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MONITORING DYNAMICS OF URBAN LANDSCAPE USING SPATIAL MORPHOLOGICAL INDICES: A CASE STUDY OF THAMES GATEWAY AREA

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Abstract: Land use changes are results of interaction (over time and space) between humans and their physical environment. Cities and urban landscapes reflect the social, economic, political, environmental as well as technological processes in their changes as evident in their pattern and structures. This study tests the use of morphological indices for monitoring landscapes in a heavily modified landscape (urban). The study analyses the spatial and temporal changes in land use and land cover pattern in the area adjoining the Thames Gateway and selected parts of Greater London, UK. The investigation focuses on an examination of the temporal changes of various land use types as well as their structural properties and distribution over this period.

1. Introduction:

Land use/cover change is at the forefront of research on environmental/global change. Changes at the earth's surface have major implications for energy fluxes and ecological balances which are essential elements for our survival on earth. Land use changes are results of interaction (over time and space) between humans and their physical environment. Cities and urban landscapes reflect the social, economic, political, environmental as well as

technological processes in their changes as evident in their pattern and structures.

It could be argued that urbanisation presents one of the most intense interactions between man and his environment. These interactions lead to various forms of urban land use changes. This change comes in different forms. Some regions witness the conversion of cultivated land to non-agricultural, while some regions experienced increased fragmentation of cultivated land as more areas are built on. The process of change is never the same for any particular place. But in most

industrialised nations government planning/policy, economic rewards (values) of land use could be identified as playing a central role in directing the path of such changes.

In the last several decades tremendous changes have occurred worldwide (Houghton, 1994). The extent of such changes in land use globally is alarming due to their consequences. In order to enhance our understanding of the recent changes in earth system and how it will change in the future, there is a need to use quantitative, spatially-explicit models in land use change analysis (IGBP, 1999). The analysis of landscape pattern has been used to provide an indication of urban sprawl, household developmental cycles, population dynamics etc (Nagendra et al., 2004). With this indicative potential, indices of pattern and change present an opportunity to model land use change at different scales of administrative units (e.g. district, ward). Indices of pattern derived from land use data could summarize and represent the processes of land use change regardless of complexity in the system (thus relating observed changes and their pattern to process). The study analyses the spatial and temporal changes in land use and land cover pattern of the selected area of London. The investigation focuses on an examination of the temporal changes of various land use type as well as there structural properties

and distribution between 1971 and 2001. The study is intended to provide more information from the pattern thereby providing more insight into the processes driving the changes across the study area.

2. Materials and Methods:

The study area (51°38' - 51°22'N, 0°9' - 0°19'W) is located within Greater London. The study area lies on the Thames basin and consist of the four major types of landscapes of the South Eastern UK, namely the Inner London, Thames Basin Lowlands, Northern Thames Basin, North Kent Plain and the Greater Thames Estuary. The second land utilisation survey maps were used as the landuse data for 1971. The survey started in 1958 and ended in 1970 with a number of resurveys carried out in the 1970s. About 15% of the coverage area was published in 1977(Coleman, 1977). The measurement and analysis were carried out using a systematic point sampling for abstraction of the required data(Best, 1981). The 1990 Land Cover Map (LCM 1990) of Great Britain compiled by the Institute of Terrestrial Ecology (ITE) was sourced as the 1990 landuse data. The survey utilized both summer and winter data from the Landsat TM sensor to enhance map accuracy (Fuller and Parsell, 1990). Data were acquired between 1988 and 1991. This data set was registered to the British

National Grid using a 25 metre output cell (Fuller and Parsell, 1990). The work of Fuller and Parsell (1990) also provides further operational justification, the procedure used for data collection and grid registration.

The Land Cover Map 2000 (LCM2000) which is basically an updated and upgraded LCM 1990, represents the 2000 landuse data set. It has significant improvements in structure, thematic detail and associated metadata (Fuller et al., 2002). The LCM 2000 benefits from hindsight with the introduction of some specific methodological improvement. A segment-based mapping (or vector-raster mapping) was employed and within this system procedures were developed for segmenting satellite images to give vector outlines (Devereux et al., 2004). The data set was also registered to the British National Grid using a 25 metre output cell.

Reclassification was carried out for the landuse types for the three maps available, in order to harmonise the classification scheme across the years. There are 3 broad groups of landuse types (LUT) identified and they are as follows:

- a) Arable lands, market gardening, field vegetables, orchards, and all other agricultural-related use are classified as cultivated area/land (CL).
- b) Heath, moor, woodlands, marsh, rough land, grassland and non-agricultural

vegetated areas classified as ecological Infrastructure (EI).

- c) All other remaining classes were classified as urban/built-up areas (these include settlement, derelict, industrial area etc.)

2.1. Metrics and Statistical Analysis

Coverage statistics and landscape metrics were calculated for each of the map-year for the entire study area. Metrics were computed using a spatial pattern analysis program - Fragstat (McGarigal and Marks, 1994). There were 34 landscape metrics computed to describe the properties of the landuse in the study. The landuse metrics we grouped into four classes – Area and Edge; Configuration; Shape and Diversity. In order to reduce this number to a manageable level and eliminate redundant metrics, a correlation analysis was carried out. Spearman's correlation analysis was carried out for each of the map-year for the 1981 wards boundary. This procedure is intended to identify a smaller number of indices which could still adequately represent the morphological properties (composition, shape, configuration, diversity) of the observed landuse. Where the analysis led to an absolute correlation coefficient of 0.85 or more, one of the two indices is retained.

The selection within the same class of indices is achieved arbitrarily except for the

diversity index. In this case, Simpson-based indices (Diversity and Evenness indices) were selected over the Shannon-based indices which has been reported to be suitable only when the number of LUT is greater than 100 (Yue et al., 1998). The resulting set of metrics is mostly similar among the map-years, and 11 indices were retained in at least one map-year and across the metric classes. Furthermore a second correlation analysis was carried out to eliminate any interclass redundancy leaving us with a smaller set of metrics (Table 1).

3. Results:

Built-up areas dominated the landuse in all the map years (Table 2). There was an increase of about 12% in the built-up area from 1971 to 1990 while between 1990 and 2000 the growth seems to be stalled.

Group Membership	Metric
Area	Mean patch Area (MPA)
Shape and Edge	Area weighted Fractal Dimension Index (FRAM)
	Mean Contiguity Index Distribution (CNMN)
	Mean Shape Index (SHMN)
Configuration	Interspersion and Juxtaposition Index (IJI)
	Contagion (CNTG)
	Effective Mesh Size (MESH)
Diversity	Patch richness density (PRD)

Table 1: Final Selection of Landscape metrics

Area(ha)	BL	AR	EI.
1971	42823.625	3374.375	16126.81
Percent	69%	5%	26%
1990	48120.438	12563.75	1640.625
Percent	77%	20%	3%
2000	47493.813	6434	8397
Percent	76%	10%	13%
Average	74%	12%	14%

BL=Built-up lands, AR=Cultivated lands, EI= Ecological infrastructures

Table 2: Landuse data for the study area between 1971 and 2000

Between 1971 and 1990 there was a big decline (90%) in the area covered by ecological infrastructures while a resurgence of about 80% was observed between 1990 and 2000. Further decrease was observed in the total coverage of ecological infrastructure between 1990 and 2000 (33% decrease).

Landuse change matrix tables were constructed to identify which land use types are being replaced and by what. Table 3 shows that over 90 % of the area remained as built-up area from 1971 to 1990, while for cultivated lands and ecological infrastructures 65% and 8% respectively remained unchanged through the same period. Built-up land was also found to have taken about 33% of the cultivated land area and less than 2% of the same area changed to ecological infrastructures. The biggest conversion figure was observed for

ecological infrastructures where about 44% of its original area in 1971 was converted to built-up area in 1990, and also 48% of its area was also found to have been converted to cultivated lands over the same period.

LU	BL	AR	EI	Ttl
BL	39918.56	2570.00	335.06	42823.63
AR	1130.31	2196.19	47.88	3374.38
EI	7071.56	7797.56	1257.69	16126.81
Ttl	48120.44	12563.75	1640.63	62324.81

Ttl=total, LU=landuse type

Table 3: Land use change matrix for the study area from 1971 to 1990 (in ha)

Table 4 shows the land use change matrix between 1990 and 2000. It was observed that over 90 % of the built-up area remained the between these map-years. From 1990 to 2000, 38% of the cultivated land remained unchanged while 70% of the ecological infrastructures remained the same. While the greater area of the ecological infrastructures remained through this period, about 24% of its area was built-up by the end of the decade. Big changes were also observed for the cultivated lands which lost about 26% and 36% of its area to built-up and ecological infrastructures LUTs respectively.

LU	BL	AR	EI	Ttl
BL	43881.88	1531.63	2706.94	48120.44
AR	3225.00	4796.81	4541.94	12563.75
EI	386.94	105.56	1148.13	1640.63
Ttl	47493.81	6434.00	8397.00	62324.81

Table 4: Land use change matrix for the study area from 1990 to 2000 (in ha)

The examination of the change map revealed that about 65% of the study area never changed over the period of this study while around 30% of the area witnessed changes twice out of the three map-years. Globally, 30% of the total area changed from one LUT to the other between 1971 and 1990; and around 20% changed between 1990 and 2000.

The area metric represented by mean patch area (MPA) show a strong decline at the landscape level between 1971 and 1990 (Figure 1a). This was followed by a similarly strong increase between 1990 and 2000 with values close to that of 1971. At the class level the mean patch size for built-up areas was highest in 2000 followed by 1971 (Figure 1b). For cultivated land and ecological infrastructures the mean patch size are more similar across the year.

Examining the shape metrics, there was an increase in the fractal dimension index from 1971 to 1990 at the landscape level while a decline was observed between 1990 and 2000 (Figure 1c). Similarly, at the class level (patch type) built-up areas showed a higher value compared to the other patch

types (Figure 1d). For cultivated areas, 1990 FRAM value was higher compared to other map-years with the smallest for this patch type recorded in 1971.

Another metric selected to represent shape is Mean Contiguity Index (CNMN). At the landscape level a strong decline was observed from 1971 to 1990. This was followed by an increase between 1990 and 2000 (Figure 1e). CNMN for cultivated land in 1971 was slightly lower than that of 2000 and these two map-years values were observed to be almost double to the observed value of CNMN in 1990 (Figure 1f).

Mean Shape Index (SHMN) was found to share some similarities with the pattern of development observed in CNMN (Figure 1g). At the patch type level the SHMN value for 2000 was observed to be the greatest across the three landuse types (Figure 1h). The SHMN values for built-up area are closer for 1990 and 1971 while the 2000 value is higher compared to these two. For cultivated lands and ecological infrastructure, values for SHMN in 1971 and 2000 are closer together than the value obtained in 1990 (Figure 1h).

IJI is calculated based on patch adjacencies while contagion is calculated based on cell adjacencies, therefore it is possible to calculate IJI for both the landscape level and the patch type (class level). For contagion index it is only possible to

calculate at the landscape level due to the unit of reference (cell) for the computation.

IJI showed a gradual increase between 1971 and 1990, followed by a very steep increase between 1990 and 2000 at the landscape level (Figure 1i). For ecological infrastructures the pattern is totally different with 1990 value approaching 100%, followed by 2000 at about 80% and 1971 with the lowest value of about 50% (Figure 1j).

Examining the configuration using the contagion index showed that there was an increase in the contagion index between 1971 and 1990 and a slight decrease between 1990 and 2000 (Figure 1m). The growth in the CNTG value observed for 1971 to 1990 was found to have been halved by the decrease recorded between 1990 and 2000.

The last metric used to represent configuration is the effective mesh size (MESH). There was a strong increase between 1971 and 1990 for this metric at the landscape level. This strong rise was followed by a much more subtle decline between 1990 and 2000 (Figure 1k). At the class level, ecological infrastructures and cultivated areas recorded MESH values which are at the lower end of the observed values for the 3 map-years (Figure 1l).

Diversity of the landscape was represented by the Patch Richness Density (PRD). This index can only be computed for the whole

landscape and the result indicates that over the map-years there is no change in the PRD value (0.0029) for the study area. Therefore, in order to reflect the change in diversity which was not captured by the PRD values, Simpson's Diversity Index (SIDI) values were examined (computed at the landscape level). The values of SIDI showed a decline of about 20% in value of the index between 1971 and 1990 and a 7% increase between 1990 and the last map-year (Figure 1n).

4. Discussion:

Across the three map-years built-up LUT showed consistency in coverage with over 90% of its area remaining the same across these periods. This is expected due to the nature of the study area (i.e. a city). Most often time the development of the city – i.e. built-up area, consumed a significant proportion of the ecological infrastructures LUT and similarly a large proportion of the ecological infrastructures (such as heath lands) were also reclaimed for agricultural purposes (Parry, 1982). Generally there is a lesser likelihood for built-up areas to change to another type of LUT while for the other LUTs the change can happen in both directions (cultivated to ecological infrastructure and vice versa). The assessment of the landuse change also confirms there is no significant growth in the built-up area but there are subtle

changes going on within the study area. The majority of such changes include conversion of arable land and ecological infrastructures, reclamation of some ecological infrastructures etc.

The result of the MPA values showed an increase in fragmentation of the study area between 1971 and 1990 with 1971 landscape of the study area being more aggregated than the 1990 landscape. The mean patch size reverted to almost the initial starting point in 2000, indicating a lesser level of disaggregation than in 1990 but a more or less similar level of aggregation between 1971 and 2000. The size and pattern of distribution of the cultivated area and ecological infrastructures are majorly responsible for the closeness observed in the MPA values. Essentially, these results indicate that the study area is currently as aggregated as it was in 1971 and that the level of aggregation is mainly influenced by the dominant landuse type (i.e. built-up areas). To examine the shape complexity, three metrics were selected – FRAM, CNMN and SHMN. The result from the FRAM and SHMN metrics indicate the landscape is tending towards a convoluted shape (i.e. departure from Euclidean geometry). The landscape witnessed an increased complexity from the first map year to the second (1990). This could be attributed to the increase in number of patches as well as

the reduction in mean patch size. Similarly the reduction in patch size and number of patches observed afterwards could account for the relative reduction in shape complexity between 1990 and 2000. The FRAM values reveal very little difference in the shape complexity both at the landscape and patch type level.

Mean contiguity index was computed to reflect the spatial connectedness of the study area, this is intended to complement the interpretation of spatial aggregation across the landscape. Its value indicates contiguity of cell within a patch providing an index of patch boundary and consequently the shape (LaGro, 1991). Patches within the study area are more connected in the 1971 map-year when compared to the 1990 while the recent map-year (2000) displayed a more contiguous landscape. This pattern is as a result of the higher patch sizes observed in 2000 and 1971 and lower value for 1990, thus confirming the influence of fragmentation on connectedness within a landscape. Except for the built-up area, the patch type level analysis indicates that connectedness across the landscape follows the same persistent trend observed in previous metrics at the patch type level (i.e. 1971 and 2000 appearing in close proximity of one another). The difference in the trend could be attributed to the significance growth of built-up area (11%) between 1971 and 1990

and the influence of patch size between 1990 and 2000. Basically the trend observed at the landscape level is predominately influenced by the contiguity index trend for the ecological infrastructure and cultivated area.

The result of the configuration metrics show that the most recent map-year is the most maximally disaggregated (i.e. each LUTs is equally adjacent to all other patch type). Contagion value for the landscape show very little changes across the map-years suggesting a more or less well mixed landscape across the year, this could also have been due to the coarseness of the maps used. IJI values show clearer trends across the map-years, with 1990 - 2000 showing a sharp increase in the interspersion and juxtaposition of the LUT. The observed trend at the landscape level could mainly be attributed to the influence of the dominant LUT (built-up area). The effective mesh size gives an indication of the level of subdivision (McGarigal and Marks, 1994). MESH values indicates the probability that two points chosen randomly in a region (on the landscape) will be connected, i.e., not be separated by roads, railroads, or urban development or other LUTs (Jaeger, 2000). Thus values observed in 1990 and 2000 is an indication of high probability that any two point selected on the landscape will be connected. This result is directly influenced by the dominance of built-up areas within

the landscape. The index has been reported to be superior over other indices in representing landscape fragmentation (Jaeger et al., 2007, Moser et al., 2007, Jaeger, 2002, Jaeger, 2000).

For diversity, the results shows that there is a high probability for diversity for the study area in 1971 when compared to the most recent map years, the implication is that the landscape in 1971 is richer when compared to the most recent map-years.

5. Conclusion

The study revealed the spatio-temporal changes of land use between 1971 and 2000. It also examined the development of spatial pattern across the study area between 1971 and 2000 in respect to the changes observed in landuse.

Built-up LUT show more stable development across the years, while ecological infrastructures and cultivated area are more dynamics over the period considered. The changes in built-up area are mostly due to the almost equal conversion of cultivated lands and ecological infrastructures. There are no big changes in the built-up area (urban growth) but there are subtle changes going on within the study area, and such changes include conversion of arable land and ecological infrastructures, and reclamation of some ecological infrastructures.

The study area was found to be more spatially aggregated in 1971 and 2000 than in 1990, the shape complexity is similarly across the map-years, but essentially a high reading was obtained for 1990 which indicates that this map-year is more fragmented than any other. The most recent map is more contiguous than any of the other map years while the older map-year is still more contiguous than the 1990. Basically, there is a similarity between 1971 and 2000 map-years. In respect of the configuration of the landscape the most recent map-year is the most maximally disaggregated (i.e. each LUTs is equally adjacent to all other patch types). In contrast to the other indices, effective mesh size indicates a similarity between 1990 and 2000 map-years. This can be attributed to the greater dominance of built-up areas within the landscape for these years. And this is reflected in the diversity metrics which show that there is a higher probability for 2 points selected in 1971 to belong to different patches in comparison to more recent map-years.

Finally, the result of the study indicates that despite the observed landuse changes over the years there is a similarity between the morphological characteristics of land use in 1971 and 2000. Therefore, presenting another question that needs to be answered; are there corresponding similarities in the

factors driving changes in the landscape structures as well?

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