Spatial Changes in Urban Landuse and Ecosystems Arising due to Subway Network

A Case Study in Sapporo, Japan using Geographical Information Systems

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Rapid population growth and migration to the cities exert pressure on the urban land units as well as its encircling ecosystem land units. Since Japan has relatively less habitable area with mostly population is concentrated in major urban centers, urban and agricultural activities have to be conducted in a very small densely populated districts. In this study we have attempted to study the landuse changes caused due to the emergence of subway network within Sapporo city during the eighties as a part of urbanization process. Present study focusses along the 500 meters buffer zone of subway network within Sapporo city. ARC/INFO GIS was used for digitization and other data entry operations along the buffer zone. In some cases, some more areas in outer polygons were also considered in order to maintain the continuity along the buffer boundaries like river, marshes. The landuse maps of 1977 and 1993 prepared by Geographical Survey Institute, Japan were used as base thematic layers for analysis. Detailed urban landuses such as residential, commercial areas, industrial areas, Recreational areas etc. and also other ecosystem units such as agricultural/fallow lands, orchards and marshy areas were re-grouped and digitized. Then landuses were integrated to derive landuse changes. Using the INFO/TABLES database integrator within the ARC/INFO GIS environment, landuse statistics tables were generated for landuses in 1977 and 1993. Based on the change trends, break-up details for landuse conversion to commercial areas in 1993 were analysed and details are tabulated. The major findings are the conversion of agricultural fallow/marshy areas into other urban uses, including the conversion of marshy canal into an expressway.

Key words: Urban land use-Urban Ecosystem-Subways-GIS and Spatial Analysis

1. Introduction

Urban settlements grew faster in order to accommodate the increasing population concentration. This results in the increase of demand for optimum utilization of land-units within metropolitan core as well as along peripheral suburban areas. Thus the overall landuse dynamics and the resultant competition within the land units in any urban environment largely depends on the demand and functional nature of cities. In general, it is observed that the transport network has direct influence on the urban landuse changes or sprawling trends. While the urban sprawling in the peripheral city zones result in the loss of land units under agricultural areas, marshes, wetland, rivers, lakes etc., landuse dynamics within urban core also undergoes conversion of open spaces,

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residential areas etc. In order to derive appropriate planning options, computerized data bases consisting landuses and other relevant socio-economic data shall be of great use to the planners and urban administrators. Essentially these mega-statistical databases, if combined with the advantages of spatial referencing shall be a great source for resources planning and management. Most of the industrialized developed nations, including Japan has better and updated information on land and its use, especially urban landuse in digital format with macro spatial dimensions. These do not satisfy the need for unit-parcel based analysis in the city environment. So even today, there is obvious and precious need of analog data available in the form of landuse/thematic maps which is derived from specific ground surveys or aerial surveys. In this context, the modern efficient tool of *Geographic Information Systems (GIS)* which has the capability to integrate and manipulate the multi-dimensional (micro-macro) databases and perform spatial analysis and modeling of future scenarios of spatial landuse dynamics and its associated environmental planning options, emerge as a viable state-of-the-art technological alternative as *Spatial Decision Support Systems (SDSS)* towards deriving better urban ecosystem conservation and planning.

2. Urban Ecosystems : A Profile

Land use is a term from agricultural economics, originally referring to a piece of ground and the economic use to which it was put—pasture, cropland or quarry. This was elaborated in urban planning and is used in several ways in contemporary literature in the eighties (Chapin, 1976). In a general sense 'urban landuse' means the spatial distribution or geographical pattern of city functions—residential area, industry, commercial areas, retail business, and the spaces set aside for governmental, institutional and leisure functions. The definition of an 'urban area/agglomeration' is derived from population size, density or occupational structure and as well as functional nature/definition of towns and cities which vary worldwide. While the minimum population for classifying a settlement as 'urban' varies from even few hundreds onwards, based upon these the whole process of urbanization/urbanism and urban sprawling trends are enumerated countrywide. While the human interaction with the natural environment results in the *ecosystem concept*, the impact of urbanization leads to the alterations to the environment. While the growth of urban population results in the environmental impact of human beings with their surrounding natural environment, the concept of ecological change derives from ancient origins. Over 2,000 years ago, Plato recorded negative effects of forest removal on the environment of Greece, suggesting that this led to soil erosion, lowering of water tables and probably regeneration among native plant species (Watts, 1971). The importance of *ecosystem concept* is more emphasized on the overriding necessity for understanding the large circle of nature in which man, his domestic animals and his energy-demanding machines are interdependent completely, along with other essential components that maintain the total life support system. The *New Encyclopaedia Britannica* describes the "ecosystem as a contraction of ecological system thorough which the term of 'ecology' is derived from the Greek word meaning 'house'. There is no size limit implied in the definition of an ecosystem. It may be a square kilometer of jungle, a square meter of desert, a pond, a woodlot, a city, a farm or a closed container of small organisms (e.g., an aquarium or a vivarium)". Thus **urban ecosystems** could be defined as "*the physical entity which encompasses the core city, its suburbs, and the transitional agricultural areas consisting mixed spatial units of built-up environment, open-spaces (non-built within the settlement area), natural ecosystem units like parks, rivers, wetlands, forests and agricultural lands etc.*"

3. GIS Techniques in Urban Spatial Analysis

Urban analysis and monitoring through computerized data bases of spatial analysis has been attempted as early as in the seventies. Since urban centers serve as critical articulate points within the region, monitoring with the third dimension, time, through geographic matrices to perform

regional analysis such as regional inter-dependence, spatial interaction was attempted by Berry (1968) in the seventies. Technological innovations in computer technology, its hardware (plotter, scanners etc.) and software's like Data Base Management Systems (DBMS), Computer Graphics (CG) and Structured Query Languages (SQLs), Earth observation Technologies (Remote Sensing), and the Graphical User Interfaces (GUIs), the modern tool of Geographical Information Systems (GIS) or sometime referred as Spatial/Land Information Systems (LIS) has emerged as an effective tool in urban planning and environmental monitoring. Recent demonstration of potentiality of GIS applications in urban planning and administration includes attempts by Sommers (1987), Yeh (1990), Openshaw (1990). Many studies were attempted focusing the utility of using various GIS packages for urban planning related research in Japan by Kubo (1984) Nakamura et al (1993). Studies on urban environmental landuse change was carried out in western suburbs of Tokyo using the "Japanese standard mesh data" of 1×1 km by Makita and Kakamura (1989). The study of urban landuse change in Sapporo was attempted using the topographical maps of 1935, 1970 and 1987, where the landuse classes were derived by coloring the major landuses into 500 meters of areal mesh and 100 meters of mesh in the CBD area (Terao and Iwasaki, 1989).

4. Scenario of Land Use Mapping and Changes in Japan :

Updated landuse maps, prepared using the satellite/aerial data as well as detailed ground surveys are regularly published by Geographical Survey Institute, the organization responsible for publication of topographical, thematic and other geographical maps. Thematic maps for landuse, land capability etc., especially for major metropolitan cities like Tokyo, Osaka, Nagoya, Sendai and Sapporo also being published and updated periodically on 1 : 25,000 scale or more. Japan has established standard areal mesh dimensions, generally corresponding to the topographical map series of 1 : 200,000, 1 : 25,000 and 1 : 10,000, thus resulted in the three-tier hierarchical mesh types. viz.,

1. First Order (1 : 200,000)	80×80 km's
2. Second Order (1 : 25,000)	10×10 km's
3. Third Order (1 : 10,000)	1×1 km's

Various thematic series are digital data also corresponds to these standard areal mesh system established as early as in 1984. These are viz., DNLI (Digital National Land Information), AMSD (Agricultural Census Mesh Data) and NEBI (National Environmental Basic Information). Each of these has their own thematic priority (like agriculture, forest, urban) in the details of levels of classification (Bito, 1989) as summarized below ;

Type	Mesh type/Landuse categories	Priority themes-classifications
DNLI	Third Order/15	Dominant landuse 1/10of third order
ASMD	Third Order/22	Crops (Cultivate 7, Harvested : 12)
NEBI	Third Order/766	Forests/Grasslands etc.

4.1 Urban Sprawl and its impact on ecosystems

As early as in 1950-70 period, Glickmann (1976) observed in his study of Regional Economic Clusters (REC's) within Japan, Yokohama and Sapporo cities had registered more than 100 percent population change other than the conurbation's of Tokyo, Osaka and Nagoya. Rapid urbanization caused disordered development of farmland and forest land, resulting frequent in urban sprawl, the formation of uncontrolled urban areas. Development of farmland and forests on the periphery of cities had not been controlled in the development of housing, because the authorities could not cope

with the rapid expansion of urban areas (Matsumoto, 1986). The GIS-ECIA (Environmental change and Industrial Activities) study where plant distribution maps were overlaid, on urban and green cover change in 1×1 km grid to assess short term environmental change (Ota et al, 1989), Changes in the green cover in western suburbs of Tokyo (Makita and Nakamura, 1989) as well as general pattern of landuse changes (Jitsu, 1980 ; Himiyama and Jitsu, 1988). The earlier studies on Sapporo which focussed on growth and landuse (Jitsu, 1977 ; Jitsu 1989) and landuse change (Teraya and Iwasaki, 1989) created from topographical maps and other data, also revealed the increased number of meshes of roads and also the development/urbanization process in Eastern and Northern lowlands of the city.

5. Objectives, Study Area and Data Used

Broad objectives have been to asses and find out the changes within the urban landuses and also on its ecosystems due to the emergence of subway network in Sapporo city, which is the fifth largest in Japan and has a population of 1,693,371 (as on 1991) and also constitutes 30% of Hokkaido's total population of 5,677,437. Present study is limited to the buffer zone of 500 meters (in some cases more areas were considered to maintain continuity) of the subway network (Refer Fig. 1), which was gradually developed in various phases from seventies during the preparations for Winter Olympics in Sapporo. The landuse maps, prepared by the Geographical Survey Institute, were used as mapsheet wise (1 map in 1993 and 5 maps in 1977). The detailed third-order Urban landuses viz., low residential (single dwelling units), medium (4 storeyed buildings), high (more than 4 storeyed buildings), public, industrial, educational etc., and other ecosystems lipe parks forests, wetlands, marshes, agricultural fallow etc., were re-coded and digitized. The outer zones of contiguous polygons were also considered to maintain the continuity of the landuse/ecosystem units classes. The accuracy of representation of land unit classes are corresponding to the classes depicted in the landuse maps.

Fig. 1 Index map of subways within Sapporo

6. Methodology using ARC/INFO GIS

The methodology adopted in this study includes the conversion of landuse maps into the mylar material (to avoid shrinkage and expansion due to climate) to enable easier and consistent data entry (digitization), storing of landuse data as layers, digitization of subway network, overlay and other spatial analysis operations which has resulted in the spatial statistics of landuses and associated units of ecosystems. In some cases landuse units smaller than 3 mm×3 mm on the original maps could not be digitized due to constraints of time. In order to derive the spatial data sets for landuse change analysis, GIS operations performed using ARC/INFO GIS in the SUN workstation and associated procedures for spatial query and analysis are ;

- a) Digitization of landuse maps on 1 : 25,000 of Geographical Survey Institute
- b) Digitization of Subway network c) Creation of Buffer zone of subways
- d) masking of buffer zone in landuse e) Overlay of themes (Landuse, 1977 and 1993)
- f) Derivation of landuse statistics of Landuse change/landuse conversions and analysis

7. Data base design, Integration and Spatial Analysis

The buffer zone of 500 meters (due to consideration of walking distance) along the subways network was generated and the smaller island polygons within the buffer zone were eliminated. This buffer coverage was used as a clip layer to limit the dimensions of inputs of landuse layer. The outer/boundary polygons were also extended beyond this clip buffer, so as to enable for

Layer	Feature	Attribute relations	GIS Functionality
Boundary	line	Urbanized Area	Buffer Generation
Subways	line	Subways network	Buffer Generation
landuse-1	polygon	Landuse-1977	Overlay
landuse-2	polygon	Landuse-1993	Overlay
Landuse-ch	composite	Landuse change	Derived layer

Table 1 Urban Land use and urban ecosystem land units (Re-grouped from Landuse maps of GSI, Japan)

Urban Landuses		Other land/Ecosystem units
1. Residential-Low*		15. Lakes
2. Residential-Medium & High*		16. Rivers (Channelised)
3. Commercial		17. Miver Banks
4. Industrial		18. Rivers
5. Public Uses		19. Expressways
6. Educational (Schools/Univ)		20. Forests
7. Welfare Centres		21. Fallow/Vegetable Farms
8. Parks		22. Orchards/Grasslands
9. Recreational/Sports		23. Marshes
10. Ware Houses	11. Transport Terminals	24. Agriculture
12. Military zones	13. Roads 14. Railway lines	25. Open Spaces

*Low : Single/Double Storied Medium : 4 Floors High : having more than 4 floors

continuity for larger landunits like river for generation of summary statistics and spatial queries. These extended landuses includes rivers, larger outer polygons etc., where micro-divisions could not be studied due to the constraints of time. Theme layers were digitized as mapsheet wise (1map in 1993 and 5 maps in 1977) and mosaic was prepared with appropriate map projection transformations. The data structures were with reference to its GIS functionality for overlay/spatial analysis as listed before Table 1 and the resultant landuses changes were compared and analysed.

8. Results and Discussion

Based on the GIS techniques, as discussed in methodology, integrated theme layer of landuse change derived from the overlay events operations revealed many interesting results two theme data sets of landuse (1977) and landuse (1993) were compared with the landuse statistics (Refer Table 2A). It is observed that there are phenomenal increase of commercial landuses (Refer Table 2B). The table shows the pattern of landuse conversions within urban landuses. The major finding of the study includes the conversion of entire marshes into urban uses, including an expressway, which was observed as marshy canal in 1977 (Refer Table 2C).

Table 2A Landuse statistics of subway network guffer zone of 500 meters plus (all figures in 10000'sq.mts) Urban Landuses (1-14) and Ecosystem land units (15-25)

Year Landuse	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1977	322	93	90	18	18	35	0	44	5	15	34	13	46	1
1993	320	88	120	10	27	41	1	53	11	26	19	13	50	6
Year Landuse	15	16	17	18	19	20	21	22	23	24	25			
1977	2	2	13	20	0	22	22	31	11	0	5			
1993	2	4	13	18	3	13	20	1	1	0	2			

Table 2B Landuse conversions (1977) to Commercial landuse (1993)

Lamduses (From)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	13.19	3.7	5.7	1.31	1.59	0.26	0.0	0.84	0.03	2.39	3.17	0.0	0.0	0.0
Lamduses (From)	15	16	17	18	19	20	21	22	23	24	25			
	0	0	0	0	0	0	1.5	0	.87	0	.43			

Table 2C Landuse conversions of Marshy areas (1977) to other uses (1993)

Lamduses (From)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	2.21	0.72	0.87	0.13	0.09	0.17	0.0	0.81	0.77	0.30	0.61	0.0	0.78	0.0
Lamduses (From)	15	16	17	18	19	20	21	22	23	24	25			
	0.0	0.0	0.0	0.0	3.06	0.0	0.44	0.0	0.0	0.0	0.04			

(Refer to Table No. 1 for the description of landuses/ecosystem units)

8.1 Landuse conversions : 1977 vs. 1993

The main landuse conversions within the urban landuses are the increase of commercial landuse along the road network (where subway network runs beneath) as well as increase in the Recreational/Sports landuse areas buffering the subway networks. Detailed break-up of summary statistics (Refer Table 2A) shows that there is a remarkable increase of area of artificial parks. It is also

observed that almost entire Agricultural fallow/Marsh areas were converted into many urban landuses. These can be well noticed near the eastern terminal node of TOZAI subway line (Kotoni-Shin Sapporo) ie., Shin-Sapporo (Refer Fig. 1) and the northern terminal nodes of Asabu (NANBO-KU line) and Sakae-machi (TOZAI line), where large tracts of agricultural fallow/marshes were converted into residential and other uses.

8.2 Conversions to Commercial uses

Landuse conversions from 1977 to 1993 (Table 2B) shows an increase of area around 30% of commercial landuses which were converted from the other urban landuses within and mainly from residential areas. (40% from the low-residential and around 10% from the high-rise residential). There is also a marginal conversions from forests, marshes and open spaces which is also tabulated in Table 2C.

8.3 Ecosystems conversions to urban uses

The Significant findings include the large-scale conversions of orchards/vegetable farms, marshes which has occurred mainly near the subway terminals of Asabu, Sakae-Machi and Shin-Sapporo (Fig.1). Major ecosystem changes observed are loss of (a) more than 95% of the orchards/vegetable farms (b) almost 90% of marshes (c) more than 60% of the open spaces and (d) around 30% forested areas (Fig. 2). One of the important and notable change of landuse is the conversion/use of marshy canal into an expressway. This can be located just south of the Asabu-Sakaemachi Terminals (an elongated east-west linear loop) and also near Shin-Sapporo (a broad linear loop running longitudinally near the north-western direction of the terminus). Other landuse changes/conversions include agricultural fallow/open spaces/marshes into residential (both low & high rise), recreational uses and other uses as well as increase of area under parks and roads etc. (Refer Table 2C and also in Fig 2).

9. Conclusion and Recommendations

The landuse change analysis brings out the current trends of conversions within urban landuses

Fig. 2 Landuse changes along the subway network (Buffer area of 500 meters plus)

(residential uses to commercial uses, increase of areas under parks) as well as the nature of transformation undergoing in conversions of natural ecosystems within or surrounding the built-up environment (wetlands to urban uses, agro-ecosystem units of both cropped area and agricultural fallow). Thus the study indicates the changing profile of built-up environment of seventies and eighties and also enables to foresee the characteristics the future urban environment. Thus the "ecofriendly urban settlements" seems to be a hard reality of future unless otherwise planning priorities focus attention to conserve natural ecosystems within the urban areas or zones or work out alternate strategies for increasing green-spaces within cities. This study demonstrates the essential utility of GIS techniques in urban spatial analysis, since its operating environment has the capabilities and allows to collate multitudes of environmental data. Thus GIS based analysis if supplemented with the regular tools like satellite/air photographs shall be an essential and effective tool for better urban spatial analysis, monitoring, planning for efficient urban management strategies.

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