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QUANTITATIVE EVALUATION OF URBANIZATION IN DEVELOPING COUNTRIES USING SATELLITE DATA

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The rapid economic growth in Asian countries is causing increasing urbanization in major urban areas and it is severely degrading the condition of the natural environment. The objective of this study is to develop the method to evaluate the urbanization quantitatively using satellite data. The urban index UI, which is estimated using Landsat TM data, is proposed and clear relations of UI with building density, population density, energy consumption, etc, are examined for the case study of Colombo City in Sri Lanka. Quantitative evaluation of the relation between urbanization and the vegetation condition which represents the natural environment in urban areas, is discussed using UI and NDVI.

Key Words: *satellite remote sensing, Landsat TM, urbanization, environmental monitoring, sustainable development. developing countries.*

1. INTRODUCTION

Many urban areas in Asian countries are growing fast due to rapid economic growth in these countries. The boundaries of these population agglomerations have receded well beyond those of the natural environment, in some cases permanently impairing the productivity of the ecosystem upon which the population is dependent. Therefore in recent times there has been an increasing interest in the relation between cities and the natural environment.

In many developing countries updated geographical information and statistical data are not adequate to evaluate urbanization and the environmental condition quantitatively and to make an effective urban plan. High cost and time are required for traditional data collection methods which have made a systematically developed urban database beyond the reach of many planning authorities. On the other hand, satellite data can be applied to evaluate urban growth because a wide area can be analyzed concurrently on a time scale due to repeated satellite coverage of these areas. Satellite remote sensing, therefore, provides a fast and affordable means of monitoring the rapidly changing conditions of urban areas.

The objective of this study is the quantitative evaluation of urbanization using satellite data. Urbanization index UI, which is estimated using Landsat TM data, is proposed in this paper and its usefulness is examined. At first, to investigate the relation between UI and the physical surface conditions of urban areas, the building coverage for 500m by 500m grid is compared with the average UI values for the grid in Colombo City, Sri Lanka. Secondly, average values of UI for urban units are compared with socio-economic parameters of urban development, in order to evaluate how much UI reflects the urbanization for relatively large planning units. Finally, quantitative evaluation of the balance between urbanization and the natural environment in the city is proposed as the practical application of UI for urban planning, considering sustainable development.

In previous studies the Normalized Difference Vegetation Index (NDVI) has been used for the quantitative evaluation of the built-up areas[1)] and for urban change detection[2)]. It is obvious that NDVI is the parameter to reflect the vegetation activity and NDVI does not represent the surface condition of the urban area directly. It is difficult to find out clear relations between the surface condition and the index UI which reflects the artificial surface, especially for small grid size, for example, 30m by 30m. Relatively large grid, 500m by 500m grid is used in this study. This grid size is different from those of the previous studies about direct evaluation of urbanization by satellite data which failed.

As a case study, Colombo City in Sri Lanka has been used. Colombo City is the commercial and industrial center of Sri Lanka. The location of the city is shown in **Fig.1**. Colombo City and the surrounding urban council areas are defined as the Colombo Urban Area(CUA). An estimated 2 million people live in the CUA which extends over 58 km^2. The Colombo Metropolitan Region(CMR) comprises of the CUA and six other sub regions surrounding it. The population densities in the most built-up areas of Colombo City are in the region of 160 persons to the hectare. Urban areas in the CMR are increasing rapidly particularly after 1977 because of the change in economic policy in Sri Lanka.

Conventional data used in the study include a 1:12672 building cover map of 1970 of Colombo City, a vegetation cover map of 1981 of the CUA, a 1:50000 land use map of 1981, a map showing the boundaries of the urban units in the CUA and statistical data relating to these urban units of the period 1991 to 1993. Satellite data used was from a Landsat TM scene over the CMR acquired on the 12th of February 1993.

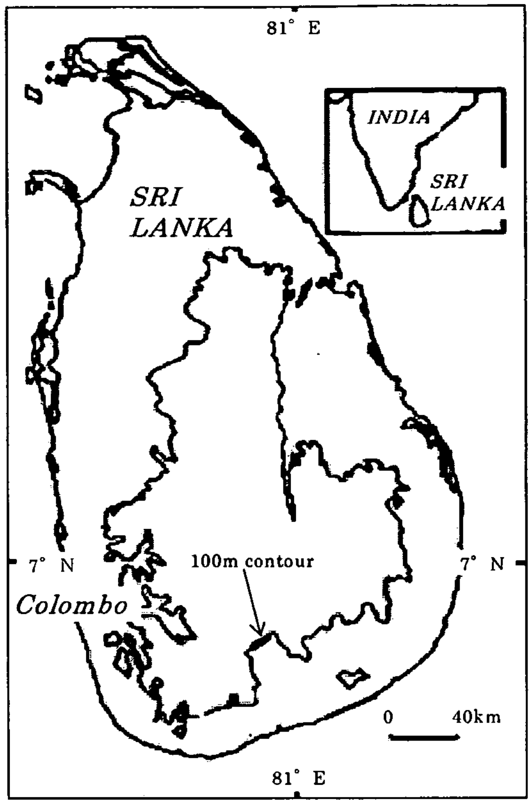

Fig.1 Location of Colombo City

2. THE PROPOSED INDEX UI AND ITS CHARACTERISTICS

(1) Definition

Many studies have been done regarding the spectral response from vegetated and non vegetated materials in the visible, near infrared and middle infrared regions of the electro-magnetic spectrum. Spectral reflectance curves for these surfaces was investigated by Jensen et al[3], Lillesand and Kiefer[4] and J.P.Ormsby[5]. They provide insight into the expected spectral response from land cover in an urban/suburban environment which is a mixture of both vegetated and non vegetated materials. In the case of the Colombo Metropolitan Area, to investigate the spectral reflectance for the 7 TM bands for the different types of land cover categories the Landsat TM band images were registered with a scanned 1:50000 landuse map of 1981 of Colombo District which is close to the Colombo Metropolitan Region prepared by the Survey Department of Sri Lanka, and the average CCT digital values for each land cover category was computed. The result is shown in **Table 1**. Bands 1,2,3 which are from the visible portion of the spectrum are influenced by the optical properties of the reflected surface. Also the shorter wavelength of these bands make them more sensitive to atmospheric effects. The choice of bands are then limited to bands 4,5 and7. From **Table 1** it can be seen that out of these bands, 7 and 4 are two bands that very clearly show the urban area. UI is therefore defined by Eq.(1) exploiting the inverse relationship between brightness of urban areas in bands 7 and 4.

Table 1 Average CCT digital values of land cover classes

TM BAND	Built Area	Water	Grass Land	Paddy	Home-steads	Rub-ber	Coco-nuts	Mixed Tree
1	87	81	85	81	82	80	80	81
2	36	29	36	34	34	33	33	34
3	56	32	51	48	48	47	47	48
4	72	31	98	97	93	99	97	97
5	97	29	104	103	99	103	100	102
6	160	145	158	157	159	157	157	157
7	40	10	34	33	33	32	31	32

$$UI = \left(\frac{B7 - B4}{B7 + B4} + 1.0 \right) \times 100.0 \qquad (1)$$

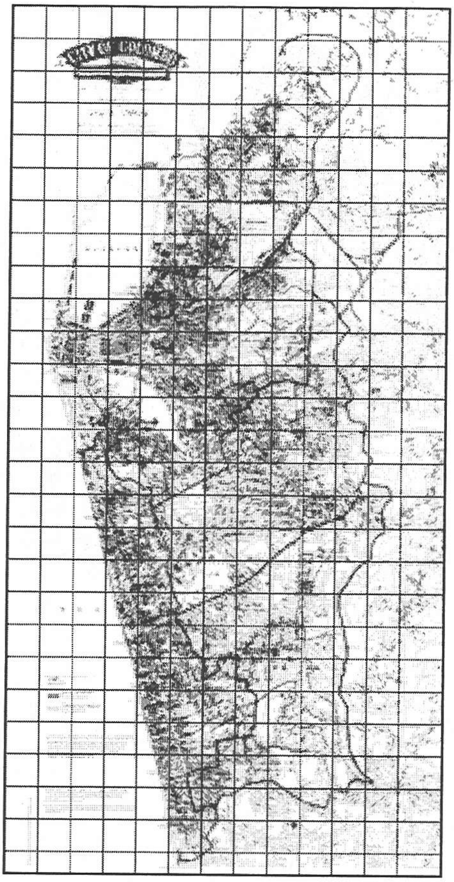

Fig.2 Building cover map of Colombo City

(2) Relation of UI with building density

To compute the building cover density or urban density in the Colombo City a 1:12672 building cover map of 1970 shown in **Fig.2**, prepared by the Survey Department of Sri Lanka, was used. This map was scanned and registered with a UI image using affine transformation for geometric correction.

Urban density, UD was defined as the percentage area covered by buildings within a raster grid cell of 500m. The building cover map was scanned in grey scale and using a threshold value of 190, all pixels from '0' to '190' were assigned as black pixels representing buildings. **Fig.3** is a part of the building cover map where the above mentioned conversion has been done for a 500m by 500m grid cell. The black pixels within the 500m by 500m grids are then counted and given as a percentage of the total pixels within the grid cell. UD is estimated as this percentage. The estimation error was checked for several grids using the value which are calculated on the original map. The average value of error is about 5%. The 500m by 500m grid used in the analysis is shown in **Fig.2**.

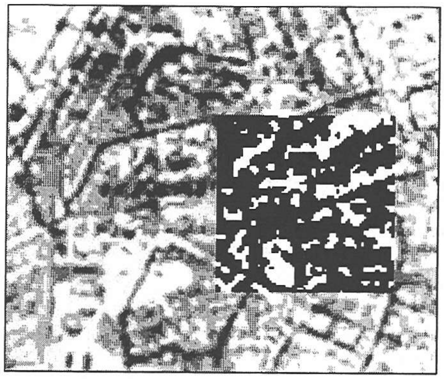

Fig.3 Calculation of UD

The densely urbanized area after 1970 was omitted by referring the report, 'Colombo City Development Plan of 1985'[6], which does not show numerical criteria for the major changed area. For the major changed area and the area with small changes, the change of UD was estimated using the air photographs of 1994 and the map of 1970. The values are 31% for major changed area and 2.9% for small change.

Grid cells which are partly in water areas also have been omitted. The average UI values corresponding to the UD values were computed for the grid cells. The average value of UI for grid is the mean of UI values for 196 pixels which are covered by one grid. The variance of UI within a 500m grid cell is 5 to 8 for densely developed commercial and administrative areas and 9 to 13 in residential areas. The computed UI and urban density values are shown in the scatter diagram of **Fig.4**. UI is strongly related to urban density. Therefore the average UI values for 500m by 500m grid represents directly, the surface condition of urban areas. A linear regression analysis gave a coefficient of correlation of 0.77 and the regression function is as shown by Eq.(2). UD refers to urban density.

$$UI = (0.47 \times UD) + 49.2 \quad (2)$$

To estimate UD from remote sensing data the coefficients for the relation between UD and UI is given as shown in Eq.(3).

$$UD = (1.65 \times UI) - 72.74 \quad (3)$$

Table 2 Coefficient of linear correlation for different grid sizes

Grid Size(m)	50	100	200	300	400	500	600
Coefficient	0.37	0.52	0.64	0.73	0.75	0.77	0.80

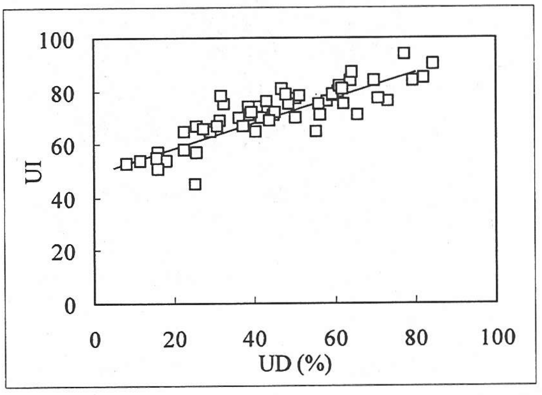

Fig.4 UI-UD Relation for Colombo City

(3) UI-UD relation for different grid sizes.

The effect of grid size on the UI-UD relation was investigated by changing the grid size and computing the UI and urban density values corresponding to each grid size. The coefficient of linear correlation for each case was computed. The results are shown in **Table 2** above. The larger grid size gives a relatively good correlation. When the grid size becomes small there will be some spatial units within which there is a high percentage of artificially paved surfaces but only a few buildings. The UI value of these units are high but UD is low and therefore these units will not give a clear UI-UD relation. In the study a grid size of 500m has been used because it gives a relatively good correlation and it is convenient to convert to 1km grid size which are often used for global databases.

3. RELATION OF UI WITH SOCIO-ECONOMIC PARAMETERS OF URBAN DEVELOPMENT

To evaluate the effectiveness of the index UI to reflect urbanization of relatively large planning units, the relations of UI with socio-economic parameters of urban development such as population, housing density, electrical energy consumption and land values of the administrative units in the Colombo Metropolitan Region (CMR) were investigated using data of the period 1991 to 1993[7]. The administrative units in CMR are shown in **Fig.5**. The geographical boundaries to which electrical

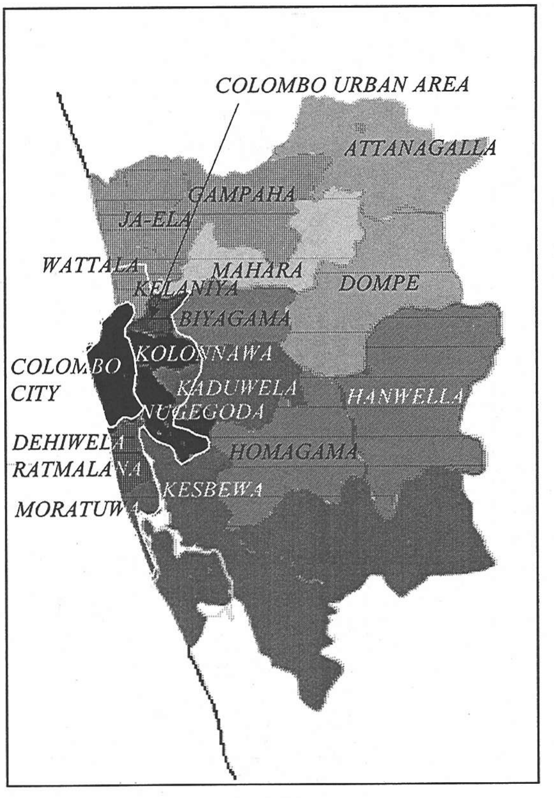

Fig.5 Administrative units in the Colombo Metropolitan Region

energy consumption and land values data relate are different from those in **Fig.5**, because responsible authorities have their own administrative boundaries. The CMR covers a land area of 1386 km^2 and has a total population of 3 million. The ranking for land values are based on the survey by the Urban Development Authority of Sri Lanka[8]. In this land survey, the average land value for a small administrative unit was estimated using the data at several points in the unit. The average land value of the unit was assigned to the rank in **Table 3**. Average value of UI for all the units belonging to that rank is shown in **Table 3**.

To compute UI values an image of 4000x2550 Landsat TM pixels was used. The UI image was registered with scanned maps showing the boundaries of the administrative units in the CMR. The relation between average values of UI and the socio-economic data corresponding to the administrative units in the CMR is shown in the scatter diagrams of **Figures 6** to **9**. The average value of UI is the mean of UI values of the pixels which covers the administrative unit. The variance of UI within these large administrative units varies from 12 to 15.

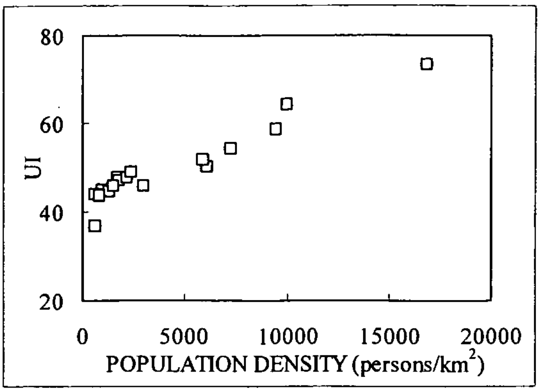

Fig.6 Relation between UI and population density

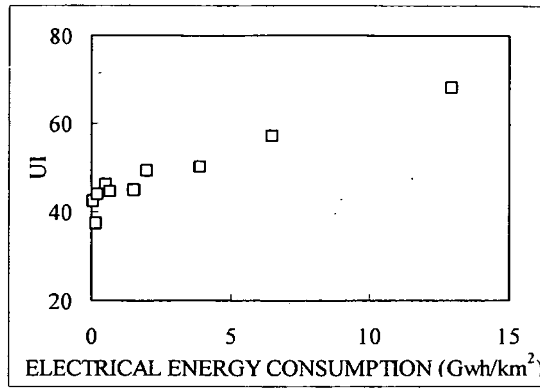

Fig.8 Relation between UI and electrical energy consumption

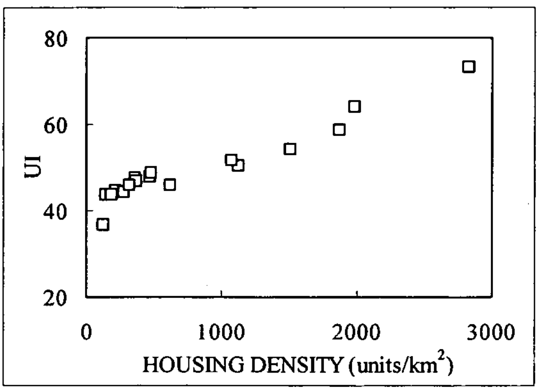

Fig.7 Relation between UI and housing density

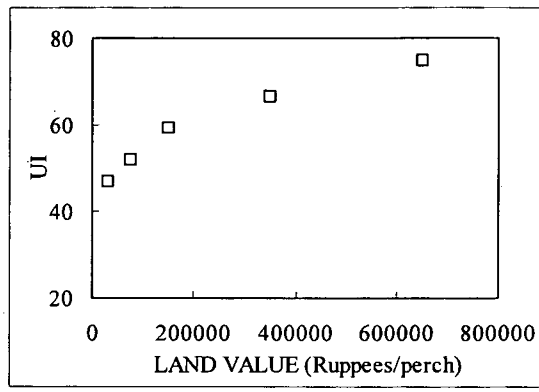

Fig.9 Relation between UI and land values

Table 3 Land values in the CMR[8]

Rank	Land Value Range (Ruppees/perch)	UI
1	>650000	74.83
2	200001-500000	66.76
3	100001-200000	59.25
4	50001-100000	52.17
5	10001-50000	47.09

These figures show that UI is strongly related to parameters of urban development of administrative units. It is convenient if the socio-economic data for developing countries are predicted using satellite data when the statistical data were not found. The above mentioned analysis was performed to confirm the applicability of UI for that purpose[9),10)]. However, if very much smaller spatial units are used UI does not give a clear relation with socio-economic data. This is because the relation of satellite data with socio-economic conditions depends on how well the spectral characteristics of the physical features on the surface represent social conditions. In the previous chapter it was shown that UI is strongly related to the density of building cover for a 500m by 500m grid. Therefore when using UI to relate satellite data with social data it is the spectral characteristics of the physical development on the surface that is used. If a small spatial unit such as a 500m by 500m area is considered in a predominantly commercial area its average UI value will be high because of the high density of development but its population density will be low. For such small spatial units therefore UI will not give a clear relation with social data. Hence the average UI value represents socio-economic conditions of urban development only of larger spatial units such as administrative units or urban planning units in the urban area. These relations therefore can be applied to other cities which have similar socio-economic development conditions. The TM data used should be of the summer season.

4. NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) AND ITS CHARACTERISTICS

(1) Definition

The Normalized Difference Vegetation Index (NDVI) is a quantitative measure based upon digital values that attempts to measure biomass or vegetative vigour. High NDVI values identify pixels covered by substantial portions of healthy vegetation.

In recent times the importance of urban vegetation in preventing the deterioration of the urban environment has been well recognized. Vegetation in urban areas strongly controls the thermal environment and moderates the extremes of the urban micro climate, reduces pollution levels in the urban atmosphere, improves urban soil conditions and the functioning of the hydrologic cycle and increases the diversity and quantity of wild life in cities. Hence the quantity and quality of urban vegetation are indicators of the environmental condition in the urban areas. Therefore NDVI is used as a measure of the environmental condition in the urban area.

Different types of vegetation indices have been used to estimate the percentage of vegetation[11]. However the accuracy of these estimations are influenced by atmospheric conditions, soil brightness, leaf optical properties, leaf inclination and vegetation density[12)13]. The soil adjusted vegetation index (SAVI) was developed to minimize soil influences on canopy spectra[14] and was later modified to produce the modified soil adjusted vegetation index or MSAVI[12]. In the studies quoted, MSAVI has been applied to vegetation areas. In this study MSAVI did not show a relatively improved result over NDVI in its application in urban areas to estimate the relation of the vegetation index with vegetation percentages. NDVI was used in this study as it is a more widely used popular index. The ratioing strategy in NDVI is based on the inverse relationship between vegetation brightness in the visible and near infrared portions of the spectrum. In the case of Landsat TM data, band3 represents visible portion of the spectrum and band4 is the near infrared portion.

$$NDVI = \left(\frac{B4 - B3}{B4 + B3} + 1.0 \right) \times 100.0 \qquad (4)$$

Fig.10 Urban vegetation map of Colombo Urban Area of 1981

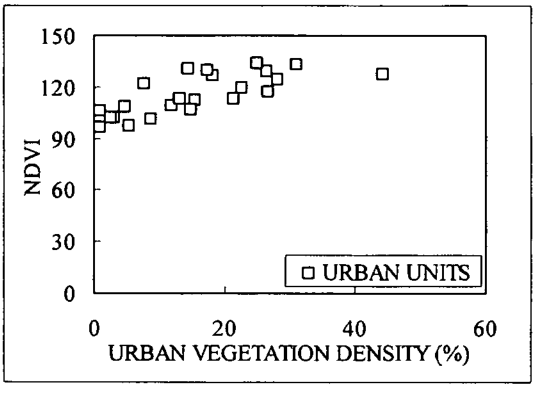

Fig.11 Relation between NDVI and the urban vegetation density in urban units

(2) Relation of NDVI with urban vegetation density

Fig.10 shows an urban vegetation map of 1981 of the Colombo Urban Area prepared by the Urban Development Authority of Sri Lanka. The vegetation areas within the urban area comprise of parks, grasslands, mixed agricultural crops, mangroves, deep and shallow marshes and artificial green areas. The vegetation map was scanned and registered with a Landsat TM scene over the metropolitan area acquired in February 1993 and a scanned map indicating the boundaries of urban units in the Colombo Urban Area shown in **Fig.12.**

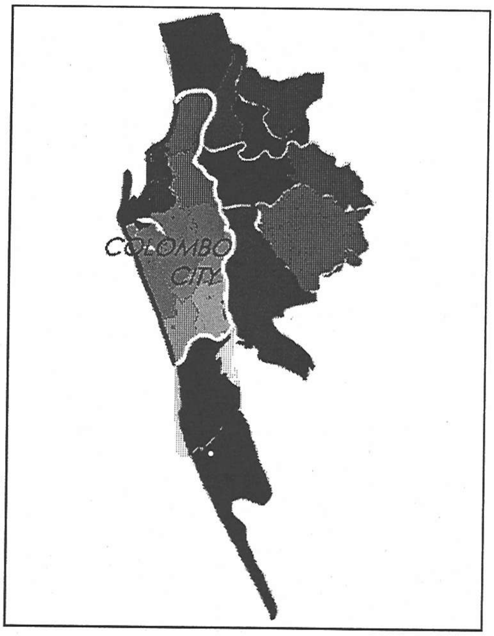

Fig.12 Urban units in Colombo Urban Area

In this study urbanization of the administrative units and 500m grid cells are investigated using UI. To know the correlation between urbanization and vegetation condition for those units and cells, average value of NDVI for the large area instead of each pixel are estimated in this chapter. The average NDVI values and the percentages of urban vegetation, which is defined as the urban vegetation density in each urban unit was computed. Computed values are plotted in the scatter diagram of **Fig.11**. NDVI is closely related with urban vegetation density. Therefore NDVI can be used as a measure of the environmental condition in the urban area because vegetation controls the urban environment.

(3) Relation of NDVI with UI for 500m by 500m Grid

By registering the Landsat TM image with the scanned building cover map of Colombo City of 1970 shown in **Fig.2** and omitting areas densely urbanized after 1970 the average UI and NDVI values for the 500m by 500m grid shown in **Fig.2** were computed. Pixels mixed with water were omitted. The scatter diagram of these computed values is shown in **Fig.13**. A linear regression analysis gives the function shown by Eq.(5). The coefficient of linear correlation is 0.96. This is the relation between UI and NDVI for a 500m by 500m grid for Colombo City. From the previously explained definition of UI for a 500m grid it is clear

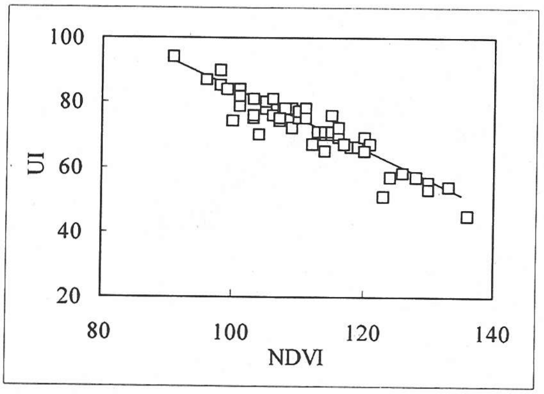

Fig.13 UI-NDVI Relation for a 500m by 500m mesh

that UI for a 500m grid represents the building cover density in the urban area. Hence **Fig.13** shows the relation between the density of development and the vegetation environment in the Colombo Urban Area.

$$UI = (-0.94 \times NDVI\ ) + 178.3 \qquad (5)$$

5. QUANTITATIVE EVALUATION OF THE RELATION BETWEEN URBANIZATION AND VEGETATION CONDITION

(1) Interpretation of the relation between UI and NDVI

From the preceding analysis of UI and NDVI it is clear that the relation between UI and NDVI for an urban area corresponds to a relation between urbanization and the vegetation condition which represents the natural environment in the urban area. It is applied to see the balance between urbanization and the environmental condition of the particular urban area. An analysis of changes using both indices UI and NDVI will show how urbanization has affected the natural environment. Further this relation could be used to compare urbanization and the environmental condition of different cities in the same region. By this analysis using both indices UI and NDVI, spatial changes in urbanization and socio-economic and environmental conditions can be recognised and quantified. This information is useful to urban planners who need to monitor the changing conditions in urban areas and update spatial data so that realistic information could be used for planning purposes.

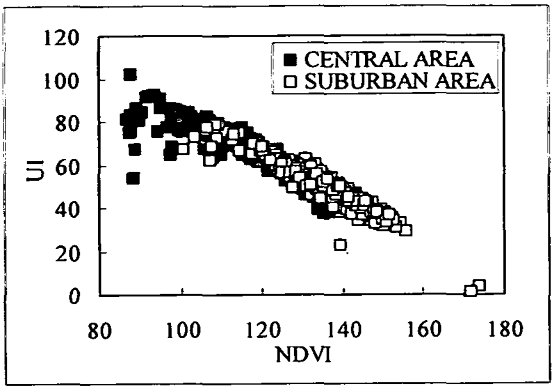

Fig.14 UI-NDVI relation for Colombo City

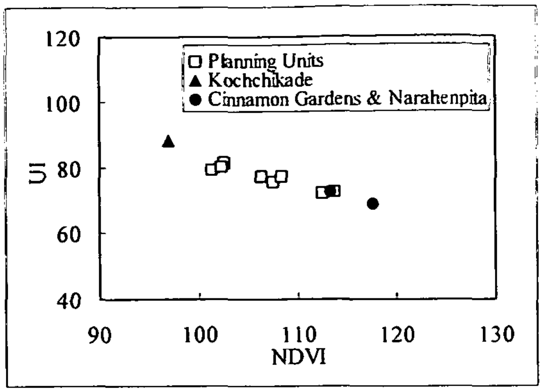

Fig.16 UI-NDVI Relation for urban units in Colombo City

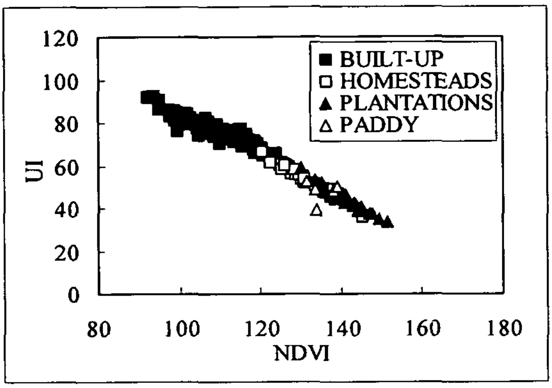

Fig.15 UI-NDVI relation based on land cover category

(2) UI-NDVI relation based on central and suburban areas

Average UI and NDVI values for pixels of 20 by 20 Landsat TM pixels corresponding to a grid of approximately 600m by 600m was computed eliminating pixels from water areas by overlaying with a classified image. These pixels were picked up from an area of 1024 by 800 Landsat TM image pixels covering Colombo City and its suburbs. The central area of the city was separated by selecting an area of 400 by 640 image pixels covering the central part of the city. The remaining pixels in the 1024 by 800 pixels image was considered to be of the suburban area. The scatter diagram of UI and NDVI for Colombo City is seen in **Fig.14**. In the densely urbanized central area of the city UI values are high and NDVI values are low.

(3) UI-NDVI relation based on land cover type

Digital land cover data of the Colombo City area was obtained by scanning the 1:50000 land use map of 1981. The UI and NDVI images were registered with the scanned land use map. Each pixel was assigned to a category if more than 80% of the original 20 by 20 image pixels within the considered pixel belonged to that category. The UI-NDVI relation based on land cover category is shown in **Fig.15**. This figure shows that the UI value increases
and the NDVI value decreases with increased urbanization.

(4) Application of the relation between urbanization and the vegetation condition in urban units in the Colombo City

By registering the Landsat TM image with the scanned map of the urban units in the Colombo Urban Area shown in **Fig.12**, the average UI and NDVI values for the urban units were computed. These urban units include administrative units in the Colombo Metropolitan area of which Colombo City itself is one unit, as well as much smaller planning units within Colombo City. The UI-NDVI relation for planning units within Colombo City shown in **Fig.16**. The planning unit shown by ▲ represents Kochchikade. It has the highest population density and the highest slum population density within Colombo City. Vegetation density in this area is the lowest in the city. Therefore this area is well known to be an overcrowded and environmentally poor area. **Fig. 16** shows that it has the highest UI value and the lowest NDVI value out of all the planning units in the City. On the other hand the planning units shown by ● represent Cinnamon Gardens and Narahenpita. Cinnamon Gardens is a high class residential area while Narahenpita is a presently expanding housing area. They have the lowest population and housing densities and the highest vegetation densities in the city and are well known for their better environmental condition. **Fig.16**

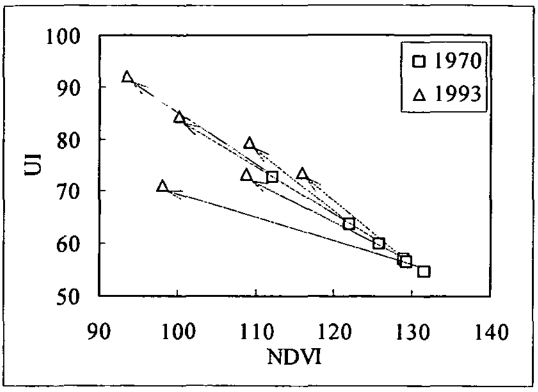

Fig.17 Change of UI and NDVI relation

shows that their NDVI values are high and that their UI values are low. From this it is clear that the UI-NDVI relation for planning units in Colombo City is a relation between the social conditions and the vegetation environment which represents the environmental condition within Colombo City.

(5) Application of the relation between urbanization and the vegetation condition for the quantitative evaluation of urban changes and environmental changes in Colombo City for the 500m by 500m grid

Using the UD values obtained from the building cover map of 1970 UI and NDVI values for 1970 was estimated by Eq.(2) and Eq.(5) in the absence of satellite data of 1970. Changes in UI which represents the change in urbanization and changes in NDVI which represents the change in the environmental condition can be easily seen on a scatter diagram of UI and NDVI values for the two dates. In **Fig.17** some of the large changes have been shown by vectors.

Evaluation of UI and NDVI in 1970 are based on the assumption that Eq.(3) and (5) are independent with time. This evaluation method for change of urbanized area is useful when the TM data is not available.

6. CONCLUSIONS

In this study it was seen that the proposed index UI is strongly related to the density of development in urban areas measured by the percentage of building cover for a grid size of 500m. Therefore UI values for the 500m by 500m grid is effective to evaluate the urbanization quantitatively. It was also seen how UI is strongly related to socio-economic data of urban units in the urban area. Therefore it is useful to estimate socio-economic conditions of urban units. NDVI can be used as a measure of the environmental condition in urban areas. The relation between UI and NDVI for the 500m by 500m grid can be applied to quantitatively evaluate the balance between urbanization and environmental condition in the urban area. Such a quantitative evaluation of urbanization and the environmental condition using satellite data is useful for urban planners particularly in developing countries where updated spatial data of the urban area is difficult to find for effective urban and regional planning and monitoring of the rapidly changing conditions in urban areas.

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REFERENCES

1) Bochenek, Z., Polawski, Z.: Use of remote sensing based GIS for urban studies, *Proc. of 12th EARSel Symposium, Hungary, Remote Sensing for Monitoring the Changing Environment of Europe*, Winkler, P. ed., A.A.Balkema Publishers, Rotterdam, pp.195-199, 1992.
2) Forster, B.: Application of Normalised Vegetation Index differencing for urban change monitoring, *Applications of Remote Sensing in Asia and Oceania*, Murai, S. ed., Asian Association on Remote Sensing, Tokyo, pp.215-221, 1991
3) Jensen, J.R., Bryan, M.L., Friedman, S.Z., Henderson, F.M., Holz R.K., Lindgren, D., Toll, D., Welch, R.A. and Wray, J.R.: Urban/suburban land use analysis, *Manual of Remote Sensing, second edition*, Colwel, R.N. ed., American Society of Photogrammetry, Falls Church, Virginia, pp.1571-1666, 1983.
4) Lillesand, T.M. and Kiefer, R.W.: *Remote Sensing and Image Interpretation, second edition*, John Wiley and Sons, New York, 1987.
5) Ormsby, J.P.: Evaluation of natural and man made features using Landsat TM data, *Int.J.Remote Sensing*, Vol.13, No.2, pp.303-318, 1992.
6) Urban Development Authority: *City of Colombo Development Plan*, Ministry of Local Government Housing and Construction, Sri Lanka, 1985.
7) Department of Census and Statistics: *Demographic Survey*, Ministry of Finance, Planning, Ethnic Affairs and National Integration, Sri Lanka, 1994.
8) Urban Development Authority: *Urban land management project Sri Lanka, Vol 1*, Ministry of Local Government Housing and Construction, Sri Lanka, 1994.
9) Kawamura, M., Jayamanna, S., Tsujiko, Y.: Relation between social and environmental conditions in Colombo Sri Lanka and the urban index estimated by satellite remote sensing data, *Proc.51st Annual Conference of the Japan Society of Civil Engineers*, pp.190-191, 1996.
10) Kawamura, M., Jayamanna, S., Tsujiko, Y.: Relation between social conditions and the vegetation environment in

Colombo City using remote sensing data, *Proc. Asian Society of Remote Sensing*, pp.L/3/1-L/3/6, 1996.
11) Purevdorj, T., Ishiyama, R., Tateishi, R., Furuya, T.: Estimation of percent vegetation cover using vegetation indices, *Proc. of the Annual Conference of the Japan Society of Photogrammetry and Surveying, Oct. 1996*, pp.101-104, 1996.
12) Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H., Sorooshiam, S.: A modified soil adjusted vegetation index, *Remote Sensing of Environment*, Vol. 48, pp.119-126, 1994.
13) Baret, F., Guyot, G.: Potentials and limits of vegetation indices for LAI and APAR assessment. *Remote Sensing of Environment*. Vol.35. pp.161-173. 1991.
14) Huete, A.R.: A soil adjusted vegetation index (SAVI). *Remote Sensing of Environment*. Vol.25. pp.295-309. 1988.

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発展途上国における都市化の衛星データによる定量的評価

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アジア地域での経済発展に伴い発展途上国の大都市では急激な都市化が進展し，都市周辺の自然破壊も甚大なものがある．本研究では都市化の定量的評価を衛星データを利用して行う手法を開発することを研究の目的としている．ランドサットTMデータから求められる都市化指標UIを提案し．UIと都市における建物占有率，人口密度，エネルギー消費量といった都市化を表す要素の間には強い相関性がありUIが都市化を定量的に評価する指標として有効であることを，スリランカ・コロンボ市を例にとり示した．また，都市化指標UIと正規化植生指標NDVIとの関係から，都市化と植生に代表される自然環境変化の関連について衛星データにより定量的に評価する手法を提案した．