

Analysis of Land Use and Land Cover Changes, and Their Ecological Implications in Wuhan, China

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Received: December 31, 2010 Accepted: January 21, 2011 doi:10.5539/jgg.v3n1p104

Abstract

This study investigated land use changes, and their ecological effects in Wuhan (1987-2005). Remote Sensing techniques extracted land use data, whilst the spatial analyst software, Fragstats quantified ecological metrics at both landscape and class levels. The results showed increased urban and agricultural land uses (1987-2005); with urban land increasing more than 250 percent. This was largely attributed to: i) state favors accorded to it as the economic, industrial, scientific and cultural hub of central China; and ii) socioeconomic reforms. This is also shown by the positive correlation between urban growth and socioeconomic variables in the order GDP > per capita GDP > per capita annual net urban income. Ecological metrics at landscape level (example, number of patches, Shannon and Simpson's diversity Indices) showed that fragmentation strengthened (1987-1994), but weakened (1994-2005). Socioeconomic factors and ecological metrics indeed explained land use changes and their effects in Wuhan.

Keywords: Land use and land cover changes, Ecological metrics, Remote sensing, Ecological implications, Fragstats, Fragmentation, Socioeconomic variables

1. Introduction

Land use in China accelerated after the open-door policy in 1978. The social and economic reforms that followed have resulted in increased economic growth and urbanization throughout the country. Urbanization rose from 17 percent in 1978 to 41 percent in 2006 (State Statistical Bureau, various years). One urban area that has been singled out for this research is Wuhan. Like most major cities in China, its population and economy has grown over the years. Unfortunately, the natural landscape, especially its arable land has been reduced significantly through various land use land cover changes. It is generally important for accurate and timely land use land cover change data to be available to policy makers, including governments at local, regional and national scales, and researchers, on the scale of such changes on the ecological system. Previous research (Chibamba, 2009; Cheng and Masser, 2002; Cheng, 2003; Yingui, 2002) related land use land cover change to socioeconomic factors such as direct foreign investment, gross domestic product, and spatial policy. This

research has taken a step further by using landscape ecological metrics to explain the effects of land use change on its natural landscape. It therefore attempts to address two main objectives: i) to analyze land use land cover changes in the study area between 1987 and 2005; ii) to analyze the relationship (if any) between urban expansion and socioeconomic variables; and iii) to analyze the ecological effects of such land use land cover changes on the natural landscape.

Following the Earth Summit in Rio de Janeiro in 1992, many studies have concentrated on environmental issues which have influenced the natural systems greatly (Benjaminson, 2001; Glickson, 2000). Dramatic changes on the natural landscape brought concern to scientists as well as policy makers. These changes are the result of past (Burgi *et al*, 2002) and present socio-economic factors (Buchecker *et al*, 2003). This makes the integration of man's activities into landscape studies most relevant (Wu and Hobbs, 2002).

Land use/ land cover change is one of those major challenges that affect the natural landscape. It is one of the main driving forces of global environmental change, and central to the sustainable development debate (Lambin *et al*, 2000). The causes and consequences of land use change on the physical and social environment have been a gray area for research (Veldkamp and Verburg, 2004). These include its impact on water quality, land and air resources, ecosystem processes and function, and climate (Lambin *et al*, 2000); biodiversity (Liu and Ashton, 1998), soil degradation (Trimble and Crosson, 2000) and the ability of natural systems to support life (Vitousek *et al*, 1997).

A number of international research projects, example, The International Geosphere-Biosphere Project (1988) and The Land Use land Cover Change program (Messerli, 1997) were initiated in a bid to construct an updated and accurate database concerning observed changes, their meaning, pace, magnitude and driving forces behind such changes (Mather, 1999). Quantifying changes in the landscape is very important for an understanding of the spatial and structural variability in land use and their associated ecological effects (Turner, 2005). The method and scope used for such land use change study depends on the ecological process under study (Wiens, 1989; Allen and Hoekstra, 1992). Often times, an interdisciplinary approach, integrating the social and natural sciences have been argued (Lambin *et al*, 1999; Briassoulis, 1999) and in many research projects (e.g. Van der Veen and Otter, 2001). The use of regression equations and models has been extensive and valuable. For example, Wu *et al* (2006) used land maximization regression and Markov chain models to monitor and predict land use change; Sonis *et al* used matrix land-use analysis; Nagashima *et al* (2002) used discriminant analysis to understand the driving forces of land use change; and Yeh and Li (2002) used neural networks and cellular automata for land use planning.

Remote Sensing and Geographical Information Systems (GIS) (Jat *et al*, 2008; Wu *et al*, 2006; Li *et al*, 2005; Yuan *et al*, 2005) approaches have added a new dimension to the understanding of these changes, not least the urban landscape. Remote sensing techniques have been useful in the quantification of land use changes, especially from arable land to impermeable surfaces (Milesi *et al*, 2003). They monitor the spatio-temporal and dynamic changes in land use/land cover at regular intervals, using multi-temporal remote sensing satellite data such as Landsat TM images. These changes are of significance in the field of environmental change (Turner, 2003; Lambin *et al*, 2001). Geographical information system provides the platform on which data on such images are stored, processed and analyzed for decision making.

In recent years, landscape ecology introduced the use of landscape ecological indices or metrics to quantitatively assess landscape fragmentation, especially forest ecosystems. However, their use has in recent times become a trend in urban landscape change studies (Palmert, 2004; Leitao and Ahern, 2002; Sepp, 2006; Aranzabal *et al*, 2008; Cushman, 2008). Their quantification has helped in understanding the spatio-temporal dimensional changes of urban growth occurring on natural landscape (Sudhira *et al*, 2004). This has been shown in previous studies (Medley *et al*, 1995; McDonnell and Pickett, 1990; Costanza *et al* 1997; Matthews, 2006; Licitignola *et al*, 2007; Wang and Zhang,; Kong and Nakagoshi, 2006; Guo, 2001) to be more effective in explaining the interrelationship between and among land use land cover changes, the drivers of such changes, and effects of such changes on urban ecological landscape. It is this interrelationship that this research has tried to analyze and understand. We have therefore tested the effectiveness of remote sensing and GIS techniques, and Fragstats (version 3.3) (McGarigal and Marks, 1994) software in this research. Remote sensing and GIS techniques were used to obtain the biophysical and man-made information from three Landsat TM images. The spatial analyst software, Fragstats 3.3 which provides a very comprehensive set of spatial statistics and descriptive metrics of pattern at the patch, class, and landscape levels (Haines-Young & Chopping, 1996), was then used to quantify landscape metrics at both landscape and class levels.

2. Materials and methods

2.1 Site description

Wuhan is the provincial seat of Hubei Province, and the largest city in central China (Fig.1). Found at the confluence of the Yangtze and Hanshui Rivers, east of Jiangnan plains, it is a conglomeration of three towns: Wuchang, Hanyang and Hankou, all three separated by the rivers. With an area extent of 8,467.11 km² (3,269.2 sq mi), its population has risen from 6.24 million in 1987 to 9.1 million in 2007 (WSYB, 2008). The economic and social reforms in late 1970s have made it emerged as the biggest industrial and commercial city in middle China, with a complete industrial system in respect of iron/steel, automobile, optical electronics, chemical making, metallurgy, textile, ship-building, manufacturing and pharmaceuticals. This is reflected in the growth of its GDP from 12.46 billion in 1987 to 223.8 billion in 2005. These growths have caused tremendous changes in its land use and land cover between 1987 and 2005 (the period under investigation), with inevitable ecological consequences. The main thrust of this paper is therefore to analyze the ecological effects of its land use land cover dynamics, giving the socioeconomic and population changes that have taken place between 1987 and 2005.

2.2 Methods

2.2.1 Remote sensing

2.2.1.1 Pre-processing image

The standard image processing techniques of extraction, layer stacking, geometric correction/ georeferencing and change detection were performed on the three Landsat TM images (Table 1) obtained on different dates. They served as the primary data for this study. The rationale for using these dates stem from the fact that it was within these periods that major decisions such as migration policy (from rural to urban), Wuhan's special economic preference, and policy on protection of agricultural land, were made. Obtaining near anniversary images would have been preferable but this proved impossible for us. The 1987 and 2005 images were geometrically corrected to a common Universal Transverse Mercator coordinate system, Datum WGS 1984; Zone 49, based on a 1:50,000 topographic map scale, the 1994 image used as the MASTER image. The resultant Root Mean-Squared (RMS) of the georeferenced process, are presented in Table 1. These were good as rectification of an image should have a root mean square error of ≤ 0.5 (Jensen, 2007). Resampling, using the nearest neighbor algorithm to keep the original brightness values of the pixels unchanged was then done on the images.

2.2.1.2 Image classification

The satellite images were classified into land use classes. Anderson *et al* (1976) and Chinese Academy of Science's land use/ land cover Classification Systems were modified to classify the images into four land use classes: built-up (impervious layers such as residential and commercial services, office blocks, educational centres, hospitals, manufacturing industries, motor roads, rails etc); water (Rivers, lakes, ponds, lagoons, dams, marsh wetlands); agriculture (all cultivated areas such as farmlands, crop fields including vegetable gardens, plantations, fallow plots) and forest (protective forests, timber forest, economic forest, firewood forest and forests of special use). Using ERDAS IMAGINE 9.2 software, the supervised classification system, using maximum likelihood algorithm was performed on the images. Goggle earth, and data collected during field trips (training sites/ground control points using GPS) served as reference data. The accuracy of the images was checked and the overall accuracy and kappa indices (Table 1) were deemed satisfactory for land use change analysis.

2.2.2 Metrics selection

The need for a quantitative description of ecological heterogeneity has long been the objective of ecology (Pielou, 1977). The introduction of landscape metrics has helped in explaining the variability (over time) of landscape structure and composition. Selecting metrics for a given study involves a number of considerations. Firstly, because a few primary measurements can be made from patches (patch type, area, edge, and neighbour type), most metrics correlate among themselves (McGarigal *et al*, 2002). Secondly, the objectives of study, spatial characteristics of the system and ecological processes under investigation determine which metrics to use (Gustafson, 1998). Taking these into consideration, seven (7) landscape level metrics and five (5) class level metrics were chosen to quantify and examine spatio-temporal changes in Wuhan's landscape composition and configuration between 1987 and 2005. Complete descriptions of these metrics and equations for their calculation are provided in McGarigal *et al* (2002) and McGarigal and Marks (1995).

2.2.3 Calculating metrics in Fragstats

For Fragstats to compute landscape metrics, reclassify and modelling processes were first carried out on the images in ERDAS Imagine 9.2 software. The resulting images were stored as signed-8 bit files. The raster version of

Fragstats 3.3 was used in this study. The Fragstats itself was embedded into ArcGIS 9.2 software for it to be enabled. The following metrics were quantified:

2.2.3.1 Landscape level metrics

(a) Number of patches (*NP*): Is the number of patches of the corresponding patch type (class). Higher *NumP* indicates greater fragmentation.

$$NP = n_i$$

Where n_i = number of patches in the landscape of patch type (class) i .

(b) Patch density (*PD*): equals the number of patches of the corresponding patch type divided by total landscape area (m^2).

$$PD = \frac{n_i}{A}(10,000)(100)$$

Where n_i = number of patches in the landscape of patch type (class) i .

A = total landscape area (m^2).

(c) Largest Patch Index (*LPI*): the area of the largest patch in each class (in hectares).

$$LPI = \frac{\max_{j=1}^n(a_{ij})}{A}(100)$$

Where a_{ij} = area (m^2) of patch ij . A = total landscape area (m^2).

(d) Shannon’s Diversity index (*SHDI*): equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion

$$SHDI = -\sum_{i=1}^m (P_i \ln P_i)$$

Where P_i = proportion of the landscape occupied by patch type (class) i .

(e) Simpson’s diversity Index equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared. Note, P_i is based on total landscape area (A) excluding any internal background present.

$$SIDI = 1 - \sum_{i=1}^m P_i^2$$

Where P_i = proportion of the landscape occupied by patch type (class) i .

(f) Contagion index (*CONT*): equals minus the sum of the proportional abundance of each patch type multiplied by the proportion of adjacencies between cells of that patch type and another patch type, multiplied by the logarithm of the same quantity, summed over each unique adjacency type and each patch type; divided by 2 times the logarithm of the number of patch types; multiplied by 100 (to convert to a percentage).

$$CONTAG = \left\{ 1 + \frac{\sum_{i=1}^m \sum_{k=1}^m \left[(P_i) \left(\frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right) \right] \cdot \left[\ln(P_i) \left(\frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right) \right]}{2 \ln(m)} \right\} \times 100$$

Where P_i =proportion of the landscape occupied by patch type (class) i .

g_{ik} =number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method

m =number of patch types (classes) present in the landscape, including the landscape border if present.

(g) Fractal Dimension (mean)equals the sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2) for each patch in the landscape, divided by the number of patches.

$$FRAC = \frac{2 \ln(.25 p_{ij})}{\ln a_{ij}}$$

Where p_{ij} = perimeter (m) of patch ij .

a_{ij} = area (m^2) of patch ij .

2.2.3.2 Class level metrics

(a) Number of patches (*NP*): Is the number of patches of the corresponding patch type (class). Higher *NumP* indicates greater fragmentation

$$NP = n_i$$

Where n_i = number of patches in the landscape of patch type (class) i .

(b) Patch density (*PD*): equals the number of patches of the corresponding patch type divided by total landscape area (m^2)

$$PD = \frac{n_i}{A} (10,000)(100)$$

Where n_i = number of patches in the landscape of patch type (class) i .

A = total landscape area (m^2).

(c) Largest Patch Index (*LPI*): the area of the largest patch in each class (in hectares).

$$LPI = \frac{\max_{j=1}^n(a_{ij})}{A} (100)$$

Where a_{ij} = area (m^2) of patch ij .

A = total landscape area (m^2).

(d) Class percentage of landscape (*PLAND*). It equals the percentage of the landscape comprised of the corresponding class type

$$\%LAND = (CA / TLA) * 100.$$

(e) Patch cohesion index (*COH*) equals 1 minus the sum of patch perimeter (in terms of number of cell surfaces) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage.

$$COHESION = \left[1 - \frac{\sum_{j=1}^m p_{ij}}{\sum_{j=1}^m p_{ij} \sqrt{a_{ij}}} \right] \left[1 - \frac{1}{\sqrt{A}} \right]^{-1} \cdot (100)$$

Where p_{ij} = perimeter of patch ij in terms of number of cell surfaces.

a_{ij} = area of patch ij in terms of number of cells.

A = total number of cells in the landscape.

3. Results and analysis

3.1 Land use/ cover change

The areal change of Wuhan (between 1987 and 2005) was calculated from land use classes in the classified satellite images (Figs 2-4). For each land use category, change was calculated as the ratio of the difference in area between a succeeding year, $k+1$ and the initial year, k .

3.1.1 Land use change: 1987 to 1994

The results show that of the four land use classes, only forest class decreased between 1987 and 1994. This is understandable, as urban expansion and agriculture/farming occur at the expense of forest cover. There was nearly 30 percent (29.7 percent) increase in urban class from 4.8 percent in 1987 to 6.2 percent in 1994. This

could best be explained by the social and economic reforms initiated in 1978. The main feature of the reform was the move from a centrally-planned economy to one of limited market economy. The possibility for indigenes to own their businesses was guaranteed during this period. More importantly, economic reforms made direct foreign investment possible. Many foreign firms began streaming into Wuhan as early as the early 1980s. Its strategic position and recognition as the cradle of economic power in central China made it to be granted preferential policies in 1980 as a port for foreign trade by the State Council. This was followed by its designation in 1984 as the experimental city for economic reform. Land reforms in mid 1980s also made it possible for individuals and private institutions to lease land from the State (as all urban land under the reform belonged to the State). This accelerated massive private and cooperate urban construction of residential, estate as well as business houses. The positive imprint on the city's economy is seen in the nearly four fold dramatic growth of its GDP (Table 3) between 1987 and 1994. Such a growth in the economy, and hence infrastructure, served as pull factor for population from rural areas and other parts of the country (Guo-hui, 1990; Shen, 2002; Yin *et al*, 2005). Even though China had limited restrictions on the movement of migrant workers, this did not deter the growth of Wuhan's population during this period from 6.29 million in 1987 to 7 million in 1994. Much of this increase could be attributed to population drift from rural areas into the city. What could have been the motivation was the increase in annual net income in the main urban administrative areas, as against rural areas as given by correlation result (Table 3). Many people abandoned the countryside to seek employment in the city, where, annual savings were healthy. Growth in population (Kundu, 2001) had been identified as one factor that contributed greatly to the growth of Wuhan's economy and its areal expansion. This is because migrant workers (from rural areas) provided cheap labour in the construction industry, and hence spur the overall economy of the city.

The result for gross agricultural output observed in the agricultural sector (Table 3) explains the huge areal extent of land put under cultivation, which increased from 44.7 percent in 1987 to over half (55.3 percent) of the entire land area of Wuhan in 1994. This increase in agricultural cultivation supports the claim that population increase necessitates food production, a key requirement for man's survival. This further supports the view that economic growth and population increase (Table 3) accelerated land use in Wuhan during this period. The increases in urban and agricultural land saw a 20.5 percent disappearance of forest cover during this period.

3.1.2 Land use change: 1994 to 2005

The increase in urban class observed between 1987 and 1994 continued during this period. It increased more than 100 percent from 6.2 percent to 13.0 percent. This could be attributed to the major economic and social policies and decisions that were taken during this period. For example, it again bagged favor from the central government for preferential policies in 2000 to become the flagship to spur economic development to the western interior under the 'Great Western Development' campaign programme. The Wuhan Master Plan of 1996-2020 prepared between 1993 and 1996 also gained State approval in 1999. Before approval though, such development as the completion of the second highway bridge (upper reaches) over the Yangtze River took place in 1994. Together with the first bridge, this helped to create the first ring road of Wuhan. The ring remarkably improved overall accessibility by linking the three towns. The approval saw it receive huge funds for key infrastructural projects such as highways and city interchanges and the subway system. This period was generally characterized by mainly two key issues: changes in urban land use otherwise referred to as urban redevelopment and transformation of existing structures in the city, and economic restructuring of the primary, secondary and tertiary industries.

One of the great achievements of this was the establishment of three (3) state-level development areas: the Wuhan Economic and technology Development Zone, the Wujiashan Taiwan Businessman Investment Zone, and the Wuhan East lake High-Tech Development Zone. These comprised the major industrial bases that were reformed and/or developed out of the previous heavy manufacturing structure.

The decision to allow foreign investment saw an increase in foreign direct investment, from 913.43 million Yuan to 1,770.01 million Yuan, within the 11-year period. This surely promoted infrastructural development and economic growth. This also increased the GDP, by nearly five times (Table 3). The population too swelled by more than a million, because influx from rural areas and other provinces was encouraged by the relaxation of movement of migrant workers to the city (Lopez *et al*, 2006). Per capital annual urban savings increased nearly three times during this period.

An interesting scenario is observed when one compares percentage increase in urban land use to that of forest. As generally expected, urban land should increase at the expense of forest land. However, figures show that percent change in forest land during the 11-year period between 1994 and 2005 is minimal compared to that in the 7-year period between 1987 and 1994. This could be attributed to the policy on the protection of forests in

1985, and that of agricultural land that was enacted in 1994. Not only was afforestation encouraged, but forest conversion to other land uses was minimized. This was translated in the amount of land put under agricultural use. Percent increase in agricultural land during this 11-year period was smaller compared to that during the 7-year period. However, such a reduction in agricultural land use did not affect or reduce agricultural output, as seen in the output figures (Table 4). Increase in mechanization and hybrid technology could have done the trick, hence the observed increase in production.

The decrease in water could firstly be attributed to the division of some water bodies into smaller ones. And as Deng, (2005) pointed out, ecosystem of small lakes and marsh wetlands is fragile and tends to decline either naturally or artificially. Secondly, some water bodies found in urban settings were reclaimed to have urban structures. This practice may have reduced the burden on forested areas.

3.2 Relationship between urban expansion and socioeconomic variables

The relationship between urban expansion and socioeconomic variables was computed using Pearson's moment correlation coefficient, r . Table 3 presents results for Pearson product moment correlation coefficient, r between urban class and socioeconomic variables. The results showed that population, GDP, per capita GDP, gross agricultural production, per capita annual net rural income and per capita annual net urban income, were all strongly correlated with urban expansion in the order: GDP > per capita GDP > per capita annual net urban income > per capita annual net rural income > population > total population > gross agricultural production > FDI. These results indeed confirm a number of literatures on drivers of urban growth (as also explained in 3.1 above). Gross domestic product is an indicator of economic growth and which in itself encourages more land use. The healthy income in urban areas, but poor income in rural areas, provoked migration into the city, as indicated by the results. This was also shown by result for population. Increased migration from the rural areas, as a result of the relaxation of migration rules from rural to urban areas, gave rise to more residential structures to be built on Wuhan's fringes. Migrant workers were also identified as the unskilled workers in the construction industry.

3.3 Ecological implications of land use change

Landscape metrics have been helpful tools in understanding the ecological implications of human-activities on the landscape. In this study, the effects of land use change on the Wuhan landscape discussed above have been quantified using various metrics. Tables 4 and 5 present metrics calculated using Fragstats 3.3 at both the landscape and class levels.

3.3.1 Changes in landscape patterns

Table 4 shows that NP, PD, LPI and CONT increased between 1987 and 1994. But while NP and PD decreased in the next period, 1994-2005, LPI and CONT continued the increase during that period. Increase in NP between 1987 and 1994 indicates that fragmentation strengthened in Wuhan during this period, giving rise to a complex assemblage of isolated and diverse landscape patches and ecological processes. Numerous studies have shown disparity in biotic and abiotic factors within adjoining patch (Harper *et al.* 2005; Ries *et al.* 2004; Sisk *et al.* 2002). Associated with this are increased edge habitats and their effects (Couvillion, 2005), and greater loss of connectivity. This is because edges have the tendency to change the biological and physical conditions around patch boundaries and within adjacent patches (Ries *et al.* 2004; Harper *et al.* 2005). Fragmentation of a landscape itself is of greater concern, not least because it creates a natural imbalance in terms of size, shape and distribution of mosaic of patches found within the human dominant landscapes (Riitters *et al.*, 2000). The significant of this is that it influences the dynamics of species and material in the landscape (Forman, 1995), giving various ecosystems their unique structure and function. Characteristic of these ecosystems include distinct requirements nutrients, temperature, of climate, physiographic, soil, water, hydrology, air and potential natural communities.

The 12.81 percent increase in NP (335962 to 379009) from 1987 to 1994 could be attributed to increased human activities (that characterized this period), in response to the economic and social reforms made across the entire country. Much of such activities could be credited to increase in impervious layers across the landscape. This increase in impervious surfaces could be attributed to increase in population, and economic growth, which is reflected in its gross domestic product. These have been found to have positive relationship with increase in NP and hence increased landscape mosaics (Xu *et al.*, 2010).

The observed decrease in NP during 1994-2005 does not indicate a reduction in human activities on the landscape such as urban expansion or agricultural activities, but could rather be the result of similar isolated patches joined to one another. Such aggregation of similar patches takes place when corridors are eliminated between similar patches, their connectivity increased, and their edges joined together. In the case of human habited areas for example, isolated settlements and villages may have joined to each other. The city itself assumed a more compact or organized expansion, rather than characterized by dispersed or isolated patches.

Smaller parcels of agricultural fields may have aggregated together by either, clearing and putting under cultivation more forest patches existing between the plots, or such patches replaced by other land use classes such as through afforestation or urban expansion. This assertion could be attributed to the land laws, especially those on construction land and urban restructuring, and agricultural land, and forest law that came into effect during this period and which saw a more or less organized and planned land use practices in both rural and urban areas, hence the 26 percent drop in NP between 1994 and 2005.

In the case of Patch Density, the 1987-1994 period saw an increase in total area of patches across the landscape as a result of increase in NP. This decreased with the NP between 1994 and 2005, as similar patches aggregated together. Such a conclusion is also supported by results for Contagion Index (CONT) and Fractal Dimension Index (FDI). Contagion Index, which shows spatial aggregation of patches, increased throughout the study period. Such an increase, away from zero, indicates more aggregation (McGarigal and Marks, 1994). There was more aggregation of patches in Wuhan's landscape during the 11-year period (1994 to 2005), than the 7-year period (1987 to 1994), which were 12.0% (45.8 to 51.3) and 6.2% (45.8 to 43.1) respectively. Such aggregation takes place when similar isolated patches joined their edges to one another. This means existing corridors between similar patches were eliminated to enable their aggregation.

Unlike Contagion, a move towards zero shown by the decrease in Fractal Dimension Index from 1987 to 1994 and then 1994 to 2005, was an indication of regularity in the landscape. The fragmentation of Wuhan generally became weakened from 1987 to 2005. Though it had many patch types (in this case land use classes), the size of the different patches became larger in relation to the total number of patches in the landscape. This reduced the number of patches in the landscape, by the aggregation of similar patches together. Such aggregation reduces the number of varied ecosystem assemblages and hence diverse ecological processes in the landscape.

Results for Largest Patch Index (LPI) clearly go with this assertion. Between 1987 and 1994, LPI increased by 46.11 percent (10.2 to 14.9), and gigantically increased by nearly 120 percent from 1994 to 2005 (14.9 to 35.7). This clearly shows that some land use classes dominated the landscape throughout these periods. For example, whilst, urban structures might have expanded, more agricultural fields were also put under cultivation, especially between 1994 and 2005 (Table 4). Impervious layers, including buildings, tarmac roads, and rails expanded and increased not only in the urban setting, but rural communities. What is seen in the urban and rural areas today is a well organized and planned city, with massive infrastructural development. Agricultural lands and water bodies have also been managed, such that there are larger agricultural and water bodies on its landscape, instead of smaller patches dotted about. Dominant landscape patches means that the biotic and abiotic factors existing within them influence the general biotic and abiotic conditions in the landscape entirely. For example, whilst forest lands have dwindled, and that of urban areas increased, factors such as temperature, humidity, precipitation, moisture, soil condition, and exchange of material and energy are all altered greatly. This also gives rise to micro climate.

Shannon's Diversity and Simpson's Diversity Indices, which explain fragmentation, show similar trends, with both decreasing throughout the period under study. Shannon's Diversity Index decreased by 3.64 percent (1.1770 to 1.1341) between 1987 and 1994, and a further 5.41 percent (1.1341 to 0.727) between 1994 and 2005. Similarly, Simpson's Diversity Index, decreased from 6.41 percent (0.6584 to 0.6162), between 1987 and 1994, to 8.71 percent (0.6162 to 0.5625), between 1994 and 2005. With both of these indices going towards zero, the landscape showed more of aggregation than fragmentation between 1987 and 2005. Fragmentation and hence ecological processes in the landscape thus receded throughout the study period.

3.3.2 General trend at the class level

Table 5 gives results of metrics at the class level in Wuhan between 1987 and 2005. It shows that the percentage of urban and agricultural land use classes increased throughout the study period in the entire landscape. Whilst percentage of water increased between 1987 and 1994 but decreased from 1994 to 2005, that of forest decreased throughout. It further shows that urban and agricultural classes occupied nearly half (49.72%) of the landscape in 1987, increased to over 60 percent (61.50%) in 1994, and to three-quarters (75.47%) in 2005

The original natural status of the landscape was thus altered and/ or transformed significantly, possibly giving rise to new biotic life forms and abiotic factors, and relationships. For example, the intensity of fragmentation caused by agricultural class indicates replacement of a greater number of fauna life forms with a few selected ones like crops. The increased in urban land class, by nearly 300 percent from 1987(4.80%) to 2005(13.00%), indicates a greater loss of the natural ecosystem to infrastructural development. And both of these classes (urban and agriculture) oftentimes increase at the expense of forest class, little wonder it decreased by more than 200 percent, from 32.61 percent in 1987 to 13.44 percent in 2005. This shows that Wuhan's landscape underwent

massive loss of its natural habitat within an 18-year period. Such fragmentation processes, and possible loss of habitats, have greater effect on biodiversity conservation in landscapes undergoing anthropogenic land use changes. Not only are flora life forms destroyed, but animals are threatened with extinction, as they migrate to other places where conditions for their existence may be different from their previous natural habitats.

This concern and conclusion is also supported by results for LPI, which increased throughout the study period for both urban and agricultural land use classes, but decreased for those of forest and water. In the case of urban land use class, one could infer that elimination of other land use classes such as agricultural, and reduction of forest and water may have taken place between urban patches. This gave urban patches greater connectivity, and hence aggregating and consolidating, with more regular pattern observed in the entire landscape. Decrease index observed in forest class is quite expected, as they always dwindle when urban and agricultural classes increase. Decrease in forest and increase in urban areas generally result in increased temperature, heat, and sunshine.

The increase in agriculture patch index could be pictured as smaller agricultural fields aggregating together outside of urban areas into the more open countryside. Agricultural practice therefore became more organized and plots regular.

This assertion is observed in its NP and PD. They decreased throughout the study period. This were not however the case in the other land use classes, where alternate increase and decrease were observed from 1987 to 1994, and 1994 to 2005 respectively. With reference to agricultural class, one could infer that either some agricultural fields were eliminated and/or replaced with other land use classes, or smaller parcels of agricultural fields were aggregated together, hence reducing the number of patches. Fragmentation of the landscape through agriculture could be said to have weakened during the period under study. This cannot be said of the other classes. Whilst their results show that fragmentation intensified during the 1987-1994, leading to more spatial variability and complex landscape, there was a turn around between 1994 and 2005, when fragmentation appeared to have receded. Heterogeneity and irregularity in the landscape was thus reduced during the 1994-2005 period. Forest patches reduced, which, as expected, might have been due to the total obliteration of some forest patches to make way for more urban land use. Aggregation of isolated urban patches might have taken place.

Results for cohesion, which increased throughout the study period for urban class and agricultural class, but decreased for the other two classes, buttress this assertion. Greater connectivity was observed in urban, and agricultural patches as their edges joined together, and corridors between similar patches eliminated. Edge effects, and smaller ecosystems, that oftentimes produce variety of ecosystem structure and function, may have been reduced considerably. This scenario explains the success of the urban land use policy adopted in the mid-1990s, which saw the elimination or shifting out of all agricultural fields from among urban areas, towards the fringes. Agricultural fields therefore expanded from the urban fringes into more rural areas. At the same time, forested areas dwindled to a point that policy on afforestation and urban green were adopted in the late 1990s to save the total extinction of forest class in Wuhan. And within the city areas, land reclamation, involving little water bodies took place. This is shown by decrease in LPI in the water class.

4. Conclusion

This study analyzed land use, and its ecological implications in Wuhan between 1987 and 2005. Results showed that urban land use increased throughout the study period. Wuhan's strategic position in central China, and special privileges accorded by the central government accelerated economic growth that led to loss of its arable land. This too resulted in changes in its landscape structure and composition, as evidenced by variability (between the time periods) in the metrics. This study therefore proved the capability of remote sensing and GIS to quantify changes in natural resource over time. Fragstats too was able to describe the ecological effects of such changes. What is needed now is to have an inventory of fauna and flora life forms in a bid to establish the numerical effects of land use land cover changes in the landscape. Variations in climatic and edaphic factors are also a gray area for research.

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Table 1. Satellite images used

Date of Acquisition	Data Source	RMSE	Accuracy	kappa
26 th Sept 1987	Landsat 5 (TM)	0.17	88.1	0.87
29 th Sept 1994	Landsat 5 (TM)	MASTER	86.55	0.85
6 th May, 2005	Landsat 5 (TM)	0.18	89.06	0.86

These three satellite images were used in the classification process to obtain land use classes in Wuhan, between 1987 and 2005. Their accuracy assessment, root mean squared error and kappa index during the supervised classification processes are also presented.

Table 2. Land use and percent change in land use in Wuhan, 1987 to 2005

Land use Class	Land use 1987 (ha)	%	Land use 1994 (ha)	%	Change '87-'94 (ha)	% change '87-'94	Land use 2005 (ha)	%	Change '94-'05 (ha)	% change '94-'05
urban	41194.8	4.8	53438.	6.2	12244	29.7	111661951	13.0	58222.2	108.9
water	151780	17.7	154587	18.0	2807	1.9	86.	11.1	-59400.	-38.4
agric	385832	44.9	474287	55.3	88455	22.9	536566	62.5	62279	13.13
forest	280134	32.6	177556	20.5	-104378	-37.3	115469	13.4	-60287	-34.30

Table 3. Socioeconomic variables, and Pearson Product moment correlation coefficient, r with urban growth

Socioeconomic and demographic variable	1987	1994	200	Pearson correlation, r
Total population(10,000)	629.3	700	801.36	0.9669
GDP(100 Million Yuan)	124.61	485.76	2238.23	0.9999
Per capital GDP (Yuan/person)	1995	6980	26279	0.9994
FDI Actually used(10,000 RMB)	328710	91343	174001	-0.8248
Gross Agric Output(10,000RMB)	216576	723819	1805957	0.9658
Per capital Annual Net Income of rural Pop(Yuan)	203	1432	4341	0.9915
Per capital Annual Net Income of urban population(Yuan)	1,267	3,765	10849.72	0.9958

Source: Wuhan Statistical Year Book, 2009; Correlation coefficient calculated in Microsoft Excel, 2007

Table 4. Landscape level Metrics

	NP	PD	LPI	CONT	FDI	SHDI	SIDI
1987	335962	39.1	10.2	43.1	1.0483	1.1770	0.6584
1994	379009	44.2	14.9	45.8	1.0461	1.1341	0.6162
2005	277783	32.3	35.7	51.3	1.0455	1.0727	0.5625

Table 5. Class Level Metrics

	Urban			Water			Agric			Forest		
	1987	1994	2005	1987	1994	2005	1987	1994	2005	1987	1994	2005
NP	88317	118293	59871	39515	40803	24931	88926	51904	29391	119204	168009	163590
PD	10.28	13.79	6.97	4.60	4.76	2.90	10.35	6.05	3.42	13.88	19.58	19.0
LPI	0.56	1.15	2.14	3.42	3.02	1.96	10.18	14.87	35.68	2.53	1.37	0.57
COH	96.31	97.99	99.04	99.26	99.05	98.52	99.81	99.93	99.97	99.15	97.04	96.19
% of LS	4.80	6.23	13.00	17.67	18.02	11.08	44.92	55.27	62.47	32.61	20.48	13.44

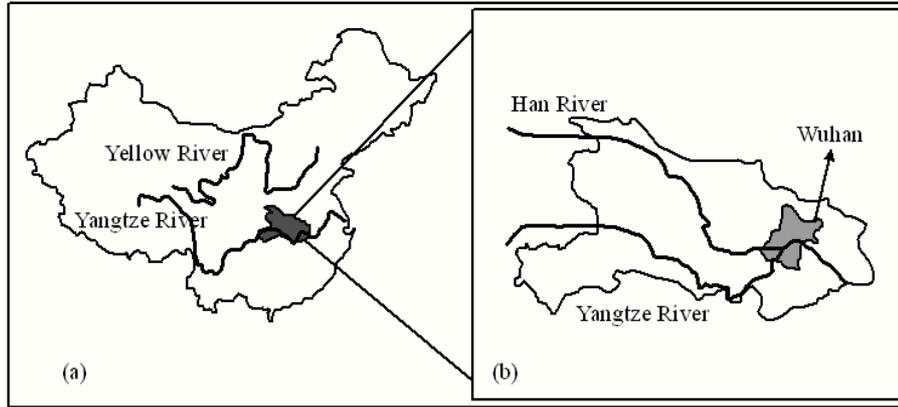


Figure 1. Map of China showing Hubei Province (a), and Hubei Province showing Wuhan (b)

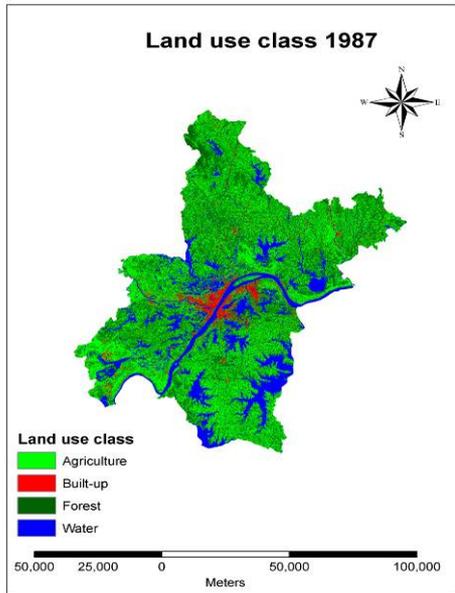


Figure 2. Land use class 1987

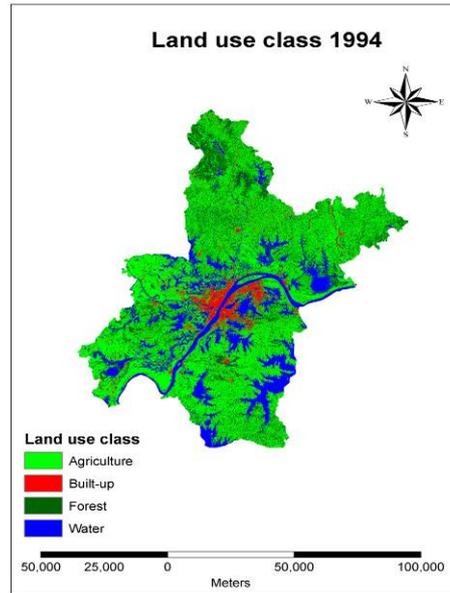


Figure 3. Land use class 1994

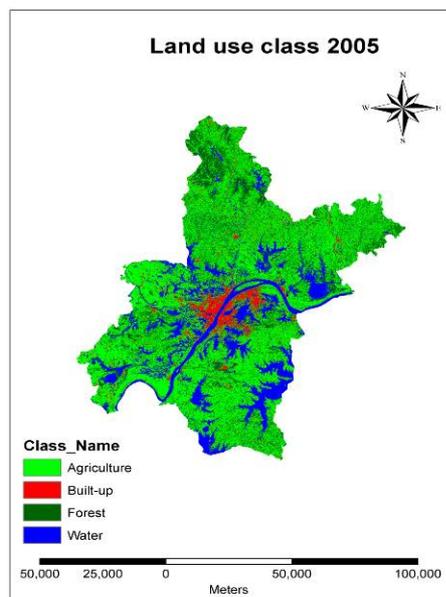


Figure 4. Land use Class 2005