to red (HD), orange (MD) and green (unS) indicate the changing degrees of coverage. For example, a red segment on the upper right image indicates a 81 percent to 100 percent degree of coverage by HD, while the lightest tone of red refers to 1 percent to 20 percent. White color corresponds to 0 percent coverage.

3.4.2 Attributation of pixel classes

Based on the fractional coverage, the ratios of spatial distribution to climate-related dimensions were calculated for each pixel class. The attributation of a dimension A was calculated as a weighted average based on fractional coverage.

$$A = \frac{1}{\sum_{i=1}^{8} f_{PC_i}} \sum_{i=1}^{8} \left(f_{PC_i} A_{PC_i} \right) \tag{3.2}$$

where f_{PC} is the fractional coverage of eight pixel classes and A_{PC} is the attribute value of eight pixel classes. In the following section, the attribute values are introduced, showing how to calculate them in detail. Surface dimensions used for calculation of LD, MD, SwVB and HD are defined in Figure 3.9.

Surface sealing ratio λ_S and plan area aspect ratio λ_P

The surface sealing ratio is the surface covered with impermeable materials as a percentage of the reference surface, whereas the plan area aspect ratio refers to a surface density ratio, i.e. the building-to-land ratio.

The impermeable pavement ratio and the building-to-land ratio offered by the biotope dataset of Seoul were employed for calculating both surface characteristics. Of all biotope types, only those that best demonstrate the characteristics of each pixel class were selected for the calculation. For instance, the PVC-covered areas, which were classified as the PC ‘SwVB’, were not taken into account for the calculation of the attribute values of ‘SwVB’. This is because the PVC-covered areas are regarded as green areas in the biotope maps. Hence, they do not contain any information on geometric characteristics, although the PVC-covered surfaces have geometric characteristics, e.g. greenhouses.

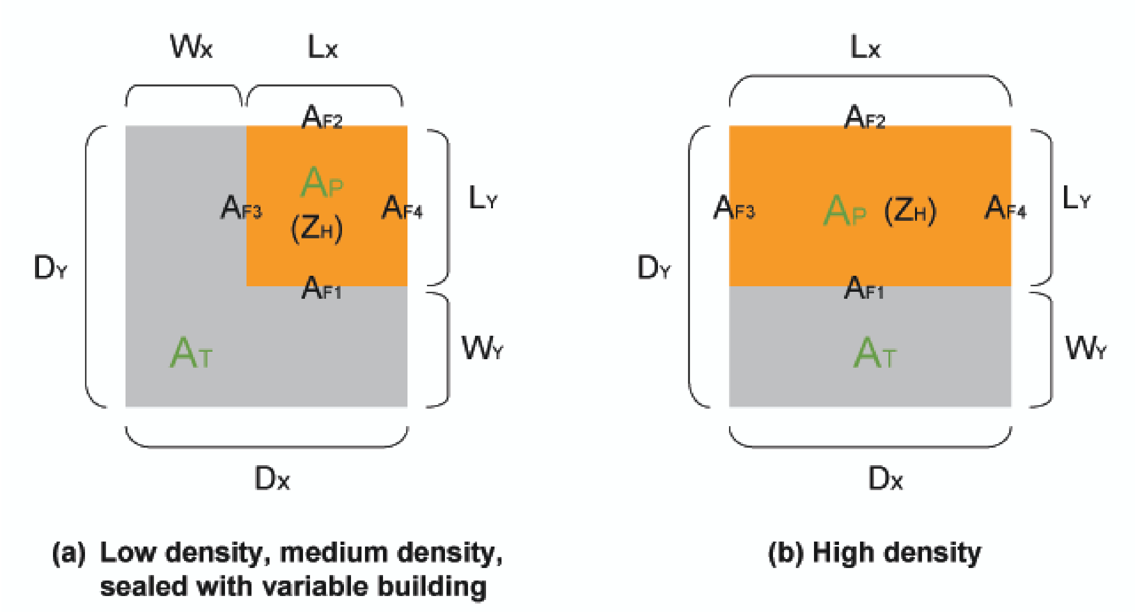


Figure 3.9 Definition of surface dimensions of two simplified patterns for LD, MD, and SwVB (a, attached pattern), and HD (b, detached pattern) applied in CAMPUS. A_T is the total lot area (m^2), while A_P is the plan area of roughness elements e.g. buildings (m^2). A_F indicates the frontal area of roughness elements (m^2), and L_X and L_Y are the horizontal dimensions of roughness element (m). The height of roughness element is expressed as Z_H (m). Hence, for example, A_{F1} is calculated by multiplying L_X by Z_H. The total lot areas of both patterns as well as the plan area of roughness element of the pattern (a) are supposed as squares in CAMPUS. Using these measurements, the plan area ratio is defined: $\lambda_P = A_P/A_T = L_XL_Y/D_XD_Y$, and the complete aspect ratio is defined: $\lambda_C = \{(A_T\text{-}A_P)+(A_P+\Sigma A_{Fi})\}/A_T = (A_T+\Sigma A_{Fi})/A_T$.

Building height $\overline{z_H}$ and effective building height $\overline{z_{eff}}$

The height of roughness elements is the simplest first-order control on surface aerodynamic properties (Grimmond & Oke 1999). In CAMPUS, two kinds of building height were introduced. The effective building height $\overline{z_{eff}}$ is the height that takes into account the plan area aspect ratio (λ_P). For calculating this height element, the mean building height $\overline{z_H}$ was first calculated by using an area-weighted average for each unit offered by the biotope dataset.

$$\overline{z_H} = \frac{\sum_{i=1}^{n}(A_{Ti} \cdot z_{Hi})}{\sum_{i=1}^{n} A_{Ti}} \quad (3.3)$$

where, AT is the total lot area. Finally, the effective building height was calculated by multiplying the mean building height by the mean plan area aspect ratio which was calculated as a straight geometric average.

$$\overline{z_{eff}} = \overline{z_H} \cdot \frac{\sum_{i=1}^{n} \lambda_{Pi}}{n} \quad (3.4)$$

Aerodynamic roughness length Z_0

This term is defined as the height at which the neutral wind profile extrapolates to a zero wind speed. It is related, but not equal to, the height of the roughness elements (Oke 1987). Although Z_0 is vital to describe the aerodynamic characteristics, assigning the value remains problematic (Grimmond & Oke 1999). Hence, Grimmond & Oke (1999) examined several methods to determine Z_0, and two of their methods were chosen to estimate Z_0 for CAMPUS.

The first method is a simple rule of thumb (Rt). It is the most common morphometric approach, related to the mean height of elements ($\overline{z_H}$).

$$z_0 = f_0 \overline{z_H} \quad (3.5)$$

where f_0 corresponds to empirical coefficients derived from observation. For CAMPUS f_0~0.1 suggested by Hanna & Chang (1992) was taken, which is a commonly quoted approximation (Grimmond & Oke 1999). This formula works quite well in the mean for Z_0, but it increasingly overestimates roughness at very high and very low densities (Grimmond & Oke 1999).

The second one employed is a method proposed by Bottema (1995 and 1997) that considers the frontal area index (λ_F) which combines mean height, breadth and density of elements. This method (Bo) was suggested by the study of Grimmond & Oke (1999) as the most useful morphometric method that can be used to predict Z_0.

$$\frac{z_0}{\overline{z_H}} = \frac{\overline{z_H} - z_{dpl}}{\overline{z_H}} \exp\left[-\frac{k}{(0.5\lambda_F C_{dh})^{0.5}}\right] \quad (3.6)$$

where

$$C_{dh} = 1.2\max\left[1 - 0.15(L_x / z_H), 0.82\right]\min\left[0.65 + 0.06(L_y / z_H), 1.0\right] \quad (3.7)$$

k is the von Kármán's constant (0.4) and z_{dpl} is a (in-plane sheltering) placement height calculated using various alternatives of equation by the density and pattern of the building arrangement (low or high density, and normal or staggered pattern). In CAMPUS, density and only normal pattern of building arrangement were considered, since the use of the equations for staggered pattern is recommended when the flow is oblique to the roughness elements (Grimmond & Oke 1999) and no direction of flow is considered in CAMPUS. Hence, z_{dpl} was calculated as follows:

low densities

$$\frac{z_{dpl}}{z_H} = \frac{L_x + 0.33(L_{ca} + L_{bo})}{D_x} \quad (3.8)$$

high densities $(W_x < L_{ca} + L_{bo})$

$$\frac{z_{dpl}}{z_H} = \frac{L_x + 0.33\left(2 - \frac{W_x}{L_{ca} + L_{bo}}\right)W_x}{D_x} \quad (3.9)$$

where

$$L_{ca} + L_{bo} = 4\left[L_y \overline{z_H} / (0.5L_y + z_H)\right] \quad (3.10)$$

In the equation 3.10, L_{ca} is the length of the frontal vortex and L_{bo} is the length of the recirculation zone.

In CAMPUS, however, the method 'Bo' was not applied for the case of $W_x = 0$ which occurs when the left or right side of the building in the attached building pattern (set for HD, see Figure 3.9) faces the prevailing wind. For this reason, two alternatives were taken into consideration to calculate Z_0 for HD and compared: No attached building pattern but a detached one was applied for HD (Bo_det), and only the case that the prevailing wind faces the front of the building in the attached building pattern was considered for calculating Z_0 of HD to avoid $W_x = 0$ (Bo_att). Building height z_H was regarded as mean building height $\overline{z_H}$ because CAMPUS does not consider individual buildings, but uses only the mean value of buildings.

Several values of Z_0 using the above-mentioned methods are showed in Table 3.11. Among them, the Z_0 calculated using the Bo_att was selected for CAMPUS, since the Bo_att method explicitly distinguishes the Z_0 properties between LD and HD as compared with the Bo-det method. Furthermore, the 'Rt' formula overestimated roughness values of Seoul compared to values established for other Asian cities with similar urban structures (e.g. Kinouchi & Yoshitani 2001).

Table 3.11 Values of aerodynamic roughness length (Z_0) using several methods

Pixel Classes	SwVB	LD	MD	HD
Z_0 (Rt)	0.850	1.240	4.720	1.510
Z_0 (Bo_det)	0.222	0.441	2.630	0.313
Z_0 (Bo_att)	0.222	0.441	2.630	0.714

The values of the previous study from Parlow et al. (2006) were used for the Z_0 of non-built-up areas such as WA, unS and SwoB, while the value of TR was calculated using the 'Rt' formula, considering f_0 ~0.1 which is a good overall mean value for land surfaces (Grimmond & Oke 1999). The data on height of trees was taken from the biotope dataset.

Complete aspect ratio λ_C

The complete aspect ratio is the ratio of the complete surface area (the total three-dimensional area of buildings) to the plan area. Hence, it gives an idea of the increase in the active surface-air interface due to the vertical dimensions of the city as compared with a flat area (Grimmond & Oke 1999).

In CAMPUS, the values of λ_C for LD, MD and SwVB were calculated based on

$$\lambda_C = 1 + 4\frac{\overline{z_H}}{D_y}\sqrt{\lambda_P} \tag{3.11}$$

and λ_C for HD was calculated based on

$$\lambda_C = 1 + 2\frac{\overline{z_H}}{D_y}(1 + \lambda_P) \tag{3.12}$$

The values of the remaining PCs were 1.00 due to no building height.

Cold air production ratio γ_{Cp}

Cold air is produced in green spaces as a result of their nightly cooling. The cold air production ratio, i.e. the volume of cold air production, shows how much cold air per square meter per hour the green spaces produce. It is usually assumed that open spaces covered with low vegetation like meadows, fields and cultivated areas produce more cold air than green spaces with trees like forests (Mosimann et al. 1999). The commonly used ratio for open spaces is $12m^3m^{-2}h^{-1}$, which was developed by King (1973). However, the cold air production ratio for forests should not be underestimated compared to that for open spaces (Nachbarschaftsverband Stuttgart 1992), because forests cool a larger volume of air than an equivalent area of open spaces (Gossmann 1987; Ministry of the Interior Baden-Württemberg 2004; Müller 2004). Concerning the calculation of cold air production ratio for forests, further research is still required (Baumbach et al. 1999). In CAMPUS, $30m^3m^{-2}h^{-1}$ and $15m^3m^{-2}h^{-1}$ were applied as the ratios for TR and unS, in accordance with the newer findings.

Contribution of area source to annual mean concentration of NO_2 C_{AS}

This attribute value, which will be used for local atmospheric loads of the chapter 4.1.3, is used for estimating the contribution of the area source to the annual mean concentration of NO_2. These attribute values were calculated based on the values used for European cities in the study REKLISO (Parlow et al. 2006) as well as the mean 2005-2006 NO_2 concentrations of 27 air monitoring stations in Seoul

Calculated attribute values used for further steps in CAMPUS are shown in Table 3.12. They are a particularly important dataset for establishing the ventilation situation in Chapter 4.2.

Table 3.12 Attribute values of individual pixel classes for surface sealing ratio λ_S, plan area aspect ratio λ_P, mean building height $\overline{z_H}$, effective building height $\overline{z_{eff}}$, aerodynamic roughness length z_0, complete aspect ratio λ_C, cold air production ratio γ_{CP}, and concentration of nitrogen dioxide measured at air pollution monitoring stations C_{AS}

PC	λ_S (%)	λ_P (%)	$\overline{z_H}$ (m)	$\overline{z_{eff}}$ (m)	z_0 (m)	λ_C	γ_{CP}	C_{AS} (ppb)
WA	0.0	0.0	0.0	0.0	0.001	1.00	0	0
TR	0.3	0.1	0.0	0.0	1.070	1.00	30	0
unS	2.7	0.1	0.0	0.0	0.100	1.00	15	0
SwoB	98.0	0.8	0.5	0.0	0.010	1.00	0	12
SwVB	70.8	42.7	8.5	3.6	0.222	1.44	0	64
LD	55.1	35.3	12.4	4.4	0.441	1.59	0	28
MD	80.6	45.9	47.2	21.7	2.630	3.56	0	56
HD	93.3	64.9	15.1	9.8	0.714	2.00	0	56

3.5 Relief

Topography plays a vital role in the formation of local climate and dispersion of air pollutants. This applies especially in the case of Seoul which is surrounded by mountainous terrain. Two topography datasets are considered for CAMPUS. One is the Digital Elevation Model (DEM) generated by contour interpolation and the other is the Shuttle Radar Topography Mission (SRTM) digital topographic dataset generated by using single-pass radar interferometry.

The DEM data, which are provided by the Korean Ministry of Environment, were produced on the basis of the topographic map in the scale 1:25,000 with the sampling interval of 1-arc second (approximately 30 meter data spacing). Their coordinate system is the Transverse Mercator projection. This cartographically-derived DEM offers original topography coverage, which does not include both man-made features and vegetation.

The SRTM digital topographic data released by the National Aeronautics and Space Administration (NASA) of the United States is a near-global digital elevation model of the Earth. The SRTM-based DEM for the Republic of Korea has a 3 arc-second resolution, referred to as approximately 90 meter data. SRTM data are organized into individual rasterized tiles, each covering one degree by one degree in latitude and longitude. Seoul and its surroundings are covered by two tiles of N37E126 and N37E127, hence it is needed to assemble them into a single raster. Since SRTM maps the shape of the Earth's surface, it includes the geometric and structural properties as well as the elevation of topography. Furthermore, the short wavelength radar on the SRTM cannot penetrate the vegetation. Hence, SRTM will lead to digital surface models showing visible surface (e.g. top of buildings and vegetation) and not the bare ground (Büyüksalih et al. 2005).

The cartographically-derived DEMs and SRTM data were compared to examine which dataset gives the higher quality and what is more suitable for climate analysis in CAMPUS. Both datasets were transformed to a 50meter grid, using a bilinear interpolation method, and the SRTM-based DEM was re-projected to match the coordinates of the Transverse Mercator map projection. To visually represent the DEMs, both datasets were converted into images of shaded topography that express each pixel's reflectance relative to the light source.

Figure 3.10 shows the images of shaded topography of both DEMs for a part of the Seoul area. The SRTM dataset had certain advantages because it contains the current status of the land surface. The landfill located in the western part had a flat topography, before being elevated by waste fillings, and was transformed into a public park with an elevation of approximately 90meters.

The SRTM dataset describes the changed topography of this landfill. Further it represents ground surface in flat areas, which is not represented in the contour-interpolated DEM by using too few sampling points in creating a TIN (Triangulated Irregular Network). Besides, comparing the elevation values of the Han River, the values in SRTM range from 2m (west) to 9m (east), while the DEM contains elevation values of zero for the river.

Despite certain advantages of the SRTM data, the contour-interpolated DEM was selected for use in CAMPUS. The mountainous topography in the cartographically-derived DEM appeared more elaborate than that in SRTM. Further, the SRTM data suffer from problems due to the geometric and structural properties of the imaged surface (Gamba et al. 2002). The tall structures in the city center as well as bridges were explicitly acknowledged in the shaded topography image of SRTM data. Further, the surface models containing the height of vegetation offered by SRTM are not ideal for climate analysis that is needed in CAMPUS.

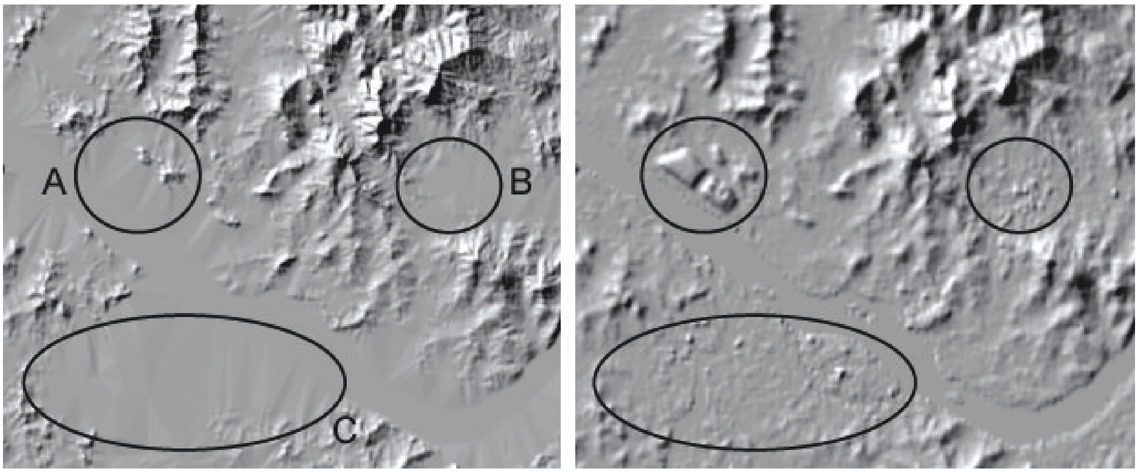


Figure 3.10 Shaded-relief maps of the cartographically derived DEM (left, 50m resolution) and SRTM DEM (right, 50m resolution) for a part in Seoul area. The circles indicate the landfill with changed topography (A), tall structures in the city center (B) and the representation of surface ground in flat areas (C).

Table 3.13 shows the terrain attributes of the Digital Terrain Model (DTM) used in CAMPUS: elevation, elevation gradient, slope, aspect, hollow depth and relative height. They are used for analyzing ventilation situations of the study area in Chapter 4.2.

Table 3.13 Terrain attributes of the Digital Terrain Model (DTM) used in CAMPUS

Attribute	Code	Unit	Description
Elevation	z	m	Elevation above sea level
Elevation gradient	$\overline{\nabla} z$	-	Vector with $\frac{dz}{dx}$- and $\frac{dz}{dy}$ -components, which indicate the ascent of elevation z in directions of x (east) and y (north), per meter of horizontal distance
Slope	a	degree	Incline measured in direction of gradient $\overline{\nabla} z$, i.e. in the direction of strongest ascent of elevation z
Aspect	Φ	degree	Azimuth that a slope faces, i.e. the angle to the Sun's position of slope; 0° = N, 90° = E, 180° = S, 270° = W
Hollow depth	$\Delta h_{M,Z}$	m	Maximum depth of 'Seas' resulting from simulated flooding of underlying topography (here z)
Relative height	Δz_{500m}	m	Deviation of elevation z from the average elevation on a 500m × 500m (25ha) area

4 Maps of climate analysis, evaluation and planning recommendations

Climate analysis and evaluation are essential research contributions to the development of climate maps, which present spatially distributed information on climatic situations of Seoul and its surrounding areas. The latter also provide essential information to generate maps with planning recommendations concerning climate and air quality.

In this chapter, based on the intermediate datasets established in Chapter 3, spatially distributed information on Areal Types, representing function-related land use, and environmental loads (chapter 4.1), as well as ventilation situations (chapter 4.2) will be analyzed and evaluated. The information will be further used in numerical evaluations to generate maps with planning recommendations (chapter 4.3).

4.1 Maps of basic function and environmental loads

The following four types of maps are included in this chapter: Areal Types (4.1.1), maps simulating wind and temperature fields based on a mesoscale meteorological model (4.1.2), maps of local atmospheric loads (4.1.3) and maps indicating local thermal loads (4.1.4). In particular, information on local atmospheric and thermal loads is especially important for maps with planning recommendations, because it helps to determine which areas should be handled with higher priority in planning processes.

4.1.1 Areal Types (AT)

Pixel Classes (PCs), which were introduced in the previous chapter, represent different land cover types with specific electromagnetic characteristics. Compared to the PCs, Areal Types (ATs) describe different land use types relevant for urban and regional planning. In CAMPUS, eight ATs which distinguish different functions were employed.

As shown in Table 4.1, ATs have the same categories and codes like PCs: water areas (WA), forest areas (TR), unsealed areas (unS), sealed without buildings (SwoB), sealed with variable buildings (SwVB), low density areas (LD), medium density areas (MD) and high density areas (HD). Yet ATs are clearly distinguished from PCs. While each PC indicates a kind of land cover, an AT includes various types of land cover. Strictly speaking, an AT contains various kinds of fractional surface coverages of PCs (see Equation 3.2). For example, the AT 'HD' is based mostly on information given by the PC 'HD', but it also contains the parts of other PCs such as 'unS', 'SwoB' or 'MD'.

Table 4.1 Areal types used in CAMPUS

No.	Code	Areal type (AT)	Land use characteristics
1	WA	Water areas	Water (streams, lakes, reservoirs, bays); water sport facility, open
2	TR	Forest areas	Forest land (Deciduous, evergreen and mixed forest); park (dominant: trees); agriculture (Orchards, nurseries); garden (botanical, historical and residential gardens)
3	unS	Unsealed areas	Agriculture (croplands, pastures); park (dominant: grass or soil); sport facility, open (golf courses, playgrounds); barren land
4	SwoB	Sealed areas without buildings	Transportation (Highways, roads, covered surface parking, runway)
5	SwVB	Sealed areas with variable buildings	Commercial; industrial; transportation (railroad sheds, other support structures)
6	LD	Low density areas	Residential; partly commercial
7	MD	Medium density areas	Residential; commercial
8	HD	High density areas	Residential; commercial; partly industrial

Table 4.2 shows the rules applied to the classification of the eight ATs, wherein the sequence number indicates the order of implementing the classification.

Table 4.2 Rule-based classification of Areal Types using the fractional coverage f_{PCi} of the pixel classes PC_i (i={1..8}; see Table 3.2). f_{SL} means the settlement limit (f_{SL} = 30% $\cdot f_{PC1-8}$)

Areal Type (AT)	Sequence	Classification's rule
Waters	1	$f_{PC4-8} < f_{SL} \wedge (f_{PC1} \geq f_{PC2} \wedge f_{PC1} \geq f_{PC3} \vee f_{PC1} \geq 25\% \cdot f_{PC1-8})$
Trees	2	$f_{PC4-8} < f_{SL} \wedge (f_{PC2} \geq f_{PC2} \wedge f_{PC2} \geq f_{PC3})$
Unsealed areas	3	$f_{PC4-8} < f_{SL}$
Sealed areas with variable buildings	4	$f_{PC5} \geq 40\% \cdot f_{PC4-8}$
High density areas	5	$f_{PC6-8} \geq f_{PC4} \wedge \{f_{PC8} - \min(LD,HD)\} \geq 50\% \cdot f_{PC6-8}$
Low density areas	6	$f_{PC6-8} \geq f_{PC4} \wedge \{f_{PC6} - \min(LD,HD)\} \geq 50\% \cdot f_{PC6-8}$
Medium density areas	7	$f_{PC6-8} \geq f_{PC4}$
Sealed areas without buildings	8	Remaining areas, which are not classified

After the classification of eight ATs, a filter processing was subsequently carried out using spatial pixel connectivity to exclude individual pixels. Through this processing, individual pixels were incorporated into the adjacent neighbor pixels. Hence, four pixels (i.e. 1ha) formed the minimum size of an AT. The spatial distribution of eight ATs is presented in Figure 4.1.

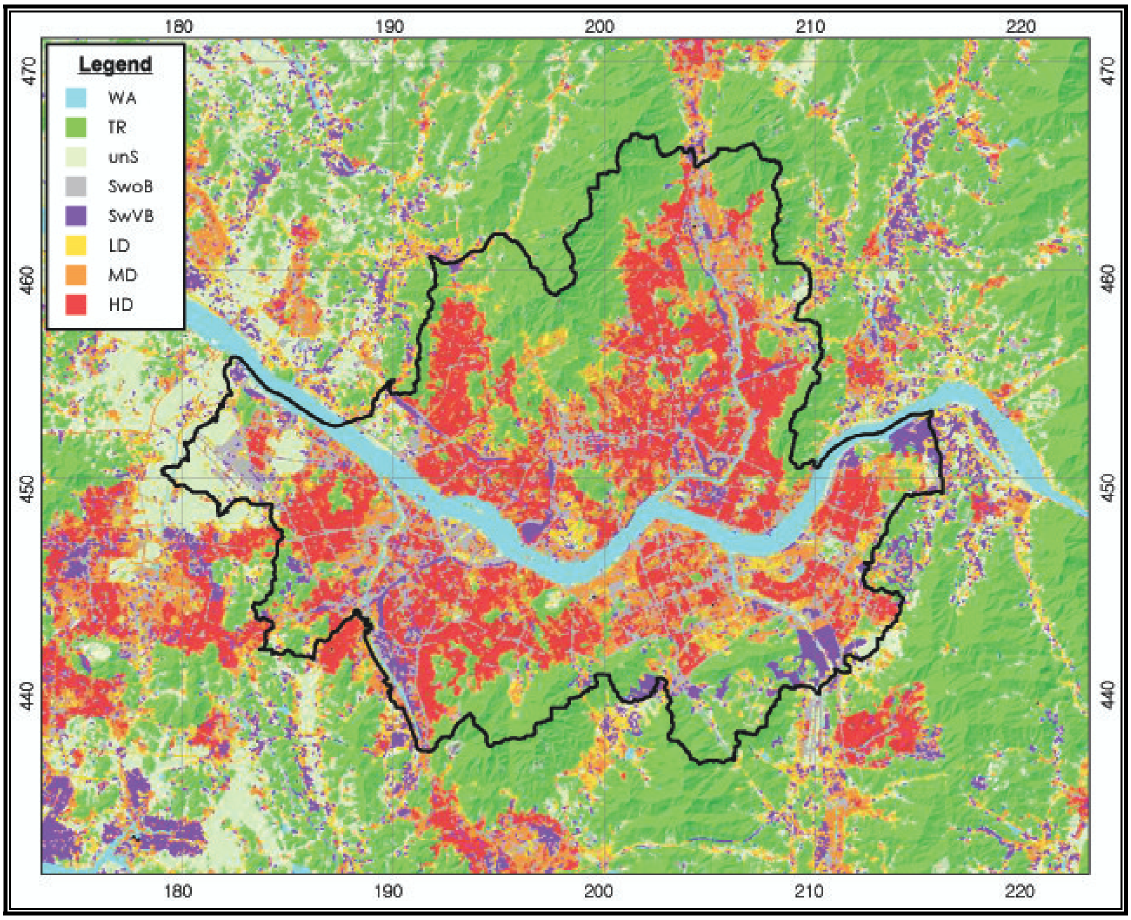


Figure 4.1 The spatial distribution of Areal Types

4.1.2 Mesoscale wind and temperature modeling

The mesoscale can be descriptively defined as an intermediate spatial scale of weather systems ranging between storm scale and synoptic scale systems. Its horizontal scale is on the order of a few kilometres to several hundred kilometres, and the vertical scale extends from some tens of meters to the depth of the troposphere (Pielke 2002).

Simulation models are often used in local spatial planning to describe synoptic atmospheric patterns. Since local atmospheric patterns are strongly influenced by nonlocal (mesoscale) atmospheric structures, mesoscale meteorological modeling has been carried out in many cases to simulate local wind and temperature profiles. The mesoscale meteorological model FITNAH (Flow over Irregular Terrain with Natural and Anthropogenic Heat Sources) was adopted to calculate wind and temperature conditions in Berlin (see Groß 1989 for further information on FITNAH, and Senate Department for Urban Development 2003 for its application in Berlin). The wind profile of Stuttgart was simulated by the mesoscale model KAMM (Karlsruhe Atmospheric Mesoscale Model; see Ministry of the Interior Baden-Württemberg 2004). Another mesoscale simulation model used to calculate mesoscale wind and temperature fields is MetPhoMod (Meteorology and Photochemistry Model) that is a three dimensional, prognostic Eulerian model for the numerical simulation of mesoscale meteorology and atmospheric chemistry (Perego 1999). This model was applied for the Upper Rhine region in Germany, as part of the larger REKLISO study (see Perego 1999 for further information on MetPhoMod, and Parlow et al. 2006 for its application in REKLISO).

Numerical models including mesoscale models have been extensively used for weather and climate research in Korea (Baik 2005). Mesoscale models have been adopted to simulate yellow sand transport (In & Park 2002), heavy rain (Park et al. 2005), summer monsoon (Kang et al. 2005) as well as air temperature and precipitation (Park & Lee 1997). Simulations of wind circumstances, like numerical simulations of wind profiles, have been carried out in small urban areas as well as in larger urban regions like Seoul metropolitan area (in this case with a model domain of 240km x 240km and two kilometer grid spacing). Both are described in Do & Chung 2005. For such simulations, the mesoscale meteorological model MM5 (the Penn State/NCAR Mesoscale Meteorological Model) has been widely used in Korea.

In CAMPUS, the mesoscale meteorological model MetPhoMod was adopted for atmospheric simulation of wind and temperature fields of Seoul and its surroundings. Figure 4.2 describes the spatial domain for the mesoscale modeling by MetPhoMod as well as the domain for CAMPUS and the domain for land cover classification used in the MetPhoMod simulation. The simulated area extends 75km in N-S and W-E direction, covering the entire area of CAMPUS as well as its surroundings. The MetPhoMod's domain covers 20 kilometers to the east of the CAMPUS study area and just five kilometers to the west of it. This is because the eastern part is mainly influenced by mountainous topography, similar to the northern and southern part. The western part, close to the West Sea, is barely influenced by topography. Using a 250m grid resolution, 300 grid cells in the x- and y- direction were set for the horizontal grid. For the vertical grid, the simulation area ranging from 20m to 4000m a.s.l. was completely covered by 30 grid cells in the z-direction.

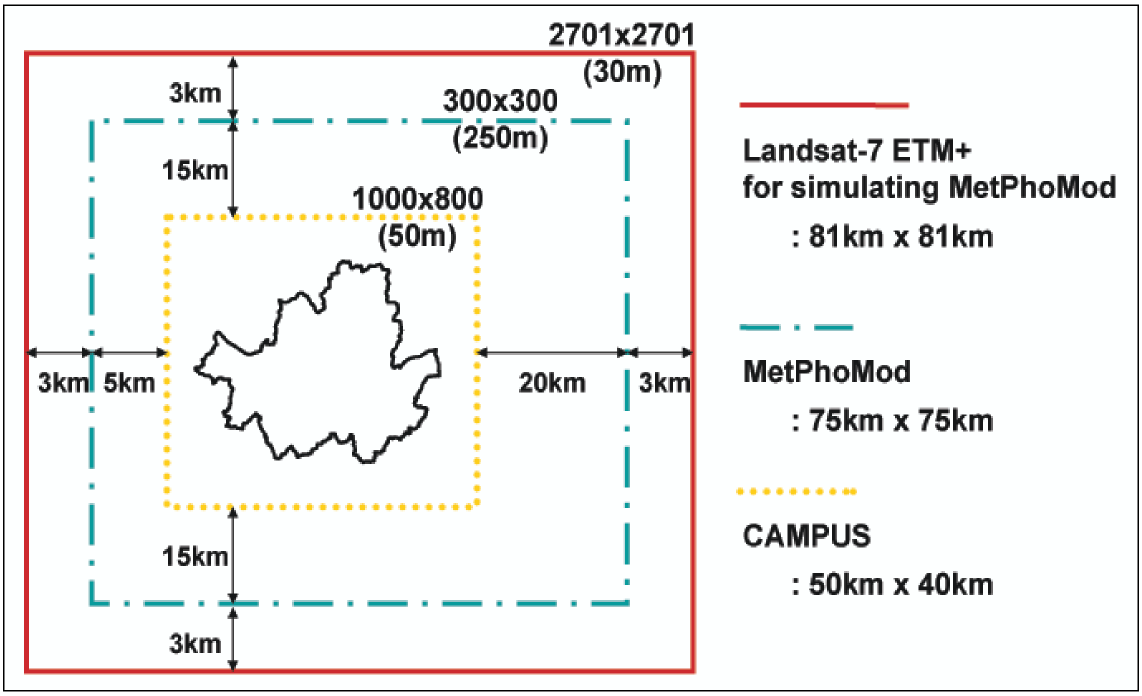


Figure 4.2 Domain for the mesoscale modeling by MetPhoMod, together with those for CAMPUS and Land cover classification by Landsat7 ETM+ used for input data for MetPhoMod

Table 4.3 shows additional parameters and their descriptions, used to perform MetPhoMod within the scope of CAMPUS. The initial values for prognostic variables, which describe the state of the atmosphere, were set according to the mean values of meteorological elements for a specific date over a 30 year-period, representing autochthonous weather conditions of Seoul. The west wind, the main wind direction of Seoul, was adopted for the simulation. In order to simulate the atmospheric structures under autochthonous weather conditions, one meter per second was defined as initial and as border condition.

Table 4.3 Parameters used for the simulation of MetPhoMod

Parameter	Value	Remark
Horizontal grid	Grid resolution = 250m; 300 grid cells in the x- and y-direction	Study area of CAMPUS and its influencing surroundings, covering 75km x 75km
Vertical grid	30 grid cells in the z-direction, covering 20m to 4000m a.s.l.	The vertical grid spacing is 20m in the lowest model level, and is stretched gradually to a maximum spacing of 1,000m. The model top is at 4,000m. The highest elevation within the study area is 874m a.s.l.
Simulation time	Start = 21/3/2007 12:00pm GMT+9; End = 22/3/2007 12:00pm GMT+9; Maximal possible time step *dt* =10sec	Simulation at the spring equinox; The possible time step is automatically shortened to 1 second.
Initial condition	Wind in west-east direction = 1m/s Wind in south-north direction = 0m/s Height-constant virtual potential temperature = 281.15K Height-constant mixing ratio = $3.6 g \cdot kg^{-1}$ Air pressure at the top level (4km) = 61200Pa	Meteorological conditions for calculating the initial conditions Air temperature = 7.4°C; Vapor pressure = 5.9hPa; Sea-level pressure = 1020hPa; The model analyzes the night-time situation (8pm to 6am). For the analysis, it requires lead time of 8 hours (from noon to 8pm).
Ground condition	Initial surface temperature = 280.55K Soil temperature 1m below surface = 280.55K	See the Table 4.4 for further ground parameters
Geographic environment	Zone difference (between local time and UTC) = 9 Map angle (between model north and geographical north direction) = 0deg Medium air pressure in the top grid cell = 61200Pa Turbidity (tunable parameter to	-

	account for the influence of aerosols on radiation) = 0.08 Stratospheric ozone = 0.35m	
Border type	Weak and height-constant west flow East component u = 1m·s^{-1} North component v = 0 Vertical component w = 0	Air temperature and humidity are mean values of each vertical layer, relative to the time of day.
Model options	Calculating soil atmosphere interactions; k-ε turbulence parameterization; Calculating advection of scalars; Coriolis forces (geostrophic); PPM-Advection algorithm; Calculating solar radiation; Calculating advection of momentum; A non-hydrostatic pressure field was calculated	No use of clouds module, damping layer and spatial filter; No chemistry input; All model options were set for mesoscale modeling of wind and temperature profiles under autochthonous weather conditions
Output	Time slices were written at an interval of 1800 seconds (30 minutes); Three dimensional wind and temperature fields (instantaneous values for the variables U, V, W and Temp with 300x300x30 grid); Wind and temperature fields in 10m height above ground (instantaneous values for the variables U, V, W and Temp with 300x300 grid); U= Wind in West-East direction (x); V= Wind in South-North direction (y); W= Wind speed in the vertical direction (z); Temp= Virtual potential temperature	The values of horizontal wind and air temperature fields at 10m height above ground, measured over a specific period of time (8pm to 6am), were used for the climate analysis in CAMPUS.

The definition of the boundary values is essential for numerical modeling. The set of ground parameters is of major importance for the simulation, because the ground is the bottom boundary of the atmosphere. Furthermore, soil-atmosphere interactions significantly affect the atmospheric patterns. Ground parameters as prognostic variables are listed in Table 4.4. All ground parameters have been estimated individually for each of the eight pixel classes, so as to accurately reflect the ground properties in the simulation. For the pixel classes 'water surface, trees, unsealed areas and sealed areas without buildings', the ground parameter values were based on the values generally accepted for the respective surfaces of 'water, trees, grass and cement/concrete'. However, the values of the other classes 'sealed with variable buildings, low density areas, medium density areas, and high density areas' were estimated by combining the values of the four surface materials mentioned above. The respective shares of each of the four surface materials were determined according to their frequency in each pixel class, which was calculated using PCs' fractional coverage.

Table 4.4 Ground parameters of pixel classes, used for MetPhoMod simulation

Parameter	WA	TR	unS	SwoB	SwVB	LD	MD	HD
Roughness Length z_0 (m)	0.001	1.070	0.100	0.010	0.222	0.441	2.630	0.714
Complete aspect ratio λ_C	1.00	1.00	1.00	1.00	1.44	1.59	3.56	2.00
Albedo α	0.10	0.12	0.15	0.18	0.20	0.17	0.16	0.15
Emissivity ε	0.98	0.98	0.95	0.92	0.92	0.92	0.92	0.92
Thermal conductivity λ (W $m^{-1}\cdot K^{-1}$)	0.63	0.50	0.50	1.28	1.28	1.28	1.28	1.28
Surface heat capacity c (J $kg^{-3}\cdot K^{-1}$)	4200	1200	1200	900	1388	1565	3261	1816
Density ρ ($kg\cdot m^{-3}$)	1000	1500	1500	2200	1996	1886	2064	2153
Volumetric heat capacity ρc (J $m^{-3}\cdot K^{-1}$)	4.20	1.80	1.80	1.98	2.77	2.95	6.73	3.91
Thermal diffusivity α ($m^2\cdot s^{-1}$)	1.50	2.78	2.78	6.46	4.62	4.34	1.90	3.27

In Figures 4.3, 4.4 and 4.5, the mesoscale wind and temperature profiles at 10m elevation above ground, averaged in the time span between 20pm and 6am, are presented as simulated by MetPhoMod. Since the mesoscale wind and temperature were simulated using grid resolution of 250m, the horizontal resolution was converted from a spacing of 250m on the coarse grid to 50m grid spacing on the finer nested grid.

Figure 4.3 shows the night-time mean wind field, including wind speed information. The simulated wind speeds are not the absolute values; they rather indicate the wind speed deviation from the average value of the entire simulation area. According to the simulated wind field, the relative wind speed in northern mountainous areas is over 200 percent higher than the area-average wind speed (blue-colored areas). However, the southern mountainous areas as well as the western outskirts have wind speed below the average value (red-colored areas). Most areas of Seoul have average or higher than average wind speed (expressed in orange, yellow and green colors).

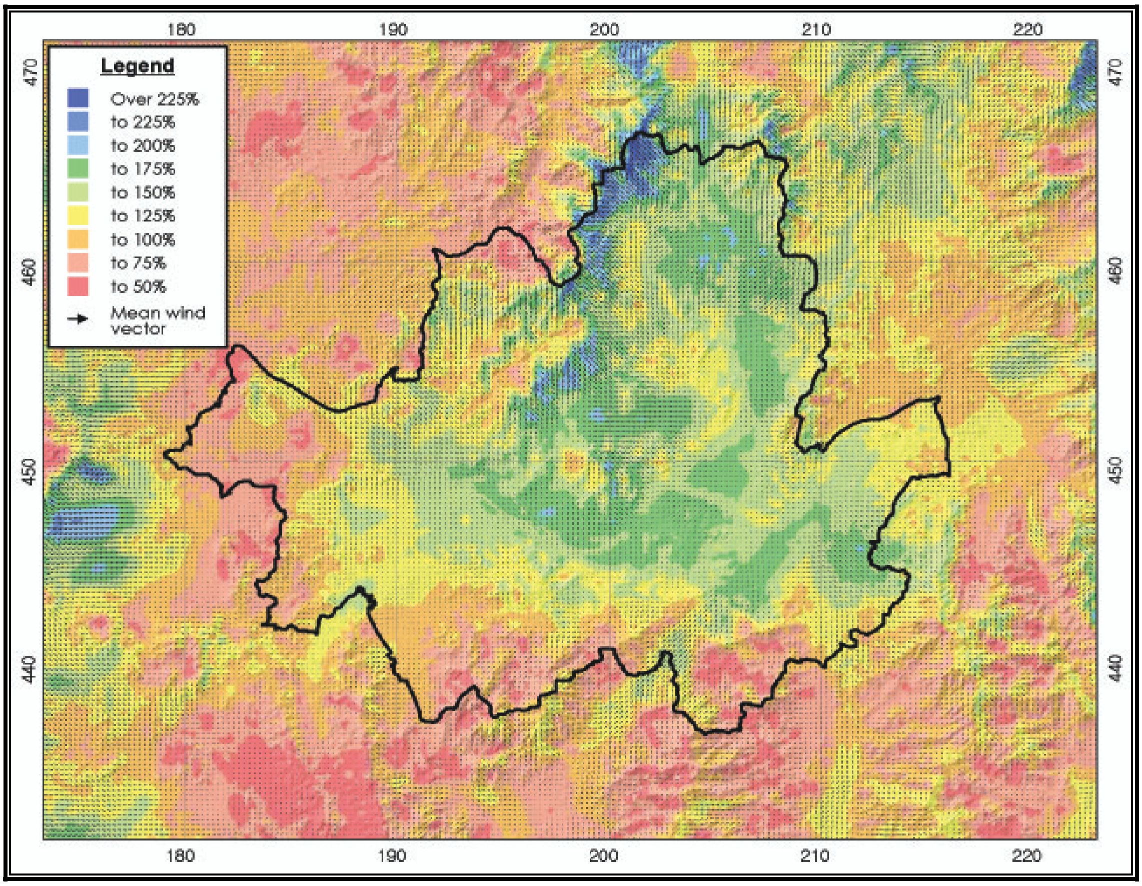


Figure 4.3 The spatial distribution of night-time mean wind speed at 10m elevation above ground, relative to the area-average wind speed during autochthonous weather conditions. This profile was simulated by the mesoscale meteorological model 'MetPhoMod'

In this wind field, the effect of topography and urban structures on local circulation was clearly simulated. The wind patterns of the northern and southern parts of Seoul are displayed in detail in Figure 4.4. Hence, it is observed that the wind patterns blowing from the surrounding areas toward the city are influenced by local topographic features on the outskirts of Seoul. In built-up urban areas, however, the wind flow is severely obstructed by urban structures like in northeastern and southeastern Seoul.

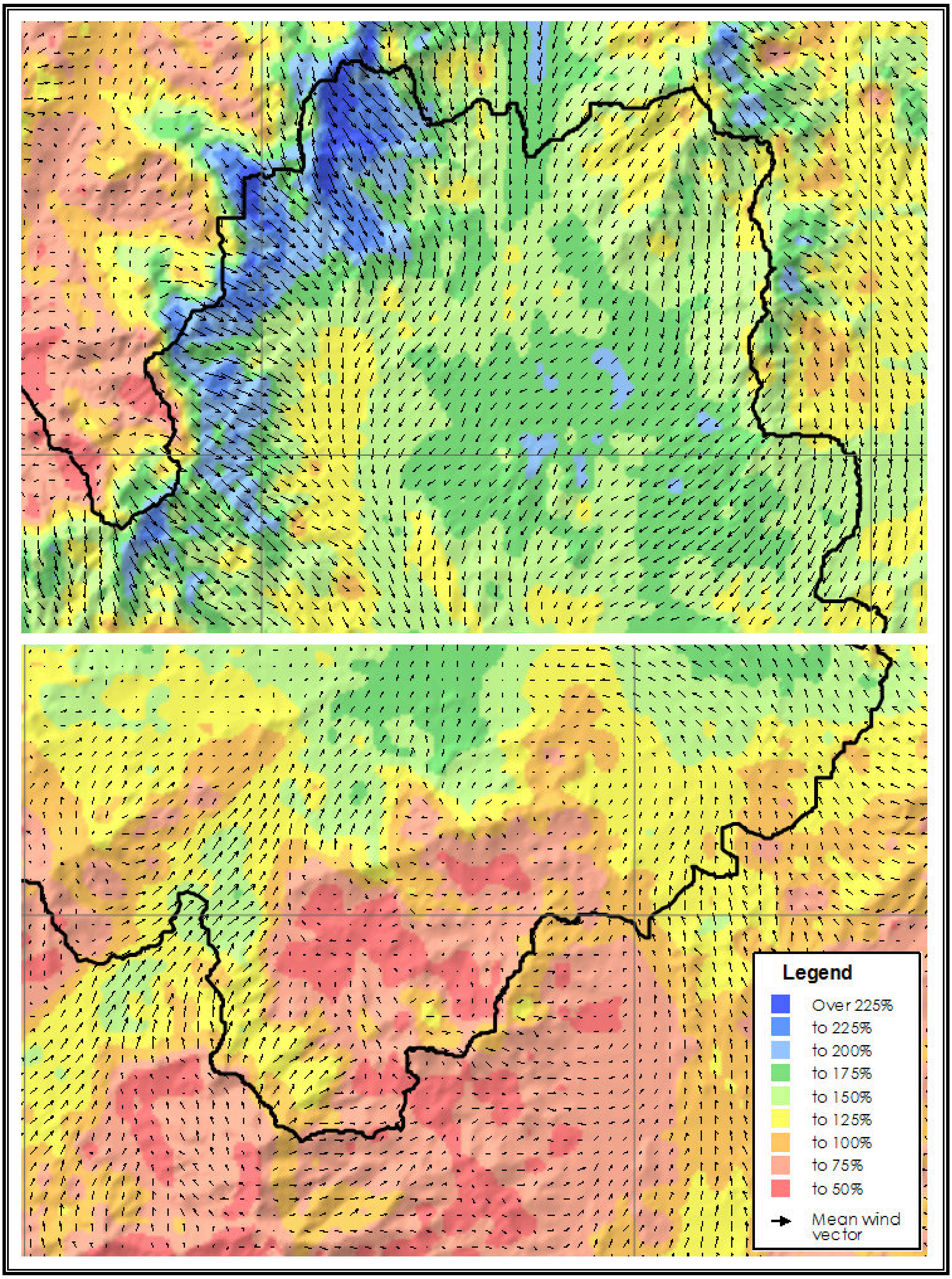


Figure 4.4 Wind fields of the northern (above) and southern (below) part of Seoul, showing night-time mean wind speed relative to the area-average wind speed as well as mean wind direction.

The night-time mean temperature simulated by MetPhoMod is shown in Figure 4.5. The simulated temperature is not the absolute value, but indicates the differences from the mean value for the entire simulation area. Apart from the relatively low temperature in mountainous topography, the deviations in mesoscale temperature are not distinct in most areas of CAMPUS. The spatial distribution of the mesoscale temperature will be used for calculating the risk of local thermal pollution.

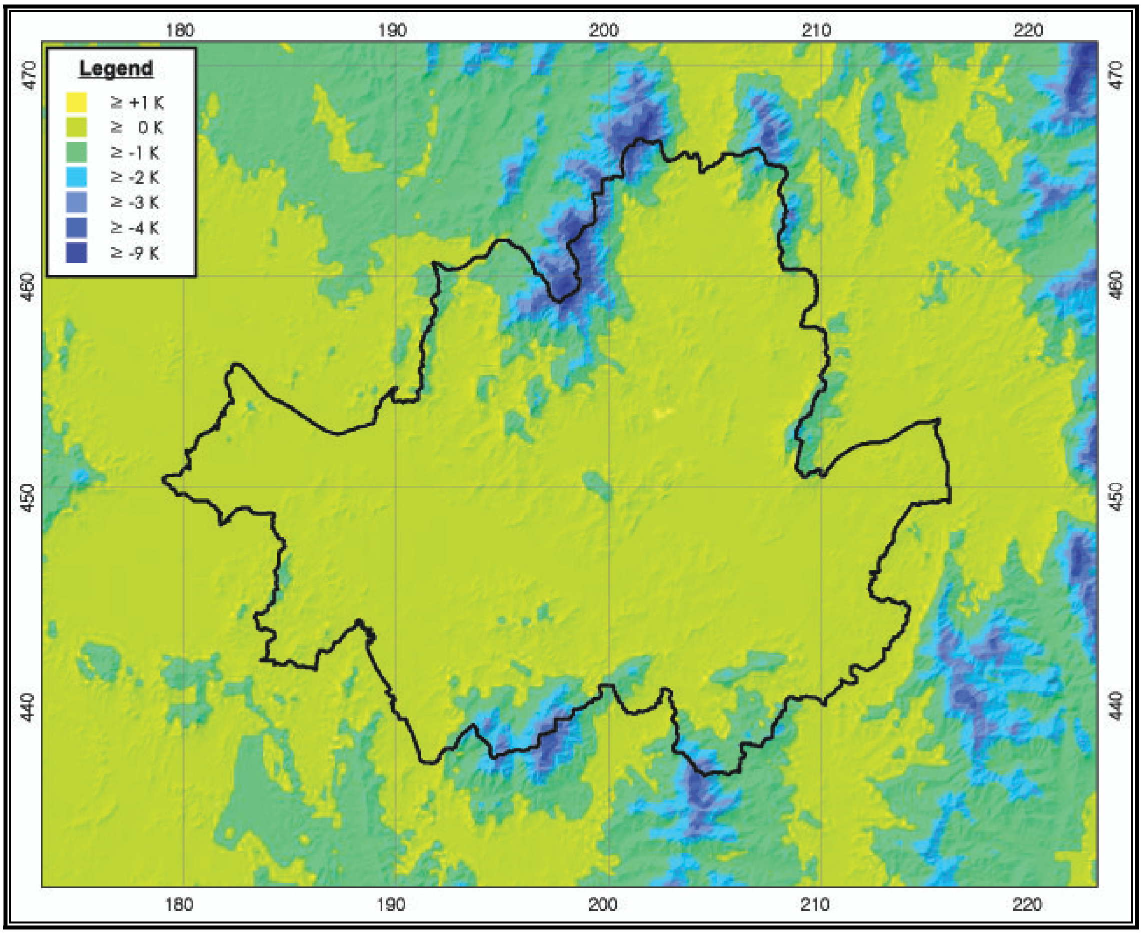


Figure 4.5 The spatial distribution of night-time mean temperature at 10m elevation above ground, relative to the area-average temperature during autochthonous weather conditions. This profile was simulated by the mesoscale meteorological model 'MetPhoMod'

4.1.3 Local atmospheric loads

It has been widely discussed that air pollution affects human health as well as ecosystems both on land and in water. Brunekreef & Holgate (2002) explained the short-term effects of air pollution on human health, such as increasing mortality and hospital admissions due to respiratory and cardiovascular disease, as well as the long-term effects like development of cancers. Pollution negatively affects sensitive ecosystems so that they are in danger of losing their biodiversity, when critical loads are exceeded over longer time periods (Madsen 2006).

Human impact, such as industrial activities and traffic, increases emissions of atmospheric pollution. The common urban air pollutants routinely monitored in Seoul are carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3) and particulate matter (PM10). Since the concentration of SO_2 and CO has decreased distinctly over the past five years (see Table 2.1), the attention has shifted to NO_2, O_3 and PM10. Among them, nitrogen compounds like NO_2 and NO cause atmospheric reactions that create ozone as a secondary pollutant. Hence, it is difficult to detect any clear trends in concentrations of ozone, because this pollutant is not emitted directly but formed by a complex series of chemical reactions. Therefore, NO_2 was adopted as the indicator to estimate the risk of local atmospheric loads in CAMPUS.

Local atmospheric loads were calculated by summing up three types of air pollutant concentrations: The regional background gives the baseline of air pollution concentration in the CAMPUS area. The second type is the area source, which is influenced by land use and indicates the two-dimensional concentration. Finally, the air pollution concentration of the line source, the one-dimensional source of air pollutant emissions, is related to road traffic.

Hence, the local atmospheric loads C_{NO_2} were calculated, based on

$$C_{NO_2} = C_{BG} + C_{AS} + C_{LS} \tag{4.1}$$

where C_{BG} is the background concentration (BG) of NO_2, C_{AS} is the concentration of area sources (AS), and C_{LS} is that of line sources (LS).

The concentrations of point sources, like industrial plants, were not directly considered for CAMPUS, because the information is not available. In addition, the calculation of local atmospheric load in C_{AS} already contains the mean concentrations of point sources to some extent.

The empirical-statistical model, which was developed for European cities in the study REKLISO, expresses and calculates local atmospheric loads in micrograms per cubic meter (µg/m^3). However, NO_2 concentration and its limit value are generally expressed in parts per million (ppm) by volume in Korea. Hence, a process of converting µg/m^3 to ppm was carried out using the following equation:

$$\text{Values in ppm} = T/p*R/m, \qquad (4.2)$$

where T is the temperature in Kelvin, P is the sea level pressure in Pascal (Pa), R is the ideal gas constant, and m is the molecular weight of NO_2 in kg/ mol.

Table 4.5 presents datasets used for modeling local atmospheric loads in CAMPUS.

Table 4.5 Datasets used for modeling local atmospheric loads in CAMPUS

Emission type	Dataset	Character	Source
Regional background	Annual mean NO_2 concentration for two years, measured at two background air monitoring stations for the capital area of Seoul	Averaged values of monthly NO_2 concentration from the years 2005 and 2006. Annual mean values of two stations are 0.01ppm (Echun) and 0.005ppm (Pochun).	Monthly report of metropolitan air quality (2005-2006)
Area source	Annual mean NO_2 concentration for two years, measured at 27 air quality monitoring stations located in Seoul	Averaged values of monthly NO_2 concentration from the years 2005 and 2006, ranging from 0.028ppm to 0.045ppm	Monthly report of air quality in Seoul (2005-2006)
	Annual mean NO_2 concentration for two years, measured at 7 air quality monitoring stations installed at main roads in Seoul	Averaged values of monthly NO_2 concentration from the years 2005 and 2006, ranging from 0.046ppm to 0.054ppm	Monthly report of air quality in Seoul (2005-2006)
Line source	Daily traffic volume	Total number of traffic movements a day, measured in city centers, main roads, bridges and city boundaries	Traffic census 2004
	Road networks of Seoul	Georeferenced vector data	Thematic maps of Seoul for the year 2000

Regional background

Three background stations in the vicinity of the CAMPUS area can be relied on as regional background for CAMPUS; they monitor the background concentration level of air pollution for regions including Seoul. One station is set up in the vicinity of West Sea to principally monitor air polluting substances originating from China, and to show the national background concentration level. The other two stations are established for monitoring the background concentration level of the Capital area, including Seoul Metropolitan city, Incheon Metropolitan city and 21 cities in Gyunggi Province.

The mean 2005-2006 NO_2 concentrations of the latter two background stations, Echun (112m a.s.l.) and Pochun (179m a.s.l.), are 0.01ppm and 0.005ppm, respectively. Between them, 0.01ppm was adopted as the regional background C_{BG} for CAMPUS. Given the standard for the NO_2 concentration of Seoul (0.03ppm), 0.01ppm is appropriate to represent the background concentration.

Area source

The contribution of area sources to local atmospheric loads was estimated on the basis of the attribute values of each pixel class (see Table 3.12). The attribute values of the annual mean concentration of each individual surface type (i.e. pixel class) were weighted by its area-fractional coverage by Equation 3.2 (see Chapter 3.4.2). The area-weighted concentrations were transformed into the actual values of C_{AS} by means of a Gaussian low pass filter to consider the transportation and dispersion of NO_2. (See Parlow et al. 2006, p.42 for more detailed information about the Gaussian low pass filter.)

Figure 4.6 shows the simulated result of NO_2 concentration generated from area sources. The NO_2 concentration ranges from 0ppm to over 35ppm, whereby areas mostly covered by medium and high density use have higher concentrations than others. In particular, PVC-covered areas as well as rail facilities, which as PC 'SwVB' were overlaid by the biotope dataset, showed a high NO_2 concentration. That is because the attribute value of NO_2 concentration given for SwVB is higher than others in principle. Furthermore, the filtering process did not considerably affect the transportation and dispersion of NO_2 in these areas: In the Gaussian low pass filter (Parlow et al. 2006) the NO_2 concentration has dropped by 50 percent compared with the original value of sources in a distance of two pixels (i.e. 100m), if there is no other source. The NO_2 concentration in these areas has not dropped because of the aggregative and successive sources.

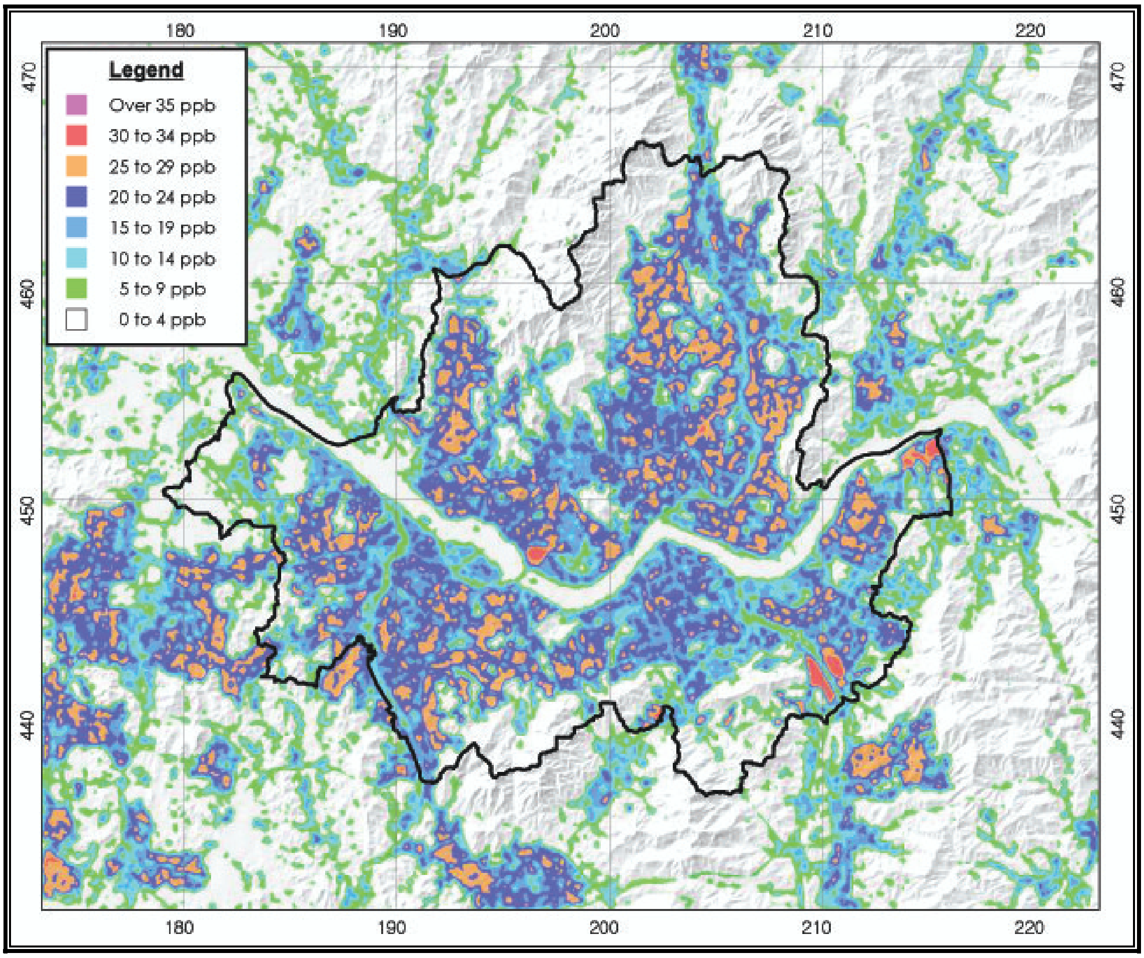


Figure 4.6 The simulated annual mean NO_2 concentration resulting from area sources

Line source

Vehicles are one of the major emission sources of NO_x and thus roads are the most common line source of atmospheric pollution. Hence, it was of great importance to estimate their contribution to local atmospheric loads. A fundamental requirement for the accurate modeling was to establish the accurate dataset of daily traffic volume on the main roads of Seoul.

Two fundamental problems made it difficult to work out the corresponding dataset: Different vehicle types have different impacts on NO_2 concentration. However, no accurate data on traffic volumes of individual vehicle types in Seoul and its surroundings were available. Hence, traffic volume data for Seoul that were not classified into individual vehicle types were used. Suitable data on traffic flows of even collective vehicle types for the surrounding areas could not be obtained. Besides, road networks outside of the administrative area of Seoul were not available. In addition, road networks that integrate traffic volume data were not accessible.

For these reasons, a simple approach was taken to generate estimates of daily traffic volume and then to simulate traffic-generated atmospheric loads. Daily traffic volume was estimated on the basis of the traffic census conducted in the year 2004 for the whole Seoul area. For this survey the relevant roads, where counting is done, were divided into sections. A section is a part between two intersections. In this way, the recorded traffic volume represents the number of vehicles passing at the designated points along the streets where counting is done.

Based on the 2004 survey and the GIS-based road network, two separate datasets were created to combine their traffic volume data. Sections where counting was done were recorded with their specific traffic counts. For other sections, the average traffic counts on the respective road were extrapolated to the other sections of that same road. For example, daily traffic volume data on a main road, running east to west through the southern part of Seoul, were established from the average traffic data counted at five points on this road, as well as the extrapolated averages for the other sections of that road. Thus the traffic dataset used in CAMPUS was established based on data from the main roads, both the sections with actual traffic counts and the other sections whose traffic volume is estimated by extrapolation.

Based on the established traffic dataset, the NO_x concentration was generated by means of a Gaussian low pass filter (see Parlow et al. 2006, p.45 for more detailed information about the Gaussian low pass filter). Finally, this NO_x concentration was converted to the traffic-generated NO_2 concentration by conversion coefficients. The following formula shows the correlation between NO_x and NO_2.

$$C_{NO_2} = C_0 \cdot In\left(1 + \frac{C_{NOx}}{C_1}\right) \tag{4.3}$$

where the empirical coefficients C_0 and C_1 are 35µg/m^3 and 110µg/m^3, respectively.

Figure 4.7 presents the simulated NO_2 concentration in ppb generated from traffic, ranging from 0 to over 35ppb. The roads along the Han River with high traffic volume show a high NO_2 concentration.

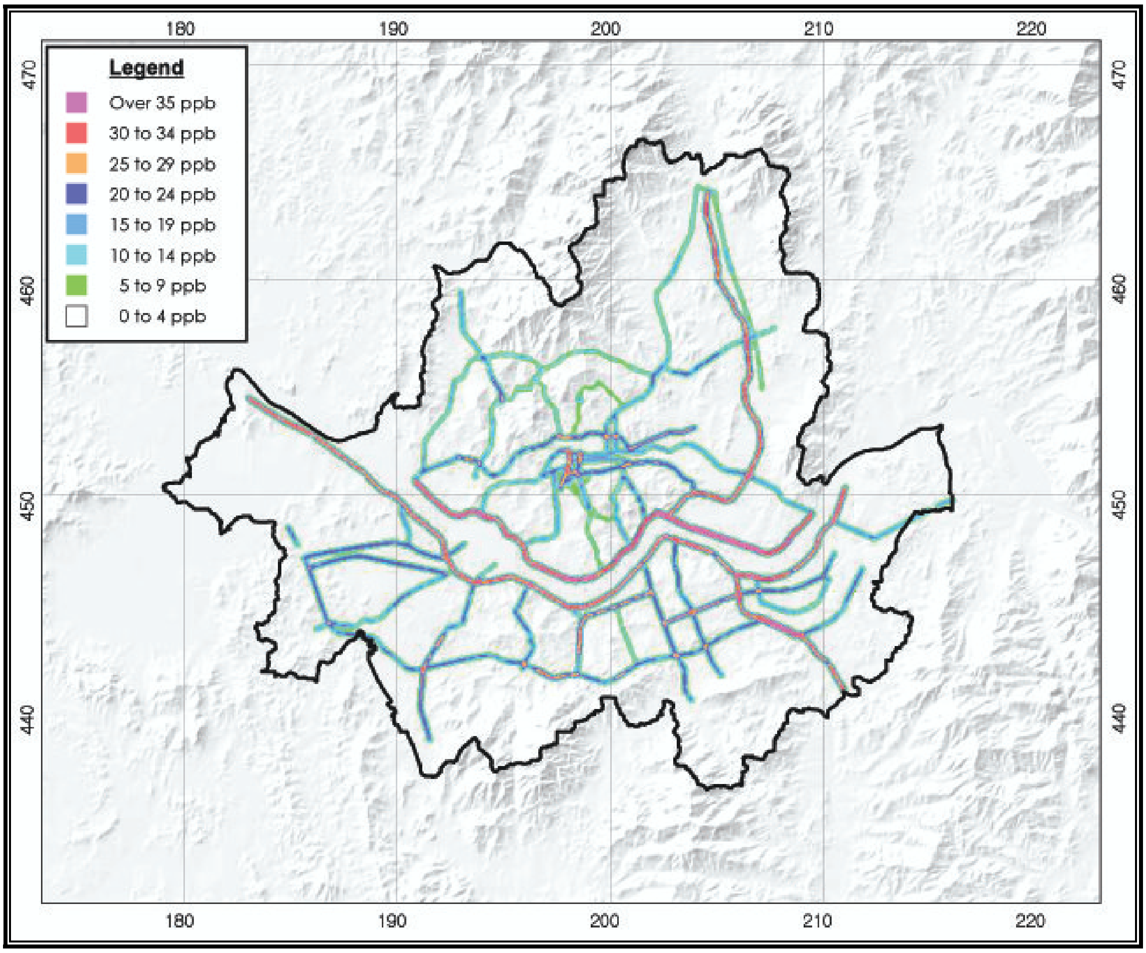


Figure 4.7 The simulated annual mean NO_2 concentration resulting from line sources

Local atmospheric loads

Figure 4.8 shows the simulated annual mean NO_2 concentration (i.e. local atmospheric loads) generated from regional background, area sources and line sources. It distinctly indicates that high atmospheric nitrogen loads are connected with traffic. Based on this simulation, the risk of local atmospheric loads was evaluated. As Table 4.6 shows, the risk is described by three levels: no increased risk, increased risk and strongly increased risk. Risk levels were evaluated according to air quality standard in Korea, which defines the maximum legally allowable concentration.

By 2006, the national ambient air quality standard for nitrogen dioxide and the standard for the administrative area of Seoul were 0.05ppm and 0.04ppm, respectively. Since 2007, new national standards for six principal air pollutants have been applied. According to the new standard, the annual average of the NO_2 concentrations shall not exceed 0.03ppm, and the same standard now applies for the Seoul area as well. Areas that barely meet this standard were therefore evaluated as having a strongly increased risk due to local atmospheric loads, whereas areas with concentrations between 0.02ppm and 0.03ppm display an increased risk. Areas with less than 0.02ppm do not have any corresponding risk. The spatial distribution of local atmospheric risks is shown in Figure 4.9.

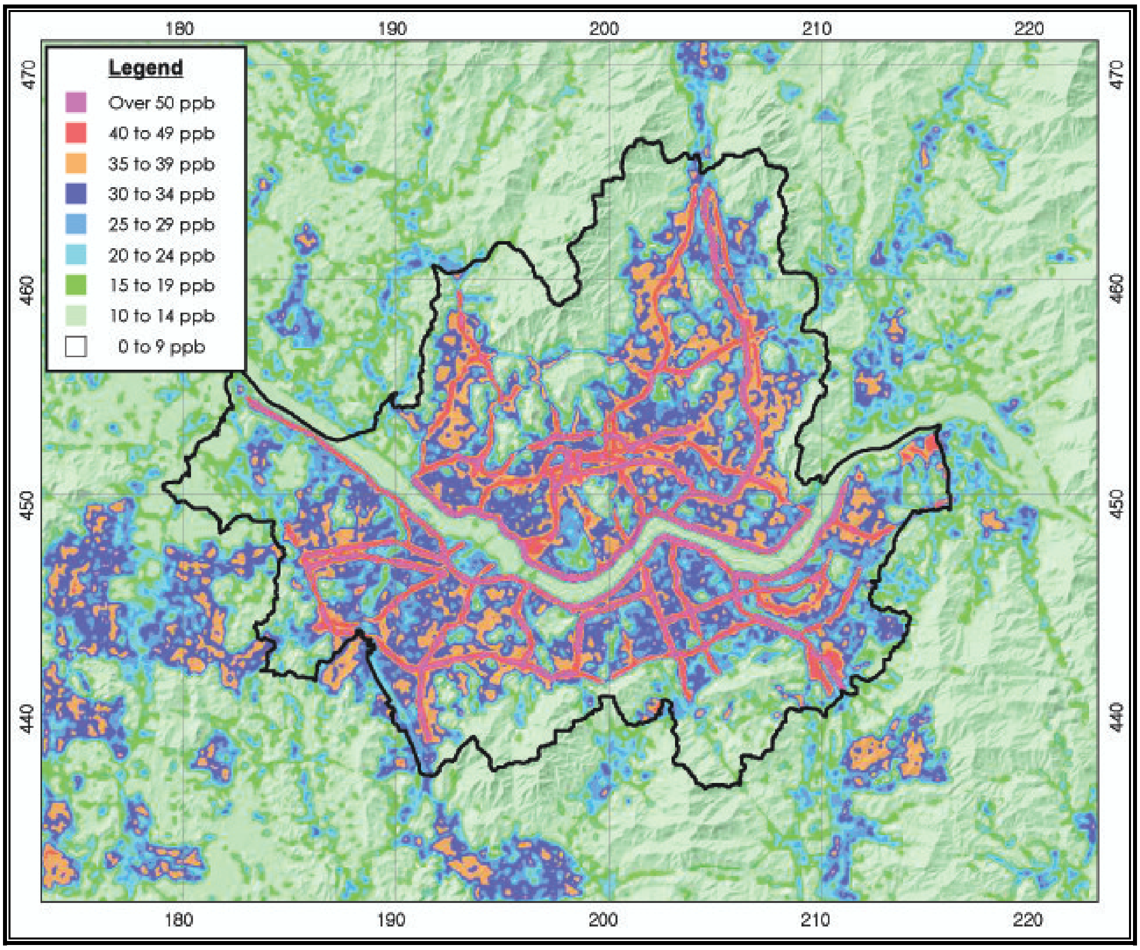


Figure 4.8 The simulated annual mean NO_2 concentration (local atmospheric loads) from regional background, area sources and line sources

Table 4.6 Formulas for assigning risk levels due to local atmospheric loads. The evaluation was carried out on the basis of simulated annual mean NO_2 concentration.

Level	Initial	Code	Assigned area*
No increased risk	AP_0	0	C_{NO_2} < 0.02ppm (20ppb)
Increased risk	AP_1	1	$C_{NO_2} \geq$ 0.02ppm (20ppb) $\wedge$ C_{NO_2} < 0.03ppm (30ppb)
Strongly increased risk	AP_2	2	$C_{NO_2} \geq$ 0.03ppm (30ppb)

* Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion): 2ha

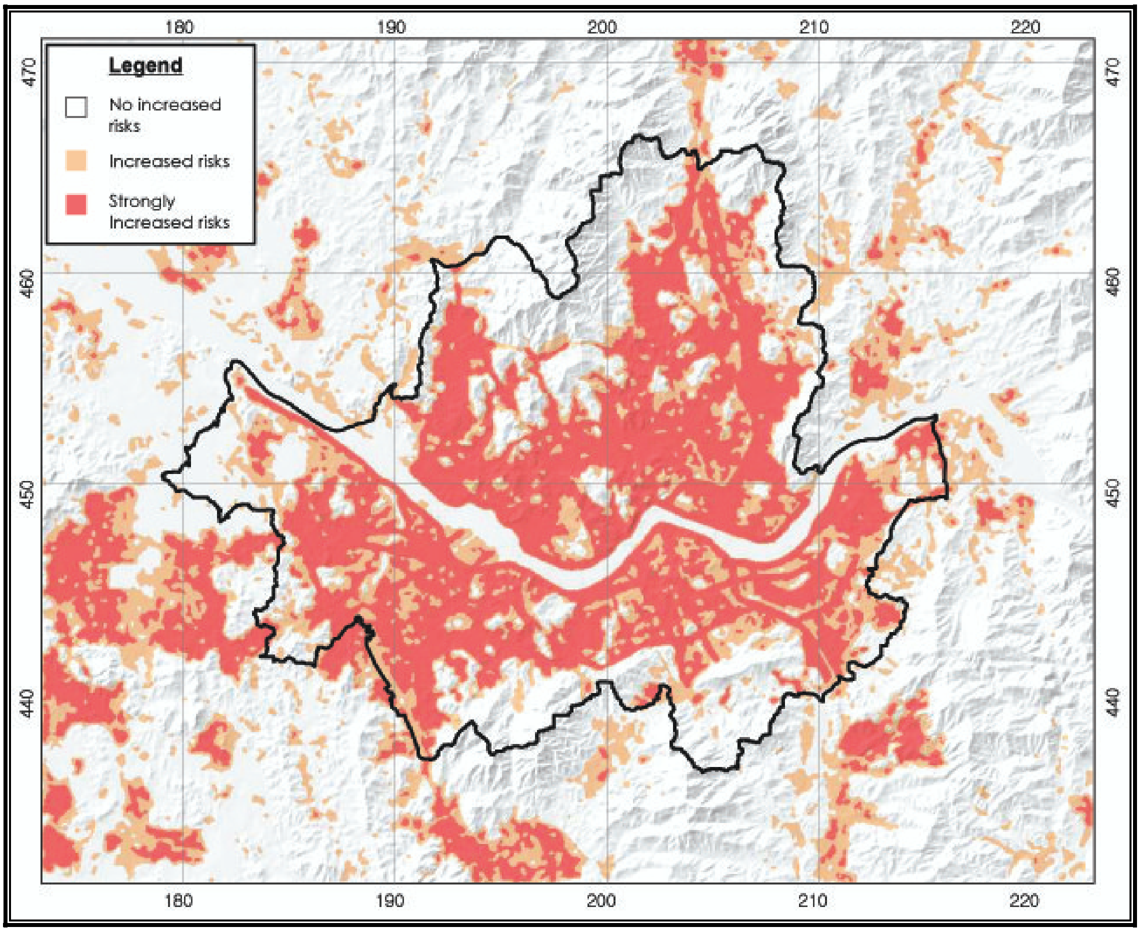


Figure 4.9 Risk of local atmospheric loads

4.1.4 Local thermal loads

Thermal factors comprise the meteorological elements of air temperature, air humidity, wind velocity and short wave and long wave radiation, which have a thermo-physiological effect on the human organism (Verein Deutscher Ingenieure 1998). Thermal load is a result of complex processes of these elements. The thermal load can seriously affect the productivity of individuals and diminish their tolerance for other environmental hazards (Epstein & Moran 2006). When heat is combined with other forms of stress, such as hard physical work, loss of fluids, fatigue or some medical conditions, it may lead to heat-related illness, disability and even death (Ontario Ministry of Labor 2003).

Thermal discomfort is more remarkable at night-time in an urban environment. The urban anthropogenic structures such as buildings absorb and store heat during day-time and slowly release it into the atmosphere at night. In contrast to the day-time when thermal discomfort may be relieved by activities like swimming, staying in shaded areas to block the sunshine or in air-conditioned buildings, one may not be active against thermal discomfort through the night.

In CAMPUS, the night-time temperature simulated by the MetPhoMod in Chapter 4.1.2 was used as the indicator for local thermal loads. In order to estimate local temperature circumstances, two different thermal types were assumed; background temperature on the regional level, and additional heat release of building materials.

The calculation of local thermal loads was defined as the equation below.

$$\Delta\tilde{T}_S = \left(\overline{T} - \left\langle\overline{T}\right\rangle\right) + f_{T_S} \cdot \left(\lambda_C - 1\right) \tag{4.4}$$

where $\overline{T}$ is the local mean air temperature near the ground, which was simulated by MetPhoMod between 20p.m. and 6a.m. under autochthonous weather conditions, whereas $\left\langle\overline{T}\right\rangle$ is the area-average air temperature (see Chapter 4.1.2). The result of $\left(\overline{T} - \left\langle\overline{T}\right\rangle\right)$, which indicates night-time mean temperature differences relative to the area-average value, was presented in Figure 4.5 for the mesoscale temperature field. Added to the temperature deviation, the anthropogenic influence on the local thermal load was calculated by $f_{T_S} \cdot \left(\lambda_C - 1\right)$. The complete surface ratio λ_C, explained in Chapter 3.4.2, was employed to estimate the contribution of buildings to locally increased anthropogenic heat. For example, the ratio of unsealed areas (unS) is 1, which stands for no emissions of anthropogenic heat. The factor f_{T_S} , which converts building impacts into thermal load, was extracted from the temperature difference between urban and rural areas (i.e. UHI intensity of Seoul). Hence, the value of 3K was adopted from the study of Kim & Baik (2004), which found that the maximum UHI intensity of Seoul over the 29 year period from 1973-2001 was 3.34℃.

In order to take into consideration the transportation and dispersion of thermal pollution due to wind and turbulence, a Gaussian low pass filter was applied over the calculated $\Delta\tilde{T}_S$, resulting in the local thermal loads ΔT_S . (See Parlow et al. 2006, p.49 for more detailed information about the Gaussian low pass filter.)

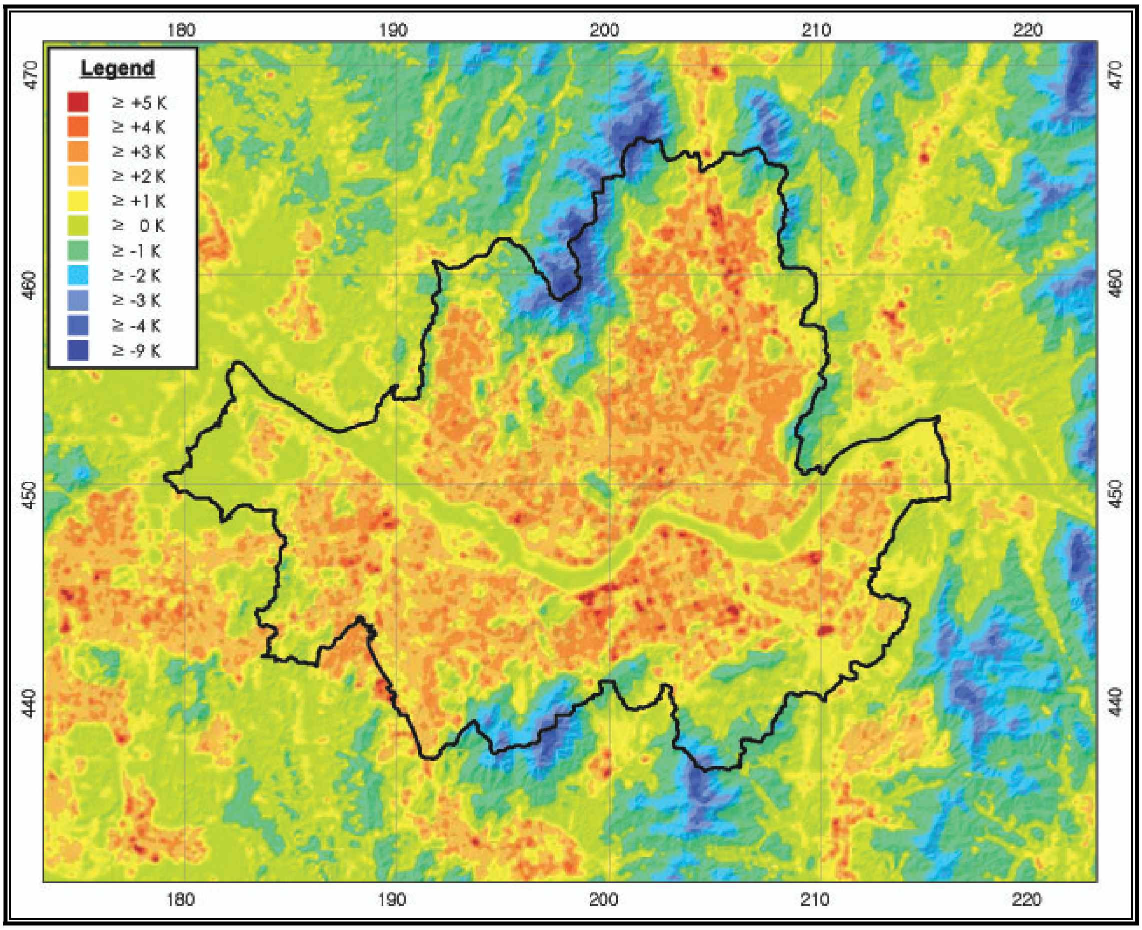


Figure 4.10 Local warming at 10m elevation above ground for the CAMPUS area, showing night-time temperature deviations from the area-average temperature during autochthonous weather conditions.

Figure 4.10 shows the simulation results at 10m elevation above ground for the area covered by CAMPUS, with temperature variations ranging from -9K to over 5K. The upper mountains have the lowest temperatures relative to the area-average value, whereas the built-up areas show higher temperatures than average.

Table 4.7 Formulas for assigning risk levels due to local thermal loads: ΔT_S is the night-time temperature variation relative to the area-average temperature during autochthonous weather conditions.

Level	Initial	Code	Assigned area*
No increased risk	HS_0	0	ΔT_S < 2K
Increased risk	HS_1	1	ΔT_S ≥ 2K ∧ ΔT_S < 3K
Strongly increased risk	HS_2	2	ΔT_S ≥ 3K

* Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion): 2ha

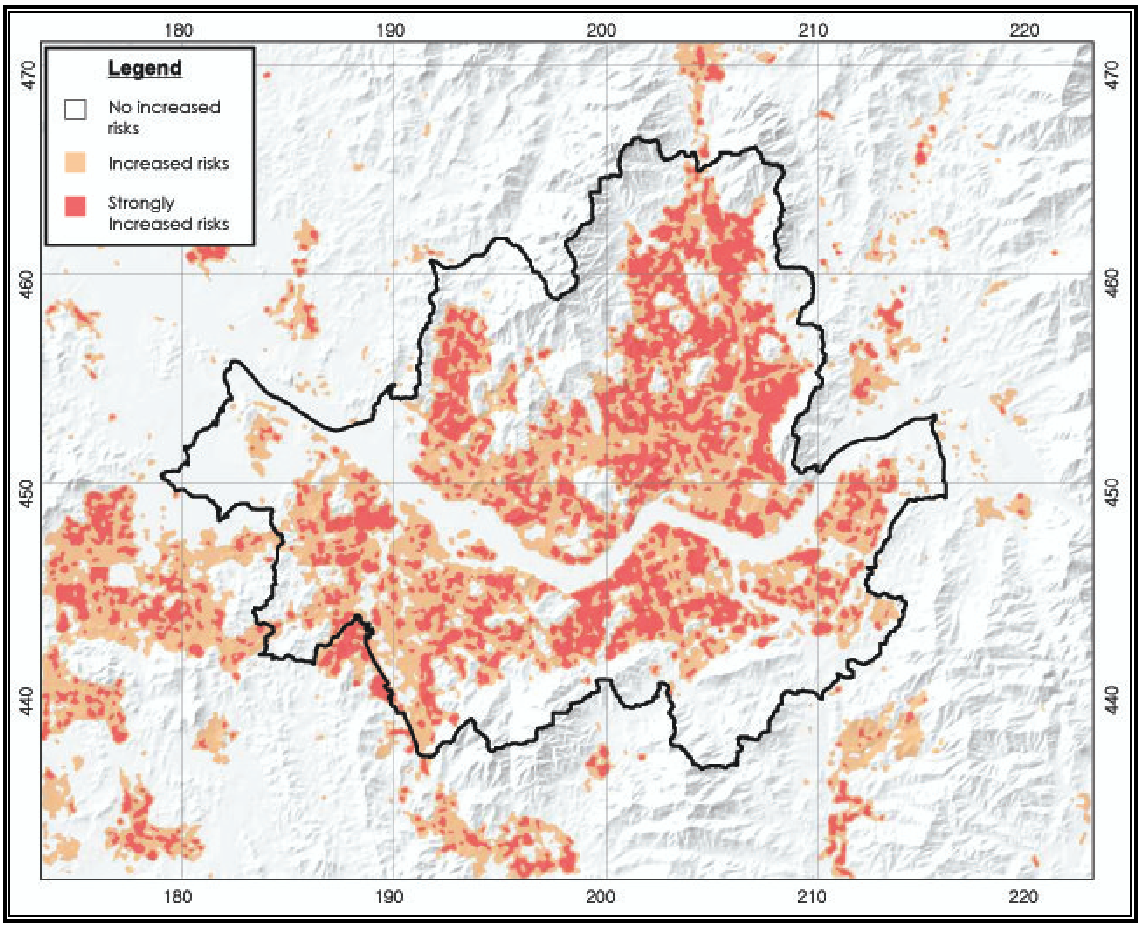


Figure 4.11 Risk of local thermal loads

Based on the simulated local thermal pollution, the risk of thermal loads was evaluated by the formulas described in Table 4.7. Both 2K and 3K were derived from the urban heat island intensity of Seoul (see Kim & Baik 2004 and 2005): The areas with local warming equal or greater than 3K were classified as having a strongly increased risk of thermal loads (i.e. heat stress), whereas areas with less than 2K pose no increased risk. According to these formulas, most built-up areas were evaluated as having increased or strongly increased risks of thermal loads (Figure 4.11).

4.2 Ventilation situation maps

Ventilation is the process in which atmospheric or thermally polluted air is replaced by fresh or cold air (Verein Deutscher Ingenieure 2003). It dilutes the polluted air through turbulent mixing with unpolluted air.

The maps described in this chapter show the characteristics of ventilation situations influenced by topography and land use properties in Seoul and its surrounding areas. The described ventilation situations cover local cold air production (4.2.1), its transport (4.2.2) and stagnation (4.2.3), local surface influences (4.2.4), local wind exposition (4.2.5) as well as mesoscale wind conditions (4.2.6). Finally, a synthetic ventilation map is established, based on individual ventilation situations (4.2.7).

4.2.1 Local cold air production

In the process of energy conversion on the earth's surface, locally developed cold air exhibits a lower temperature than air at the upper limit of the corresponding ground inversion (Verein Deutscher Ingenieure 2003). Cold air is of importance in regional planning and urban land use planning because of its positive influence on the thermal and air pollution control. However, cold air can also cause negative aspects like frost and cold stress.

Cold air production depends on meteorological conditions as well as on land use patterns. In the context of the nocturnal radiation process, cold air is most intensively produced on the surface under calm and clear weather conditions. Further, cold air production is determined by the thermal characteristics of the land surface. Generally speaking, cold air develops over a natural surface covered with vegetation.

Cold air production was calculated in CAMPUS by using the cold air production ratio introduced in chapter 3.4.2. As shown in Table 3.12, both PC 'TR' (forests) and PC 'unS' (open spaces) were used to analyze their contribution to cold air production.

Figure 4.12 shows the mean nocturnal cold air production under autochthonous weather conditions, which exhibits four different types of areas with varying volumes of cold air produced in each. In the region covered by CAMPUS, high volume of cold air emerges mainly in the northern and southern outskirts of Seoul, as well as east of the city limits in the surrounding areas. Apart from these areas, most areas of Seoul barely display cold air production.

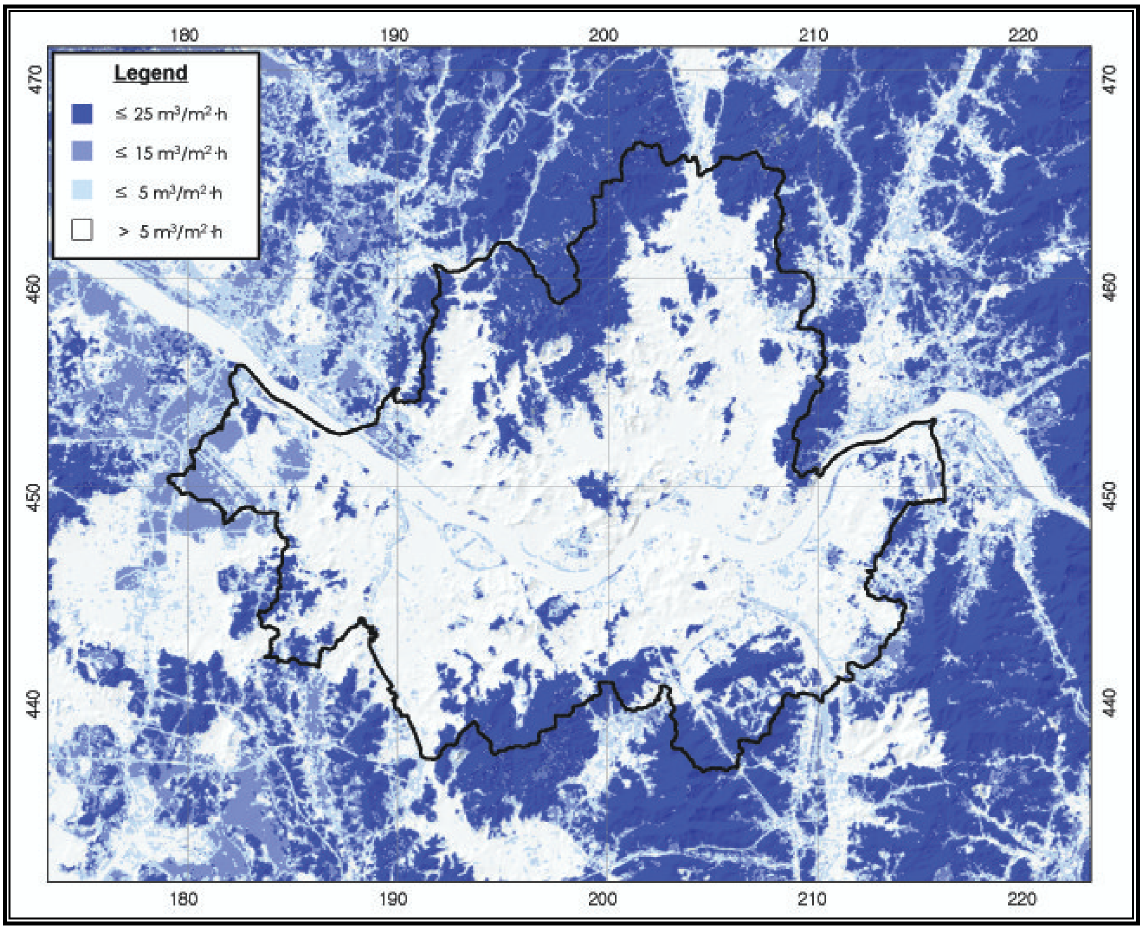


Figure 4.12 The spatial distribution of mean night-time cold air production under autochthonous weather conditions

Cold air drains from higher situated areas towards lower ones following the descending terrain gradient (cold air transport), and it may stagnate and accumulate in lower, concave terrain such as valleys and depressions (cold air stagnation; Verein Deutscher Ingenieure 2003). Both cold air phenomena immediately cause a decrease in air temperature, dispersion of air pollutants as well as frost occurrence, which is causing cold stress. The simulation of cold air production is not directly included in maps with planning recommendations (see chapter 4.3) in CAMPUS; rather, it is used for simulating cold air transport or stagnation. The resulting information will be also used for implementation measures on thermal compensation effects, which are dealt with in chapter 4.3.3.

4.2.2 Local cold air transport

Cold air, produced at night, begins to flow when it encounters sloped terrain: These nocturnal cold air flows are induced when the air adjacent to a sloping surface cools and becomes denser than the surrounding air (Soler et al. 2002). These so-called nocturnal drainage flows are important for the thermal situation and air quality. On one hand, nocturnal drainage ventilates built-up areas overheated during day-time (cold air effect). On the other hand, if this cold air flows from unpolluted areas, it may dilute the air of polluted areas by dispersing air pollutants in the ambient air (fresh air effect).

Cold air transport takes place predominantly on the local level. Weak mesoscale wind at a lower speed than 3m/s does not obstruct the formation and direction of cold air flows, because cold air on the ground keeps its characteristics at a relatively low geostrophic wind speed (Verein Deutscher Ingenieure 2002). Therefore, a local cold air transport model, which had been developed in the REKLISO study, was adopted to simulate transport of local cold air for the CAMPUS area. This model calculates cold air volume that flows vertically through the width of one meter per second during the night under autochthonous weather conditions. In CAMPUS, this cold air volume averaged over a time period of five hours during the night was simulated, using cold air production rate, effective building height (see Table 3.12), and the digital terrain model. (see Parlow et al. 2006, p.54 for more information on the local cold air transport model.)

Table 4.8 Evaluation formulas for the ventilation situation ‚Local cold air transport'. Volume flow density $\bar{j}$ represents the cold air volume that flows vertically through the width of one meter per second.

Level	Initial	Code	Assigned area*
Low volume flow density	CT_0	0	$\bar{j} \leq 20m^3 \cdot m^{-1} \cdot s^{-1}$
Medium volume flow density	CT_1	1	$\bar{j} > 20m^3 \cdot m^{-1} \cdot s^{-1} \wedge \bar{j} \leq 120m^3 \cdot m^{-1} \cdot s^{-1}$
High volume flow density	CT_2	2	$\bar{j} > 120m^3 \cdot m^{-1} \cdot s^{-1}$

* Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion): 4ha

Three levels of local cold air transport emerged when the vertical volume flow density of cold air was analyzed, as it passed the space of one meter per second. Table 4.8 shows the evaluation formulas for simulated local cold air transport, taken from the REKLISO study and adapted in CAMPUS.

Figure 4.13 shows the spatially distributed information about local cold air transport. High volume flow densities of cold air are seen mainly in the northern and southern outskirts of Seoul and east of the city limits in surrounding areas. For some areas in the western surroundings and in western Seoul, where the topography is not hilly but high-rise buildings exist, low volume flow densities of cold air (≤ $20 m^3 \cdot m^{-1} \cdot s^{-1}$) were simulated.

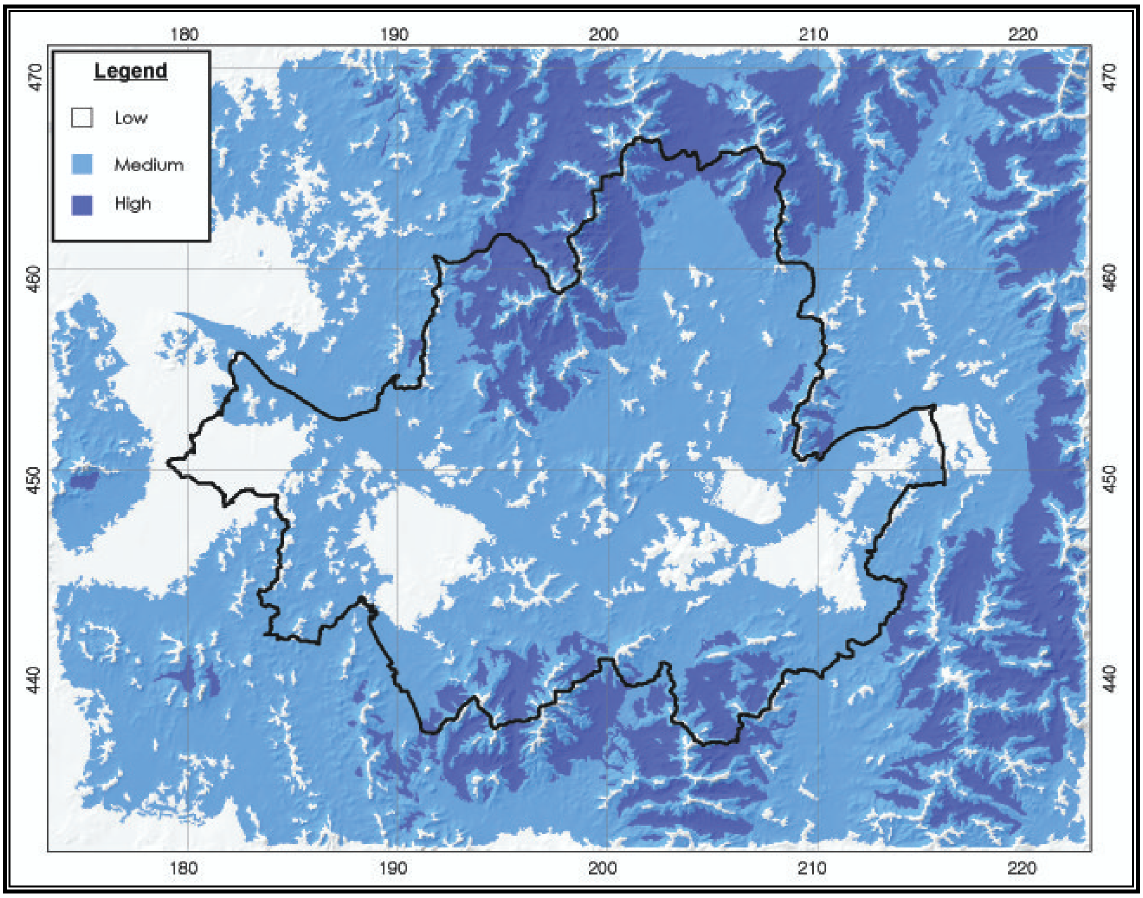


Figure 4.13 The spatial distribution of mean night-time cold air transport under autochthonous weather conditions

4.2.3 Local cold air stagnation

Stagnations occur when atmospheric flows decrease in speed, or stop altogether, thus allowing pollutants to build up in stagnant air in the vicinity of the pollutant sources

(Allwine & Whiteman 1994). Cold air that drains to lower places from its production areas tends to stagnate and accumulate in concave terrain like bowl shape valleys. Similarly, large constructions areas, e.g. road embankments, also hinder cold air flow.

Areas where cold air stagnates and accumulates pose a risk to human health and agricultural activities because the accumulation of air pollutants is enhanced. Moreover, high frequency of frost in such areas can cause serious losses of agricultural crops.

Table 4.9 shows the evaluation formulas for simulated local cold air stagnation. Three levels of stagnation emerge: Areas not affected by local cold air stagnation, areas with cold air stagnation influenced by terrain, and areas affected by both terrain and buildings. The Digital Elevation Model (DEM) and the effective building height were used for evaluation.

Table 4.9 Evaluation formulas for the ventilation situation ‚local cold air stagnation'. While $\Delta h_{H,Z}$ is the hollow depth that was calculated based on elevation Z of DEM_{50m}. (See chapter 3.5), $\Delta h_{H,Z+h_{eff}}$ indicates the hollow depth of artificial elevation, based on both Z and the effective building height h_{eff} of settlements (See chapter 3.4.2).

Level	Initial	Code	Assigned area
No local cold air stagnation	CS_0	0	$\Delta h_{H,Z} < 4m \wedge \Delta h_{H,Z+h_{eff}} < 4m$
Terrain influenced stagnation	CS_1	1	$\Delta h_{H,Z} \geq 4m$
Terrain & building influenced stagnation	CS_2	2	$\Delta h_{H,Z+h_{eff}} \geq 4m$

The stagnation of cold air was simulated at an elevation of 4 meters or higher, in order to overcome misrepresentations of ground surface terrain in flat areas of the DEM used for CAMPUS. Such misrepresentations have previously resulted when too few interpolating points were chosen in the creation of a TIN (Triangulated Irregular Network) on flat areas. This emerged when surface was analyzed at an elevation of one or two meters.

The spatial distribution of local cold air stagnation is presented in Figure 4.14, showing that local cold air stagnation mainly occurs in the west and south-west parts of the outskirts of Seoul.

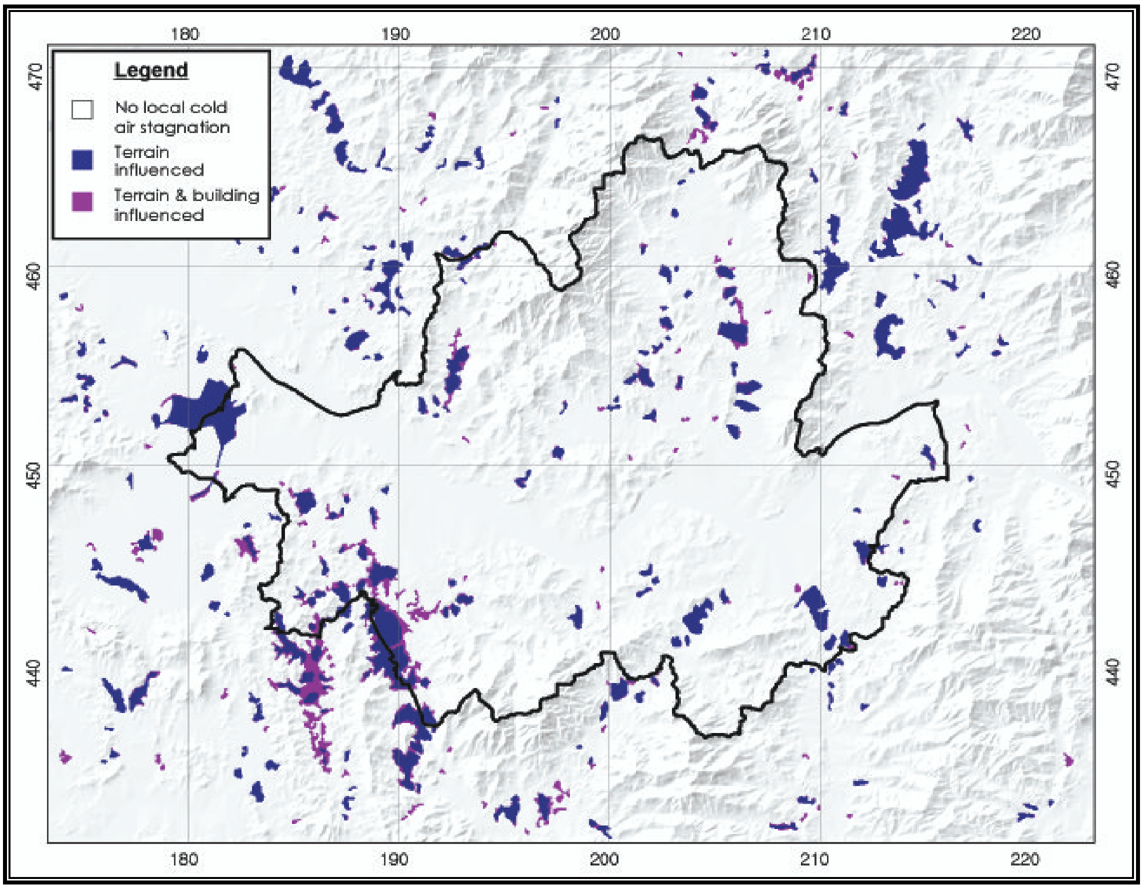


Figure 4.14 The spatial distribution of cold air stagnation under autochthonous weather conditions

4.2.4 Local surface influence

Wind in the atmospheric boundary layer is influenced by the surface friction that is caused by topography and vegetation (OKE 1987). In particular, wind speed and direction are influenced by the surface roughness in the surface layer. Besides the surface roughness, building geometry modifies flow and dispersion patterns within the surface layer (see Camelli et al. 2006).

In CAMPUS both aerodynamic roughness length and effective building height were applied to simulate the local surface influence. The formulas for evaluating the local surface influence are shown in Table 4.10. The values of surface roughness and effective building height, which were previously calculated for every PC (described in Chapter 3.4.2, Table 3.12), were used here again for simulation. This resulted in three levels of local surface influences; low, medium, and high.

Table 4.10 Evaluation formulas for the ventilation situation ‚Local surface influence'. Z_0 is the aerodynamic surface roughness and heff is the effective building height

Level	Initial	Code	Assigned area*
Low	SI_0	0	$Z_0 \leq 0.2m \wedge h_{eff} \leq 5m$
Medium	SI_1	1	$(Z_0 > 0.2m \wedge h_{eff} \leq 5m) \vee (Z_0 \leq 0.2m \wedge h_{eff} > 5m)$
High	SI_2	2	$Z_0 > 0.2m \wedge h_{eff} > 5m$

* Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion): 2ha

Figure 4.15 shows the spatial distribution of local surface influence. Those areas which exhibit a high level of local surface influence show similar spatial patterns as do the areas classified as the PCs 'MD and HD'. Areas with medium local surface influence resemble the spatial distribution of the PCs of 'TR, LD and SwVB'. Low local surface influences were simulated for the areas with roughness length ≤ 0.2m and building height ≤ 5m, e.g. water surfaces, agricultural areas and roads, previously classified as the PCs 'WA, unS and SwoB'.

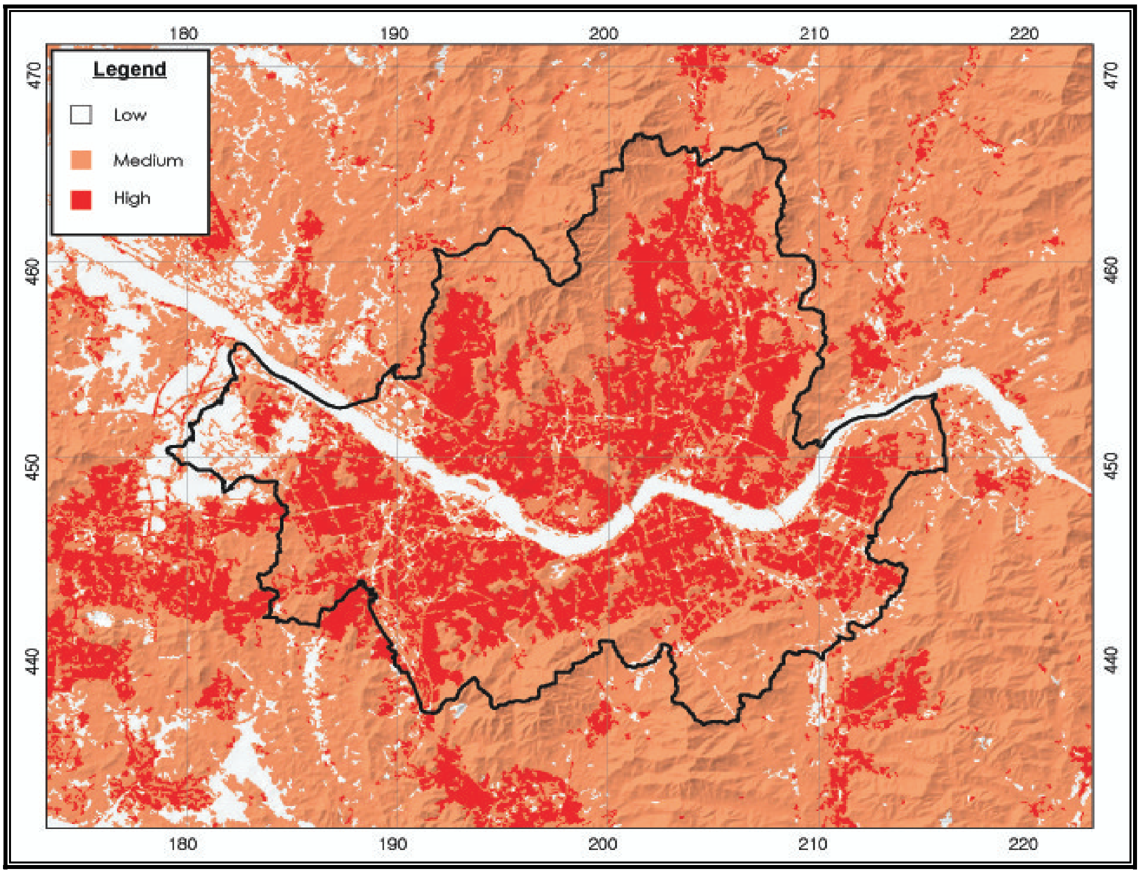


Figure 4.15 The spatial distribution of local surface influence

4.2.5 Local wind exposition

Under identical mesoscale wind conditions, wind speed may be recorded differently in accordance with the degree of topographic exposure. Under extreme wind conditions, e.g. in case of a storm or a typhoon, surfaces with high topographic exposure have higher susceptibility to wind damages than others. Because extreme wind conditions like typhoons arise two or three times per year in Seoul (see Chapter 2), areas exposed to wind require special attention in spatial planning.

In simulating the local wind exposition, relative heights extracted from the Digital Terrain Model was used. These relative heights, which indicate the deviation of various elevation points from the average elevation of the 500m × 500m (25ha) surrounding area (reference points), were already calculated in Chapter 3.5. The local wind exposition simulated in CAMPUS was focused on the classification of elevation points with a high frequency of higher wind speed, due to topographic exposure. Such points are more susceptible to wind damages than others.

Table 4.11 shows the evaluation formulas for the ventilation situation 'local wind exposition', distinguished by three different levels.

Table 4.11 Evaluation formulas for the ventilation situation ‚Local wind exposition'. ΔZ_{500m} is the deviation of elevation Z from average values in the 500m×500m (25ha) surrounding area (relative height)

Level	Initial	Code	Assigned area*
Low	WE_0	0	$\Delta Z_{500m} \leq$ -15m
Medium	WE_1	1	$\Delta Z_{500m} >$ -15m $\wedge$ $\Delta Z_{500m} \leq$ 15m
High	WE_2	2	$\Delta Z_{500m} >$ 15m

* Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion): 25ha

Figure 4.16 shows the spatial distribution of local wind exposition. Upper parts of mountainous topography, near the mountain's summit, are mainly identified as surfaces most susceptible to wind exposition (level 'high wind exposition'). The areas with medium wind exposition mostly are situated right below the areas with high exposition. Both are found on north and south outskirts of Seoul as well as east of the city limits in the surrounding areas, where mountainous topography exists.

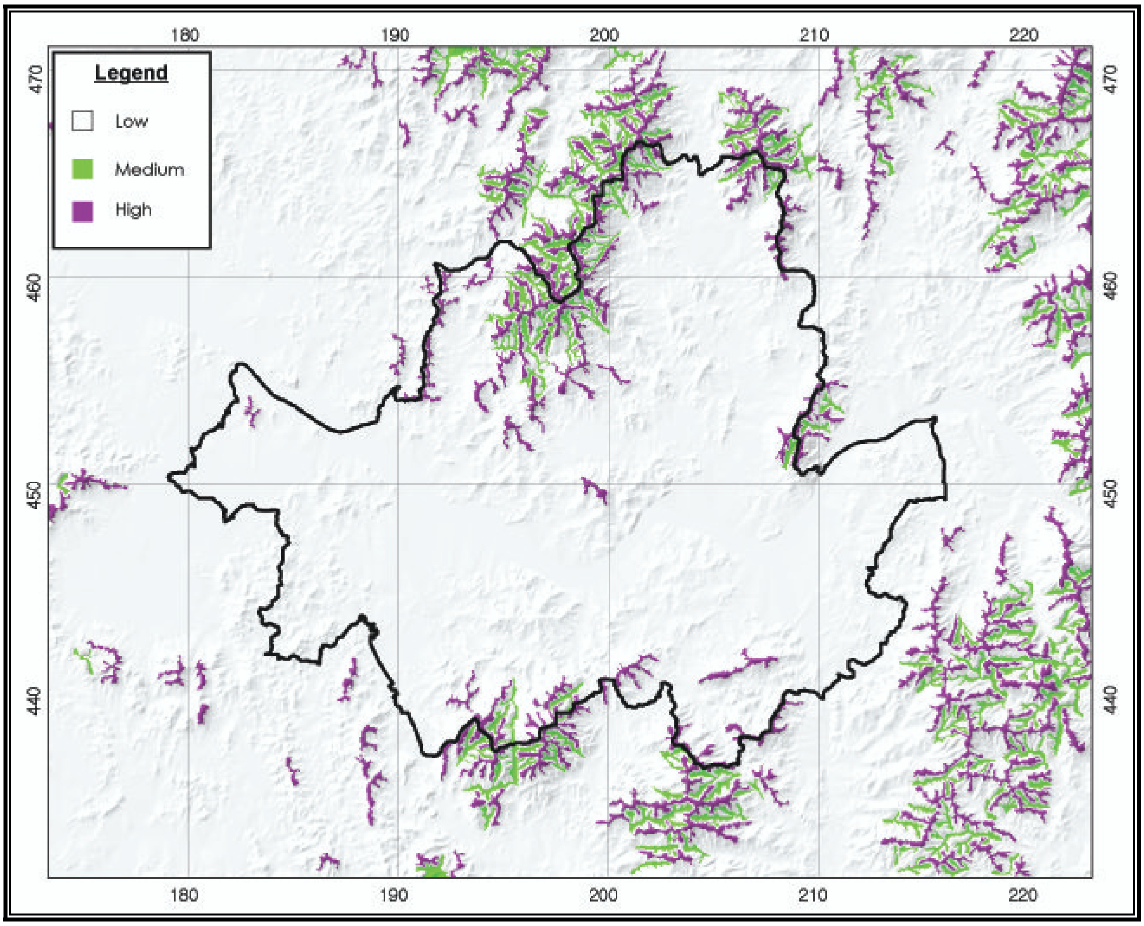


Figure 4.16 The spatial distribution of local wind exposition

4.2.6 Mesoscale wind conditions

Terrain-induced mesoscale wind circulation transports air pollutants across large distances. Since pollutants are mainly dispersed by differential advection and turbulent mixing in the atmosphere, the dispersion process will thus be controlled by these terrain-induced mesoscale systems (Yu & Pielke 1986). Hence, the mesoscale wind circumstances should not go unnoticed when simulating local ventilation situations.

In CAMPUS the ventilation situation 'mesoscale wind conditions' was extracted from the simulation of the wind field in the mesoscale model 'MetPhoMod' (Chapter 4.1.2). If the wind speed in the area of interest is higher than average, this area has a high potential for reducing air and thermal pollution. Contrary to this case, an area may have increasing risks of these pollutions, if the wind speed is lower than average.

In this context, the evaluation formulas for mesoscale wind conditions indicate the three categories of unfavorable, average and favorable wind conditions (Table 4.12). Areas where wind speed is 75 percent or less than the overall mean wind speed were defined as having unfavorable mesoscale wind, whereas areas at 125 percent or more above the mean wind speed were considered as favorable wind conditions. The other areas with wind speeds between both values were assigned to the category average mesoscale wind conditions.

Based on the simulation with 50m grid spacing, the wind conditions for the CAMPUS area are shown in Figure 4.17. According to the simulation, most parts of Seoul have average or favorable mesoscale wind conditions. Unfavorable wind conditions are found in western outskirt of Seoul. Besides, they emerge in southern and north-western mountainous terrain at the city limits.

Table 4.12 Evaluation formulas for the ventilation situation ‚Mesoscale wind conditions': $\overline{|V_h|}$ is the horizontal wind speed at 10m above ground, averaged between 20pm and 6am, whereas $\left\langle \overline{|V_k|} \right\rangle$ indicates the overall average for the whole area.

Level	Initial	Code	Assigned area*
Unfavorable	MW_0	0	$\overline{|V_h|} \leq \left\langle \overline{|V_h|} \right\rangle *0.75$
Average	MW_1	1	$\overline{|V_h|} > \left\langle \overline{|V_h|} \right\rangle *0.75 \wedge \overline{|V_h|} \leq \left\langle \overline{|V_h|} \right\rangle *1.25$
Favorable	MW_2	2	$\overline{|V_h|} > \left\langle \overline{|V_h|} \right\rangle *1.25$

* Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion): 25ha

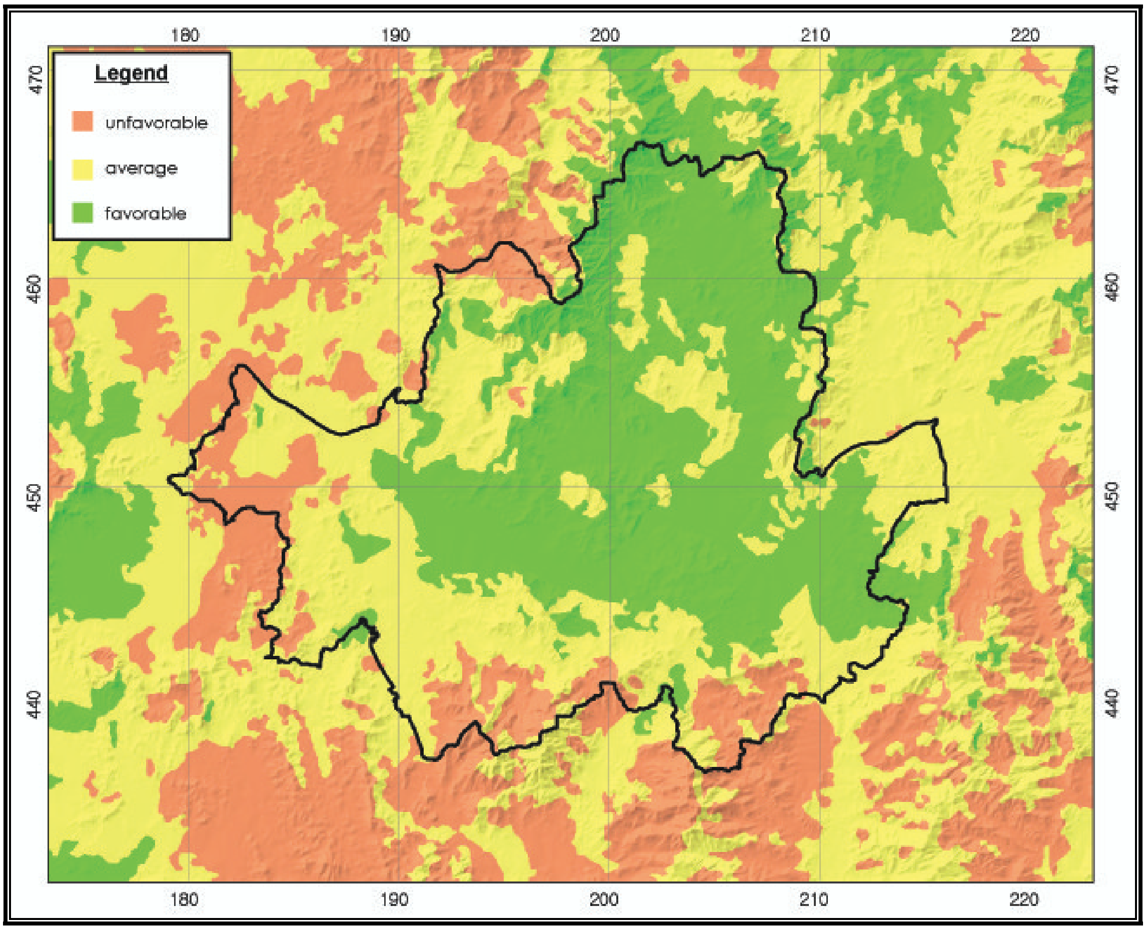


Figure 4.17 Mesoscale wind conditions

4.2.7 The Synthetic ventilation situation in Seoul and its surroundings

Based on five ventilation situations presented in this chapter – local cold air stagnation, local surface influence, local cold air transport, local wind exposition and mesoscale wind circumstances – a synthetic ventilation map of Seoul and its surroundings was generated. This synthetic map offers a comprehensive overview of ventilation conditions that regularly occur in Seoul and its surroundings.

Figure 4.18 shows the synthetic map for the spatial distribution of ventilation situations in CAMPUS. The overlay of individual maps was carried out in the order of significance from the viewpoint of urban and spatial planning. Hence, the synthetic map was intended to contain significant elements relevant for spatial planning. Due to the overlay procedure, some information from individual maps does not emerge in the synthetic map. This information is available in individual maps, to be consulted as required.

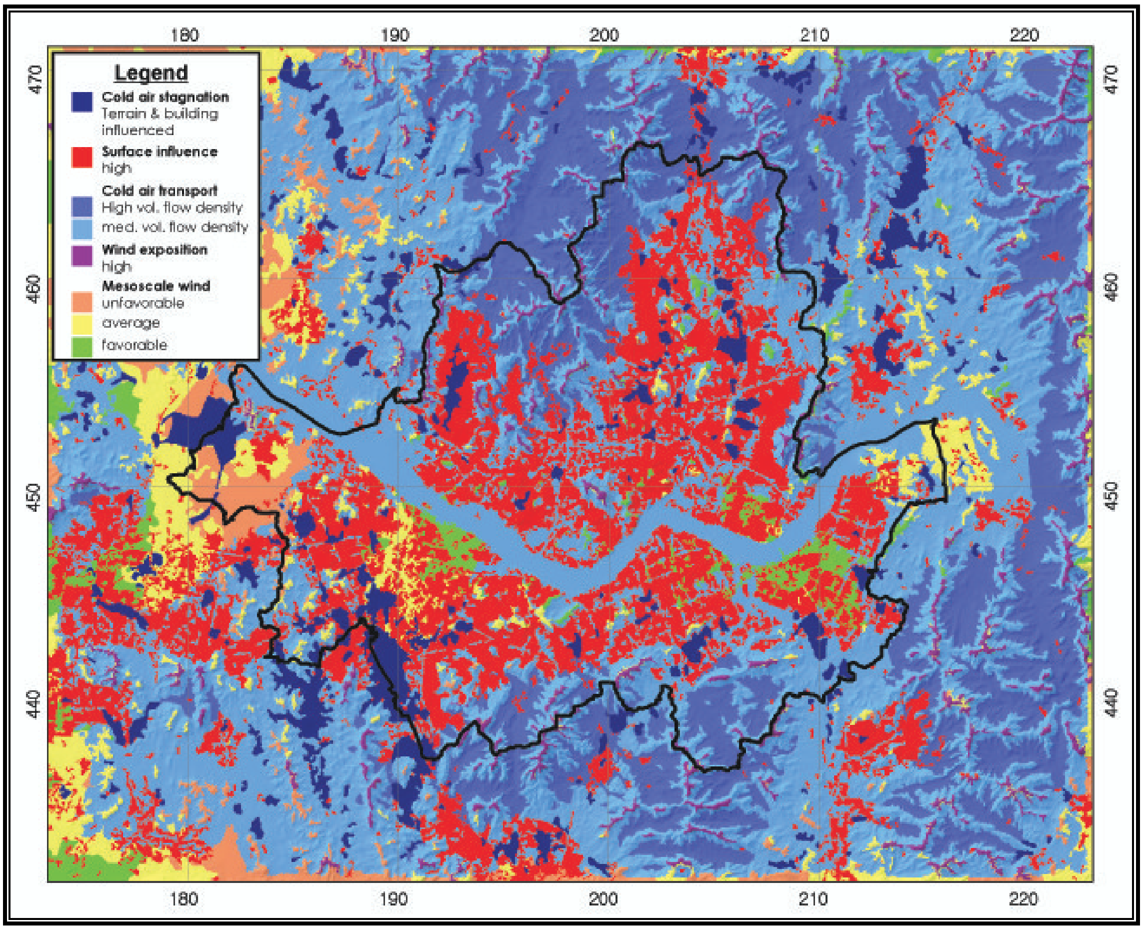


Figure 4.18 Synthetic map of the spatial distribution of ventilation situations in CAMPUS area

Table 4.13 show the list of individual ventilation conditions used for generating the synthetic map. This list contains characteristics of the eight ventilation conditions in relation to ventilation, air quality and thermal situation, as well as the sequence of the overlay procedure. The code stands for the steps in this sequence of overlaying the various maps.

Table 4.13 Characteristics of individual ventilation situations relevant to ventilation, air quality and thermal situation

Initial	Code	Ventilation situation	Ventilation	Air quality	Thermal situation
$CS_{1\text{-}2}$	1	Local cold air stagnation: *terrain & buildings influenced*	Reduced ventilation	Increased risk of air pollution	Reduced risk of thermal pollution; Increased risk of frost and increased heat loss
SI_2	2	Local surface influence: *High*	Reduced ventilation	Increased risk of air pollution	Increased risk of thermal pollution; Reduced risk of frost and reduced heat loss
CT_2	3	Local cold air transport: *high*	Improved ventilation	Reduced risk of air pollution	Reduced risk of thermal pollution; Increased risk of frost and increased heat loss
CT_1	4	Local cold air transport: *medium*	Slightly improved ventilation	Slightly reduced risk of air pollution	Reduced risk of thermal pollution; Increased risk of frost and increased heat loss
WE_2	5	Local wind exposition: *high*	Improved ventilation; Increased risk of wind disadvantage	Reduced risk of air pollution	Reduced risk of thermal pollution; Increased heat loss
MW_2	6	Mesoscale wind circumstances: *favorable*	Improved ventilation	Reduced risk of air pollution	Reduced risk of thermal pollution
MW_1	7	Mesoscale wind circumstances: *average*	Indifferent	Indifferent	Indifferent
MW_0	8	Mesoscale wind circumstances: *unfavorable*	Reduced ventilation	Increased risk of air pollution	Increased risk of thermal pollution

4.3 Maps with planning recommendations

The climate analysis and evaluation maps produced in sections 4.1 and 4.2 contain spatially distributed information on local climate and air quality, based on transparent and commonly accepted evaluation formulas. The maps to be presented in this section contain planning indications for spatial planning.

Based on the climate analysis and evaluation maps of previous sections, three maps with recommendations for planning are generated, which emphasize the three targets of ventilation, air quality and thermal situation. Each target contains various planning objectives, each of which is divided into three levels according to their priorities in the planning process. The levels 1 and 2 represent a low and a high priority respectively, whereas the level 0 indicates there is no significant need for implementing any planning objective. The use of high and low priority levels makes the planning process more flexible. Finally, suitable implementation measures are recommended for each planning objective. These measures indicate the actions to be considered in spatial planning.

In the following sections, three targets, the maps with recommendations for planning, and the implementation measures are introduced in detail.

4.3.1 Ventilation

The risks of air pollution and heat stress in urban areas can be reduced by favorable urban ventilation, while an unfavorable one can cause disadvantages to settlements as well as habitats of fauna and flora. In CAMPUS the term ‘ventilation’ is defined as the ground-level air flow and its dispersion characteristics, which does not refer to the air flow of atmospherically or thermally polluted wind. For this reason, the target ‘ventilation’ is explained independently from the other two targets related to fresh and cold air flows.

Three planning objectives were proposed for the ventilation target (Table 4.14). The current urban ventilation in areas, where there is an increased risk of air pollution or heat stress, should be maintained (A1) or improved (A2) to reduce the risks. Furthermore, the possibility of wind damage should be avoided and reduced in areas susceptible to strong wind (A3).

Table 4.14 Scheme of the planning objectives related to the target A 'ventilation'

Planning Objectives		Initial*	Code	Priority
A1	Maintenance of urban ventilation in areas with increased risk of air pollution or heat stress	$A1_1$ $A1_2$	1 2	Low High
A2	Improvement of urban ventilation in areas with increased risk of air pollution or heat stress	$A2_1$ $A2_2$	3 4	Low High
A3	Avoidance and reduction of the risk of wind damage	$A3_1$ $A3_2$	5 6	Low High

* The initials $A1_0$, $A2_0$, $A3_0$ ($Code_{TA}$ = 0) indicate the areas not considered for each planning objective. They do not show up in the table.

Table 4.15 shows the formulas for rule-based evaluation for the target 'ventilation', to assign planning objectives to each space. To assign areas for planning objectives A1 and A2, air pollution and heat stress risks are used. However, land use properties are additionally applied for assigning the A1 areas: urban morphometry (i.e. positive surface influences causing low barrier effects on ventilation) and topography (causing no or low local cold air stagnation). High priorities in A1 and A2 are determined based on the intensity of local pollution risks. Hence, the areas with high increased risk of atmospheric or thermal pollution are designated as high priority.

Table 4.15 Formulas for rule-based evaluation of the target A 'ventilation'

PO[1)]	Sequence[2)]	Assigned area[3)]	High Priority
$A1_{1\text{-}2}$	1	$(AP_{1\text{-}2} \vee HS_{1\text{-}2}) \wedge (SI_0 \vee (SI_1 \wedge AT_{1\text{-}5})) \wedge CS_{0\text{-}1}$	$AP_2 \vee HS_2$
$A2_{1\text{-}2}$	2	$AP_{1\text{-}2} \vee HS_{1\text{-}2}$	$AP_2 \vee HS_2$
$A1_2$	3	$A2_{1\text{-}2} \wedge (AT_{1\text{-}4} \vee AT_6)$	-
$A2_0$	4	$A2_{1\text{-}2} \wedge A1_2$	-
$A3_{1\text{-}2}$	5	WE_2	$AT_{3\text{-}8}$

1) PO: Planning Objectives

2) Grid elements already allocated to a sequence are not reallocated, even if the allocation criteria are fulfilled.

3) Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion, concerned only for A3): 2ha

4) See Chapters 4.1 and 4.2 for the information of further abbreviations.

The areas A2 are reassigned for two reasons: Green areas in Seoul were classified as A2 where urban ventilation and its compensation effects should be improved, after performing the 2. Sequence (see Table 4.15). Actually, they should be preserved. Furthermore, little spatial differentiation within the Seoul area was resulted after the performance. Therefore, among the areas A2, those areas corresponding to the Areal

Types (ATs) ‘water surfaces, forests, unsealed areas, sealed without buildings or low density’ are reassigned to A1 with high priority ($A1_2$). By the reassignment, the green and open spaces classified to the planning objective ‘improving urban ventilation’ are assigned to that ‘maintaining urban ventilation’. This also enhances the spatial differentiation on the map.

The areas relevant for planning objective A3 are those with a high degree of local wind exposition; high priority is assigned to all Areal Types except for water surfaces and forests.

Figure 4.19 shows spatially distributed information on the target ventilation, which was determined by the evaluation formula of Table 4.15. Many built-up areas in Seoul fall into the category A2, where the urban ventilation should be improved to reduce high risks from air pollution or heat stress (orange-colored areas). Mountains in northern and southern parts as well as the Han River were found to be of level A_0 and were not included in the planning objectives as there is little risk of air pollution or heat stress.

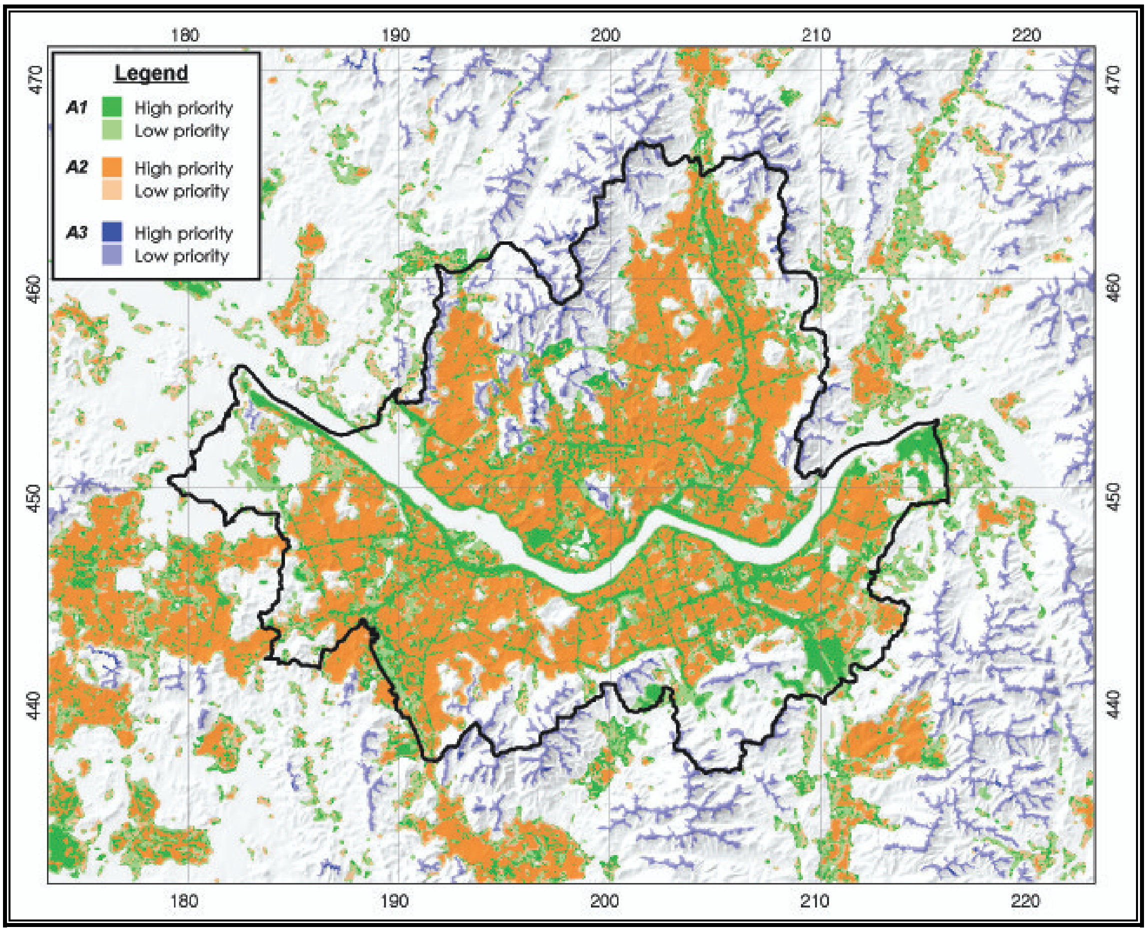


Figure 4.19 Map with planning recommendations for the target ‘ventilation’

Table 4.16 gives an overview of the whole area under examination, presenting the complete CAMPUS area and the sub-segment of Seoul metropolitan area and indicating the percentage of area to which planning objectives have been assigned. In the entire area of CAMPUS, the sections corresponding to 58.5 percent were not assigned to any planning objective. Among the sections to which planning objectives were assigned, the largest group of 14.6 percent was determined to be A2 with high priority. For the Seoul area, A2 with high priority was also the largest area (33 percent), followed by A1 with high priority (18.2 percent). Approximately 30 percent of the areas within Seoul were not assigned any planning objective. It indicates that surrounding areas have low ventilation problems, in contrast to Seoul which is affected by ventilation problems. Suitable planning measures for improving ventilation conditions are highly required for the Seoul area.

Table 4.16 Areas to which planning objectives for the target 'ventilation' were assigned (in percentage), within the entire area of CAMPUS and within the Seoul area only

	CAMPUS		SEOUL	
	Area (km^2)	**Percentage (%)**	**Area (km^2)**	**Percentage (%)**
Unassigned area	1,170.2	58.5	184.2	30.3
$A1_1$	125.9	6.3	47.5	7.8
$A1_2$	189.9	9.5	110.7	18.2
$A2_1$	117.2	5.9	42.7	7.0
$A2_2$	292.6	14.6	200.8	33.0
$A3_1$	101.8	5.1	21.7	3.6
$A3_2$	2.3	0.1	0.8	0.1
Total	2,000.0	100.0	608.4	100.0

Implementation measures for the target 'ventilation' are recommended in Table 4.17. For example, one might aim to keep the ratio of green areas in the A1 segments by avoiding new construction which might cause barriers to air flow; this would maintain advantageous urban ventilation in these already built-up areas.

Increasing the urban green ratio and reducing the building height and building density can reduce disadvantageous effects in the areas classified as A2. The recommended implementation measures for A3 do not aim to remove the sources that cause unfavorable wind conditions, such as wind exposition due to natural topographic properties; they rather deal with reducing and avoiding risks resulting from those.

Hence, measures like planting trees to protect crop fields from strong wind and to lessen erosion are suggested for these areas.

Table 4.17 Measures to implement the planning objectives related to the target 'ventilation'

Planning Objective	Implementation measures
$A1_{1-2}$	▪ Keep the ratio of parks, green areas and unoccupied areas ▪ Restrict the building height and density ▪ Avoid extensive construction ▪ Align road developments with prevailing direction of the urban air exchange ▪ Avoid attached building developments and planting of trees in settlement boundaries ▪ Avoid new construction causing significant barriers to ventilation ▪ Align unavoidable constructions, which could cause barriers to ventilation, with the prevailing direction of the air flow or lay them out permeably ▪ Avoid the establishment of closed forests
$A2_{1-2}$	▪ Implement measures to maintain urban ventilation (planning objective A1) ▪ Increase the ratio of parks, green areas and unoccupied areas ▪ Reduce the building height and density ▪ Lay out settlement areas permeably by securing the ventilation path ▪ Lay out settlement boundaries permeably ▪ Reduce barrier effects caused by existing barriers to ventilation
$A3_{1-2}$	▪ Do not keep vacant lots in settlements; rather plant trees to function as wind barrier ▪ Make constructional arrangements against wind disadvantages ▪ Implement measures of wind protection along traffic routes ▪ Plant trees to protect crop fields from wind and to reduce erosion ▪ Implement measures concerning forest establishment to avoid or reduce windbreak risks

4.3.2 Air quality

The planning objectives for the target 'air quality' deal with dispersion of air pollutants by ground-level air flow, as well as with areas facing air pollution risks.

Table 4.18 explains three planning objectives concerning this target. The current compensation effects through fresh air (i.e. ventilation containing little concentration of air pollutants) for areas facing increased air pollution loads should be maintained (B1) or improved (B2) to reduce the risk of atmospheric pollution. Furthermore, new atmospheric pollution should be avoided, or at least reduced (B3), in areas of potentially poor air exchange (especially during autochthonous weather conditions).

Table 4.18 Scheme of the planning objectives related to the target B 'air quality'

Planning Objectives		Initial*	Code	Priority
B1	Maintenance of compensation effects of fresh air flow to reduce air pollution loads	$B1_1$ $B1_2$	1 2	Low High
B2	Improvement of compensation effects of fresh air flow to reduce air pollution loads	$B2_1$ $B2_2$	3 4	Low High
B3	Avoidance and reduction of risks of air pollution in areas of potentially poor air exchange	$B3_1$ $B3_2$	5 6	Low High

* The initials $B1_0$, $B2_0$, $B3_0$ (CodeTA = 0) indicate the areas not considered for each planning objective. They do not show up in the map.

Table 4.19 shows the formulas of rule-based evaluation for this target 'air quality'. Both high wind speed at the mesoscale (e.g. mountain wind) and sufficiently strong flow of locally produced cold air play an important role as compensation effects of air flow on air pollution loads (Parlow et al., 2006). Hence, high wind speed as simulated by MetPhoMod (chapter 4.1.2), as well as medium and high local cold air transport (chapter 4.2.2) were employed to determine the areas of B1 and B2. Beside these conditions, advantageous properties of land use, urban morphometry (beneficial surface influences causing low barrier effects on ventilation) and topography (causing no or low local cold air stagnation) for urban ventilation were included as criteria in the rule-based evaluation for B1.

In contrast to the formulas employed to analyze the target 'ventilation', what matters most for the target 'air quality' is the distance to an area with local air pollution risks. The ground-level concentration generally decreases significantly with increasing distance from the emission source, at least during advantageous weather conditions. During disadvantageous conditions for air transport and dispersion, such as a low wind speed affecting the natural horizontal transport and a temperature inversion affecting the vertical dispersion, the air pollution concentration remains high within a certain distance from the emission source. For this reason, in CAMPUS it is assumed that ventilation for reducing air pollution loads is effective if the advantageous ventilation exists within a distance of 1.5km to areas with air pollution risks.

The areas with medium volume flow density of cold air were given high priority, since these areas are more susceptible to the interference from human activities like construction than areas with high volume flow (Parlow et al. 2006). In areas where cold air stagnates, risks of air pollution could increase. Hence, such areas are also to be given high priority.

Of the areas classified as B2, those corresponding to the ATs 'WA, TR, unS, SwoB and LD' are reclassified as B1, where the high priority is to maintain the current compensation effects.

Table 4.19 Formulas for rule-based evaluation of the target B 'air quality'. The initial 'd_{APR}' indicates the distance to an area with locally increased as well as strongly increased air pollution risks.

PO[1)]	Sequence[2)]	Assigned area[3)]	High Priority
$B1_{1-2}$	1	$(MW_2 \vee CT_{1-2}) \wedge d_{APR} \leq 1.5$km $\wedge AP_0 \wedge (SI_0 \vee (SI_1 \wedge AT_{0-5})) \wedge CS_{0-1}$	$CT_1 \vee CS_{1-2}$
$B2_{1-2}$	2	$(MW_2 \vee CT_{1-2}) \wedge d_{APR} \leq 1.5$km	$AP_{1-2} \vee CT_1 \vee CS_{1-2}$
$B1_2$	3	$B2_{1-2} \wedge (AT_{1-4} \vee AT_6)$	-
$B2_0$	4	$B2_{1-2} \wedge B1_2$	-
$B3_{1-2}$	5	$(MW_{0-1} \vee CT_0 \vee CS_{1-2}) \wedge AP_{1-2}$	$AP_2 \vee CS_{1-2}$

1) PO: Planning Objectives

2) Grid elements already allocated to a sequence are not reallocated, even if the allocation criteria are fulfilled.

3) See Chapters 4.1 and 4.2 for the information of further abbreviations.

The planning objective B3 is assigned to areas with disadvantageous wind condition at the mesoscale, and to areas facing low local cold air transport. Furthermore, areas where cold air stagnates also belong to this category. The areas with (strongly) increased risks of atmospheric pollution as well as significant cold air stagnation are classified as B3 high priority.

Figure 4.20 shows spatially distributed information on this target area, which were assigned by the evaluation criteria of Table 4.19. In many built-up areas in Seoul the compensation effects of ventilation should be improved in order to reduce air pollution loads (orange-colored areas). The compensation effects in northern and southern mountains, urban green areas as well as around the Han River should be maintained (green-colored areas). Large areas in the south-western part of Seoul as well as some areas at the eastern outskirts were classified as areas of potentially poor air exchange (negative urban ventilation of fresh air). Therefore, any new air pollution risks in these areas should be avoided and existing risks reduced (blue-colored areas).

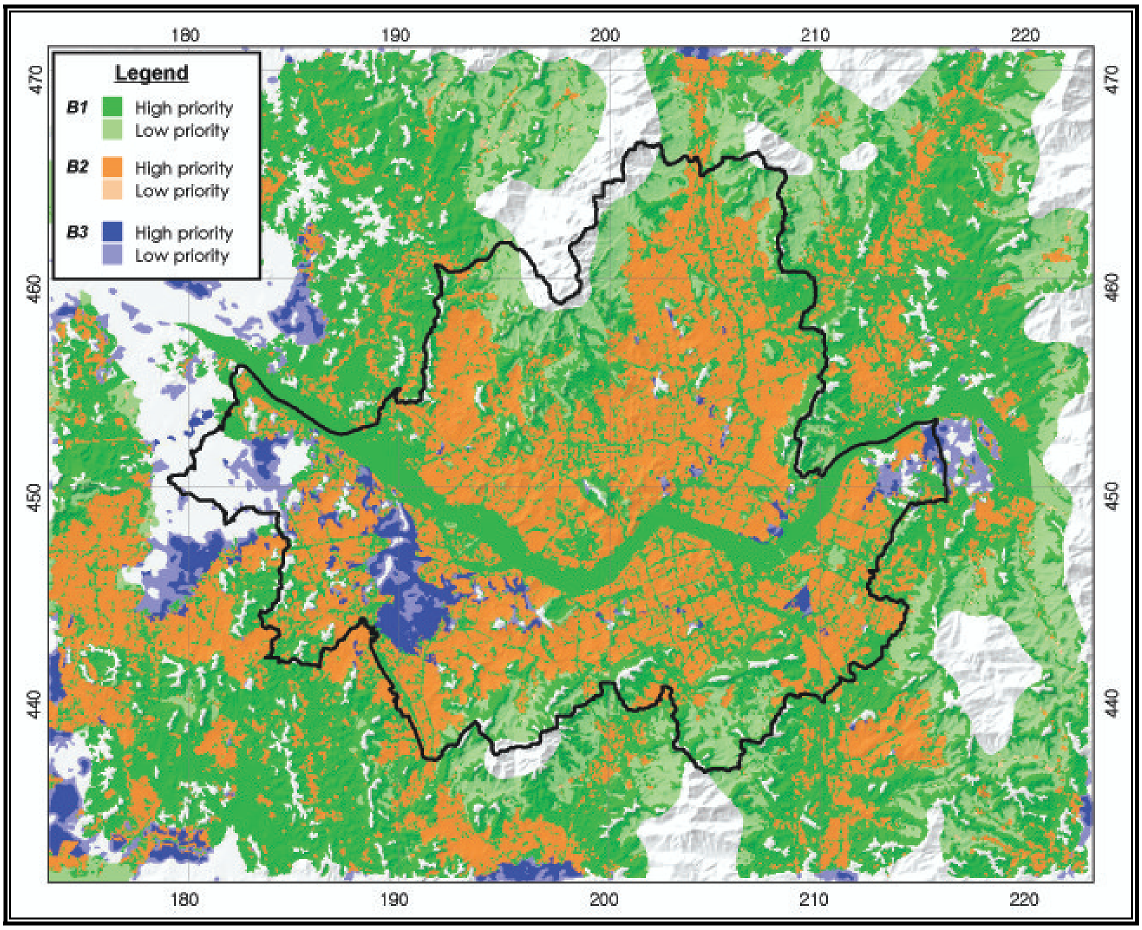


Figure 4.20 Map with planning recommendations for the target 'air quality'

Table 4.20 gives an overview of the whole area under examination, presenting the complete CAMPUS area and the sub-segment of Seoul metropolitan area and indicating the percentage of area to which planning objectives have been assigned. In the entire areas of CAMPUS, the largest areas were assigned to B1 with high priority (41.7 percent), followed by B2 with high priority (21.4 percent) and by B1 with low priority (11.2 percent). 20 percent of the whole CAMPUS area was not assigned any planning objective. Within the Seoul area, however, about 80 percent was classified as areas B1 with high priority (38.9 percent) or B2 with high priority (40.8 percent). It indicates that Seoul and its surrounding areas are affected by air pollution problem. In particular, Seoul area is highly concerned with this problem. Hence, suitable planning measures for improving atmospheric conditions are required for most areas of Seoul and surroundings.

Table 4.20 Areas to which planning objectives for the target 'air quality' were assigned (in percentage), within the entire area of CAMPUS and within the Seoul area only

	CAMPUS		**SEOUL**	
	Area (km^2)	**Percentage (%)**	**Area (km^2)**	**Percentage (%)**
Unassigned area	399.9	20.0	37.3	6.1
$B1_1$	224.3	11.2	49.9	8.2
$B1_2$	834.0	41.7	236.3	38.9
$B2_1$	5.3	0.3	0.8	0.1
$B2_2$	428.4	21.4	248.1	40.8
$B3_1$	62.3	3.1	14.6	2.4
$B3_2$	45.8	2.3	21.4	3.5
Total	2,000.0	100.0	608.4	100.0

Implementation measures concerning the target 'air quality' are shown in Table 4.21. The measures recommended for maintaining (B1) and improving (B2) air quality focus on the preserving and enhancing beneficial effects of ventilation like fresh air transport, which has a compensating effect on air pollution loads. Measures regarding B1 and B2 also deal with the reduction or avoidance of disadvantageous effects of air pollutions. Because compensation effects of air flow on air pollution loads are accomplished by both advantageous ventilation conditions and low air pollution emissions, the implementation measures used to achieve A1 and A2 are recommended for B2 as well. In order to keep emissions low, road constructions or settlements causing significant traffic loads or the emission of air pollutants should be avoided.

The implementation measures recommended for B3 do not only engage in improving ventilation conditions that cause poor air exchange, they also aim to reduce air pollution emissions. If these measures are not applicable for some areas, appropriate adaptation strategies serve to avoid or reduce negative effects of disadvantageous ventilation.

Table 4.21 Measures to implement the planning objectives related to the target 'air quality'

Planning Objective	Implementation measures
$B1_{1-2}$	▪ Implement measures to maintain the urban ventilation (Planning objective A1) ▪ Avoid road constructions causing significant traffic loads ▪ Avoid settlements causing significant emissions of air pollutants ▪ Restrict the building height and density ▪ Implement measures to improve compensation effects of air flow on air pollution loads (Planning objective B2) in case of unavoidable road constructions or settlements
$B2_{1-2}$	▪ Implement measures to maintain or improve urban ventilation (planning objectives A1 and A2) ▪ Implement measures to maintain compensation effects of air flow to air pollution loads (Planning objective B1) ▪ Implement measures to avoid and reduce risks of air pollution in areas of potentially poor air exchange (Planning objective B3)
$B3_{1-2}$	▪ Implement measures to maintain or improve compensation effects of air flow to air pollution loads (Planning objectives B1 and B2) ▪ Implement measures to avoid and reduce emissions caused by traffic and industry ▪ Facilitate use of regenerative energy (e.g. solar and geothermal energy) to provide low-emission local heat supply ▪ Facilitate access of residential areas to remote heat supply, unless low-emission local heat supply is possible. ▪ Implement measures to avoid and reduce industry-related emission ▪ Arrange for the displacements of factories and industrial plants causing high and irreducible emissions, so that they are relocated to less sensitive locations ▪ Carry out detailed analyses of air quality before planning constructions that may reduce air quality, e.g. residential areas ▪ Reduce air pollution by planting trees

4.3.3 Thermal situation

The planning objectives for the third target 'thermal situation' refer to areas facing thermal pollution risks as well as transport conditions at ground level, which can reduce or even avoid the problems of thermal pollutions.

Table 4.22 lists four planning objectives available to achieve this target. The current compensation effects from cold air flow (ventilation containing little thermal pollution) for areas facing increased thermal pollution loads should be maintained (C1) or improved (C2) to reduce the risk of heat stress. Furthermore, the risk in areas of potentially poor air exchange, especially during autochthonous weather conditions (C3), as well as increased risks of frost or heat loss (C4) should be avoided or at least reduced.

Table 4.22 Scheme of the planning objectives related to the target C 'thermal situation'

Planning Objectives		Initial*	Code	Priority
C1	Maintenance of compensation effects of cold air flow to reduce thermal stress	$C1_1$ $C1_2$	1 2	Low High
C2	Improvement of compensation effects of cold air flow to reduce thermal stress	$C2_1$ $C2_2$	3 4	Low High
C3	Avoidance and reduction of risks of thermal stress in areas of potentially poor air exchange	$C3_1$ $C3_2$	5 6	Low High
C4	Avoidance and reduction of increased risks of frost or heat loss	$C4_1$ $C4_2$	7 8	Low High

* The initials $C1_0$, $C2_0$, $C3_0$, $C4_0$ (CodeTA = 0) indicate the areas not considered for each planning objective. They do not show up in the map.

Table 4.23 shows the formulas for rule-based evaluation for this target. Both high wind speed on the mesoscale and a sufficiently strong flow of locally produced cold air are important in order to compensate for thermal pollution loads. The cold air transport is especially important for this compensation effect, because it has positive effects on thermally polluted areas due to the lower temperature it exhibits during low wind speed conditions (Parlow et al. 2006). The areas with medium volume flow density of cold air were classified as high priority, since these areas are more susceptible to the interference from human activities like construction than areas with high volume flow.

During autochthonous weather conditions, particularly in summer, air temperature remains high even at a great distance from the source of thermal pollution. For this reason, not only the risks of local thermal pollution but also the transportation and dispersion of the pollution were taken into account. Like for the target 'air quality', it is assumed for C1 and C2 that ventilation is effective to transport and disperse the thermal pollution if the advantageous ventilation exists within a distance of 1.5km to areas with thermal pollution risks. In order to classify areas as C4 (reduce risks of frost or heat loss), the area-average night-time mean air temperature at ground level simulated by MetPhoMod serves as criteria (see chapter 5.4).

Table 4.23 Formulas for rule-based evaluation of the target C 'thermal situation'. The initial 'd_{HSR}' indicates a distance to an area with locally increased as well as strongly increased heat stress risks. $\overline{T}$ indicates the night-time mean air temperature at ground level, simulated by using MetPhoMod, while $\langle\overline{T}\rangle$ represents the overall mean value of the area (see chapter 5.1.4).

PO[1)]	Sequence[2)]	Assigned area[3)]	High Priority
$C1_{1-2}$	1	$(MW_2 \vee CT_{1-2}) \wedge d_{HSR} \leq 1.5\text{km} \wedge HS_0 \wedge (SI_0 \vee (SI_1 \wedge AT_{0-5})) \wedge CS_{0-1}$	CT_1
$C2_{1-2}$	2	$(MW_2 \vee CT_{1-2}) \wedge d_{HSR} \leq 1.5\text{km}$	$HS_{1-2} \vee CT_1$
$C1_2$	3	$C2_{1-2} \wedge (AT_{1-4} \vee AT_6)$	-
$C2_0$	4	$C2_{1-2} \wedge C1_2$	-
$C3_{1-2}$	5	$(MW_{0-1} \vee CT_0) \wedge HS_{1-2}$	HS_2
$C4_{1-2}$	6	$(CS_{1-2} \vee \overline{T} \leq \langle\overline{T}\rangle) \wedge AT_{3-8}$	$CS_{1-2} \vee AT_{5-8}$

1) PO: Planning Objectives

2) Grid elements already allocated to a sequence are not reallocated, even if the allocation criteria are fulfilled.

3) See Chapters 4.1 and 4.2 for the information of further abbreviations.

4) Minimum area for spatial analysis (spatial connectivity for inclusion and exclusion, concerned only for C4): 2ha

Figure 4.21 shows spatially distributed information on this target area, which were assigned by the evaluation criteria of Table 4.23. In many built-up areas in Seoul the compensation effects of ventilation to reduce thermal pollution should be improved (orange-colored areas). The compensation effects in northern and southern mountains, urban green areas as well as around the Han River should be maintained (green-colored areas). Large areas in the south-western part of Seoul as well as some areas in the eastern outskirts were classified as areas of potentially poor air exchange (negative urban ventilation of cold air). Therefore, heat stress risks in these areas should be avoided and the existing ones reduced (red-colored areas). Because risks of frost or heat loss might increase in the western outskirt of Seoul, they are to be avoided and reduced in these areas (blue colored areas).

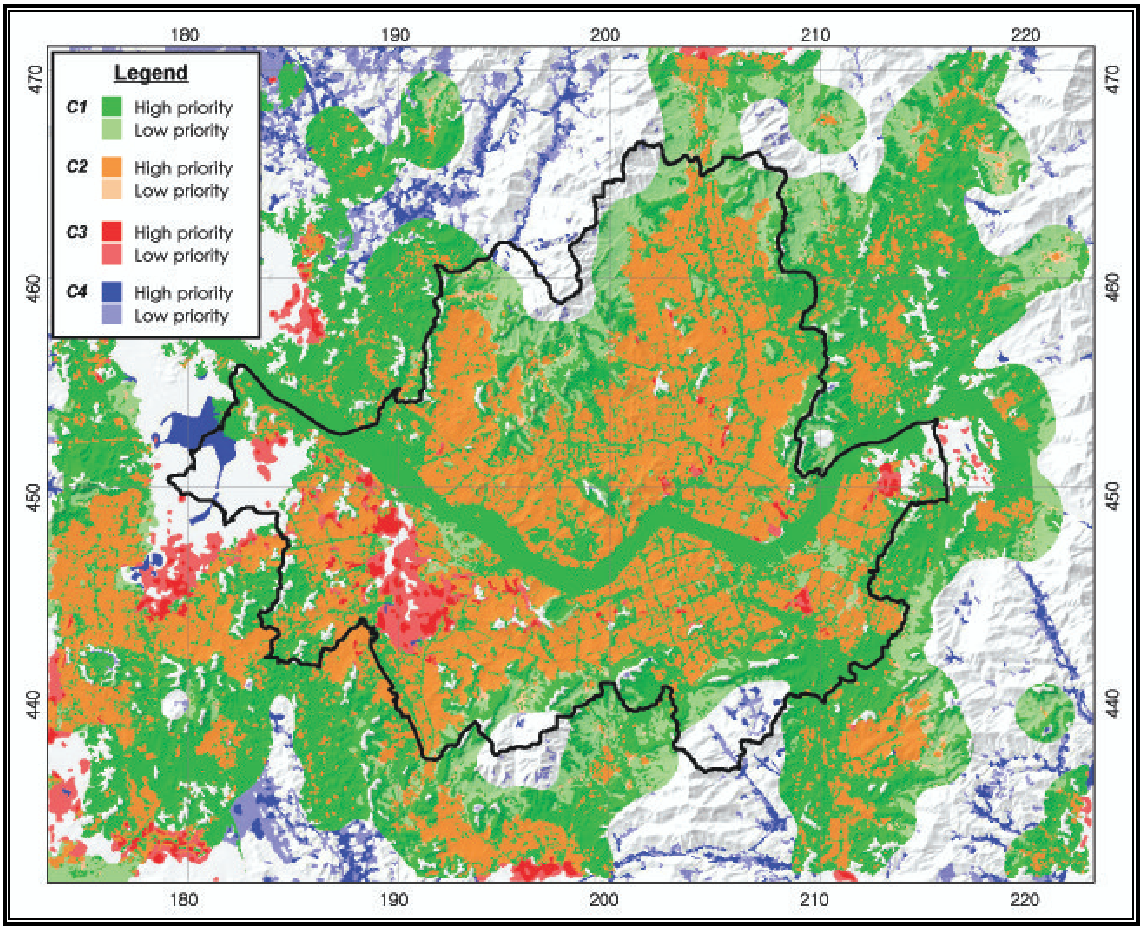


Figure 4.21 Map with planning recommendations for the target 'thermal situation'

Table 4.24 gives an overview of the whole area under examination, presenting the complete CAMPUS area and the sub-segment of Seoul metropolitan area and indicating the percentage of area to which planning objectives have been assigned. In the entire areas of CAMPUS, the largest part was classified as C1 with high priority (35 percent), followed by C2 with high priority (18.2 percent). 30.4 percent areas were not assigned any planning objective. Within the Seoul metropolitan area, however, 76 percent was classified as areas C1 with high priority (38.7 percent) or C2 with high priority (37.3 percent). It indicates that surrounding areas have relatively low effects of thermal problems compared to Seoul and large areas of Seoul are concerned with thermal problems. Hence, suitable planning measures for improving thermal conditions are required for most areas of Seoul.

Table 4.24 Areas to which planning objectives for the target 'thermal situation' were assigned (in percentage), within the entire area of CAMPUS and within the Seoul area only

	CAMPUS		SEOUL	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Unassigned area	608.7	30.4	62.9	10.3
$C1_1$	145.6	7.3	47.4	7.8
$C1_2$	699.2	35.0	235.1	38.7
$C2_1$	13.0	0.6	4.4	0.7
$C2_2$	365.0	18.2	227.1	37.3
$C3_1$	43.1	2.2	17.2	2.8
$C3_2$	19.2	1.0	9.2	1.5
$C4_1$	64.8	3.2	2.2	0.4
$C4_2$	41.4	2.1	2.9	0.5
Total	2,000.0	100.0	608.4	100.0

The implementation measures for the target 'thermal situation' are depicted in Table 4.25. The recommendations for C1 and C2 are focused on maintaining and facilitating favorable effects of cold air transport, as well as on avoiding and reducing thermal emissions. In order to ensure favorable ventilation conditions, it is recommended to implement the measures for A1 and A2. Thermal emissions can be avoided or at least reduced by avoiding settlements causing significant waste heat or by preserving areas producing cold air.

The implementation measures recommended for C3 gear to the sources of increased thermal pollution loads. They are targeting the improvement of ventilation conditions that cause poor air exchange (e.g. by implementing measures of A2) and the reduction of thermal emissions causing increased risks of heat stress in concerned areas (e.g. by enlarging green areas, reducing sealing ratio or displacing waste heat-intensive plants).

To achieve the objective 'C4', implementation measures focus on reducing/avoiding unfavorable effects of disadvantageous ventilation conditions, because the sources of frost or heat loss (e.g. meteorological conditions or topography) cannot be impacted with spatial planning.

Table 4.25 Measures to implement the planning objectives related to the target 'thermal situation'

Planning Objective	Implementation measures
$C1_{1-2}$	▪ Implement measures to maintain the urban ventilation (Planning objective A1) ▪ Preserve areas of cold air production ▪ Avoid settlements causing significant waste heat
$C2_{1-2}$	▪ Implement measures to maintain or improve urban ventilation (planning objectives A1 and A2) ▪ Implement measures to maintain compensation effects of air flow to thermal stress (planning objective C1) ▪ Implement measures to improve cold air transport in areas of cold air stagnation ▪ Implement measures to avoid and reduce risks of thermal stress in potential areas of poor air exchange (planning objective C3)
$C3_{1-2}$	▪ Implement measures to improve urban ventilation (planning objective A2) ▪ Implement measures to maintain or improve compensation effects of air flow to thermal stress (planning objectives C1 and C2) ▪ Enhance greening in residential areas including streets by facilitating roadside trees, planting in gardens, green facades and roofs ▪ Enable the establishment of shadows when designing new buildings, e.g. arcades ▪ Reduce the sealing ratio ▪ Implement technical measures to reduce the production of waste heat ▪ Examine displacements of manufacturing and industrial plants with waste heat-intensive processes
$C4_{1-2}$	▪ Avoid cultivation of crops susceptible to frost ▪ Implement measures to improve cold air transport in areas of cold air stagnation ▪ Avoid extensive enlargement of residential areas ▪ Condense residential areas with constructions, if it causes no other climatic or air quality problems ▪ Support initiatives by owners/occupants to reduce the heat loss of buildings

5 Applications of spatially distributed climate information in the spatial planning of Seoul

This chapter shows how the spatially distributed information on urban climate generated by CAMPUS can be applied to the current spatial planning of Seoul. At first, the existing regulatory systems of Germany and Korea are examined to show how the regulatory systems generally function and how they handle climatic issues in spatial planning (chapter 5.1). Subsequently, general strategies for urban development are suggested for three different levels of spatial planning in Korea: the urban comprehensive plan (chapter 5.2) on the regional level (city and suburbs), the urban master plan (chapter 5.3) on the city level, and the urban management plan (chapter 5.4) on the district level.

5.1 Regulatory system and spatial planning

5.1.1 Regulatory system for protecting and improving urban climate

The German Federal Building Code (Baugesetzbuch, BauGB) was amended in 2004 to incorporate Directive 2001/42/EC of the European Parliament and the Council on the assessment of the effects of certain plans and programs on the environment. The amended law seeks to implement the issue 'climate protection' in spatial planning: The urban land use plan shall safeguard sustainable urban development to respond to general climate protection (Article 1(5) of BauGB).

In addition, the Federal Nature Conservation Act (Bundesnaturschutzgesetz, BNatSchG) basically incorporates the protection of 'climate and air' in spatial planning. This act, amended in 2002, demands in its Article 1 (concerning aims of nature conservation and landscape management) that nature and landscape both inside and outside the areas of human settlement shall be conserved, managed, developed and, where necessary, restored in order to safeguard a functioning ecosystem. Climate and air are the components of the ecosystem to be conserved, managed, developed as well as restored (Article 10(1)1 of BNatSchG). Hence, the protection and improvement of climatic conditions, including local climate, shall be strived for by measures of nature conservation and landscape management pursuant to its Article 2(1)6. Particularly, forests and other areas with favourable climatic effects as well as local air-exchange pathways (ventilation) shall be preserved, developed or restored pursuant to the same Article.

The requirements and measures of nature conservation and landscape management shall be set out in landscape planning (Article 14(1) of this act). The landscape planning shall contain information about the requirements and measures needed to protect, improve the quality and allow regeneration of air and climate (Article 14(1)4e). The contents of landscape planning must be taken into consideration in other planning and administrative procedures as well as in environmental assessments (Article 14(2)). The format of graphs, legends, maps or similar material from landscape planning shall allow their inclusion in spatial/regional plans (Raumordnungspläne) and building master plans (Bauleitpläne), pursuant to Article 14(1)4 of this act. This facilitates the inclusion of both items 'climate and air' in spatial planning. Implementation of requirements and measures relating to climate and air in spatial planning is also guaranteed by the fact that landscape planning, which shall contain climate-related requirements and measures, shall comply with the objectives of spatial planning and take account of the principles and other requirements of spatial planning (Articles 15(1) and 16(1)).

Unlike Germany, Korea has two environmental laws concerned with nature conservation and management. The Framework Act on Environmental Policy (FAEP), a comprehensive and intermediate environmental law, aims to make all the people enjoy healthy and pleasant lives

- by preventing environmental pollution and environmental damages, and
- by properly managing and preserving the environment (Article 1 of FAEP).

In order to manage and preserve the environment, the rights and duties of citizens and the obligations of the State with regard to environmental preservation shall be defined and the fundamental matters for environmental policies shall be determined in this law. There is a significant difference between Germany and Korea, in that Germany has no environmental law resembling the Korean FAEP (Lee & Bückmann 2004). The second environmental law in Korea, the Natural Environment Conservation Act (NECA), aims for sustainable utilization of the natural environment and for allowing people to lead a leisurely and healthy life in a comfortable natural environment. It therefore defines integral principles for systematically conserving and managing the natural environment (Article 1 of NECA).

Both Korean environmental laws define the components of environment in Article 3 of FAEP and Article 2 of NECA. While the 'air' is defined as an environmental element being conserved and managed, the ‘climate’ is not clearly defined in either law. This could result in the overlooking of climatic elements when it comes to implementing their objectives in the planning and policy making processes.

Environmental planning shall be established for conserving and managing environmental issues pursuant to Articles 12 and 14(2), (3) and (4) of FAEP. While no timetable is given in the German law (BNatSchG) for regular updating of landscape planning[2], environmental planning in Korea shall be regularly updated at different intervals. National comprehensive environmental plans (comprehensive plans for environmental conservation on the national level) and mid-term comprehensive environmental plans (plans for implementing the national plans) shall be updated every ten years and five years, respectively (Articles 12 and 14(2) of FAEP.) The updating of municipal environmental plans may be provided by each communal government. For instance, environmental plans for Seoul shall be updated every ten years (Article 11(1) of Basic Environmental Ordinance of Seoul Metropolitan Government). This regular updating guarantees that the current environmental stipulations are consistently considered in the environmental plans.

However, environmental planning is not oriented towards spatial planning, but rather toward strategic planning in all important sectors of policy in Korea (International Institute for Sustainable Development 2004). The environmental plan of Seoul contains the following strategic contents pursuant to Article 11(2) of the above-mentioned ordinance of Seoul Metropolitan Government:

- Changes and perspectives in environmental conditions
- Objectives of environmental conservation
- Strategic plans for achieving the objectives in all sectors and steps
- The costs for implementing the plans, and its funding arrangements

Ultimately, the implementation of requirements and measures relating to climate and air in spatial planning is guaranteed neither by FAEP nor NECA.

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[2] Updating of landscape programs (Landschaftsproramme) covering the entire territory of a Federal *Land* as well as landscape master plans (Landschaftsrahmenpläne) is not defined in BNatSchG. However, landscape plans (Lanschaftspläne) concerning local nature conservation and landscape management shall be updated when any significant changes to landscape are envisaged or to be expected (Article 16(1) of BNatSchG).

As the focus on urban ventilation has increased in Korean cities in order to improve atmospheric conditions, the Clean Air Conservation Act (CACA) has added a new provision concerning implementations in spatial planning that is valid since January 2006. Hence, in establishing and implementing all kinds of development plans, obstacles to the circulation of air pollutants shall be neutralized as much as possible, taking into consideration the topography of the planned areas and the neighboring areas, and the direction and velocity of wind, the arrangement of and space between buildings, the passage of wind, etc. therein (Article 7(4) of CACA).

5.1.2 Spatial planning in Korea

Since 1960s the national territory of the Republic of Korea had mainly been managed by three laws, namely the “Act on Comprehensive plans for Construction in the National Land (CCNL)”, the “Act on the Utilization and Management of the National Land (UMNL)” and the “Urban Planning Act (UPA)” (Choi et al. 2002). The “Framework Act on the National Land (FANL)” and the “National Land Planning and Utilization Act (NLPU)” aim at sustainable development. They were laid down in February of 2002 and came into force in January of 2003, while the former three laws were abrogated and replaced by them. The CCNL was abrogated and its legal instruments were enhanced by FANL (Lee 2004). Further, the legal instruments of the abrogated UMNL and UPA were integrated into NLPU and enhanced (Choi et al. 2002).

The FANL and NLPU, which concern the development and management of the national land, have different properties. The former aims to contribute to the sound development of the national land and the improvement of the national welfare (Article 1 of FANL). Hence, it provides for fundamental matters concerning the formulation and implementation of plans for and policies on the national land. The latter provides for matters necessary for the formulation and implementation of plans to develop and preserve the national land (Article 1 of NLPU).

As both laws focus on different aspects, they support different planning systems for managing the national land. The FANL classifies the planning system into five levels pursuant to Article 6: the comprehensive national land plan for the national level, the ‘Do’ comprehensive plan for province level, the ‘Si/Gun’ comprehensive plan for city level, the regional plan for specific regions, and the sector plan for specific sectors (Table 5.1).

The plans supported by FANL are abstract plans which specify long-term national strategies for managing national areas (Ministry of Environment 2006). For example, the comprehensive national land plan, which is the highest-ranking plan on land development, provides policies for management and development of the national land for 20 years (Article 7 of FANL). Currently, the 4th comprehensive national land plan is in action (2000-2020).

Table 5.1 Comprehensive plan for the national land according to Framework Act on the National Land (Ministry of Environment 2006; revised)

Covering area	Land plan	Description
Entire areas of national land	Comprehensive national land plan	A comprehensive plan indicating a long-term development direction for the national land
Areas under the jurisdiction of a province	'Do' comprehensive plan	A comprehensive plan indicating a long-term development direction for the relevant areas
Areas under the jurisdiction of a city (including Metropolitan City)	'Si/Gun' comprehensive plan	A plan to be formulated for land utilization, traffic, environment, safety, industry, information and communications, health, welfare and culture, etc., indicating the basic spatial structures of relevant areas, i.e. an urban plan to be formulated under the National Land Planning and Utilization Act
Specific regions	Regional plan	A plan to be formulated in order to achieve the objectives of special policies
The entire national land	Sector plan	A plan indicating a long-term development direction for the specific sectors

In contrast to the plans designed by FANL, those supported by NLPU are spatial plans for urban areas, which are the main plans for managing urban land use (Ministry of Environment 2006). These spatial plans are divided into three levels according to NLPU: the comprehensive urban plan, the urban master plan and the urban management plan (Table 5.2).

The comprehensive urban plan sets the long-term (20 years) framework for future development of more than two adjacent cities (Article 2(1) of NLPU). This plan shall adjust to objectives of national plans like the comprehensive national land plan. Besides, as the uppermost urban plan, the comprehensive urban plan gives guidelines for urban development to its subordinate plans like the urban master plan and the urban management plan (Ministry of Environment 2006).

The urban master plan, a binding plan, defines basic land use structures for subordinated spatial plans as well as long-term (20 years) strategies for urban development on a city level (Article 2(3) of NLPU). It includes overall goals of a city, designation of zones in accordance with population distribution, plans for conserving the environment, urban infrastructure, urban parks and open space, and others (Article 19). Since subordinate plans like the urban management plan are to adjust to the objectives of the urban master plan, the master plan governs the future physical planning of the city.

Table 5.2 Urban planning according to the National Land Planning and Utilization Act (Ministry of Environment 2006; revised)

Covering area	Land plan	Description
More than two adjacent cities	Comprehensive urban plan	The long-term (20 years) framework for future development of more than two adjacent cities
Areas under the jurisdiction of a city	Urban master plan	The long-term (20 years) development plan and a binding plan, providing overall goals for a city, designation of zones in accordance with population distribution, plans for conserving the environment, urban infrastructure, urban parks and open space, providing basic land use structures for subordinated spatial plans
Areas under the jurisdiction of a city	Urban management plan	The mid-term (10 years) plan, regulating construction and general design of the urban physical development. It comprises land use plans, zoning districts, district unit plans etc.

The urban management plan, as a mid-term (10 years) plan for urban physical development, comprises designation of zoning districts, district unit plans, and other plans concerning land use, transport, environment, industry, culture and so on (Article 2(4) of NLPU). As a subordinate plan of the comprehensive urban plan and the urban master plan, it shall adjust to the long-term development goals of its superior plans (Article 25).

These three plans, supported by the NLPU, are more suitable for examining the applicability of the spatially distributed information on urban climate to spatial planning than the plans provided by FANL: The former are spatial plans that designate urban development. Hence, the current spatial plans of Seoul supported by the NLPU are applied for this examination in the following sections.

5.2 Applications in comprehensive urban plans

The current comprehensive urban plan covering Seoul is the comprehensive urban plan for the Capital region 2020, which was set for developing and managing of the Capital region for 20 years (the base year: 2000) according to the National Land Planning and Utilization Act (NLPU, Article 10). The Capital region comprises Seoul Metropolitan city, Incheon Metropolitan city and 21 cities in Gyunggi Province. This plan seeks to coordinate the relevant spatial developments and to suggest ways of coordinating Restricted Development Zones (RDZs). The whole region comprising Seoul is included in this plan that covers an area of 11,754km^2. Hence, in the following sections, possible strategies for spatial developments as well as the coordination of restricted development zones are suggested to show the potential of applying the spatially distributed information gained from CAMPUS in the comprehensive plan.

Because the study area analyzed by CAMPUS does not cover the entire area of the 2020 Metropolitan comprehensive plan, the suggestions focus on the Seoul Metropolitan area and its directly adjacent areas.

5.2.1 Suggestions for spatial developments in areas bordering on Seoul

Strategies for spatial developments aim to protect the local climate. Advantageous climate conditions are to be protected, and harmful influences are to be avoided.

Finke et al. (1993), who investigated 24 regional plans in Germany, suggest the following four measures to protect the climate at the regional level (Verein Deutscher Ingenieure 2004):

- Protection of areas that are important for the climate (among others, areas of origin of cold air and cold air drainage areas)
- Prohibition of polluting activities in certain areas (e.g. industrial production in valleys)
- Promotion of equalizing effects on the climate (e.g. removing obstructions to cold air drainage)
- Application of instruments of air quality protection (e.g. greenbelt)

Based on these measures mentioned above, three aspects were set to be examined at the level of the comprehensive urban plan: protection of areas of cold air origin and cold air drainage areas, prohibition of certain uses in cold air stagnation areas, and promotion of equalizing effects on the climate by removing obstructions of the cold air drainage. These three aspects are designated on the satellite image in Figure 5.1. In the examination, the climate analysis and evaluation maps as well as maps with planning recommendations, which were produced by using CAMPUS in the previous chapter, offer indications where the measures could be implemented.

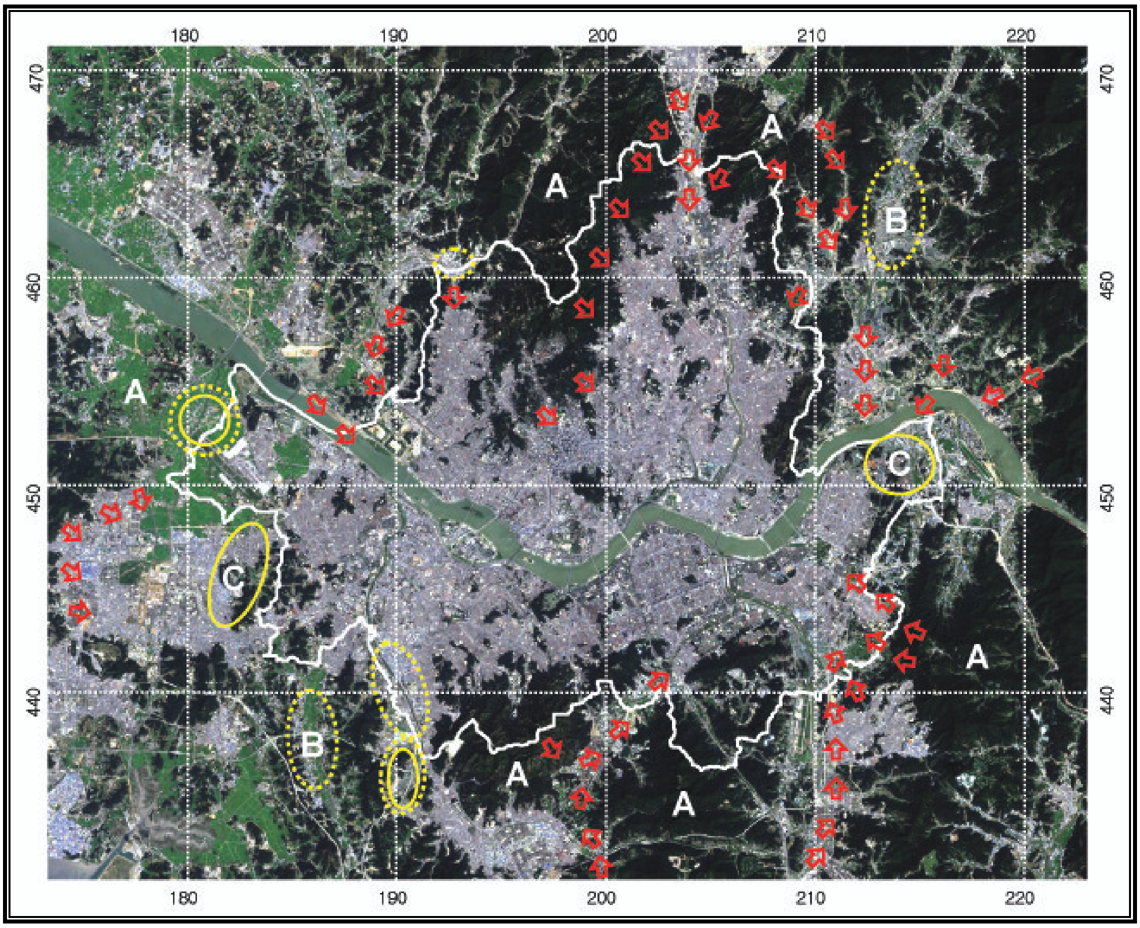


Figure 5.1 Applications in the comprehensive urban plan

Protection of areas of cold air origin and cold air drainage areas (designated A in Figure 5.1)

It is important to utilize areas of cold air origin on the outskirts of Seoul in order to compensate for the poor cold air productivity within the city (see Figure 4.12). Hence, the areas producing cold air, which are adjacent to Seoul in northern and southern parts, are to be preferentially protected. The origins of cold air, located on the eastern outskirts of Seoul, also belong to the protected areas. On the western outskirts, cold air productivity is lower than in other areas, therefore they require special protection against constructional activities, because they contribute valuable cold air to western Seoul, where few cold air origins exist.

Local wind systems like valley and mountain winds often guarantee minimum ventilation during calm wind conditions. Hence, these cold air drainage areas, which largely appear in mountainous surroundings of Seoul, on northern, southern and eastern outskirts, must be protected. In particular, the protection of cold air drainage areas adjacent to settlements with disadvantageous ventilation circumstances should be taken into account in advance of any new construction. This will preserve the existing compensation effects for the relevant settlements.

Prohibition of certain uses in cold air stagnation areas (B in Figure 5.1)

The three cold air stagnation areas formed by both relief and buildings (shown as B in Figure 5.1) should be protected from any additional sources of pollution. They are found in the western, southwestern, and eastern outskirts of Seoul (see Figure 4.14). Where cold air stagnates, air quality will be low due to poor air exchanges and the accumulation of pollutants. Hence, the air quality might worsen further (see Figure 4.9). Developments of new settlements, industries, and road construction causing additional traffic should be avoided. Furthermore, agricultural activities susceptible to frost are unsuitable in these areas due to the high risk of frost damage to crops.

Promotion of equalizing effects on the climate by removing obstructions of the cold air drainage (C in Figure 5.1)

Cold air drainage areas play a role in the supply of cold and fresh air into the built-up areas of Seoul. However, constructions may obstruct incoming ventilation to Seoul. Western and eastern parts outside of Seoul have high surface influences that obstruct incoming ventilation to Seoul (see Figure 4.15). Hence, continuous vertical developments should not be permitted in the western and eastern parts outside of Seoul. Besides, it is required to reduce surface influences in the reconstructions in these areas, e.g. by restricting construction to low-rise buildings.

The part that is located between built-up areas in Seoul and those outside the city limits on the eastern and western boundaries has medium volume density of cold air (see

Figure 4.13). Hence, the present conditions of this area are to be kept against urban sprawls of both built-up areas.

5.2.2 Coordinating strategies of Restricted Development Zones

The Restricted Development Zone (RDZ) is a land use designation to retain undeveloped or agricultural areas surrounding or neighboring urban areas. This zone, referred to also as a greenbelt, was introduced in the City Planning Law of 1971 and shaped by the 1972-1981 National Comprehensive Physical Plan of 1973 (Lee S. 2004). In the Capital region, an area of 1,566.8km^2 was designated as greenbelts from 1971 to 1976, which amounts to 13.3 percent of the entire metropolitan area (Bengston & Youn 2006). Table 5.3 shows the spaces designated as restricted development zones in this area.

Almost 60 percent of the restricted development zones of Seoul consist of mountains and forests (Bae & Jun 2003). They have played a role to control urban sprawl, to reduce rapid population growth and industrial concentration in the Capital region, and to protect environmental and natural resource (Bae 1998). Hence, most development was strictly prohibited in these zones, and landowners in the zones have not been compensated for their loss of development rights (Bae 1998; Lee 1999).

South Korea’s greenbelt policy has remained essentially unchanged for almost 30 years (Bengston & Youn 2006). However, this policy has been reformed since 1998, when the former President Kim promised to eliminate a part of the greenbelts during the presidential election of 1997 (Park 2001). Since then, the Ministry of Construction and Transportation (MOCT) has announced a reform of the greenbelt policy in 1999, sections of restricted development zones (RDZs) in the Capital area have been eliminated. In late December 2006, an area of 1,472.9km^2 was still registered as RDZs in the Capital area (Table 5.3).

Table 5.3 Restricted Development Zones in the Capital area

Designation date	Administrative areas	Designated areas (km^2)	
		Dec. 1976	Dec. 2006
Jul. 1971 – Dec. 1976	- Seoul metropolitan area (19 districts) - Incheon metropolitan area (6 districts) - 21 cities in Gyunggi province	1,566.8	1,472.9

*Source: Ministry of Construction and Transportation 2007

Within Seoul city, a total of 124.2km^2 of RDZs will have been re-designated for development by the year 2020 (the base year being 1998) according to the 2020 Metropolitan comprehensive plan, announced in September 2007. By late 2006, an area of 9.72 km^2 has been re-designated, compared to the year of 2000 with 166.82km^2 of greenbelts (Table 5.4).

Table 5.4 Restricted Development Zones in the Seoul area

	Until 2000	2001	2002	2003	2004	2005	2006
Area (km^2)	166.82	166.81	166.18	163. 75	160.50	157.85	157.1

* Source: Seoul statistical yearbook (2001-2007)

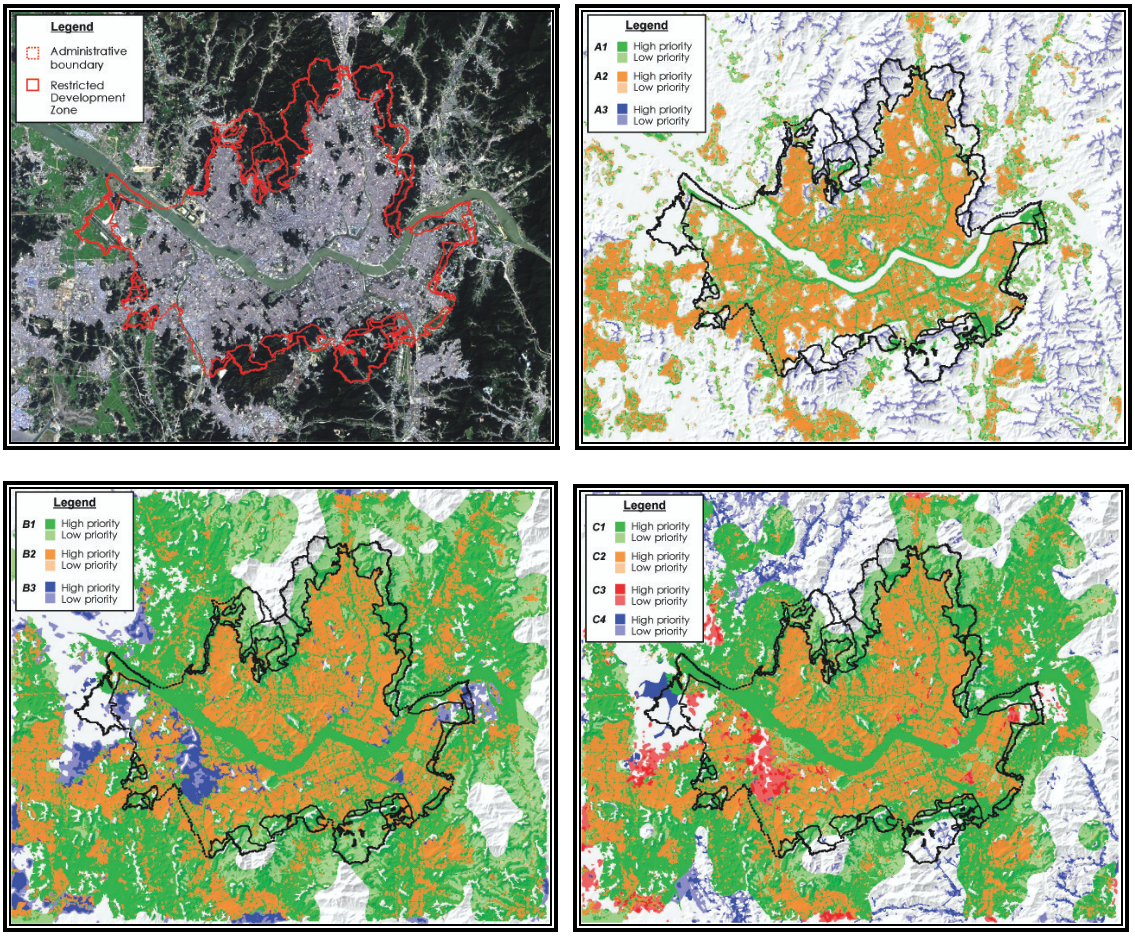


Figure 5.2 The current restricted development zones (RDZs) of the Seoul city, represented on the Landsat7 ETM+ (above left) as well as three planning maps (above right: ventilation, below left: Air quality, below right: thermal situation)

Figure 5.2 shows the current restricted development zones (RDZs) of the Seoul area, represented on the Landsat7 ETM+ as well as three planning maps ‘ventilation, air quality and thermal situation’. Most of southern and northern RDZs are located in mountainous topography, and it is recommended that these areas remain RDZs so as to improve the compensation effects of air flow against atmospheric or thermal loads. The RDZs in the western part, which are currently used agriculturally, are little affected by atmospheric or thermal pollution. Hence, these areas are suggested for possible development in the future. Since they contribute to cold air production, however, planning measures to offset any negative effects should be discussed before any construction begins, like preserving green areas or enlarging them by planting trees, green roofs and facades.

5.3 Applications in urban master plans

5.3.1 Seoul Master Plan 2020

The Seoul Master Plan 2020, the urban master plan for the time being, involves a vision statement, land use concept, guidelines and strategic objectives pursuant to the National Land Planning and Utilization Act (NLPU, Article 18). Besides, it establishes a direction and more specific policies for each sector, e.g. environment, transport and industry of Seoul.

This plan, announced in the year 2006 as strategic plan, has four visions for developing Seoul city for 20 years (the base year: 2000). These four visions are world city, cultural city, welfare city and eco city (Seoul Metropolitan Government 2006B). Among them, the vision ‘Eco City’ pursues a sustainable development with four main topics: air quality, water, ecosystem and environmental management. In addition, each topic suggests planning objectives and general implementation measures in detail. Table 5.5 shows the four topics of ‘eco city’, the planning objectives and their implementation measures.

As shown in Table 5.5, topics on urban climate are treated in the Seoul master plan 2020 together with topics on air quality. Hence, three detailed planning measures are suggested: enlarging green areas and establishing green networks to mitigate urban heat island effects, considering effective urban ventilation in land use plans, and protecting urban microclimate and managing climate comfort zone. In order to implement these planning measures in spatial planning, comprehensive information on the climatic conditions of the whole Seoul area is needed to give an overview of where the measures should be implemented.

Table 5.5 Main topics for 'eco city' dealt with in the Seoul Master Plan 2020, planning objectives and their implementation measures (Seoul Metropolitan Government 2006B; revised)

Topics	Planning objectives	Implementation measures
Air quality	Reducing the emissions of air pollutants	• Improving quotient of clean air • Offering real-time information on air quality • Promoting lifestyles that reduce emissions of air pollutants • Establishing transport policies and environmental management concerning environmental loads of roadsides
	Cleanup of the polluted air	• Enlarging green areas and establishing green networks to mitigate urban heat island effects • Integrating effective urban ventilation into land use plans • Protecting urban microclimate and managing climate comfort zone*
Water	Improving the quality of drinking water	• Enhancing quality of drinking water • Enhancing quality management of water sources
	Improving sewage disposal	• Sustainable management and reconstruction of sewer systems • Establishing information system of sewer management • Enhancing control of pollutant source
	Enhancing river management; securing water resources	• Facilitating conservation and restoration of water resources of rivers • Establishing utilization of ground waters and treated wastewater for reuse • Promoting the conservation and low consumption of tap water
Ecosystem	Establishing the conservation of the natural ecosystem	• Establishing ecological axes • Planting trees in urban areas • Supporting activities for conserving

		natural environment • Preserving important fauna and flora and their habitats • Promoting biodiversity and open spaces
	Establishment of environment-friendly urban management system	• Enhancing environment-friendly land use and management system • Natural regeneration of riverbed (removing concrete) and managing the surroundings environmentally • Designating districts for integrated management of transport and environment • Establishing citizen participation in conserving the urban ecology • Implementing environmental education to citizens
Environmental management	Enhanced management of low-energy consumption	• Enacting provisions concerning energy management • Enforcing energy-saving certification • Enhancing the management of discharging waste • Establishing a system to manage resource recycling • Enhancing resource-saving and low consumption of resources
	Establishing reasonable and integrated environment management system	• Establishing unified environmental strategies between environment, urban planning and transport sector • Enhancing partnerships between citizens, industry and administration • Establishing environment-related information system and opening it to the public • Establishing and implementing comprehensive environmental administration system in the capital region • Introducing the system of ecological budgeting

* The climate comfort zone, introduced by Olgyay (1973), is a tool available as the urban bio-climate indicator. He created a bioclimatic chart, which shows zones of human comfort in relation to ambient air temperature and humidity, mean radiant temperature, wind speed, solar radiation, and evaporative cooling. A comfort zone is created in the center of the chart, which emphasizes the correct temperature and humidity for maximum comfort.

5.3.2 Strategies on the spatial planning for development zones

In order to effectively manage the urban development, the Seoul master plan 2020 divides the Seoul area into five zones; urban core zone, northeastern zone, northwestern zone (north of the Han River), southwestern zone, and southeastern zone (south of the Han River). They are distinguished by topographical and physical properties (like river, road), administrative divisions, land use, and residential characteristics (Seoul Metropolitan Government 2006B). Among them, some zones with big areas are further divided into two to three sub-zones each, constituting nine sub-zones. Figure 5.3 shows the five zones and their sub-zones of Seoul, divided in the Seoul master plan 2020. In addition, areas, population figures and characteristics of each zone are explained in detail in Table 5.6.

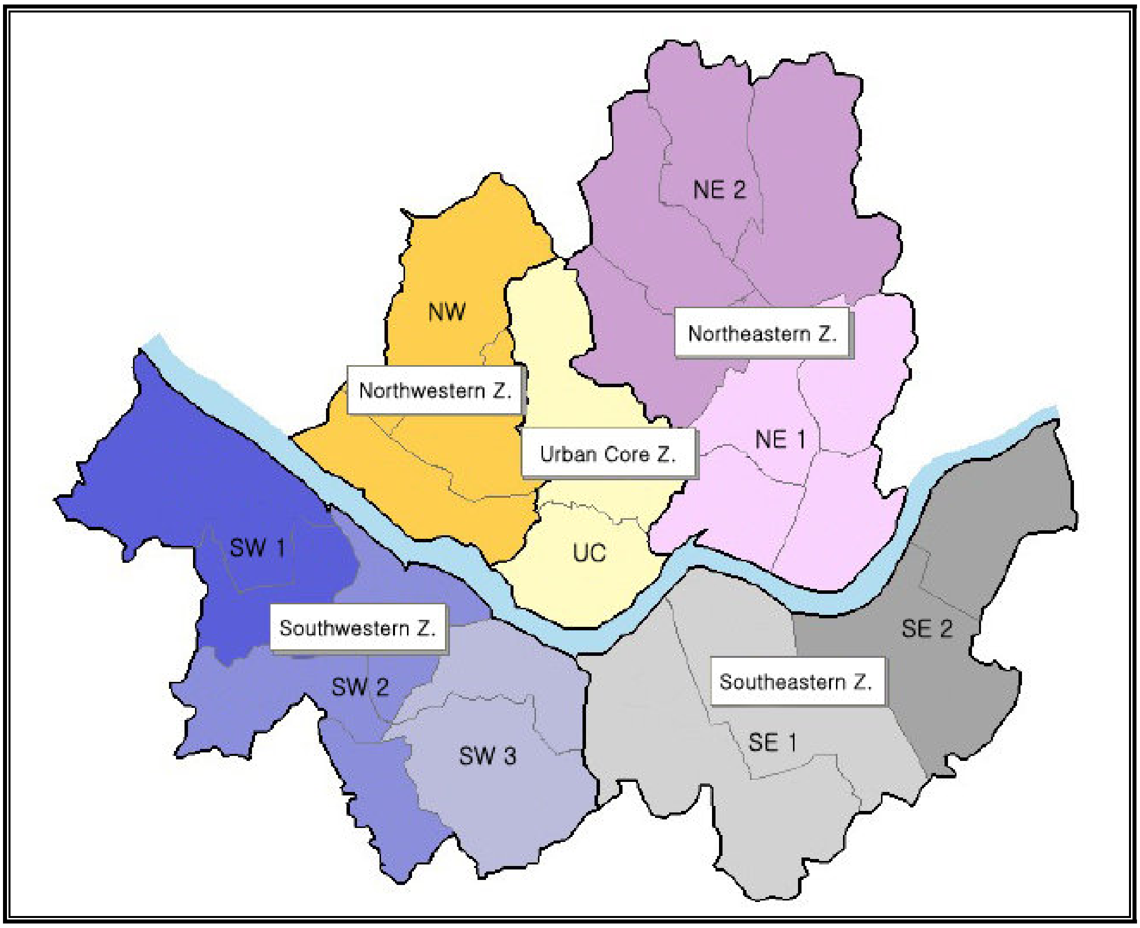


Figure 5.3 Five zones and their sub-zones of Seoul in the Seoul master plan 2020 (Seoul Metropolitan Government 2006B; revised)

Table 5.6 Areas, populations and characteristics of five zones of Seoul (Seoul Metropolitan Government 2006B; revised)

Zone	Sub-zone	Nr. of districts	Area (km^2)	Population (Person)	Characteristics
Urban core zone (UC)	UC	3	55.75	583,923	• Concentration of backbone functions of administration, economy, diplomacy • Gradual decrease of population • Antiquated physical structures
Northeastern zone (NE)	NE 1	4	66.62	1,567,358	• Linkage between urban core and northern-eastern parts of surroundings • Lots of natural landscape • Residential areas with huge apartment areas and antiquated high density areas
	NE 2	4	104.39	1,826,767	
Northwestern zone (NW)	NW	3	71.19	1,222,753	• Linkage between urban core and northern-western outskirts • Plenty of natural green areas • Antiquated settlements with high density and low-rise buildings
Southwestern zone (SW)	SW 1	2	58.80	1,009,637	• Linkage between urban core and southern-western outskirts, particularly well-developed transport linkage • Mixed land uses of residential, commercial and industrial type • Crowded and antiquated residential buildings
	SW 2	3	57.68	1,090,434	
	SW 3	2	45.92	937,534	
Southeastern zone (SE)	SE 1	2	86.70	944,021	• Linkage between urban core and southern-eastern outskirts • New district shaped by urban planning in 1970s • Residential areas mostly of apartment blocks. • Dedevelo pment of low or medium height-apartment buildings
	SE 2	2	58.46	1,148,827	
Total	9	25	605.52	10,331,224	

Based on the maps with planning recommendations generated in chapter 4.3, strategies of the spatial planning for five zones as well as their sub-zones are suggested in this study. Tables 5.7, 5.8 and 5.9 show the planning strategies according to ventilation, air quality and thermal situation, respectively.

The urban core zone should be strategically planned to maintain the urban ventilation in combination with the maintenance and improvement of the compensation effects of air flow to reduce air pollution loads and thermal stress. For implementing these strategies, planning measures are recommended, e.g. keeping the current open spaces, avoiding new settlements that might cause significant air pollution, and keeping building height and density low by reconstruction.

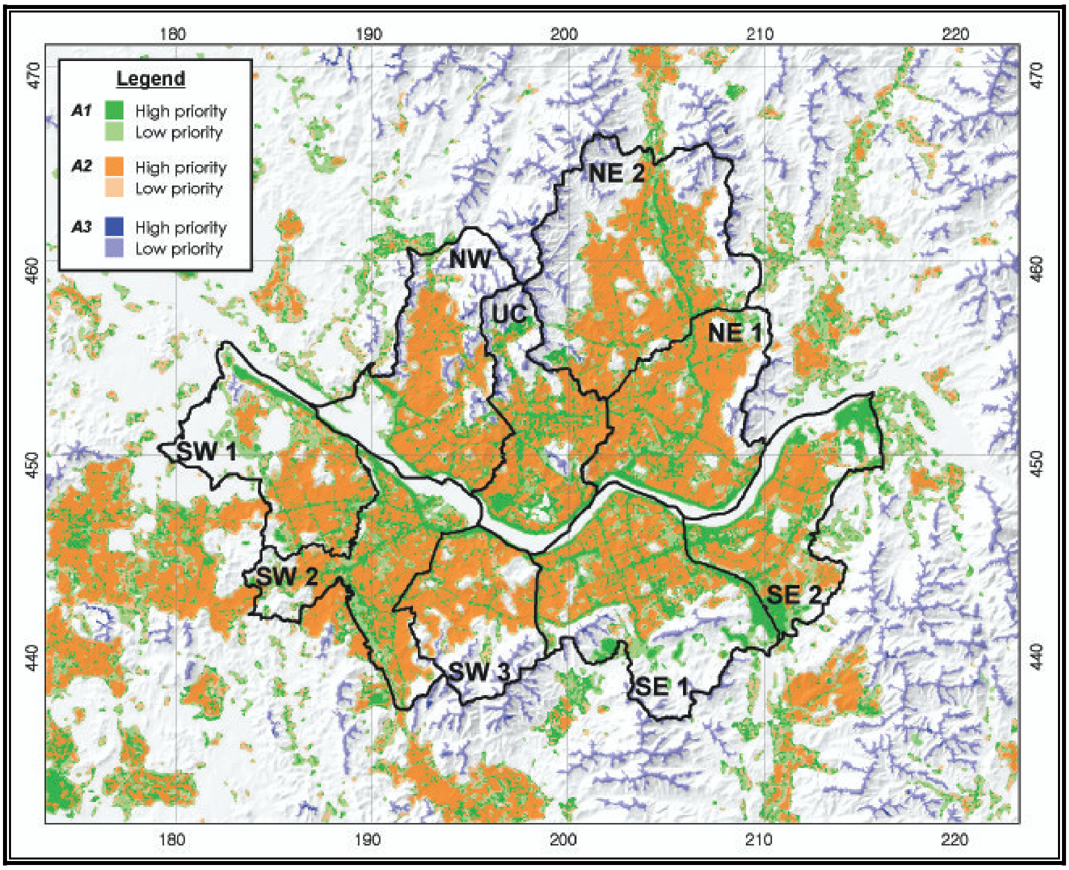
Both the northeastern and northwestern zones need strategies to improve the urban ventilation. In addition, in these zones it is also required to reduce present air pollution loads and thermal stress. Hence it is suggested as planning measures for these zones to increase open and green spaces, to lay out settlement areas permeably by securing the ventilation path, and to reduce traffic emissions, e.g. by avoiding large residential or commercial districts causing significant traffic loads.

For the southwestern zone, various strategies can be introduced. Its western parts are largely available for further development. However, its central parts should be protected against further air pollution and thermal stress, e.g. by reducing traffic and industrial emissions, by planting roadside trees, green roofs and green facades.

The southeastern zone can be strategically planned to maintain and improve the urban ventilation, as well as to preserve the compensation effects of air flow to air pollution risks and thermal stress. However, strategies to avoid or reduce air pollution and thermal stress risks are needed for eastern parts of this zone. Further planning measures for implementing the strategies are presented in chapter 4.3.

Table 5.7 Planning strategies on the spatial planning for five zones (ventilation)

Spatially distributed information : Ventilation



Strategies on the spatial planning for five zones

Urban core zone

- Maintaining the urban ventilation for most built-up areas

Northeastern zone

- NE1: Combination of maintaining and improving the urban ventilation
- NE2: Improving the urban ventilation for most built-up areas

Northwestern zone

- Improving the urban ventilation for most built-up areas

Southwestern zone

- SW1: Western parts available for development. Improving the urban ventilation for the remaining parts
- SW2: Maintaining the urban ventilation for most built-up areas
- SW3: Improving the urban ventilation for most built-up areas

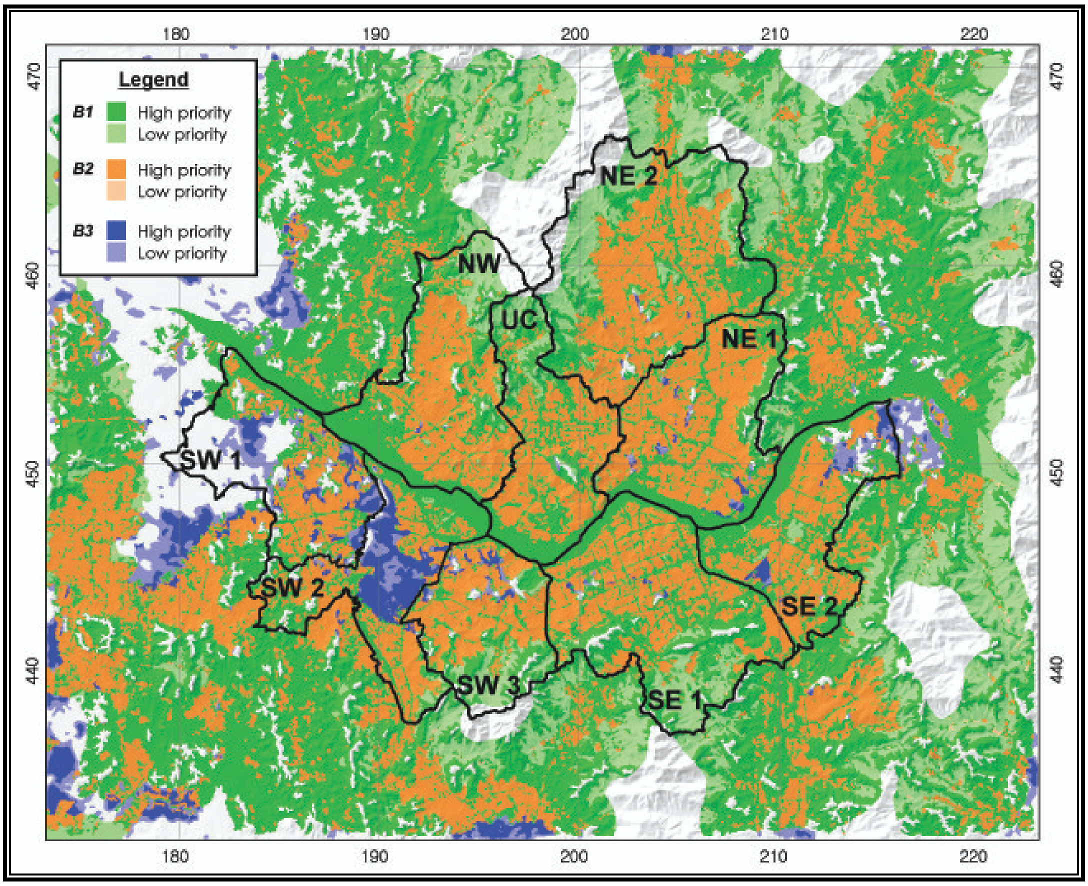
Southeastern zone

- SE1: Combination of maintaining and improving the urban ventilation
- SE2: Maintaining the urban ventilation largely for western parts. Improving the urban ventilation largely for eastern parts

* See Table 4.14 for planning objectives of A1, A2 and A3, and Table 4.17 for implementing measures of each strategy

Table 5.8 Planning strategies on the spatial planning for five zones (air quality)

Spatially distributed information : Air quality



Strategies on the spatial planning for five zones

Urban core zone

- Combination of maintaining and improving the compensation effects of air flow to air pollution loads for most areas

Northeastern zone

- NE1 / NE2: Improving the compensation effects for most built-up areas

Northwestern zone

- Improving the compensation effects for most built-up areas

Southwestern zone

- SW1: Western parts available for development. Improving the compensation effects for the remaining parts
- SW2: Avoiding or reducing of risks of air pollution for central parts
- SW3: Improving the compensation effects for most built-up areas

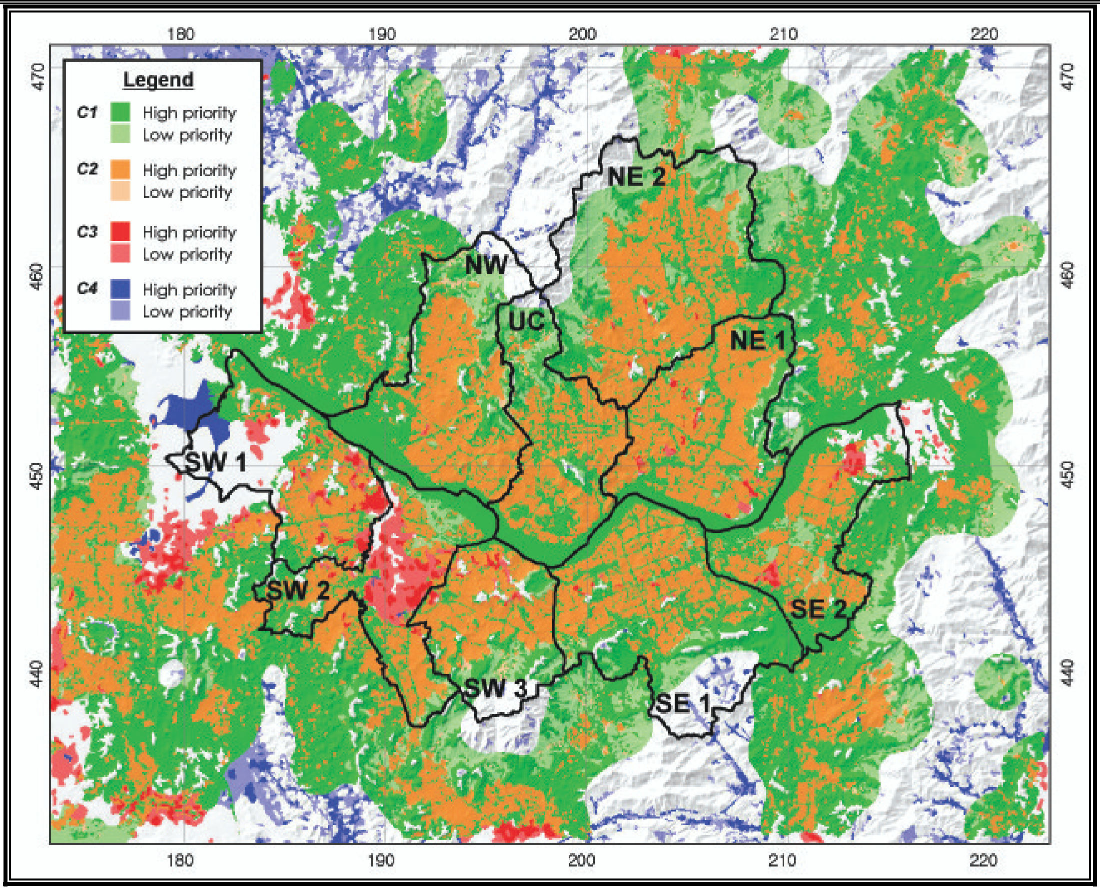
Southeastern zone

- SE1 / SE2: Combination of maintaining and improving the compensation effects. Avoiding or reducing of risks of air pollution for eastern parts of SE2

* See Table 4.18 for planning objectives of B1, B2 and B3, and Table 4.21 for implementing measures of each strategy

Table 5.9 Planning strategies on the spatial planning for five zones (thermal situation)

Spatially distributed information : Thermal situation



Strategies on the spatial planning for five zones

<u>Urban core zone</u>

- Combination of maintaining and improving the compensation effects of air flow to thermal stress for most areas

<u>Northeastern zone</u>

- NE1 / NE2: Improving the compensation effects for most built-up areas

<u>Northwestern zone</u>

- Improving the compensation effects for most built-up areas

<u>Southwestern zone</u>

- SW1: Some western parts available for development, yet risks of frost or heat loss should be avoided. Improving the compensation effects for the remaining parts
- SW2: Avoiding or reducing of risks of thermal stress for central parts
- SW3: Improving the compensation effects for most built-up areas

<u>Southeastern zone</u>

- SE1 / SE2: Combination of maintaining and improving the compensation effects, while avoiding or reducing of risks of thermal stress for SE2

* See Table 4.22 for planning objectives of C1, C2, C3 and C4, and Table 4.25 for implementing measures of each strategy

5.4 Applications in urban management plans

The Seoul Master Plan 2020 introduces five important undeveloped areas available for future development within the city, as follows (Seoul Metropolitan Goverment 2006B).

- The surroundings of the Yongsan rail station and the U.S. military base in the urban core zone;
- The Ttukseom area, where both the Han River and the Jungrang River cross in the northeastern zone;
- The Sangam and Susaek areas in the northwestern zone;
- The Magok area, where the Gimpo airport is located and is the gate for connecting with the Incheon air port; and,
- The Munjeong and Jangji areas, which are located on the bordering area in the southeastern zone.

Because of the high density of most areas in Seoul, the management of these five areas is of prime concern for city planners. Among these five, the future utilization of Yongsan U.S. Army base, which will be relocated in near future, is actively discussed because it is located on main transport and green networks of Seoul. Hence, this study of applications of climate information is concentrated on the example of Yongsan Garrison.

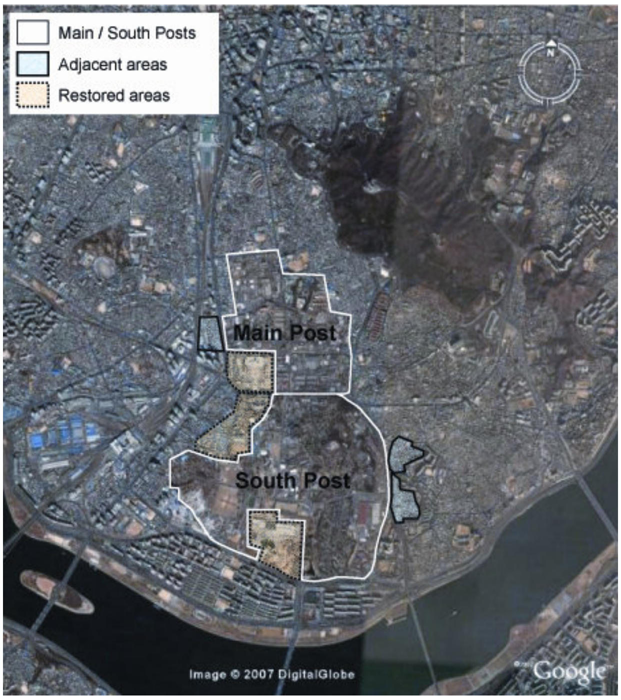
5.4.1 General information on Yongsan military base

The Yongsan Garrison area, located in the heart of Seoul, has been used as a U.S. military base since 1945, when the Japanese Army withdrew from the Korean Peninsular, thus ending 35 years of Japanese occupation. Since the MOA (Memorandum of Agreement) regarding the relocation of the U.S. Army base has been signed by the Korean and U.S. government in 1990, suitable future developments for the area have been subject of heated debates since then (Kim & Bae 2006). It was only in 2004, that both governments agreed to relocate Yongsan Garrison outside of Seoul, which contains the headquarters for the US military presence in Korea, by the year 2009.

Table 5.10 shows the constitutions of Yongsag military base. This military base occupies some 3,676,200m^2 of land just south of Mt. Namsan. It is divided into three major areas: the Main Post (some 792,000m^2, northern part) and the South Post (some 1,881,000m^2), with several smaller adjacent areas (some 191,400m^2). Some

811,800m² of land has been already given back to the city of Seoul to become Yongsan Family Park, the National Central Museum and the War Museum (Kim & Bae 2006).

Table 5.10 Yongsan military base and its constitutions

Aerial photograph of the Yongsan military base	Constitution**
	▪ **Main Post:** 792,000m² (21.5%) ▪ **South Post:** 1,881,000m² (51.2%) ▪ **Three adjacent areas:** 191,400m² (5.2%) ▪ **Already restored areas:** 811,800m² (22.1%) ; Yongsan Family Park, the National Central Museum, the War Museum, The Ministry of National Defense ▪ **Total areas:** 3,676,200m² (100%)

* Image source: Google earth

** Source: Kim & Bae (2006); revised

The base has provided all the support facilities for U.S. military personnel and their family members, i.e. a hospital, a police force, schools, theaters, restaurants, a hotel, sports and recreational facilities (Park 2005). In contrast to most areas of Seoul, the density of Yongsan garrison has remained low, similar to suburban areas. Based on the population density of Seoul in 2001 (17,062 person/km²), the density of Seoul is 4.4 to 6 times as much as that of the Garrison area (Park 2005).

For the development of the Yongsan base after its relocation, the Seoul Metropolitan government has declared that it will turn this area into an open space, and planned to use the whole area of the Main Post and the South Post as a park (Seoul Metropolitan Government 2006B). The most important consideration was that Seoul city does not have lots of neighborhood parks. As shown in Table 5.11, Seoul with the park area of 4.66m² per person has lower ratio than other built-up cities like Tokyo with 5.2 m²/person and Berlin with 23.9m²/person.

Table 5.11 Population densities and available park areas per person in built-up cities (Park 2005)

	Seoul	Tokyo	Beijing	New York	Berlin
Population density (p/km^2)	17,062	13,084	27,000	9,602	3,798
Available park area per person (m^2)*	4.66	5.2	3.7	14.1	23.9

* National parks, urban natural parks and funeral parks were not calculated.

Furthermore, the base area is located on the green network of Seoul (Seoul Metropolitan Government 2006B). Beside the Circle Network surrounding the Seoul area, the North-South network is running from Mt. Bukhansan (North) over Mt. Namsan to Mt. Gwanaksan (South). Yongsan base is located on this N-S green network (Figure 5.4).

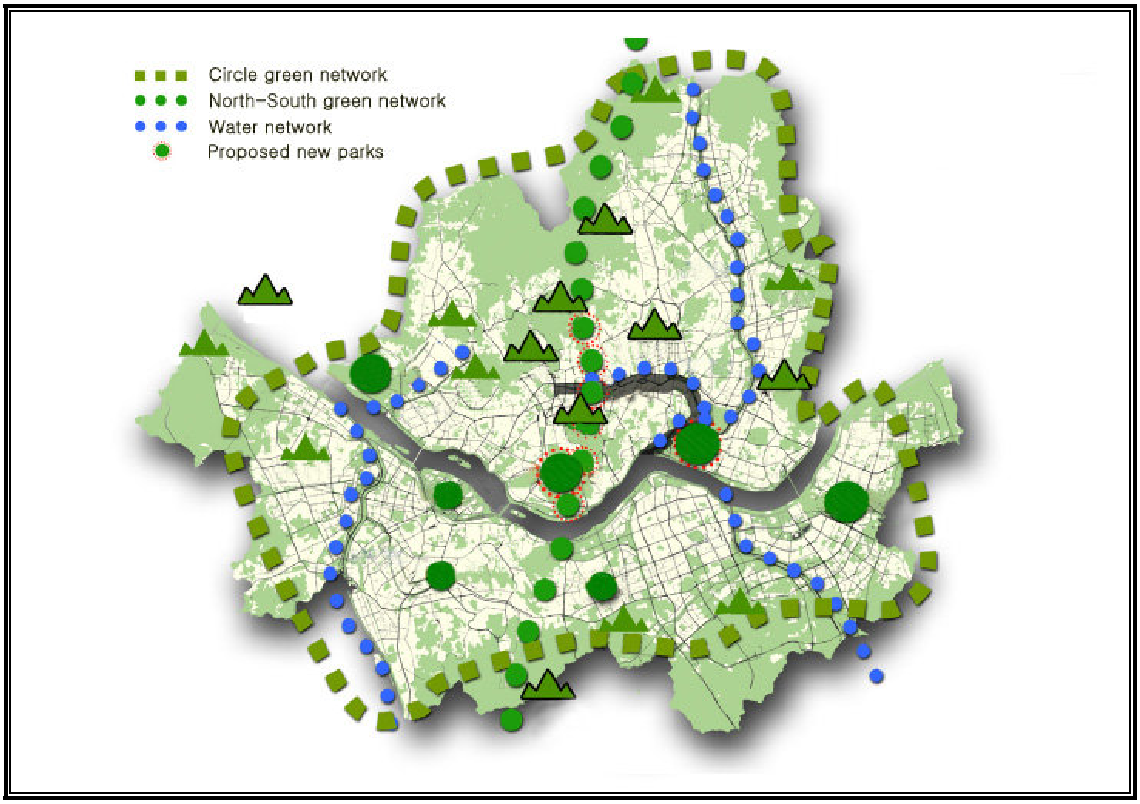


Figure 5.4 Green Network of Seoul in Seoul Master Plan 2020 (Seoul Metropolitan Government 2006B; revised)

However, the Ministry of Construction and Transportation has made plans to sell part of the land for commercial development to cover the relocation costs, because the government has agreed to share the financial burden of the base relocation with the US military. After long discussions between the national government and the Seoul city government, a special law for constructing a new Yongsan park was enacted in July 2007 (Legislation No. 8512), which comes into force in January 2008. According to this law, both Main and South Posts shall be used as a park, and shall not be available for other uses like commercial development (Article 4(2) of this law). If the entire military base is turned into a park, the neighborhood park area per a person will increase from 4.66m^2 to 5.02m^2, based on the populations and park areas of the entire area of Seoul in 2001 (see Table 5.11).

5.4.2 The climatic situations of Yongsan military base (based on the CAMPUS results)

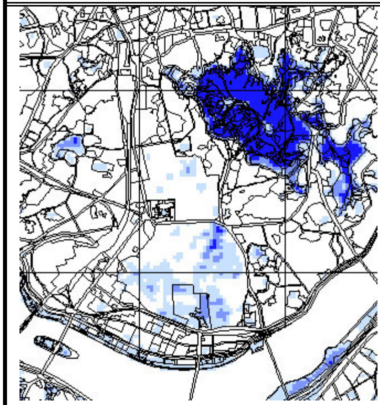
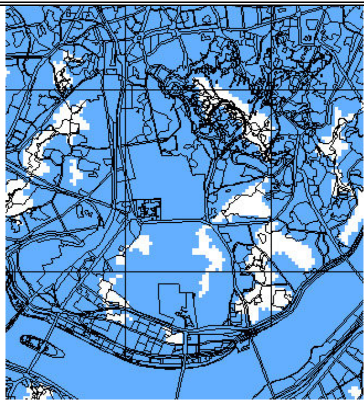
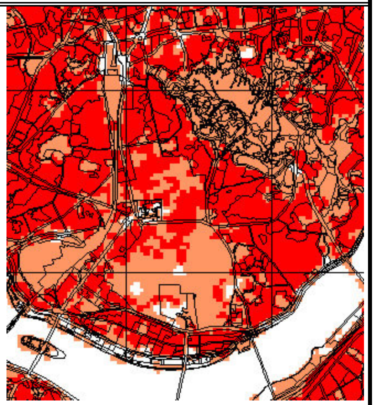
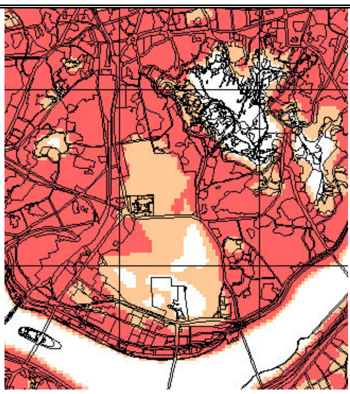
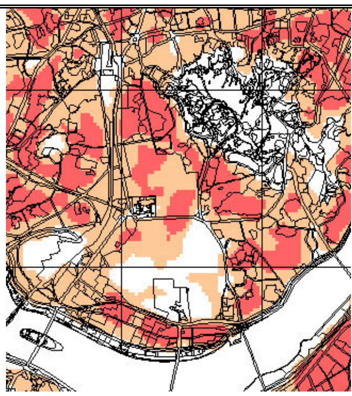
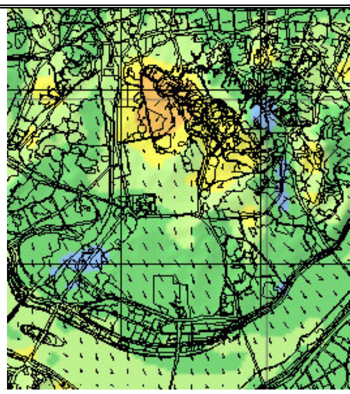
According to the climate analysis and evaluation by CAMPUS, Yongsan military base itself has advantageous climatic conditions in comparison with its neighboring areas. The climatic characteristics of Yongsan military base are described in Table 5.12, using the CAMPUS results: local cold air production and transport, local surface influence, local atmospheric and thermal risks, and mesoscale wind circumstances.

Although the Main Post partly has a high local surface influence and a medium volume flow density of local cold air, the open spaces within it produce local cold air, and it has moderate effects on local ventilation due to its medium local surface influence. However, it shows increased risks of both local atmospheric and thermal loads, as well as partly strongly increased risk of thermal loads.

While the Main Post partly shows typical climatic conditions of urban districts of Seoul, the South Post has more advantageous conditions than its neighboring areas. It contributes to local nocturnal cold air that offers neighboring areas at least some cold air. Both a medium volume flow density of local cold air and a medium local surface influence, which appeared in most parts, contribute to advantageous ventilation conditions. Compared to the neighboring areas with strongly increased risks of atmospheric loads, that risk is less serious in the South Post. The larger part of the South Post area, particularly in the eastern and southern parts, has no increased risks of thermal loads.

Neighboring natural areas like Mt. Namsan and the Han River contribute to beneficial effects on climatic conditions. Mt. Namsan, located just north of the military base, plays an important role for the neighboring areas due to its high cold air productivity.

Table 5.12 Climatic characteristics of Yongsan military base (See Chapters 4.1 and 4.2 for the legends of maps)

Local cold air production	Local cold air transport	Local surface influence
		
▪ **Mt. Namsan located just north of the base:** High cold air productivity ▪ **South Post:** Contribution to produce local nocturnal cold air ▪ **Neighboring areas adjacent to the base:** No concern with local cold air production	▪ **Main Post / the surrounding areas of the base (except eastern parts):** Medium volume flow density of local cold air ▪ **Some parts of South Post & the eastern parts of the base:** Low volume flow density	▪ **Most parts of Main Post / the surrounding areas of the base:** High local surface influence ▪ **Most parts of South Post:** Medium or low local surface influence
Local atmospheric loads	**Local thermal loads**	**Mesoscale wind**
		
▪ **Main Post:** Mostly increased risk of local atmospheric loads ▪ **South Post:** No increased risk as well as increased risk ▪ **Neighboring areas adjacent to the base:** Strongly increased risk, Mt. Namsan and Han River with no increased risk within a near distance	▪ **Main Post:** Increased & strongly increased risks of local thermal loads ▪ **South Post:** Mostly no increased risk, but partly increased risk ▪ **Neighboring areas adjacent to the base:** Strongly increased risk in northern and eastern parts of Main Post, as well as in southern part of South Post	▪ **Wind direction:** Wind from NNW in both Posts and neighboring areas ▪ **Wind speed:** Relative wind speed in both Posts is generally over 150 percent higher than the area-average value of the entire simulation area. Average or higher than average wind speed in Neighboring areas.

Furthermore, it does not have any disadvantageous effect on atmospheric and thermal loads, showing no increased risks of either. The Han River, which is located south of this base, shows advantageous properties for local ventilation due to the absence of local surface influence and due to a medium volume flow density of local cold air. No risks of atmospheric and thermal loads exist over the river.

The rail facilities, located just west of the base, also offer advantageous ventilation conditions of a medium local surface influence and a medium volume flow density of local cold air. Due to the absence of thermal load risks, this area does not affect the thermal situation negatively.

Apart from the areas mentioned above, neighboring areas of the base mostly show disadvantageous climatic conditions, similar to typical urban districts of Seoul. They don't contribute to local cold air production. Eastern parts of the base have a low volume flow density of local cold air. Furthermore, most neighboring areas consist of high-rise buildings and thus have high local surface influence, which contributes to unfavorable ventilation conditions together with a low volume flow density. The neighboring areas adjacent to the base mostly show significant risks of atmospheric and thermal loads. In particular, they have strongly increased risks of atmospheric loads. Strongly increased risks of thermal loads appeared in northern and eastern parts of the Main Post, as well as in southern part of the South Post.

Both Posts and neighboring areas adjacent to the base have favorable mesoscale wind circumstances. The wind speed in both Posts is generally over 150 percent higher than the area-average value of the entire simulation area. Neighboring areas adjacent to the base have average or higher wind speed than the area-average value. Winds on both Posts and neighboring areas prevail from a northwest direction.

5.4.3 Recommendations for spatial planning

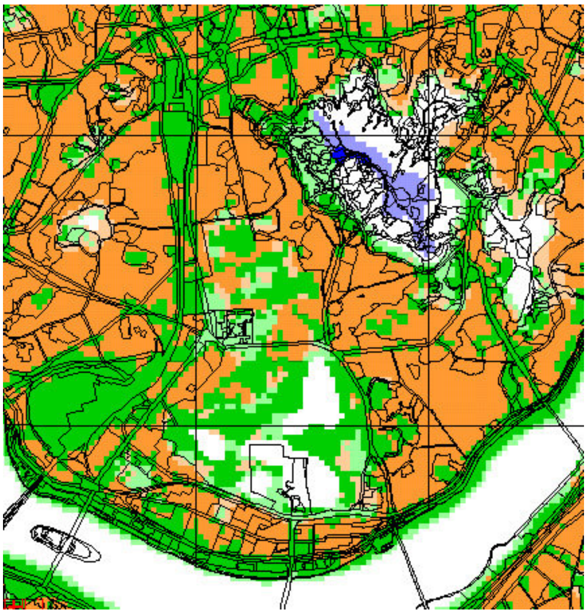
The urban management plan comprises designation of zoning areas and districts, district unit plans, and other plans concerning land use, transport, environment, industry, culture and so on (Article 2(4) of NLPU). Zoning is a tool for regulating land use, which designates the permitted uses, building heights and densities of land (Min 2007). According to Article 36 of NLPU, the urban areas include four zones: residential, commercial, industrial and green area (open spaces) zones. Among them, both Main and South Posts are designated as green area zones, while the three adjacent parts are to remain residential zones. Hence, based on maps with planning recommendations generated in Chapter 4.3, general recommendations are suggested for spatial planning and possible implementing measures for the Main and South Posts, and the three adjacent areas in relation with their zoning areas in this section. Table 5.13, 5.14 and 5.15 show the general recommendations for spatial planning in Yongsan military area and possible implementing measures for ventilation, air quality and thermal situation respectively.

Since the South Post has an advantageous ventilation situation as a whole, the planning objective for this area is to maintain its advantageous urban ventilation. Besides, risks of both atmospheric and thermal pollution are offset by the advantageous ventilation conditions. Hence, the planning strategy to maintain the offset effects should be pursued to keep the risks of both pollutions to a minimum. In order to implement these planning strategies, planning measures such as keeping the ratio of green areas and preserving areas of cold air production are recommended (see Chapter 4.3 for more possible measures).

For the Main Post, the planning strategies for maintaining as well as improving the advantageous effects of air flows for atmospheric and thermal pollution loads are suggested, because its ventilation situation is partly unfavorable. Hence, planning measures for both strategies should be implemented in this area, e.g. keeping and partly increasing the ratio of green areas and unoccupied areas, reducing the sealing ratio by keeping the low building-to-land ratio, and reducing barrier effects caused by existing barriers to ventilation.

The three adjacent areas face a beneficial ventilation situation, so they provide compensating effects to reduce atmospheric and thermal pollution. Hence, in spatial planning it is suggested to maintain their beneficial ventilation conditions. Possible planning measures are as follows: avoid settlements causing significant atmospheric and thermal pollution, restrict the building height and density.

Table 5.13 General recommendations for spatial planning as well as possible planning measures for three targets in Yongsan military area (Ventilation)

Spatially distributed information	General recommendations
Ventilation	
	The military base has a good overall ventilation situation. The current urban ventilation in the South Post should be maintained to offset the increased risk of air pollution or thermal loads. However, the current ventilation situation in the Main Post should be partly improved. Compared to neighboring areas, the three adjacent parts have a relatively beneficial ventilation situation. Hence spatial planning should preserve their ventilation conditions. Apart from the rail facilities, located just west of the base, most neighboring areas face disadvantageous ventilation conditions, which might be improved.

Possible planning measures *

Main Post (green area zone) **

- Keep and partly increase the ratio of green areas and unoccupied areas
- Reduce barrier effects caused by existing air flow barriers

South Post (green area zone) **

- Keep the ratio of green areas and open spaces
- Avoid new constructions causing significant air flow barriers
- Avoid the establishment of dense forests

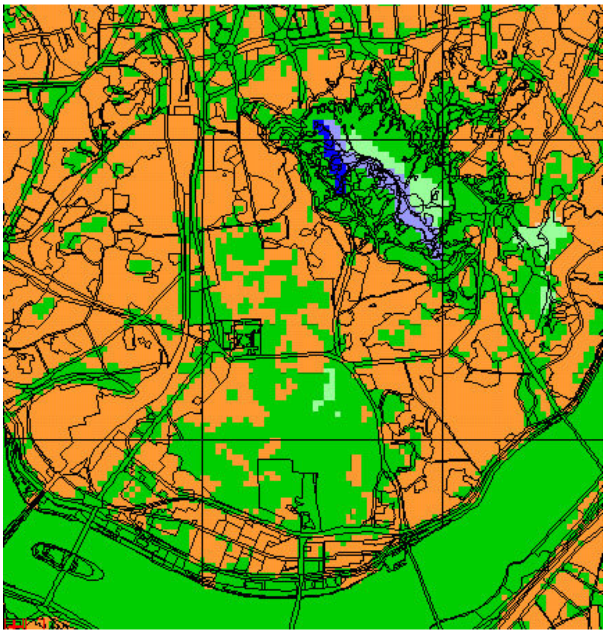
Three adjacent parts (residential zone) **

- Avoid attached building developments as well as planting in settlement boundaries
- Restrict the building height and density
- Align unavoidable constructions, which could cause air flow barriers, with prevailing direction of the urban ventilation or lay them out permeable

* See Tables 4.17 for more planning measures about ventilation, air quality and thermal situation, respectively.

** See Table 5.10 for the designation of Main Post, South Post and three adjacent parts.

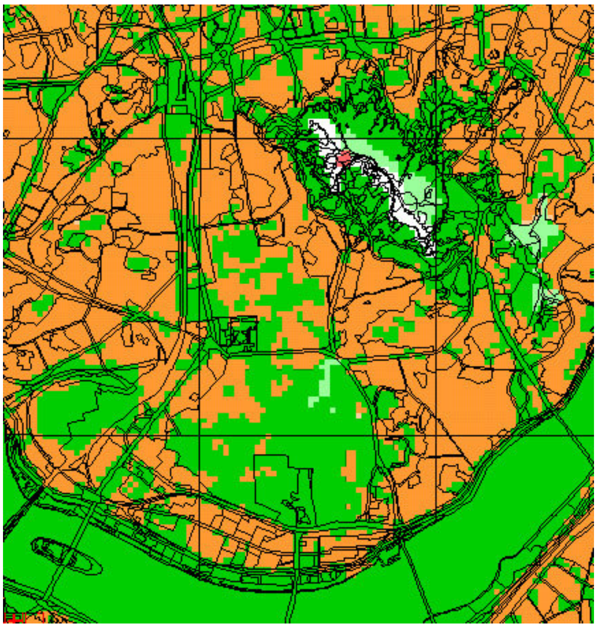
Table 5.14 General recommendations for spatial planning as well as possible planning measures for three targets in Yongsan military area (Air quality)

<table>
<tr><th>Spatially distributed information</th><th>General recommendations</th></tr>
<tr><td colspan="2">Air Quality</td></tr>
<tr><td></td><td>The air pollution loads in the military base are offset by the current overall ventilation conditions. The current offsetting effects in the South Post should be maintained to keep the risks of air pollution to a minimum. However, in the Main Post, planning measures should be implemented to maintain or even improve the offsetting effects. Three adjacent parts face a beneficial ventilation situation, which spatial planning should maintain.
It is important to preserve the beneficial offsetting effects provided by the military base, since most neighboring areas face air pollution risks.</td></tr>
<tr><td colspan="2">Possible planning measures *
<u>Main Post (green area zone)</u>
▪ Keep and partly increase the ratio of green areas and unoccupied areas
▪ Reduce barrier effects caused by existing air flow barriers
<u>South Post (green area zone)</u>
▪ Keep the ratio of green areas and unoccupied areas
▪ Avoid new constructions causing significant air flow barriers
▪ Avoid an establishment of closed forests
<u>Three adjacent parts (residential zone)</u>
▪ Avoid settlements causing significant sources of air pollution
▪ Restrict the building height and density
▪ Align unavoidable constructions, which could cause air flow barriers, with prevailing direction of the urban ventilation or lay them out permeable</td></tr>
</table>

* See Tables 4.21 for more planning measures about ventilation, air quality and thermal situation, respectively.

** See Table 5.10 for the designation of Main Post, South Post and three adjacent parts.

Table 5.15 General recommendations for spatial planning as well as possible planning measures for three targets in Yongsan military area (Thermal situation)

Spatially distributed information	General recommendations
Thermal Situation	
	The thermal pollution loads in the military base are offset by the overall ventilation conditions. Hence, spatial planning should maintain the current offsetting effects of ventilation to thermal pollution loads in the South Post. However, in the Main Post, planning measures of maintaining as well as improving the offsetting effects should be implemented to keep this risk to a minimum. The three adjacent parts have a beneficial ventilation situation. Hence, planning measures should maintain the offsetting effects. Apart from the rail-related facilities, most neighboring areas face unbeneficial offsetting effects to thermal pollution risks. Hence, spatial planning should keep the beneficial offsetting effects to a maximum in the military base.

Possible planning measures *

<u>Main Post (green area zone)</u>
- Reduce the sealing ratio
- Preserve areas of cold air production
- Keep and partly increase the ratio of green areas and unoccupied areas

<u>South Post (green area zone)</u>
- Preserve areas of cold air production
- Keep the ratio of green areas and unoccupied areas
- Avoid new constructions causing significant air flow barriers

<u>Three adjacent parts (residential area zone)</u>
- Avoid settlements causing significant waste heat
- Keep the ratio of green areas and unoccupied areas
- Avoid planting trees in settlement boundaries

* See Tables 4.25 for more planning measures about ventilation, air quality and thermal situation, respectively.

** See Table 5.10 for the designation of Main Post, South Post and three adjacent parts.

Finally, general strategies for regulating the acceptable building density and heights in green area (Main and South Posts) and residential zones (three adjacent areas) are proposed, based on the legal requirements of zoning and on respective neighborhoods (See Table 5.10 for the designation of Main Post, South Post and three adjacent parts).

Main and South Posts (approximately 260 ha, green areas zones)

As mentioned in Chapter 5.4.1, both Main and South Posts shall be developed as a park pursuant to Article 4(2) of the special law for constructing a new Yongsan park. According to Article 54 of the Seoul Metropolitan Government Ordinance on Urban Planning (Ordinance No. 4569), the maximum building-to-land ratio permitted is 20 percent in green areas. Hence, a maximum of 20 percent of both Posts can be covered by buildings. Furthermore, the maximum allowable floor-area ratio is 0.5 in this zoning pursuant to Article 55 of this ordinance.

Three adjacent areas (about 20ha, residential areas)

Figure 5.5 shows the building floor and the building-to-land ratio (in percent), presented in the biotope maps (Seoul Development Institute 2005).

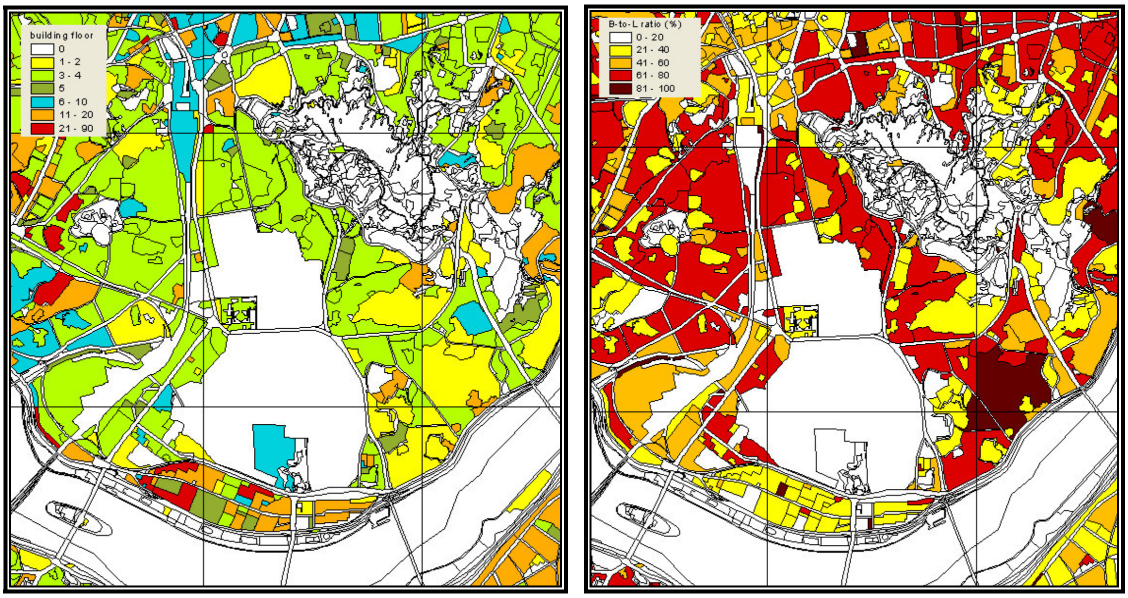


Figure 5.5 Building floors (left) and building-to-land ratio (right) of the concerned areas and their neighboring areas. See Table 5.10 for the designation of the concerned areas. (Source: The biotope maps of Seoul, Seoul Development Institute 2005)

According to these images, the three adjacent areas have low building heights (zero to two floors), and low building-to-land ratios (zero to 20 percent). Concerning the building floors in their neighboring areas, the majority have one to five floors. Compared to the three areas, the building-to-land ratio in the neighboring areas is ranging from 21 percent to 80 percent, which shows fairly intense site utilization. According to the Seoul Metropolitan Government Ordinance on Urban Planning, the building-to-land ratio in the residential zones should be in the range of 40 percent to 60 percent (Article 54 of this ordinance). Furthermore, the floor-area ratio is in the range of 100 percent to 250 percent for this zoning (Article 55 of this ordinance).

In order to enhance the compensating effects of the park areas on climate conditions of both three adjacent areas and their neighboring areas, restrictions on development of these three areas are suggested: The building height is recommended to be kept under four floors and the building-to-land ratio ought to be less than the maximum 60 percent. It may ensure, for example, that the cold air produced in the green areas can be transported into the heavily built-up neighboring areas.

These above-mentioned suggestions for regulating building densities and heights of Yongsan military area offer only general overviews on how to approach to regulate them. In order to set building heights and forms in detail, more detailed analysis on microclimate in and around this military area must be generated by using models simulating microclimate conditions. In addition, measurements and monitoring of climatic conditions in and around this area should be accompanied, too.

6 Conclusions and outlook

In this chapter the findings regarding the four aspects of research, which were proposed to examine in this dissertation, are summarized (Chapter 6.1): the newly developed datasets for Seoul (6.1.1), the usefulness of the already existing datasets (6.1.2), the modification of evaluation criteria and formulas taken from a previous European study (6.1.3), and the applicability of the information provided by CAMPUS to spatial planning in Seoul (6.1.4). Furthermore, it is pointed out, what kinds of research are further needed to more effectively integrate spatially distributed climate information into spatial planning in Korea (Chapter 6.2).

6.1 Conclusions

6.1.1 Datasets to be newly established for Seoul

What type of datasets should be newly established for Seoul, and which methods should be used to establish them?

The CAMPUS procedure used for providing spatially distributed information for planning usages in Seoul is performed by rule-based climate analysis and evaluation tools that have previously been applied to European cities in studies like KABA, CAMPAS-CH and REKLISO (see Chapter 2.3). Drawing on these former studies, the following new datasets were established to apply these tools to Seoul.

Pixel classes (PCs), which are explained in Chapter 3.2, designate land cover classes that describe surface structures. Pixel classes are the most important intermediate dataset in the CAMPUS procedure, because further analysis and evaluation are performed on the basis of them. In this study, eight pixel classes were gained from the land cover classification extracted from Landsat-7 ETM+: water surfaces, trees, unsealed areas, sealed areas without buildings, sealed areas with variable buildings, low density areas, medium density areas and high density areas (see Table 3.2).

In contrast to the REKLISO study, which introduced seven pixel classes for European cities, the additional class ‘medium density areas’ was introduced in this study to represent surface properties distinctive for Seoul. This new class indicates residential housing blocks (i.e. apartment areas), which are a very popular type of residential construction in Korea and occupy approximately 75 percent of the whole residential types of Seoul (Seoul Development Institute 2000).

By adding this new pixel class, the surface properties of this residential type are effectively included in the subsequent applications of CAMPUS: Based on these eight classes, the structural parameters and ground parameters are estimated, which are further used for generating climate analysis/evaluation maps and for simulating a mesoscale model, respectively.

Another new dataset established for this study is that of structural parameters, which describe urban structures of Seoul (see Chapter 3.4.2). Due to Seoul's distinct urban morphometry, which differs from that of European cities, the following eight structural parameters were newly estimated: surface sealing ratio, plan area aspect ratio, mean building height, effective building height, aerodynamic roughness length, complete aspect ratio, cold air production ratio, and concentration of nitrogen dioxide (see Table 3.12).

The parameters were calculated using literature-based equations (e.g. Grimmond & Oke 1999; see Chapter 3.4.2) on the basis of the fractional coverage of eight pixel classes. Various values needed for the calculation like building heights were supplied from the biotope maps of Seoul.

Ground parameters were also newly estimated in this study in order to simulate the mesoscale meteorological model MetPhoMod. According to Baik (2005), urban effects have so far not been included in numerical models performed in Korea, or were only very roughly parameterized. The parameters estimated for MetPhoMod performance are albedo, emissivity, thermal conductivity, surface heat capacity, density, volumetric heat capacity, and thermal diffusivity.

All ground parameters have been estimated individually for each of the eight pixel classes, so as to accurately reflect the ground properties in the simulation. For pixel classes 'water surface, trees, unsealed areas and sealed areas without buildings', the ground parameter values were based on the values generally accepted for the respective surfaces of 'water, trees, grass and cement/concrete'. However, the values of the other classes 'sealed with variable buildings, low density areas, medium density areas, and high density areas' were estimated by combining the values of the four surface materials mentioned above (see Chapter 4.1.2 and also Table 4.4). The respective shares of each of the four surface materials were determined according to their frequency in each pixel class, which was calculated using PCs' fractional coverage.

Finally, this led to the following results: The pixel classes generated from satellite imagery were adjusted to fit Seoul's urban situation. Apartment areas were newly introduced as a pixel class and designated as 'medium density areas'. Such apartment areas are the representative type of urban residential areas of Seoul, therefore the introduction of this new class has great significance for the analysis of Seoul's urban structure. In addition, two types of parameters were estimated at length for all pixel classes: structural parameters and ground parameters. They permit a more exact representation of the urban structure and surface characteristics, and hence enhance the results of climate analysis and evaluation.

6.1.2 Integration of existing datasets

To what extent are the existing datasets useful as input data for climate analysis to be applied in spatial planning in Seoul?

The CAMPUS procedure requires geo-coded and spatially distributed information on land cover and topography as input data. Hence, the satellite-derived information and the Digital Elevation Model (DEM) / the Shuttle Radar Topography Mission (SRTM) dataset were mainly used for land cover and topography, respectively.

The existing biotope maps of Seoul contain information about land use structures and offer another dataset for space-related information. Containing information on urban structures and land use types, these biotope maps have been used for various planning purposes in Seoul. This already existing and widely used dataset might offer a convenient source of input data for planning-oriented climate analysis and evaluation. Actually, in a study about generating climate analysis maps of Seoul (Seoul Development Institute 2007), biotope types of Seoul were used to generate climatopes, which describe geographic areas with similar microclimatic characteristics (as defined in the study by Ministry of the Interior Baden-Württemberg 2004). Hence, in this study the existing biotope dataset of Seoul was examined to check its usefulness for climate analysis (see Chapter 3.3).

The examination was done by comparing the biotope maps of Seoul with the land cover information extracted from Landsat-7 ETM+ imagery. It was found that these already existing biotope maps are not suitable as main input in climate analysis for planning usage in Seoul: Since the biotope dataset is available only for the administrative area of Seoul, the effects of the surroundings on climate and air quality in Seoul cannot be analyzed. Besides, the classification of 65 biotope types, which actually represent land use types, is not suitable for expressing land surface properties. In addition, no land use data are available for inaccessible areas like military areas. Furthermore, due to an interval of five years for updating, the biotope dataset does not reflect the rapid changes in land use taking place in Seoul over short time periods.

Nevertheless, the usefulness of this biotope dataset as supplementary to satellite-based pixel classes has been established in this dissertation. The misclassifications by Landsat-7 ETM+, like those between apartment areas and agricultural areas covered with Polyvinyl Chloride, can be corrected by replacing them with the corresponding dataset of biotope maps. Furthermore, various pieces of information on land properties, like building height and building-to-land ratio of the biotope dataset, are necessary to calculate various kinds of attribute values needed for climate analysis (see Chapter 3.4.2).

Then the usefulness of the Digital Elevation Model (DEM) is discussed, which has been generated by the Korean Ministry of Environment. The accuracy of DEMs is an essential issue in the acquisition of spatial data, and the spatial distribution of the sampling points is decisive for its accuracy (Zhu et al. 2005). The DEM used in CAMPUS was generated by using a Triangulated Irregular Network (TIN) interpolation on the basis of the topographic map in the scale 1:25,000. In the creation of a TIN from sampling points, too few points in flat areas result in misrepresentations of surface size and structures, as is the case in the western part of Seoul (see Chapter 3.5). Such misrepresentations of ground surface in flat areas may influence the analysis and evaluation of urban climatic conditions. For example, these misrepresentations occurred in the western outskirt of Seoul negatively affected the selection of suitable evaluation criterion for cold air stagnation areas (see Chapter 4.2.3). This emerged when surface was analyzed at an elevation of one or two meters. Hence, to overcome these misrepresentations of ground surface terrain in the DEM, the analysis was conducted at an elevation of four meters.

The SRTM digital topographic data released by the National Aeronautics and Space Administration (NASA) of the United States has certain advantages in comparison with DEM. This dataset represents ground surface in flat areas, which is not represented in the contour-interpolated DEM. Since SRTM reflects the current status of the land surface, it also describes the altered topography, like e.g. the Nanji Park, located in western Seoul, which was created over the landfill that has previously been a flat terrain.

However, it is decided not to use the SRTM dataset because it does not adequately reflect the geometric and structural properties of Seoul (as explained in Gamba et al. 2002). The SRTM explicitly includes tall structures in the city center and bridges, while information on the ground surface terrain is primarily needed. Furthermore, the SRTM dataset is not ideal for climate analysis in CAMPUS since it contains the height of vegetation. In addition, compared to the cartographically-derived DEM, the mountainous topography in SRTM appears less elaborate than that in DEM. Hence, the SRTM dataset was not applied for analyzing the local ventilation situation in and around Seoul, but only for simulating the mesoscale meteorological model.

Finally, the section is concluded with the following findings: The biotope dataset is not suitable as main input but is useful as supplementary data in climate analysis for planning usage in Seoul. Besides, the biotope maps offer various data used for estimating structural parameters of individual pixel classes (explained in Chapter 6.1.1). The DEM used in this study is useful for simulating mountainous terrain, but not for flat terrain. The DEM with high resolution in flat areas may reduce errors in simulations and further contribute to generate more accurate analysis results. The SRTM is not suitable for analyzing the local ventilation situation, but useful for simulating the mesoscale meteorological model in the study.

6.1.3 Modification of evaluation criteria and formulas

> In evaluating results from climate analysis for Seoul, how should the evaluation criteria and formulas be modified?

Climate analysis is a process of obtaining reliable data, which describe climate conditions of the analyzed areas. This process can be applied evenly for different areas and the results can be interpreted in the same fashion. However, climate evaluation includes normative criteria to reflect different social conditions, because this process should include and balance the various interests of society. Howarth (2000) stresses that climate change policy decisions are strongly contingent on the normative criteria, as the policies should mediate the conflicting preferences in framing long-run social decisions.

Since acceptable criteria for evaluation are different in every society, it is important to find proper and acceptable criteria for Seoul. For example, 0.03ppm has been applied in Seoul as the air quality standard for NO_2 since 2007. This value was used as the criterion for evaluating local atmospheric loads: Areas that barely meet this standard are considered to have a strongly increased risk of local atmospheric loads. If a new air quality standard were applied, new areas with strongly increased risk would be identified. Consequently, the spatial distribution of local atmospheric risks would look different from that in Figure 4.9. CAMPUS offers a convenient updating to suit changes in air quality standard.

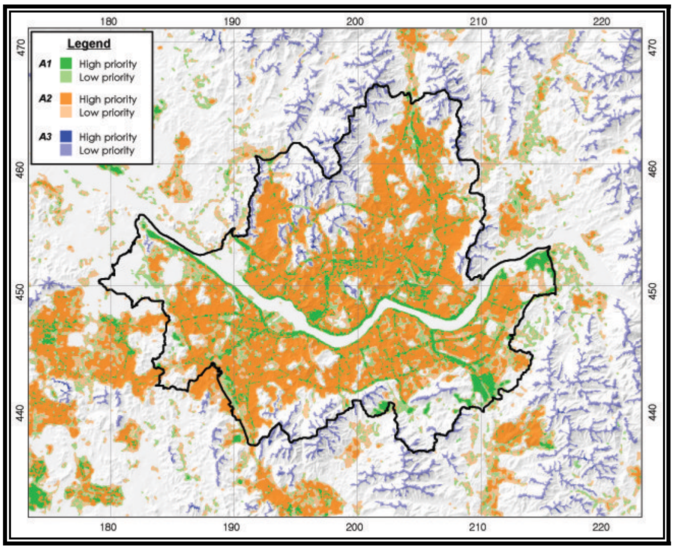
In addition to the modifications in evaluation criteria, the formulas used for generating maps with planning recommendations also have to be modified. Tables 6.1, 6.2 and 6.3 show the original formulas used for the REKLISO study as well as the modified ones used for CAMPUS for the targets ‘ventilation, air quality and thermal situation’, respectively. The formulas were modified for two reasons: The use of the original formulas leads to little spatial differentiation within the Seoul area. Besides, they classify green areas in Seoul as areas where urban ventilation and its compensation effects should be improved, while in fact they should be preserved.

The formulas were modified by using the Areal Types. As shown in Table 6.1, the areas classified for the planning objective A2 ‘improving urban ventilation in areas with increased risk of air pollution or heat stress’ are reclassified. If areas of A2 are designated as water surfaces, forests, unsealed areas, sealed without buildings or low density by their Areal Types, they are reassigned to A1 ‘maintaining urban ventilation’ with high priority. The same adjustments are made for the targets ‘air quality (Table 6.2)’ and ‘thermal situation (Table 6.3)’.

The three Tables also contain maps with planning recommendations, generated by both original formulas and the modified ones. The top image of each table shows that most areas of Seoul are classified as improving urban ventilation and its compensation effects by the original formulas. They give little spatial differentiation within the Seoul area, which may not enable planners to offer diverse recommendations. After the modification of formulas, the spatial differentiation in Seoul is enhanced (lower image in Tables). Furthermore, by the modified formulas, many green and open spaces as well as low density areas are classified as areas to be preserved with high priority.

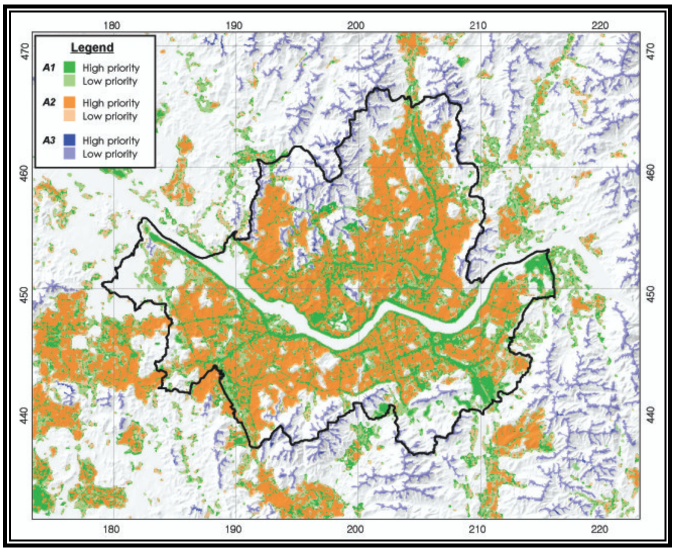
Table 6.1 Maps with planning recommendations for the target 'ventilation' by original (upper) and modified formulas (lower)

Former formulas



PO[1)]	Assigned area	HP[2)]
$A1_{1-2}$	$(AP_{1-2} \vee HS_{1-2}) \wedge (SI_0 \vee (SI_1 \wedge AT_{1-5})) \wedge CS_{0-1}$	$AP_2 \vee HS_2$
$A2_{1-2}$	$AP_{1-2} \vee HS_{1-2}$	$AP_2 \vee HS_2$
$A3_{1-2}$	WE_2	AT_{3-8}

Modified formulas



PO	Assigned area	HP
$A1_{1-2}$	$(AP_{1-2} \vee HS_{1-2}) \wedge (SI_0 \vee (SI_1 \wedge AT_{1-5})) \wedge CS_{0-1}$	$AP_2 \vee HS_2$
$A2_{1-2}$	$AP_{1-2} \vee HS_{1-2}$	$AP_2 \vee HS_2$
$A1_2$	$A2_{1-2} \wedge (AT_{1-4} \vee AT_6)$	-
$A2_0$	$A2_{1-2} \wedge A1_2$	-
$A3_{1-2}$	WE_2	AT_{3-8}

Planning Objectives

A1: Maintenance of urban ventilation in areas with increased risk of air pollution or heat stress

A2: Improvement of urban ventilation in areas with increased risk of air pollution or heat stress

A3: Avoidance and reduction of the risk of wind damage

1) PO: Planning objectives,

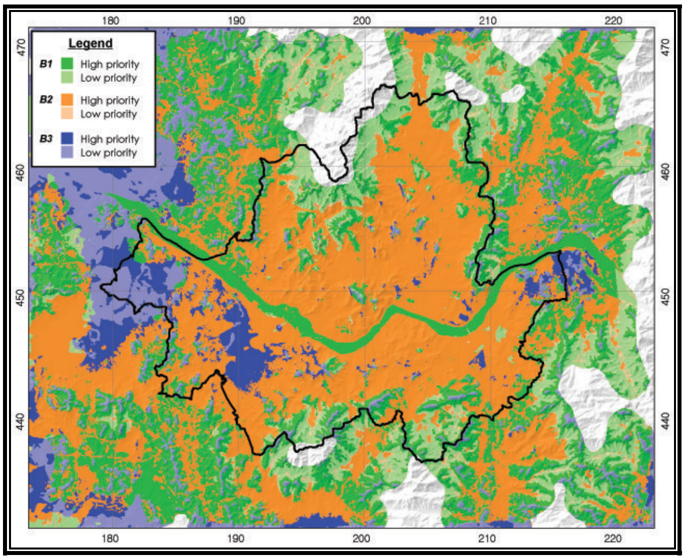
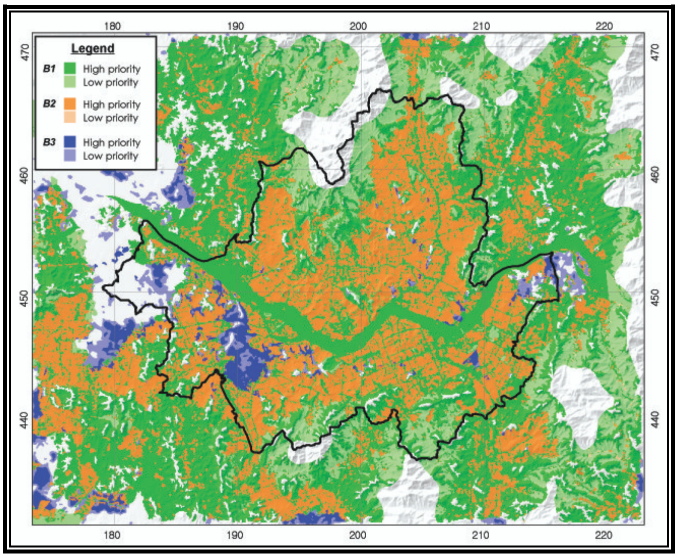
2) HP: High priority

3) The initials $A*_1$ and $A*_2$ represent a low and a high priority respectively, whereas the initials $A*_0$ indicate there is no significant need for implementing any planning objective.

4) The modified formulas are represented in gray.

5) See Table 4.13 for the information on abbreviations.

Table 6.2 Maps with planning recommendations for the target 'air quality' by original (upper) and modified formulas (lower)

<table>
<tr><th colspan="4">Former formulas</th></tr>
<tr><td rowspan="4"></td><th>PO[1)]</th><th>Assigned area</th><th>HP[2)]</th></tr>
<tr><td>$B1_{1-2}$</td><td>$(MW_2 \vee CT_{1-2}) \wedge d_{APR} \leq 1.5km \wedge AP_0 \wedge (SI_0 \vee (SI_1 \wedge AT_{0-5})) \wedge CS_{0-1}$</td><td>$CT_1 \vee CS_1$</td></tr>
<tr><td>$B2_{1-2}$</td><td>$(MW_2 \vee CT_{1-2}) \wedge d_{APR} \leq 1.5km$</td><td>$AP_{1-2} \vee CT_1 \vee CS_{1-2}$</td></tr>
<tr><td>$B3_{1-2}$</td><td>$(MW_{0-1} \vee CT_0 \vee CS_{1-2}) \wedge d_{APR} \leq 1.5km$</td><td>$AP_{1-2} \vee CS_{1-2}$</td></tr>
<tr><th colspan="4">Modified formulas</th></tr>
<tr><td rowspan="6"></td><th>PO</th><th>Assigned area</th><th>HP</th></tr>
<tr><td>$B1_{1-2}$</td><td>$(MW_2 \vee CT_{1-2}) \wedge d_{APR} \leq 1.5km \wedge AP_0 \wedge (SI_0 \vee (SI_1 \wedge AT_{0-5})) \wedge CS_{0-1}$</td><td>$CT_1 \vee CS_{1-2}$</td></tr>
<tr><td>$B2_{1-2}$</td><td>$(MW_2 \vee CT_{1-2}) \wedge d_{APR} \leq 1.5km$</td><td>$AP_{1-2} \vee CT_1 \vee CS_{1-2}$</td></tr>
<tr><td>$B1_2$</td><td>$B2_{1-2} \wedge (AT_{1-4} \vee AT_6)$</td><td>-</td></tr>
<tr><td>$B2_0$</td><td>$B2_{1-2} \wedge B1_2$</td><td>-</td></tr>
<tr><td>$B3_{1-2}$</td><td>$(MW_{0-1} \vee CT_0 \vee CS_{1-2}) \wedge AP_{1-2}$</td><td>$AP_2 \vee CS_{1-2}$</td></tr>
<tr><td colspan="4">Planning Objectives
B1: Maintenance of compensation effects of fresh air flow to reduce air pollution loads
B2: Improvement of compensation effects of fresh air flow to reduce air pollution loads
B3: Avoidance and reduction of risks of air pollution in areas of potentially poor air exchange</td></tr>
</table>

1) PO: Planning objectives ; 2) HP: High priority

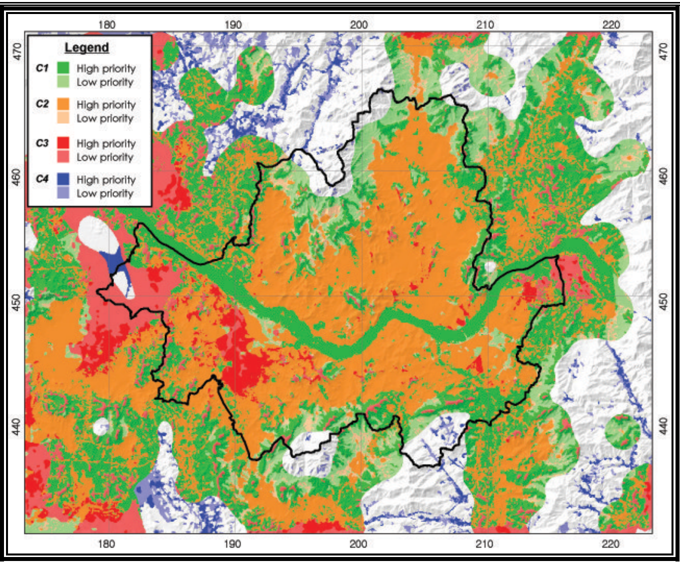
3) The initial 'd_{APR}' indicates a distance to an area with locally increased as well as strongly increased air pollution risks. See Table 4.13 for the information on further abbreviations.

4) The initials $B*_1$ and $B*_2$ represent a low and a high priority respectively, whereas the initials $B*_0$ indicate there is no significant need for implementing any planning objective.

5) The modified formulas are represented in gray.

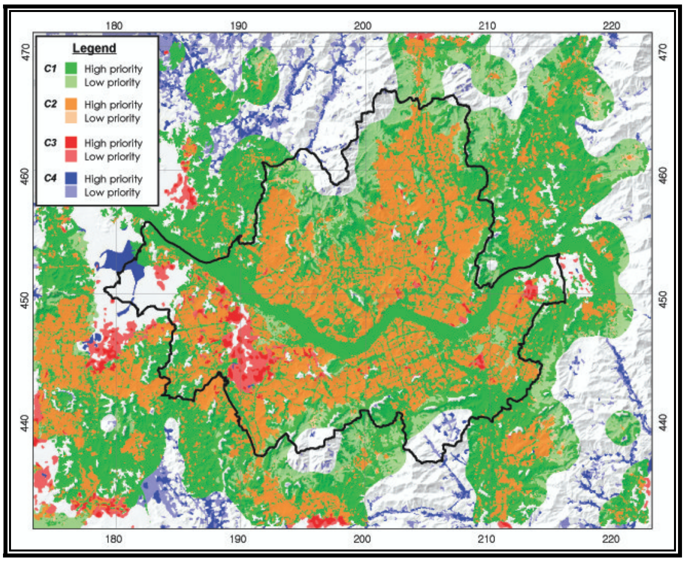
Table 6.3 Maps with planning recommendations for the target 'thermal situation' by original (upper) and modified formulas (lower)

Former formulas



PO[1)]	Assigned area	HP[2)]
$C1_{1-2}$	$(MW_2 \vee CT_{1-2}) \wedge d_{HSR}$[3)] $\leq 1.5km \wedge HS_0 \wedge (SI_0 \vee (SI_1 \wedge AT_{0-5})) \wedge CS_{0-1}$	CT_1
$C2_{1-2}$	$(MW_2 \vee CT_{1-2}) \wedge d_{HSR} \leq 1.5km$	$HS_{1-2} \vee CT_1$
$C3_{1-2}$	$(MW_{0-1} \vee CT_0) \wedge d_{HSR} \leq 1.5km$	HS_{1-2}
$C4_{1-2}$	$(CS_{1-2} \vee \overline{T} \leq \langle\overline{T}\rangle) \wedge AT_{3-8}$	$CS_{1-2} \vee AT_{5-8}$

Modified formulas



PO	Assigned area	HP
$C1_{1-2}$	$(MW_2 \vee CT_{1-2}) \wedge d_{HSR} \leq 1.5km \wedge HS_0 \wedge (SI_0 \vee (SI_1 \wedge AT_{0-5})) \wedge CS_{0-1}$	CT_1
$C2_{1-2}$	$(MW_2 \vee CT_{1-2}) \wedge d_{HSR} \leq 1.5km$	$HS_{1-2} \vee CT_1$
$C1_2$	$C2_{1-2} \wedge (AT_{1-4} \vee AT_6)$	-
$C2_0$	$C2_{1-2} \wedge C1_2$	-
$C3_{1-2}$	$(MW_{0-1} \vee CT_0) \wedge HS_{1-2}$	HS_2
$C4_{1-2}$	$(CS_{1-2} \vee \overline{T} \leq \langle\overline{T}\rangle) \wedge AT_{3-8}$	$CS_{1-2} \vee AT_{5-8}$

Planning Objectives

C1: Maintenance of compensation effects of cold air flow to reduce thermal stress

C2: Improvement of compensation effects of cold air flow to reduce thermal stress

C3: Avoidance and reduction of risks of thermal stress in areas of potentially poor air exchange

C4: Avoidance and reduction of increased risks of frost or heat loss

1) PO: Planning objectives ; 2) HP: High priority

3) The initial 'd_{HSR}' indicates a distance to an area with locally increased as well as strongly increased heat stress risks. See Table 4.13 for the information of further abbreviations.

4) The initials $C*_1$ and $C*_2$ represent a low and a high priority respectively, whereas the initials $C*_0$ indicates there is no significant need for implementing any planning objective.

5) The modified formulas are represented in gray.

The formulas were further modified for the planning objective B3 (target: air quality) and C3 (target: thermal situation), which aim to reduce or avoid loads of atmospheric and thermal risks in areas of potentially poor air exchange. By these modifications, areas that are directly facing atmospheric or thermal loads heat stress are classified as B3 and C3, respectively. It is clearly shown in the lower images of Table 6.2 and 6.3, that the agricultural areas in western outskirt of Seoul don't meet this planning objective any longer.

Finally, this led to the following results: The original formulas developed for European cities are not suitable for establishing maps with planning recommendations for the densely build-up area of Seoul. The modified formulas enable planners to provide diverse spatial recommendations.

6.1.4 Applications in spatial planning

Is the information provided by the methodology applicable to spatial planning in Seoul?

In order to show the applicability of the spatially distributed information produced in CAMPUS, it was applied on three different levels of spatial planning (see Chapter 5); the comprehensive urban plan on the regional level (city and suburbs), the urban master plan on the city level, and the urban management plan on the district level.

For these applications, the 2020 Metropolitan Comprehensive Plan and the Seoul Master Plan 2020 were examined by means of the information produced in CAMPUS:

- For the urban comprehensive plan, development strategies for neighboring areas of Seoul and coordination of Restricted Development Zones (RDZs) were examined, which are two main objectives of the Metropolitan Comprehensive Plan.
- For the urban master plan, strategies of spatial planning for five zones and their sub-zones of Seoul were suggested, which are set in the Seoul Master Plan.
- For the urban management plan, development guidelines of Yongsan U.S. Army base are suggested, which is introduced as an important undeveloped area available for future development in Seoul Master Plan 2020.

The examination for three spatial plans was done as follows:

Areas being climatically important on the regional level were identified, e.g. areas where polluting activities should be prohibited or where the equalizing effects on the climate should be promoted. Furthermore, the spatial information gathered from CAMPUS was used to coordinate development strategies for RDZs, as well as to determine which RDZs should remain restricted so as to improve cold air flow and which are available for further development. From these applications it emerges that the spatially distributed information on climate analysis and evaluation done in this study is suitable for use in the urban comprehensive plan. However, the domain of CAMPUS performance has to be enlarged to apply this information for areas covered by the Metropolitan Comprehensive Plan.

In the Seoul Master Plan 2020, the consideration of urban ventilation is an important aspect of land use plans for improving air quality of Seoul. However, suitable tools to give an overview of the urban ventilation situation are missing in Seoul. Hence, the results of CAMPUS are useful for the urban master plan, since they reflect for the first time the comprehensive urban ventilation situation of Seoul, e.g. local cold air production, transport and stagnation (see Chapter 4.2). For the city-level applications, the spatially distributed information was used to suggest development strategies for five zones and their sub-zones. It was recommended how each zone may be strategically planned to maintain or improve the urban ventilation, air quality and thermal situation (see Chapter 5.3.2 and also Tables 5.7, 5.8 and 5.9).

The results of climate analysis and evaluation show that the Yongsan U.S. Army base has advantageous climate conditions in comparison with its neighboring areas. For example, this base contains areas producing cold air, and it has lower local surface influence and lower risks of atmospheric and thermal pollutions than its surroundings (see Table 5.12). Therefore, suitable planning measures for preserving these advantageous climate conditions should be implemented. Hence, this study suggested which strategies of spatial planning are needed and how these strategies might be implemented in spatial planning (see Tables 5.13, 5.14 and 5.15). Furthermore, the general strategies about construction, like the acceptable building density and heights, were suggested for residential or commercial areas, based on respective neighborhoods and on the legal requirements. However, detailed climate analysis and measurement are needed to offer more detailed information relating to construction at the district level of spatial planning.

Finally, the following results were obtained: In general, the information generated by CAMPUS is applicable to spatial planning in Seoul. The information is spatially distributed and presented in the Geographic Information System (GIS). Hence, it can be easily combined with other planning information. The methodology offers consistently evaluated climate information for the entire areas. The easy updates of input data enable the prompt reflection of changes in urban structures in spatial planning. Since the spatial information aims at the three targets (ventilation, air quality, thermal situation) individually, the information can be gathered separately for each topic, as required.

This study demonstrates that the potential of CAMPUS to integrate information varies according to the level of planning. Comparing the three different levels of spatial plans of Seoul, the information generated is most suitable for the two levels of the urban comprehensive plan (regional level) and the urban master plan (city level). For the urban management plan (urban district level), the information can offer only general overviews of climate situation. However, more detailed climate analysis and measurements are needed to apply it on this level.

6.2 Outlook

The main goal of this study is to integrate urban climate information in spatial planning of Seoul, particularly by using spatially distributed information on climate and air quality. This dissertation contributes to a suitable methodology for generating maps of climate analysis/evaluation and planning recommendations of Seoul, and further to apply the spatial information for spatial planning on three different levels. This methodology was performed with the CAMPUS (Climate Analysis Maps for Planning Usage in Seoul) framework.

This dissertation also contributes to establish structural parameters suitable for detailed description of urban structural properties of Seoul as well as ground parameters used for mesoscale climate modeling of Seoul for various types of land cover. Furthermore, it is valuable to examine the usefulness of existing datasets for climate analysis and evaluation of Seoul, which has been done in this study. It may induce further development of the existing datasets or the generation of datasets suitable for urban climate research in Korea. The various types of climate analysis and evaluation maps as well as maps of recommendations for planning, which were generated in this study, will offer urban and environmental planners valuable tools that meet their practical requirements.

Ultimately, this study will contribute to a discussion on how climate information can be integrated into the spatial planning in many Korean cities, and further to an growing interest in the topic 'climate and air quality' in spatial planning process.

However, further research is needed to more effectively apply spatially distributed climate information for spatial planning and to facilitate this application:

The Digital Elevation Model (DEM) used in this study does not represent precise ground surface in flat areas, which resulted in misrepresentations in calculations using the DEM. Hence, a DEM with high resolution can enhance the representation of flat areas where the contours are widely separated, and consequently, it can result in more accurate results. In addition, high resolution satellite images like IKONOS may be used to extract land cover classification which is not obtained from the Landsat-7 ETM+ used in this study, such as smaller areas than 30 meters like roads and railways. However, due to the high cost for covering the whole study size, the use of high resolution images does not seem to be a cost-efficient way for creating the land cover dataset needed for this study. But, it may be used for the specific areas where a detailed study is needed.

The road network in the surrounding areas of Seoul has not been included in this study. Yet it is needed to supplement land cover classes and to simulate complete traffic-related air pollution for the whole study area. In CAMPUS, only the road network for the administrative area of Seoul was included. The misclassifications in roads, which occurred based on the Landsat data, could only be corrected within Seoul by overlaying corresponding road data from biotope maps (in vector format) covering Seoul, as the corresponding dataset for the surroundings was not included. If the complete dataset of road network for the surroundings is included, pixel classes can be supplemented and a more accurate climate analysis and evaluation may result. This also requires the availability of data regarding traffic volumes outside of the Seoul administrative area. In this case, local atmospheric loads calculated by using traffic volumes on roads can be simulated beyond the Seoul area. By supplementing these datasets for the surroundings, local atmospheric loads can be completely simulated for the entire CAMPUS area.

The simulation of air pollution loads can be improved by using data on daily traffic volume for all corresponding road networks. Since the road networks integrating traffic volumes of Seoul area were not available for CAMPUS processing, a simple approach was used to estimate daily traffic volume and to simulate traffic generated atmospheric loads (see Chapter 4.1.3). It may lead to misrepresentations in the simulation of air pollution loads. The most recommended dataset is the traffic volumes of individual vehicle types, by which different effects of various vehicle types on NO_2 concentration can be simulated.

Validations of CAMPUS output should be performed by comparing the output of obtained climate datasets like weather station data. The station data have the advantage of recording climate variables with a high degree of certainty for a limited area (Snyder et al. 2005). The air pollution loads simulated in CAMPUS can be validated with measured data from air quality monitoring stations, which are evenly distributed across Seoul. In particular, the simulation of traffic-related air pollution can be compared with measured data from seven monitoring stations installed on main roads in Seoul. Since areas where cold air stagnates and accumulates may have lower temperature than others, temperature data observed at stations located in such areas can be applied to compare their temperatures with those of surroundings. If no station exists there, extra measurements should be performed.

An additional process of maps with planning recommendations may enhance the application of these maps for various kinds of spatial planning. The raster-based spatial distribution of CAMPUS results doesn’t coincide with the existing spatial boundary such as the land use district boundary. Hence, before the application of the CAMPUS output to spatial planning, an intermediate process of adjusting the study area to the existing spatial boundary of the land use district of Seoul is needed. For this process, the use of vector-based biotope dataset can be taken into account.

Scenario planning is often used to assess and manage environmental risks in environmental planning like landscape planning or environmental impact assessment, and to set strategic direction of development. Hence, it is useful to analyze and evaluate changed climate situations by several development scenarios. The applied CAMPUS framework enables scenario planning, because changed input and intermediate data can be easily integrated into the analysis and evaluation procedures.

Traffic is the main emission source for air pollution in Seoul (see Chapter 2.2.2). In this case, planning of urban transportation systems may be directly relevant for regulating traffic-related air pollution. However, traffic-related implementation measures were not mainly handled in spatial planning in this study (see Chapter 5). Therefore, it is needed to further integrate the urban transportation planning of Seoul into spatial planning to implement planning objectives for the target ‘air quality’.

In environmental assessment processes such as strategic environmental assessment (SEA), urban climate is not efficiently dealt with as an assessment item due to the lack of suitable criteria of evaluating climate and air quality in Korea (see Eum & Köppel 2007 for detailed evaluation criteria). In this context, the information generated in CAMPUS can support to develop an evaluative framework for the integration of the climate information into the assessment process, e.g. the implementation of SEA in spatial planning (see Herberg et al. 2006 for the example of Berlin, Germany). This information can be further used for other planning instruments like environmental impact mitigation, whose utilization is just discussed in Korea (see Choi 2008). A study of Köppel & Deiwick (2005) provides a way to integrate the climate information into the environmental impact mitigation with an example of the Berlin city.

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