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Potential Effects of Land-Use Change on the Local climate

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토지이용 변화가 국지기후에 미치는 영향

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Abstract

The land-use has changed rapidly during the last two decades in accordance with urbanization in the Seoul Metropolitan Region. As a result of these changes, the local climate has undergone changes as well. This study intends to define the land-use changes, and then to show how they have brought in significant changes in the local climates. Land-use changes in the study area so rapidly that up-to date maps and documents are not available at present. Therefore, Landsat data for land-use classification and NOAA AVHRR thermal data for the temperature fields were analyzed. Additionary, to visualize the effect of the land-use on the local climate, computer-enhanced brightness temperatures, Green Belt and city boundaries were overlaid on land-use patterns obtained from satellite images using GIS techniques. The results of analysis demonstrate that Green Space in the Seoul Metropolitan Region decreased from 94% to 62% while urban land-use increased ten times, from 4% to 39% for the period of 1972-1992. The resulting disappearance of biomass caused by land-use changes may have implications for the local- and micro-climate. The results show that the local climate of the study area became drier and warmer. This study also suggests a need for further studies of man's effects on local climate to minimize adverse influences and hazardous pollution and efficacious ways for urban planning.

Key words: Green Belt, land-use classification, land-use change, urbanization, climate change, adverse influence, Landsat, NOAA AVHRR, GIS.

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요 약

한국의 수도권 지역에서는 토지이용의 변화가 근래 급격하게 이루어지면서 국지기후에도 변화가 나타나고 있다. 본 연구는 지난 20년간의 토지이용변화의 특성 및 규모를 분석하여 이 변화가 국지기후에 미치는 영향을 파악하고자 하였다. 연구지역에서의 도시화는 상당히 빠른 속도로 진행되고 있어 현시점에서는 토지이용변화의 규모를 지도나 문헌조사 만으로는 충분히 조사할 수 없기 때문에 본 연구에서는 Landsat 자료를 이용하여 토지이용 변화의 양상 및 규모를 밝히고, 기상자료(온도, 습도, 안개 등)의 시계열적 분석으로 토지이용의 변화가 국지기후에 미치는 영향을 파악하고자 하였다. 그러나 측후소에서 관측된 기상자료 만으로는 기상요소의 공간적 분포를 이해할 수가 없기 때문에 NOAA-AVHRR 열적외선 자료를 이용하여 온도의 공간분포를 규명하고, GIS 기법(Geographic Information Systems)을 활용하여 시각적 효과를 높이므로 써 지역정책을 수립할 때 의사결정에 도움을 주고자 하였다. 분석결과에 의하면 수도권지역의 녹지는 지난 20년간(1972-1992)에 94%에서 62%로 감소된 데 반하여 도시적 토지이용은 4%에서 39%로 크게 증가되었다. 토지이용의 변화에 따른 생물자원의 감소는 열수지 및 수분수지에 변화를 초래하여 국지기후 내지 미기후에 영향을 미칠 것을 암시하고 있으며, 실제로 연구지역내의 국지기후는 점차 건조화 · 온난화 추세를 보이고 있다. 그러므로 인간의 활동이 국지기후에 미치는 바람직하지 못한 영향과 위험한 오염을 효율적으로 저감시키려면 토지이용의 변화가 환경에 미치는 영향에 관한 보다 깊은 연구가 절실히 요청된다.

1. Introduction

Humans have modified their environment for thousands of years with little thought given to the side effects of the modifications (Lamb, 1985). Rapid population growth and industrialization have led to constantly increasing demands for energy, food, and living space, which in turn, have affected the balance of heat and moisture in the atmosphere. These changes to the climate were inadvertent; the actions that caused them were not carried out for these purposes, but yielded such results any way. Most of the individuals who are presently performing land modification that could lead to climate change are still unaware of the possible consequences of their acts. Nevertheless, numerous examples of such impacts have already been observed on local and regional scales, and far-reaching changes are likely to occur on a global scale in the near future (Kellogg and Schware, 1981). There are also considerable evidences suggesting that major urban areas are causing alterations to some weather elements due to changes in surface roughness with land-use change and low-level convergence (Ashworth, 1929; Kratzer, 1956; Landsberg, 1956; 1970; Changnon, 1968; 1981; Changnon and Huff, 1977: 1986).

The present work attempts to define the land-use changes, and the impact of the land-use changes on the climate of the Seoul Metropolitan Regions (figure 1) where land-use has been changed dramatically during the last two decades. The study area, including Seoul and its 17

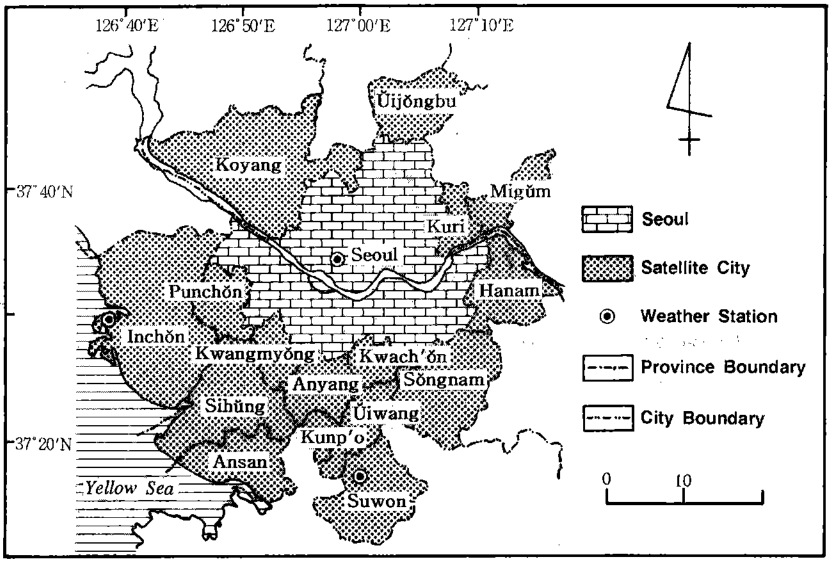


Figure 1. The study area.

satellite cities, had a population of over 18 million in 1994. This area of 15,000 km^2 contained 42% of the total population of South Korea.

2. Data Analysis

2.1 The Data

Changes of land-use in the study area are too drastic to obtain the dimension and intensity of the change by maps and documents. Three sets of Landsat images for the Seoul Metropolitan Region were analyzed to identify the changes of land-use due to urbanization (Table 1).

In plotting the temperature fields, NOAA_10 AVHRR Local Area Coverage data with a nominal spatial resolution of 1.1 km were used. AVHRR is a five channel-sensor of the NOAA series satellites in a sun-synchronous orbit. The approximate local over-pass times of NOAA_10 are 09:00 and 18:00. The data were acquired in the HRPT format from the Research Institute of Oceanography, Seoul National University (SNU/RIO).

Weather data for the period of 1954-1994 from Monthly Weather Report published by Korean Meteorological Administration (KMA) were also used.

Table 1. Characteristics of the Landsat data used in the study

Date	Satellite	Sensor	Band used	Nominal IFOV	Rectification RMSE	Cloud cover
09/22/72	L_3	MSS	5, 6, 7	79 x 79 (m)	0.771	0
10/04/79	L_3	MSS	5, 6, 7	79 x 79 (m)	0.730	0
09/22/92	L_5	TM	3, 4	30 x 30 (m)	0.772	0

IFOV : Instantaneous Field of view.
RMSE : Root-mean-square error.

2.2 Method of analysis

Most remote sensing investigations related with land-cover have ignored the atmospheric correction problems (Jensen, 1996). The amount of atmospheric attenuation is not sufficient to drown out the important terrain signal because of the strong signals from soil, water, vegetation and urban phenomena, and each of those is different from one another. The data used in this study also were neither corrected for atmospheric attenuation nor calibrated for surface thermal inertia and moisture capacity.

Three predominantly cloud free dates of Landsat data were collected by two sensor systems for the Metropolitan Seoul Region from 1972 to 1992. Landsat Multispectral Scanner (MSS) data were obtained in 1972 and 1979 and Landsat Thematic Mapper (TM) data in 1992. The specific date, type of imagery, bands used in the analysis, and nominal spatial resolution of the various sensor systems are summarized in Table 1. Twenty-five ground control points (GCP) were obtained in maps and image spaces (row and column) coordinates and used to rectify the September 22, 1972. The satellite data were rectified to a Transverse Mercator (TM) map projection having 30 x 30 m pixels using a nearest-neighbor resampling algorithm and a root-mean-square error (RMSE) of 0.8 pixel. All other images were resampled to 30 x30 m pixels using nearest-neighbor resampling and registered to the 1992 TM data for change detection purposes. The RMS error statistic for each image is summarized in Table 1.

Urban (densely developed), forest, agricultural and water were determined as the categories of land-use for training sites. The spatial frequency filtering techniques with low frequency were used to enhance urbanized area using TM Band 4 (0.76-0.96μm). The original TM band 4 images and filtered images were added to give the much enhanced image in which the boundaries of build-up and rural area were greatly enhanced (Duggin et al., 1988). Low pass filtering method was applied to enhance agricultural area using TM 4 and MSS band 6 (0.7-0.8μm). NDVI (Normalized Difference Vegetation Index) images of the study area were computed using band 5 (0.6-0.7μm) and 6 for MSS, bands 3 (0.63-0.69μm) and 4 for TM to enhance forest after following equation.

$$NDVI_{MSS} = \frac{MSS_6 - MSS_5}{MSS_6 + MSS_5}$$

$$NDVI_{TM} = \frac{TM_4 - TM_3}{TM_4 + TM_3}$$

To delineate the water body, specific percentage linear contrast stretch technique was applied to the TM band 4 and MSS band 7 (0.8-1.1μm). Land-uses were analyzed using supervised classification with MLC (Maximum Likelihood Classifier) with the supplement of aerial photographs and field survey.

Temperature, precipitation, humidity, and fog are all subject to change in the process of urbanization. These data from the Monthly Weather Report over twenty years were statistically quantified to identify a "trend" in the direction and magnitude of changes of weather. However, the lack of a network of weather stations was a major limiting factor to describe quantitatively in the study area. Therefore, NOAA-10 AVHRR data at channel_4 were enhanced and rectified for the corresponding area. Finally, the thermal data were processed to obtain brightness temperatures of the study area using TeraScan.

Since satellite-sensed temperature data are unsatisfactory, the information from the AVHRR data at channel_4 can be used as a valuable source of temperature data at present. The correlation coefficient between air temperatures (AT) and brightness temperatures (BT) from the images is 0.85. The relationship is expressed by the regression: AT =0.59 BT-2.54 in South Korea for the study of heat islands (Lee, 1993). This equation explains 73% of variances at the 0.02% significance level when calm and cloudless weather was considered.

Finally, the layers of city boundary, Green Belt and computer-enhanced brightness temperature-field were overlaid on land-use map obtained from Landsat images using Geographical Information System techniques through ARC/INFO to visualize the effect of the change of land-use on temperature fields.

3 . Land-Use Change for the period of 1972-1992

3.1 The Causes of Land-Use Change

There are many factors causing land-use changes. Amongst them, three should be stressed. The first is the government policies and plans for land-use. The second is population growth. The third is industrialization. In examining the impact that government planning policies have on land-use, three aspects should be considered. They are the level, the intensity, and the quality of the impact. Because urbanization transforms some of the physical processes in the environment, such as the climate and hydrology (Detwyler and Marcus, 1972), land-use planning is essential in the developing countries, like Korea. Urbanization beyond restraint in these nations is a major problem. Many of farmland or forest are cleared extensively each year as cities expand.

The success in part of Korean land-use plan lied in protecting land from the market system, which, left on its own, appropriates land irrespective of its intrinsic value. In Korea, the entire country has been placed under a nationwide land-use planning program since 1972, and a zoning system has been adopted as a tool for land-use planning since 1991. Such an accelerating land-use change has been controlled by the National Developing and Management of Land-Use Plan for more than 20-years. One method of control was the establishment of differential tax assessment laws. However, urban green space in Korea has decreased from $143.7m^2$ per person in 1980 to $114.8m^2$ per person in 1990. In 1993, land development specialists estimated that the rate of potential land development to the whole country would increase from 15.0% to 41.7% during the progress of the New Economic 5-year Plan (1993-1997). This plan puts special emphasis on potential economic growth and the effectiveness of land-use (Yun et al., 1993).

The effects of the land-use planning regimes in Korea are clearly visible. As can be seen from satellite images, cities are fully built-up to a clearly defined edges reminiscent of the sharp boundaries of settlements. 20 km north from the center of Seoul, the boundary of the Green Belt as defined in 1971, coincides exactly with the physical edge of the metropolis of Seoul today. Some cities such as Koyang and Sungnam have a looser texture, with rice paddies and crop-fields interspersed through built-up suburbs. In these places buildings remain scattered through the landscape, with their frequency diminishing as the distance from the urban center becomes greater (Plate 1-1).

The rapid population growth is one of the major causes of land-use change. Korea is one of the most densely populated nations in the world and its population in recent years has been agglomerated in urban areas, particularly in a few metropolitan areas. The Seoul Metropolitan Region contains more than 18 million population, that is 42% of the nations in an area of 1,500 km^2. Seoul, the capital and largest city in Korea had a population of one-quarter of the nation's entire population at the end of 1995.

The Korean government has attempted many different approaches to control the concentration of population in urban areas. A policy to decentralize the population of Seoul became effective in the early 1980s. Several towns with populations over 50,000 in the Seoul Metropolitan Region were designated as cities for new urban growth. The introduction of special tax and credit incentives in these cities has succeeded in dispersing industrial activities out of Seoul. As a result, the annual growth rate of population (1980-1994) in the satellite cities accelerated between 2.4~119.7%, making the average of 18.4%. Compare this to 2.3% growth

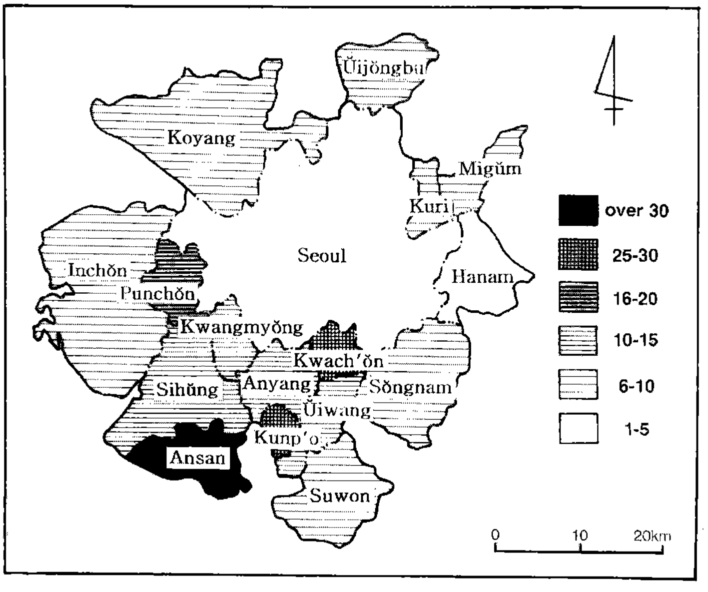


Figure 2. The annual population growth rate (%) for the period of 1982-1994.
(source: The Municipal Yearbook)

rate of Seoul, as shown in figure 2. The largest growth rate appeared in Ansan, 119.7% annually. This city is becoming an industrial frontier since 1980 and developed as one of a large-scale industrial complex. The rapid growth of population in these areas has been attributed to the change of land-use from rural to urban. Manufacturing complexes and high-rise apartments now are founded on the areas which were rice paddies or forest.

More than 40% of manufacturing work force of Korea was concentrated in Seoul until the 1970s. However, since then Seoul's share of this population has decreased considerably because of the policy of government to decentralize manufacturing. The Korean Government not only prohibited the construction of new industrial plants in the Seoul area after the 1970's, but also urged various existing establishments to move out to rural areas. As a result, several satellite cities and their surrounding rural areas experienced a rapid increase in the number of manufacturing plants. This industrialization stimulated the changes of land-use from rural to urban.

3.2 The Change of Land-Use

Urbanization in the Seoul Metropolitan Region caused the land-use change. One can recognize easily from figure 4 (Plate 2) that land-use in the region changed remarkably from

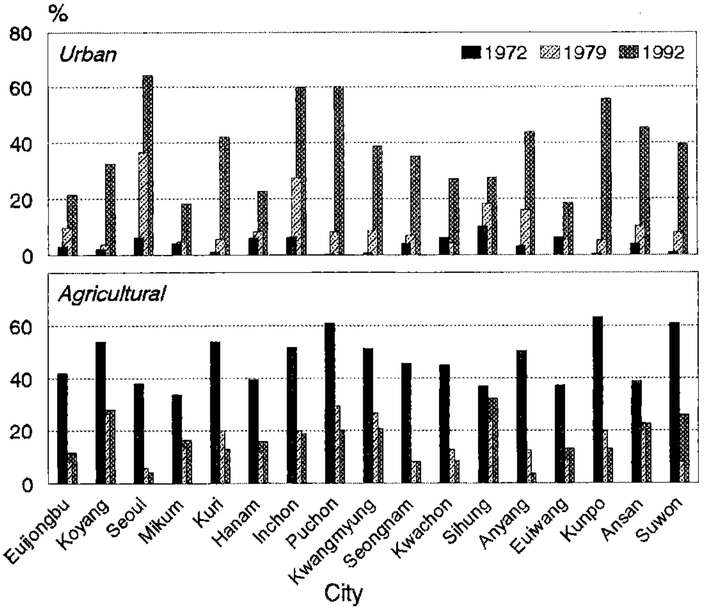


Figure 3. The trends of land-use by types.

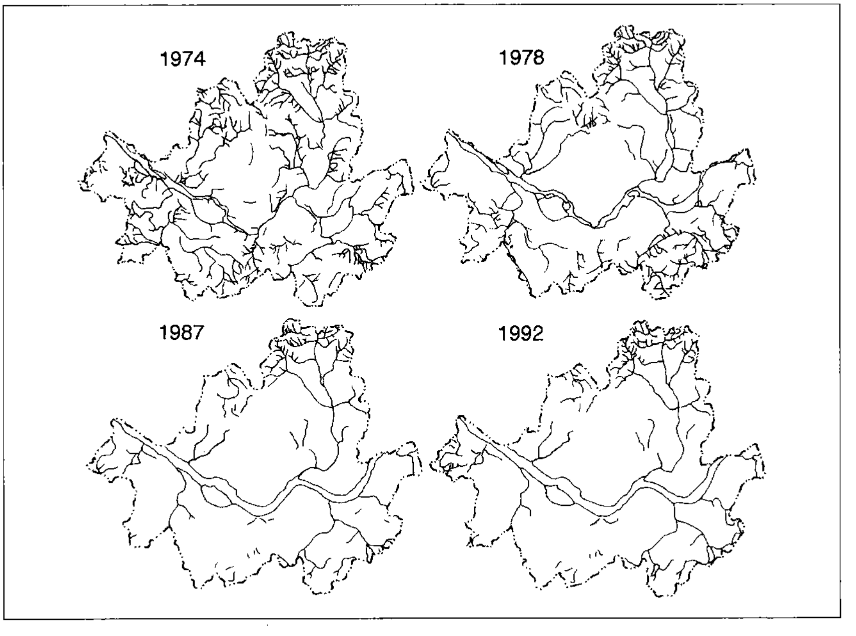


Figure 4. The changes of drainage patterns in Seoul (Sung, 1994).

rural to urban in the period of 1972-1992. While urban land-use increased ten times from 3.9% to 38.4% with urbanization, the total green space or permeable land decreased from 94% to 62%. Permeable land-cover/use such as forest and agricultural land also decreased. Forest decreased from 46.2% to 43.8% while agricultural land decreased from 45% to 16%. This decrease of biomass may have implications for the local climate, biodiversity, carbon cycle, and the meso-scale atmospheric circulation.

Urbanization also caused morphological changes in the drainage system. Figure 6 demonstrates that many tributary channels of the Han-River were diminished by straightening or covering channels for the period of 1974-1992 (Sung, 1994).

4. Results and Discussion

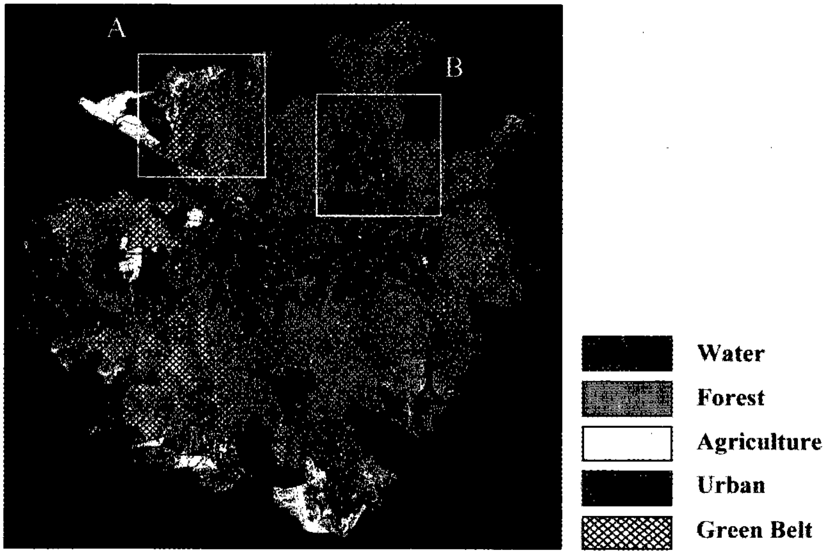
4.1 The Impacts of the Land-Use Change on the Heat balance

There are potential regional and global climatic impacts associated with landscape changes. The changes in surface properties alter the surface energy budget. The interaction of solar, atmospheric, and terrestrial radiation at the earth's surface without any complicating anthropogenic factors is itself a very complex phenomenon. Add the man-made changes and it becomes a formidable problem. Climate of a region largely depends upon its synoptic condition. But geographical location and land-cover also affect a regional climate. When land-cover is altered by urbanization, meteorological variables such as albedo, and evaporation are modified as well. Two of the most important changes in these variables are changes in the fraction of solar radiation reflected back to space (e. g. albedo) and changes in the reaction of heat which is used to evaporate and transpire water to the atmosphere.

Nonabsorbing aerosols also increase the albedo of the atmosphere, thus reducing the amount of solar radiation reaching the surface. If the aerosol absorbs in the short-wave portion of the spectrum, energy is directly transferred to the atmosphere. The effect is a heating of the atmosphere and a cooling of the underlying surface. The net effect depends on the ratio of the absorption coefficients in the visible and infrared, and also on the albedo of the surface. The change in the radiative fluxes due to the aerosols thus leads to changes in the atmospheric temperature profiles and stability, as well as in surface temperatures.

The most obvious climatic characteristic of urbanization is the trend toward higher air temperatures known as heat islands. Temperatures depend upon the microclimate associated with the amount of insolation, relief and ground coverage. Due to Seoul's growth, the number of tropical nights, with a minimum daily temperature of over 25°C, has increased. As the size of a city increases, so does the magnitude of its heat islands (figure 5).

The magnitude of heat islands is 2~4°C on average. However, an extreme value of heat



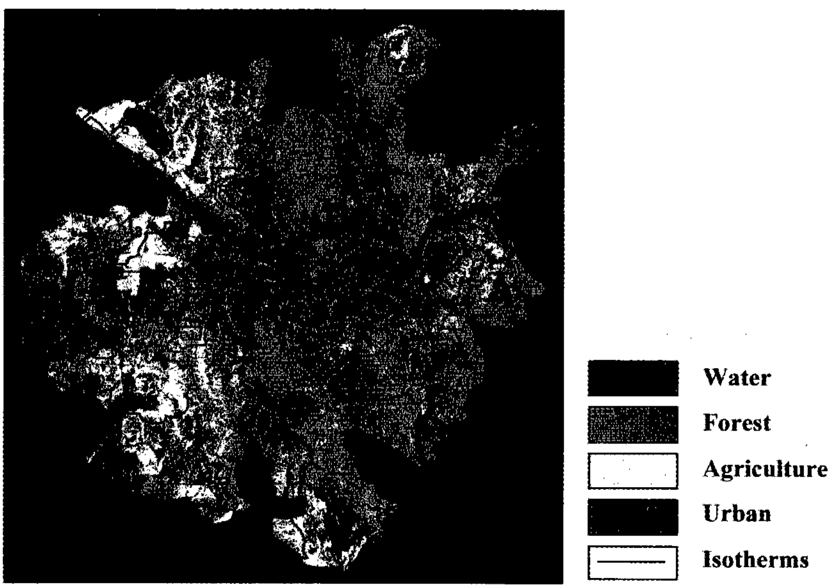


Plate 1-1 (upper). The effects of policy on land-use. About half the developments in this area were built after 1990s. The settlements are interspersed among agricultrual area in Koyang, a commuter satellite city of Seoul (A). The boundary of the metropolitan Green Belt defined in 1970s coincides almost exactly with the physical edge of the metropolis today (B).

Plate 1-2 (lower). Surface temperature field over land-use patterns. Temeratures were derived from NOAA AVHRR Channel_4 at 9:00 LST, September, 1992. Isotherms are in °C.

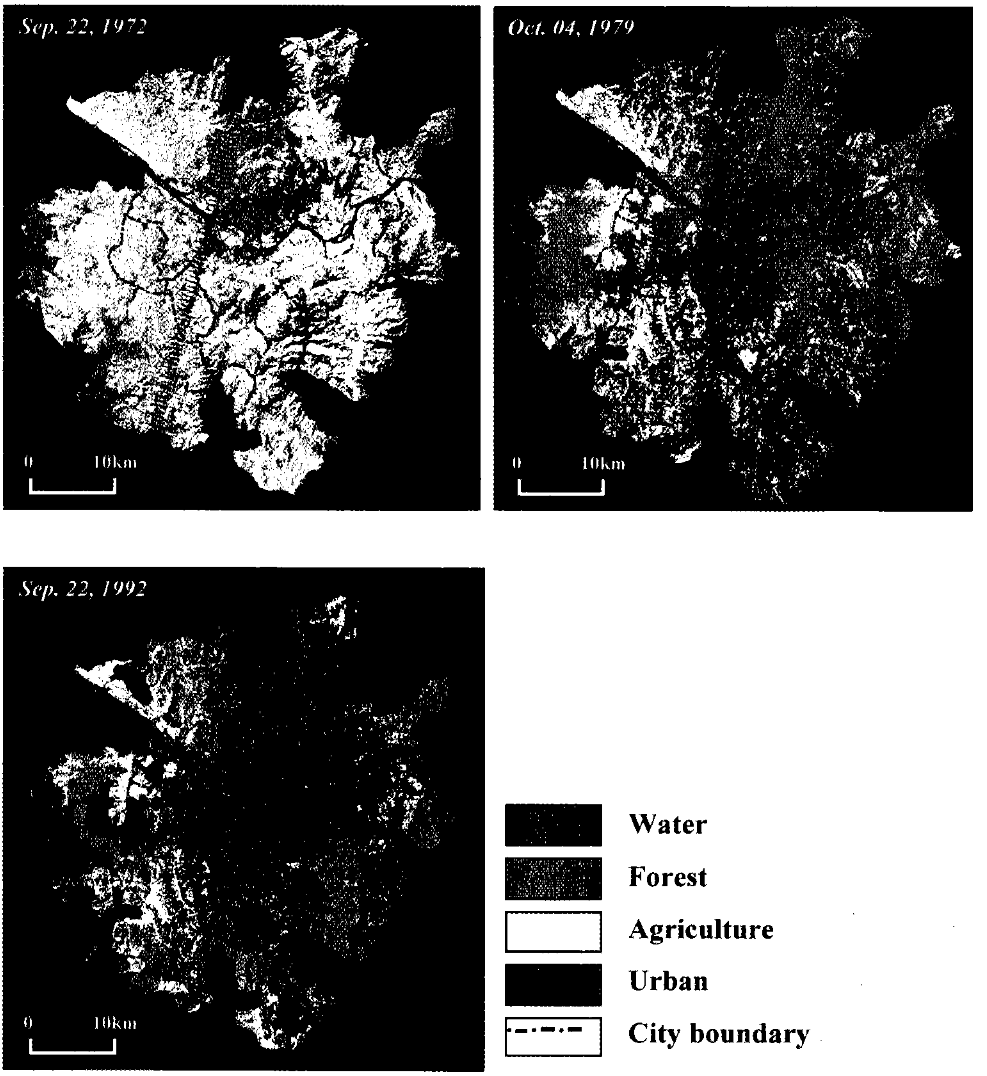


Plate 2. The change of land-use for the period of 1972-1992.
These figures obtained from Landsat images using supervised classification methods.

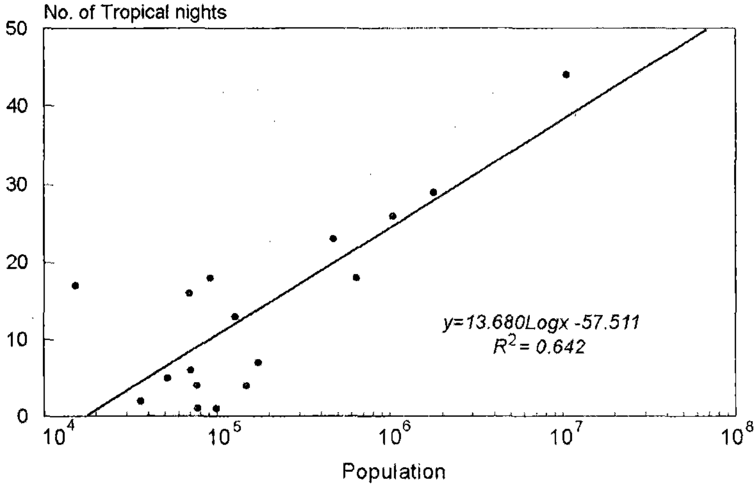


Figure 5. Relationship between the number of tropical night and city size.

island was 9℃ in Seoul (1993). The increased daily temperatures have a number of implications. The earlier blossom in the city is a favorable phenomenon. The added warmth stress requires less winter space-heating, but in summer, more air-conditioning is necessary. For instance, the exceptionally hot summer of 1994 doubled the domestic use of electricity compared to that used in a normal summer. During July and August of that summer in Seoul, additional electricity costs, due to air-conditioning, came to about 250 million dollars.

Satellite observations support the existence of gradients in the temperature field across the boundaries of urban-rural areas. This is illustrated in Plate 1-2, where the highest surface brightness temperature is seen in the central business district (CBD) of Seoul. Outskirts of Seoul, several enclosed isotherms also appear on the satellite cities as measured by the Landsat_5 TM image. There is only a small portion of land to be used for further urban development because of

Table 2. Trends of minimum temperature (1972~1992)

City	Area (km^2)	Population* (1000)	Ratio**	The slope of regression equation
Seoul	605	10,612	10.2	0.102
Inchon	388	1,818	9.1	0.089
Suwon	106	645	39.4	0.156

* : 1992, ** : Increasing ratio of urban area(1992/1972).

the Green Belt Act. As a result, urbanization will expand vertically and its effect on the atmosphere will become a more serious problems.

Table 2 shows that the trends of minimum temperatures of the cities. The increasing ratios are in the order of expanded urban area size for the period of 1972-1992.

4.2 The Impacts of the Land-Use Change on the Moisture balance

The amount of annual precipitation in Seoul has also increased more than that of surrounding rural areas since 1970, as most recent researches have reported. The urban enhancement of annual precipitation was maximized in the center of Seoul, but the enclosed isohyte is more extended for the convective rainfall in summer toward the northeastern part of the city, that is, the downwind area of the prevailing wind (Lee, 1988).

The number of light rainfall-days (less than 1 mm) and heavy rainfall-days (more than 80 mm) supported a hypothesis of the positive relationship between light rain and aerosols. The areas showing the highest number of light rain-days were Dae-bang Dong which is located just north of one of the sub-centers of Seoul and 4 km north of the Ku-ro industrial district. The condensation nuclei from industrial plants is believed to form more cloud droplets, resulting in light precipitation. Analysis of convective heavy rainfall with storms showed that the number of occurrences in the inner city is twice that of its surrounding rural area, and the time of occurrence of storms was delayed one or two hours in rural areas (Lee, 1988). On the basis of the climatic studies of precipitation for Seoul and its surrounding satellite cities, it can be stated that the extra increment of heat by the urban fabric is often the trigger for the occurrence of convective precipitation. Annual and seasonal precipitation in Seoul increased by about 50-60 mm, corresponding to 4% of the total, which was greater than that of small surrounding cities. The number of precipitation days in Seoul also increased.

In spite of the increase of condensation nuclei, the number of days with fog has decreased in such large cities as Seoul and Inchon since the 1970s, contrary to the findings of other

Table 3. Trends of annual precipitation and relative humidity (1972～1992)

City	Area (km^2)	Population* (1000)	Increasing Ratio of Urban Area (1992/1972)	The slope of regression equation	
				Precipitation**	RH***
Seoul	605	10,612	10.2	26.706	-0.169
Inchon	388	1,818	9.1	14.707	-0.135
Suwon	106	645	39.4	15.399	-0.206

* : 1992, **: Annual precipitation, ***: Relative humidity for autumn.

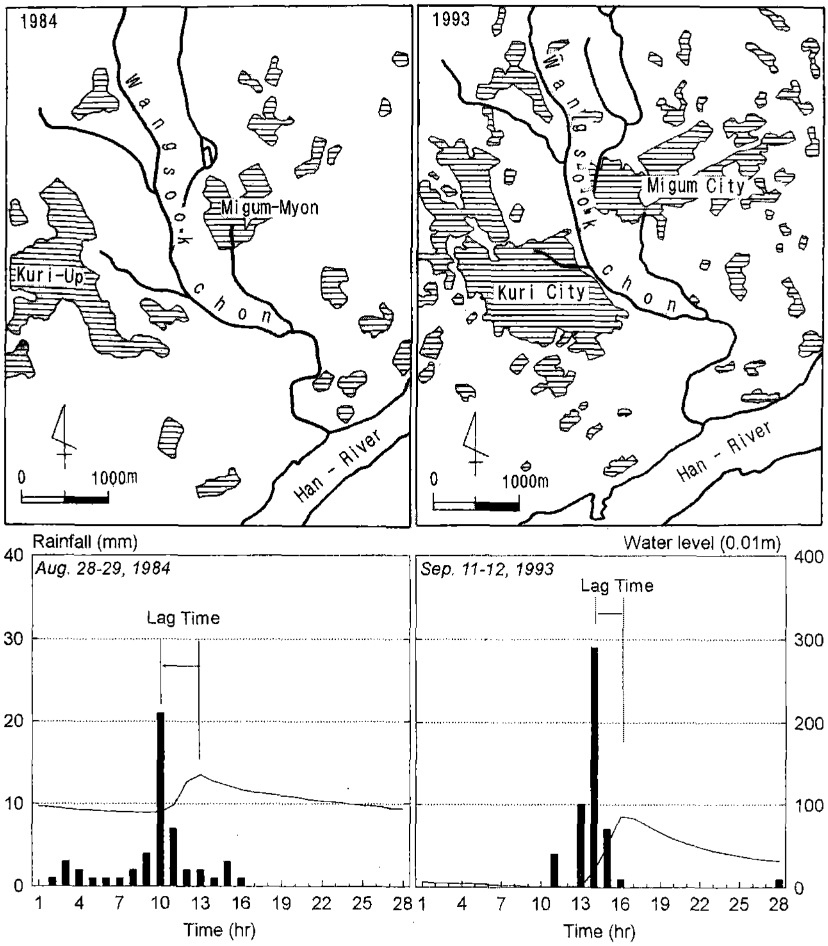


Figure 6. Urbanization and flood hydrographs in Wanksook-chon, a tributary of Han-River (source: Ministry of Construction and Transportation).

researches. One might explain that this decrease is caused by the development of heat islands and the lack of humidity for fog formation, because the decrease in relative humidity is striking in the dry season for the period of 1974-1994. Fog now dissipates about 2 hours later than in 1970s, with blue sky usually visible between 10:00 and 11:00. The depth of the fog layer in the cities has generally become thick.

These phenomena can be explained by morphological changes in the drainage system caused by the change of land-use due to urbanization. Figure 4 demonstrates the diminution of tributary channels of the Han-River over a twenty-year period.

Channels were straightened and tributaries were covered in the process of urbanization. Consequently, much of the storm run-off has been carried by conduits, thus reducing the moisture available for evaporation into the atmosphere and evapotranspiration through vegetation. The increasing expansion of urban areas in some satellite cities such as Kuri and Migum, which are located northeast of Seoul along Wangsook-chon has led to increasingly higher peak flows with a short time lag (figure 6).

4.3 The Impacts of the Land-Use Change on the Living Environment

The most difficult urban atmospheric problem to counteract is pollution. Most urban air pollution comes from motor vehicle emissions powered by an internal combustion engine using gasoline or diesel fuel recently. Several provisions for alternative transportation are the essential task for the city planner.

The effects of land surfaces on climate extend beyond biophysical exchanges. Land surface contains large quantities of carbon (Post et al., 1982). This raises several scientific controversies. They are concerned about the question of whether changes in carbon storage are due to land use practices (Houghton, 1987) or are due to climate-induced changes in the areal extent of terrestrial ecosystems. Scientists also are concerned about the role of terrestrial ecosystems play in the seasonal dynamics of atmospheric CO_2.

Urbanization is likely to increase the energy consumption and emission of air pollutants such as SO_x, CO, NO_x, and HC. With the expansion of the Seoul Metropolitan Region, vehicular

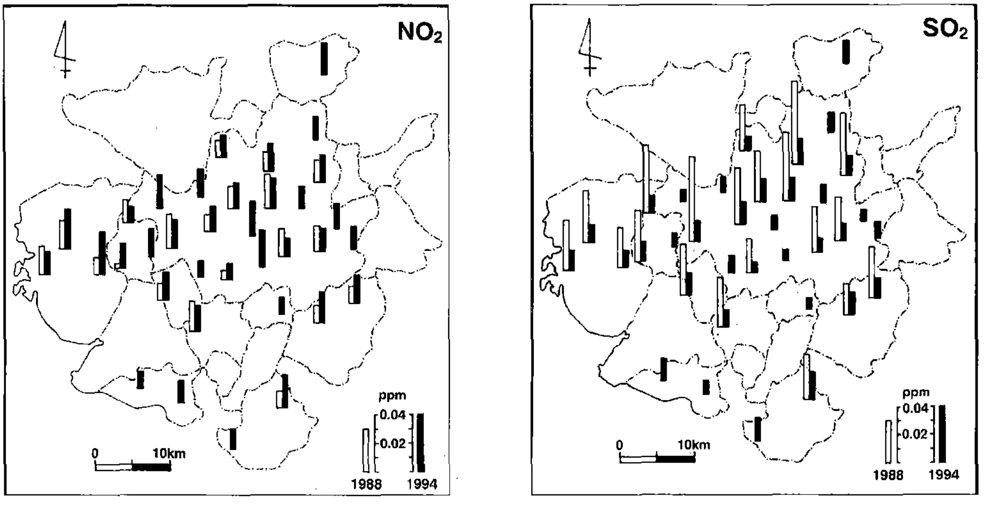


Figure 7. Changes of pollutant levels in Seoul Metropolitan Regions prior to and after enactment of Clean Air Act (source: Environmental Statistics Yearbook, Ministry of Environment).

traffic has contributed significantly to increased air pollution in the study area. Until the end of the 1970s, the level of SO_2 concentration in Seoul was notorious, ranking 3rd in the world. There has been, however, a measurable decrease in SO_2, suspended material (TSP) and CO with the inauguration of clean air acts[1] in the last decade. Nevertheless, the NO_2 values seem to remain steady or even show local increases because of the increase of vehicles. Figure 7 shows time series for SO_2 and NO_2 of the study area.

5. Conclusion

Land-use in Korea has changed rapidly during the last two decades in accordance with urbanization, and many cities and their surrounding areas are still expanding with alarming speed. The policy of land-use and the growth of population in the process of urbanization were the main causes for the change of land-use. These changes have had a noticeable impacts on the local climate in the Seoul Metropolitan Region. The adverse influences of rampant urbanization on local climate are widespread, and without proper regard for climatological considerations the quality of the city environment in the study area cannot be sustained satisfactorily. To quantify the impacts of land-use on the local climate, however, considerable field measurement and theoretical work are yet to be carried out. Among the major needs are field experiments at representative sites around the urbanized area, in order to characterize in detail the weather and climate changes over natural areas, as compared with those in the same region which have been substantially modified by man.

Recent changes in the local climate due to urbanization indicate that the climate has become drier and warmer in the study area. This study also suggests a need for further studies of man's effects on local climate to minimize adverse influences and hazardous pollution for the Seoul Metropolitan Region. One of the remedies is to enhance albedo, that is to increase evaporative cooling by means of creating more green space. Green space not only reduces city air temperatures, but also improves air quality by absorbing gaseous pollutants and intercepting particles. Green space also helps to prevent flooding by reducing the rate of runoff. To avoid temperature and moisture extremes and yet to maintain a certain amount of ventilation, city designs that take climate change in account are also required.

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1) The Korean government restricted unleaded gasoline in 1981 and briquette (1985). Since 1987 LNG use was obliged in the Seoul area.

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