Satellite Monitoring of Urban Spatial Growth in the Amman Area, Jordan

Samih Al Rawashdeh[1] and Bassam Saleh[2]

Abstract: The detection and analysis of land use changes in the urban environment is an important issue in planning. Remote sensing and geographic information systems are considered as the most efficient techniques for this type of studies. These techniques had been applied to investigate the effects of urbanization on fertile lands and to quantify urban growth of Amman area. Five land covers were identified in space and time using aerial photographs, LANDSAT and IKONOS images acquired at different dates. The study showed that the urban area was increased by 162 km^2 over the period 1918–2002, which represents 509 times the original urban area. The fertile lands decreased by 86 km^2, which represents 23% of loss. Moreover, the urban expansion over 1918–2002 was analyzed and its impacts on the Amman area environment were assessed. The results of our study were compared to other similar studies for Istanbul and Bangkok. The comparison showed that Amman has the largest percent annual rate of urban expansion.

DOI: 10.1061/(ASCE)0733-9488(2006)132:4(211)

CE Database subject headings: Urban areas; Remote sensing; Geographic information systems; Land usage.

Introduction

Several decades of population explosion and accelerating urban growth have had profound environmental and socioeconomic impacts felt in both developing and developed countries alike (Leao et al. 2004; Longley 2002). Understanding the growth and change brought on by urbanization is critical to those who study urban dynamics and those who must manage resources and provide services in these rapidly changing environments (Sanchez 2004; Yang 2002; Chen 2002; Aysan et al. 1997; Wright 1996; Clark and Jantz 1995).

Urbanization in Jordan is the result of a rapid population increase caused by a mass immigration and a flow of refugees. This essentially unplanned and therefore uncontrolled urbanization results in the destruction of green areas and water resources. Conventional surveying and mapping methods cannot deliver the necessary information in a timely and cost-effective manner. Remote sensing (RS) and geographic information systems (GIS), given their cost effectiveness and technological soundness, are increasingly being used to develop useful sources of information and to support decision making in connection with a wide array of urban applications (Lo and Yang 2002; Souleyrette and Anderson 1998; Cowen and Jensen 1998). Satellite images are potentially useful source of land cover information. Further, they can be used to identify and map urban land cover with a fine spatial resolution (Tapiador and Casanova 2003; Yang 2002, Madhavan et al. 2001; Ridd and Liu 1998; Jensen 1996). RS along with GIS tools are used now to gather, store, retrieve, analyze, display, and output data related to the urban and suburban environment and can provide planners with certain data sets (Donnay et al. 2001; Bahr 2001) that help in managing the urban and suburban areas.

The study focuses on Amman area (see Fig. 1), which includes Amman city and its surrounding suburbs with an area of around 618 km^2. It is populated by more than two millions inhabitants in 2002 (Department of Statistics—Jordan 2002). Amman is an ancient city and has been under the domination of the Ammonite,

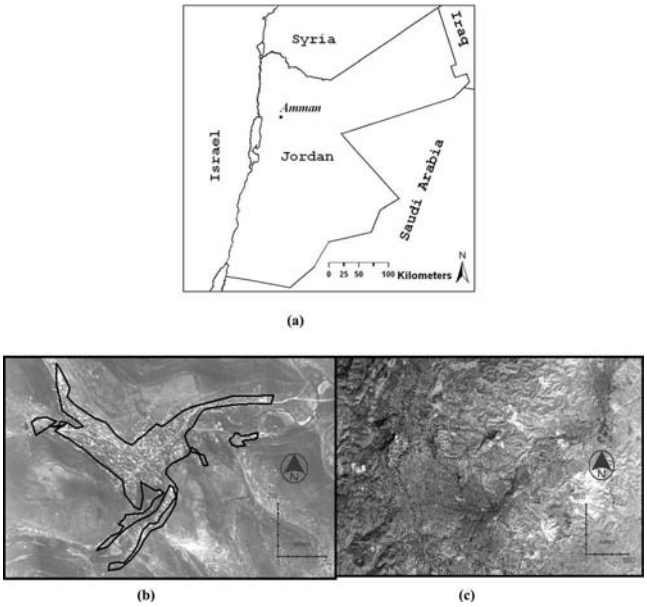

Fig. 1. (a) Amman location map; (b) aerial photo of Amman acquired in 1918; and (c) Landsat image of Greater Amman acquired in 2002

[1]Assistant Professor, Dept. of Surveying and Geomatics Engineering, Faculty of Engineering, Al-Balqa' Applied Univ., Al-Salt 19117, Jordan. E-mail: rsamih@hotmail.com

[2]Associate Professor, Dept. of Surveying and Geomatics Engineering, Faculty of Engineering, Al-Balqa' Applied Univ., Al-Salt 19117, Jordan. E-mail: bsaleh@wanadoo.jo

Note. Discussion open until May 1, 2007. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this case study was submitted for review and possible publication on March 22, 2005; approved on December 12, 2005. This case study is part of the ***Journal of Urban Planning and Development***, Vol. 132, No. 4, December 1, 2006. ©ASCE, ISSN 0733-9488/2006/4-211–216/$25.00.

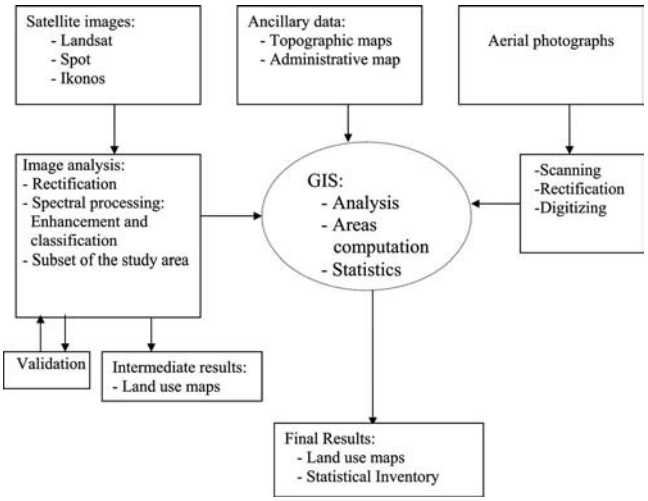

Fig. 2. Flow chart of the applied methodology in this study

Assyrian, Persian, Greek, Roman, Byzantine, and Arab civilizations (Laveau 1996). During the last century, Amman had offered a safe heaven for immigrants from the neighboring countries at war. Amman is located at 32°N and 36°E and has a Mediterranean climate; it is situated in the mountain heights plateau of Jordan and limited by the desert from the East and South with an elevation ranging from 400 to 1,000 m above sea level. Before urbanization, the northern and western parts of Amman area were considered as fertile lands suitable for cereals cultivation with a production enough to subsidize the needs of the central part of Jordan. Amman population was approximately 5,000 inhabitants in 1918 and has increased approximately 400 times in less than a century. The huge increase in population created many planning and environmental problems. Consequently planned and unplanned housing is increasing whereas green areas are decreasing. Monitoring Amman area growth will enable us to better understand and manage this complex urban area. RS and GIS techniques will be applied in this study for land use change detection. Aerial photographs, LANDSAT, SPOT, and IKONOS images for different dates will be used to quantify the urban growth of Amman area and its environmental impact.

Methodology

The adopted methodology in this study is illustrated by the flowchart shown in Fig. 2. The main steps of this methodology are: (1) Geographical analysis; (2) satellite images, aerial photographs and ancillary data acquisition; (3) land use mapping using digital image processing system; and (4) data analysis and interpretation using GIS.

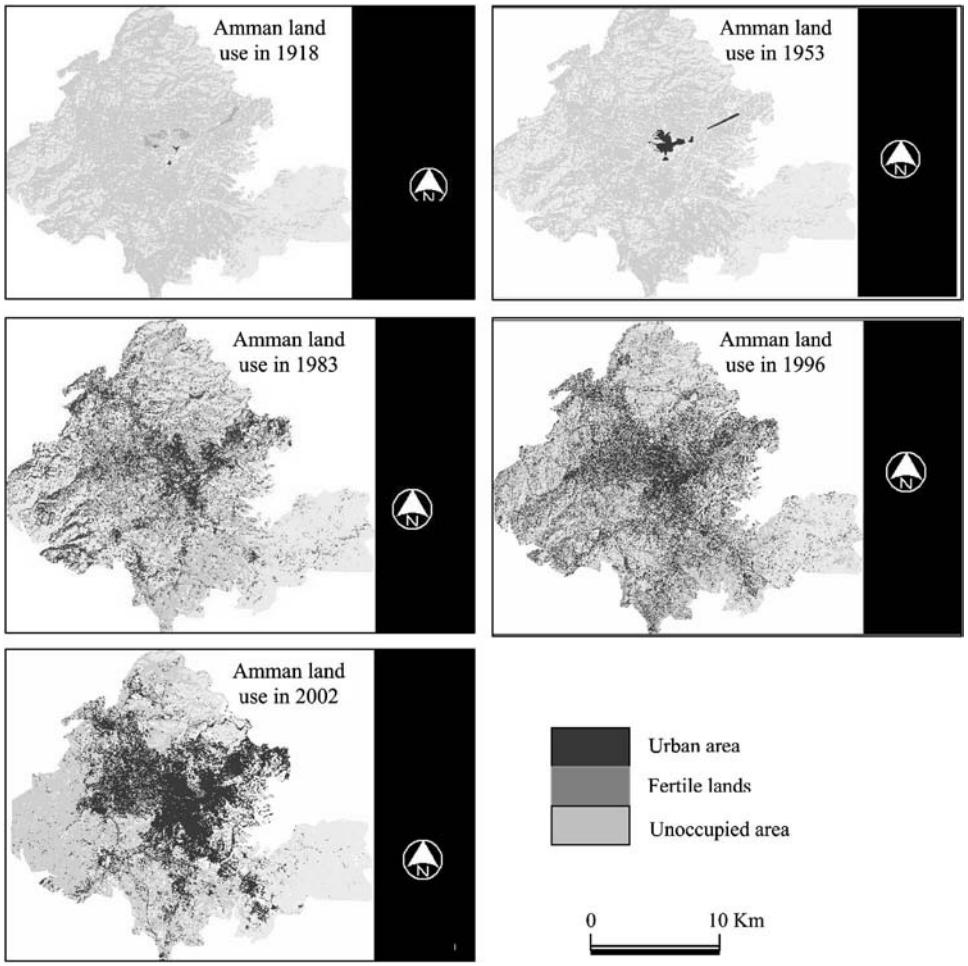

Fig. 3. Land covers of Greater Amman obtained from aerial photographs for the years 1918 and 1953, and from Landsat images for the years 1983, 1996, and 2002

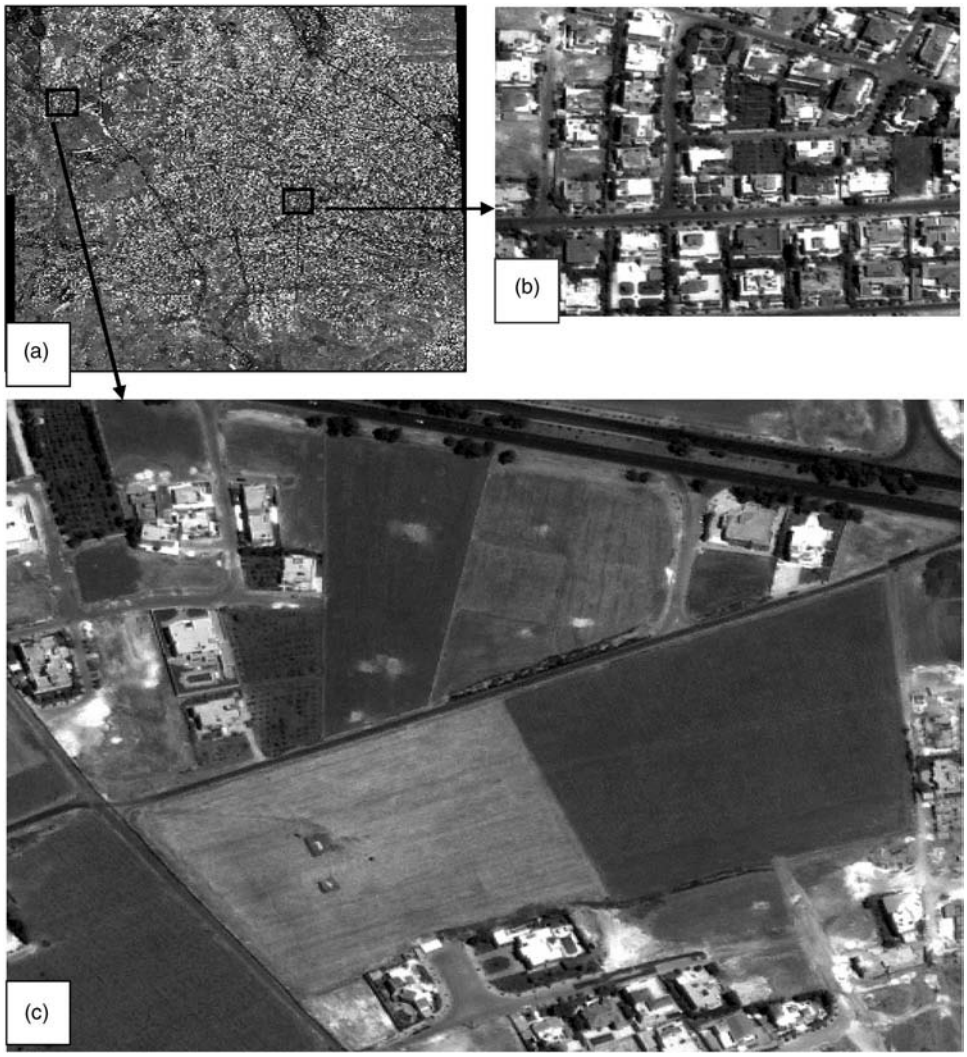

Fig. 4. (a) Part of Landsat image of Amman area acquired in 2002; (b) and (c) Samples from an IKONOS image of 1 m resolution acquired in 2002, representing two areas in the Landsat image shown in (a)

Geographical Analysis

An intensive geographical study was conducted through the existing and available bibliography. It included a description of physical conditions like climate, topography, soil, and vegetation. The study focuses on urbanization encroachment, population/demography, and agricultural aspects of the area.

Data Collection

Different types of data were used for this research: (1) Aerial photographs taken in 1918 and 1953, (2) LANDSAT images 1983, 1996, and 2002, (3) SPOT image 2002, (4) IKONOS images 2002, (5) topographic and administrative boundaries maps, and finally (6) ground control points.

Image Rectification

Remotely sensed data acquired at different dates, by different satellite sensors were rectified geometrically, along with the topographic maps into the same Jordan transverse mercator coordinate system.

Classification

A subpixel classification for rendering the effect of mixed pixels was established for LANDSAT images acquired in 1983, 1996, and 2002. At the beginning, the number of classes was 16. These classes were then reduced to three principle classes, which are urban areas, fertile lands, and unoccupied areas. The aerial photographs taken in 1918 and 1953 were used to obtain the land covers for these years. The classification was based on photograph interpretation and cartographic maps of 1945 using GIS software. The results of classification were checked out using maps, aerial photographs, SPOT and IKONOS images, and ground surveys.

Statistical Inventory

The three classes produced by classification for different dates were transformed to vector polygon layers using remote sensing software. Then, the vector layers were used by GIS software to calculate the areas of different polygons and to store them as attribute data in the database. Statistical analyses were performed to calculate the increase and decrease in area of a specific class and period.

Table 1. Areas of Land Use Zones over the Period 1918–2002 in Greater Amman

	Area (km^2)				
Class name	1918	1953	1983	1996	2002
Urban area	0.321	4.444	105.675	150.764	162.924
Fertile lands	383.856	383.593	331.693	301.346	297.413
Unoccupied area	234.425	230.576	181.237	166.492	158.267

Results and Discussion

Our study emphasizes the efficiency of RS and GIS techniques in detecting land use changes in Amman area over an extended period of time (84 years). Due to the scarcity of data for the previous periods, remotely sensed data were an excellent and important source of data which enabled the extraction of the land covers at different periods and the estimation of the annual rate of the urban expansion. RS and GIS technologies allowed carrying out the study easily, in a short time and with little expenses.

The land covers of Amman area (Fig. 3) were obtained from old aerial photographs for the years 1918 and 1957 and LANDSAT images for the years 1983, 1996, and 2002. The first two land covers indicate that the urbanization in 1918 and 1953 was mainly oriented toward the unoccupied area, while this urbanization expanded in 1983, 1996, and 2002 toward the agricultural lands (Fig. 4). The area of each class of each land cover was calculated using GIS (Table 1). The results show an increase in the urban area from 0.3214 to 162.9243 km^2 during the study period. This increase represents 509 times the area of the old city. This important urban expansion could be explained by the important increase in the population (400 times of the original population). Table 1 shows as well, a decrease in the fertile lands from 383.8565 to 297.4132 km^2, which represents a loss of 23% of this area. Table 2 presents the land use changes (km^2) over the periods of 1918–1953, 1953–1983, 1983–1996, and 1996–2002 and presents as well, the percentage of changes. Extraordinary urban expansions were observed and analyzed during the mentioned periods as follows:

1. For the period of 1918–1953: The urban expansion is estimated at 4.123 km^2, which represents an increase of 1,284% due to the first Palestinian immigration to Jordan in 1948 and the adoption of Amman as the capital of Jordan. The expansion was contained in the valley area and started to take the direction of Zarqa city, which is located at 25 km to the East of Amman, house the army and some industry. The road which connects the two cities was one of the major roads in Jordan.
2. For the period of 1953–1983: The urban expansion is estimated at 101 km^2, which represents an increase of 2,277% is due to the second immigration of Palestinians to Jordan in 1967. Two major axes and an area of expansion appear clearly. The first axis is oriented toward the northeast direction and follows the road to Zarqa. The other axis is oriented toward the northwest direction and follows the road to Jerash and Irbed cities. A new area of urban expansion in the west direction of Amman (Biader Wadi Alsir) was growing over the fertile lands to create industrial and commercial part of the city.
3. For the period of 1983–1996: The urban expansion is about 45 km^2, which represents a growth of 43% is due to the Gulf war in 1991. A lot of refugees from Jordanian and Palestinian origins came back from Kuwait and Iraq and settled in the Amman area. The urban expansion over the fertile lands was

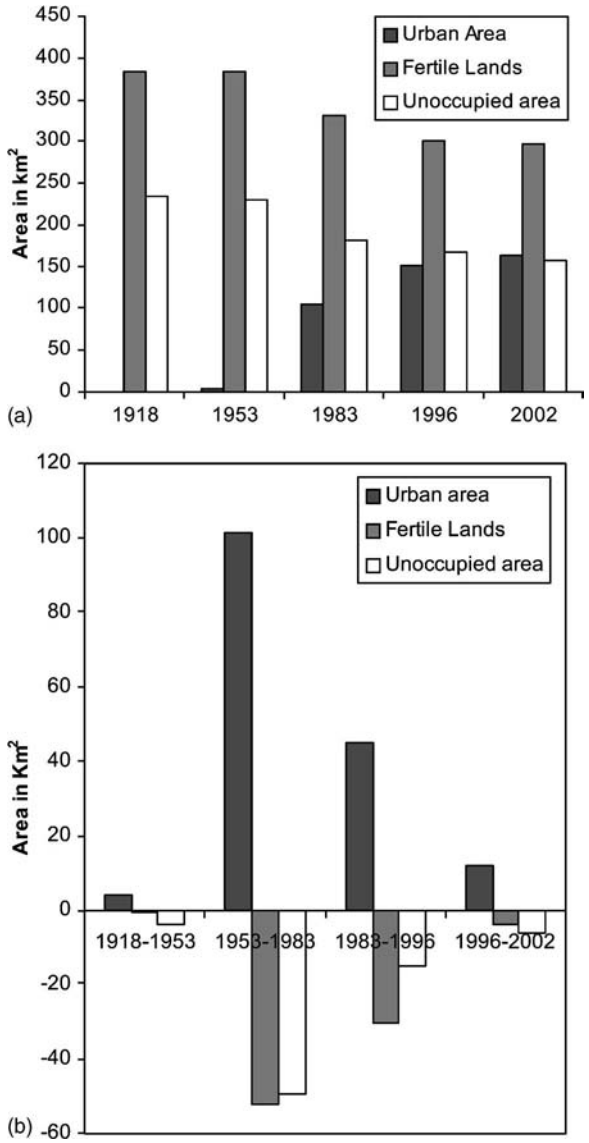

Fig. 5. (a) Land use of Greater Amman; (b) area of land use changes

Table 2. Area and Percentage of Land Use Changes in Greater Amman for Different Periods

	1918–1953		1953–1983		1983–1996		1996–2002	
Class name	(km^2)	%	(km^2)	%	(km^2)	%	(km^2)	%
Urban area	+4.123	+1284.4	+101.231	+2277.9	+45.089	+42.7	+12.160	+8.1
Fertile land	−0.263	−0.1	−51.900	−13.6	−30.347	−9.2	−3.933	−1.3
Unoccupied area	−3.849	−1.6	−49.339	−21.4	−14.745	−8.1	−8.225	−4.9

Table 3. Annual and Percent Rate of Urban Expansion in Amman, Istanbul, and Bangkok Cities Estimated over the Last 20 Years

City name	Annual rate of expansion (km^2/year)	Percent annual rate of expansion (%)
Amman	02.10	2.70
Istanbul	10.00	0.36
Bangkok	42.70	2.20

twice more than the urban expansion over the unoccupied lands (Fig. 5). Fig. 5 shows as well, that the loss of fertile lands before 1953 was negligible (0.264 km^2), and became very important (86 km^2), during the last 50 years. More urban growth was noticed in the city and around the previous axes in addition to a new axis oriented toward the southeast direction. This axis as well follows a major road and connects the new airport. Once again the fertile lands around the airport road started to provide a new heaven for single family housing and universities. The unusual urban growth during this period was due to the third immigration after the gulf war.

4. For the period of 1996–2002: More and more growth can be noticed around the city and the previously mentioned axes due to the Iraq war.

We conclude from the analysis that the expansion of Amman over the years was oriented by the major roads that connect the major cities and it always expanded over the agricultural land.

Similar international studies were conducted to analyze the urban expansion for important cities such as: Istanbul in Turkey (Kaya and Curran 2003), Bangkok in Thailand (Tachizuka et al. 2003), Atlanta in the United States (Yang 2002), and Kaoshiungin in Taiwan (Cheng-Ming 2003). Our results were compared with those of Istanbul and Bangkok which are known for their extraordinary annual urban expansion (Table 3). The rate of the urban expansion for Istanbul over the period of 1987–2001 was 10 km^2/year, for Bangkok over the period of 1993–2002 was 42.7 km^2/year and for Amman over the period of 1983–2002 was 2.1 km^2/year. Then the percent annual rate for urban expansion was calculated for the above-mentioned cities. Amman showed the largest percent annual expansion rate (2.7%), in comparison with Istanbul and Bangkok.

If the urban expansion continues at this rate in Amman area, the fertile lands will disappear by the middle of the next century. A reduction in fertile lands has vastly unknown consequences for biological diversity, but it translates to less available energy for the species that make up Earth's complex food web. The loss of highly fertile lands for farming also puts pressure on other means to meet the food and fiber needs of an increasing population. The fast growing of population created new problems to Amman city. It is suffering from traffic jams, air pollution, and severe water shortages. Such severe water shortages had forced the government to impose a rationing program, whereby domestic supply is pumped twice a week during summer months. Urbanization is not always a bad thing. It is a very useful way for societies to get together and share resources. But it would be better if it were planned in conjunction with other environmental factors.

Conclusion

This study enabled the analysis of urbanization in Amman area over the period of 1918–2002. Five land use maps were obtained at different dates during the study period; each has three main classes. The accuracy of these land use maps was determined using aerial photographs, IKONOS images, field surveys, and topographic maps. The study showed that a great urban expansion in Amman area of 162 km^2 had occurred during the past century which led to the destruction of about 86 km^2 of fertile lands. The expansion was mainly due to the immigration of people from neighboring countries at war. Our results showed that Amman has an important annual rate of urban expansion compared to other cities known for their excessive expansion.

This study shows that urbanization in Amman follows the major roads and the fertile lands; for easier transportation and lower price of land. We recommend that the planning of urbanization in Amman to be in conjunction with the protection of the precious fertile lands around the city. We recommend as well, the improvement of the other lands, to make it suitable for urbanization while keeping in mind the economical factors. This type of analysis could be applied to all cities in Jordan to find out the pattern of urbanization. We need such studies for better decision-making and planning. This will help as well in avoiding the expansion in the wrong directions, constructing in the hazardous sites and protecting the fertile lands

References

Aysan, M., Demir, O., Altan, Z., and Dokmeci, V. (1997). "Industrial decentralization in Istanbul and its impact on transport." *J. Urban Plann. Dev.*, 123(3), 40–58.

Bahr, H. P. (2001). *Image segmentation for change detection in urban environments*, Taylor and Francis, London, 96–113.

Chen, K. (2002). "An approach to linking remotely sensed data and a real census data." *Int. J. Remote Sens.*, 23, 37–48.

Cheng-Ming, Y., Torii, K., Mori, Y., and Shu-Shr, Y. (2003). "Trend of urbanization in the suburbs of a large city in south Taiwan." *Proc., 23rd Asian Conf. on R.S.*, Kathmandu, Nepal, 1–6, ⟨http://www.gisdevelopment.net/aars/acrs/2002/urb/234.pdf⟩ (Jan. 14, 2005).

Clark, D., and Jantz, S. C. (1995). "Growth management techniques in the city of Carlsbad." *J. Urban Plann. Dev.*, 121(1), 11–18.

Cowen, D. J., and Jensen, J. R. (1998). "Extraction and modeling of urban attributes using remote sensing technology, people and pixels." *Linking remote sensing and social science*, D. Liverman, E. F. Moran, R. R. Rindfuss, and P. C. Stern, ed., National Academy Press, Washington, D.C., 164–188.

Department of Statistics—Jordan. (2002). "Jordan in figures—2002." Department of Statistics, Issue 4, Amman, Jordan, 4–10.

Donnay, J. P., Barnsley, M. J., and Longley, P. A. (2001). *Remote sensing and urban analysis*, Taylor and Francis, London, 3–18.

Jensen, J. R. (1996). *Introductory digital image processing: A remote sensing perspective*, Prentice Hall Inc., Englewood Cliffs, N.J., 197–256.

Kaya, S., and Curran, P. J. (2003). "Monitoring urban growth on the European side of the Istanbul metropolitan area." *Proc., RSPSoc 2003: Scales and Dynamics in Observing the Environment*. Nottingham, U.K., Remote Sensing and Photogrammetry Society, 1–9, ⟨http://eprints.soton.ac.uk/14848/⟩ (Dec. 18, 2004).

Laveau, N. (1996). *Le guide de la Jordanie*, 1st Ed., Editions La Manufacture, Lyon, France, 102–114.

Leao, S., Bishop, I., and Evans, D. (2004). "Simulation urban growth in a developing nation's region using a cellular automata—based model." *J. Urban Plann. Dev.*, 130(3), 145–158.

Lo, C. P., and Yang, X. (2002). "Drivers of land use/land-cover changes and dynamic modeling for the Atlanta, Georgia Metropolitan Area." *Photogramm. Eng. Remote Sens.*, 68(10), 1073–1082.

Longley, P. A. (2002). "Geographical information systems: Will develop-

ments in urban remote sensing and GIS lead to 'better' urban geography?" *Progress in Human Geography*, 26(2), 231–239.
Madhavan, B. B., Kubo, S., Kurisaki, N., and Sivakumar, N. (2001). "Appraising the anatomy and spatial growth of the Bangkok metropolitan area using a vegetation-impervious-soil model through remote sensing." *Int. J. Remote Sens.*, 22, 789–806.
Ridd, K. M., and Liu, J. (1998). "A comparison of four algorithms for change detection in an urban environment." *Remote Sens. Environ.*, 63, 95–100.
Sanchez, T. (2004). "Land use and growth impacts from highway capacity increases." *J. Urban Plann. Dev.*, 130(2), 75–82.
Souleyrette, R. R., and Anderson, M. D. (1998). "Developing small area network planning models using desktop GIS." *J. Urban Plann. Dev.*, 124(2), 55–71.
Tachizuka, S., Hung, T., Ochi, S., and Yasuoka, Y. (2003). "Monitoring of long-term urban expansion by the use of Remote Sensing images from different sensors." *Proc., 23rd Asian Conf. on R.S.*, Kathmandu, Nepal, 1–7. ⟨http://www.gisdevelopment.net/aars/acrs/2002/urb/213.pdf⟩ (Jan. 14, 2005).
Tapiador, F., and Casanova, J. L. (2003). "Land cover mapping methodology using remote sensing for the regional planning directives in Segovia, Spain." *Landsc. Urban Plann.*, 62, 103–115.
Wright, D. W. (1996). "Infrastructure planning and sustainable development." *J. Urban Plann. Dev.*, 122(4), 111–117.
Yang, X. (2002). "Satellite monitoring of urban spatial growth in the Atlanta metropolitan area." *Photogramm. Eng. Remote Sens.*, 68, 725–734.