Fusion of Multi Resolution Remote Sensing Data for Urban Sprawl Analysis

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Today’s Presentation

- Introduction
- Study area and Data
- Method
- Results and Discussion
- Conclusion

Urbanisation: Overview

- The urban population in India is growing at around 2.3% per annum.
- An increased urban population in response to the growth in urban areas is mainly due to migration.
- There are 35 urban cities having a population of more than one million in India (in 2001).

Urbanisation

Urbanisation is the growth in response to many factors –

- Economic,
- Social,
- Political,
- Physical geography of an area, etc.

Urbanisation types

There are two forms of urbanisation:

- Planned in the form of townships.
- Unplanned or organic [Outskirts, Peri urban] – leads to sprawl

- Happens when two towns are connected through roads, infrastructure improvements, etc.,

Urban sprawl: Characteristics

- Dispersed development in the outskirts.
- Leads to land use and land cover change.
- Devoid of any infrastructure.
- Left out in Government surveys [e.g. national population census].
- Understanding this kind of growth is very crucial for regional planning .
  - Requires temporal and spatial data to understand the urban dynamics
    - Remote sensing data – provides spatial data on temporal scale (since 1970's)

Urban sprawl: Quantification and Mapping

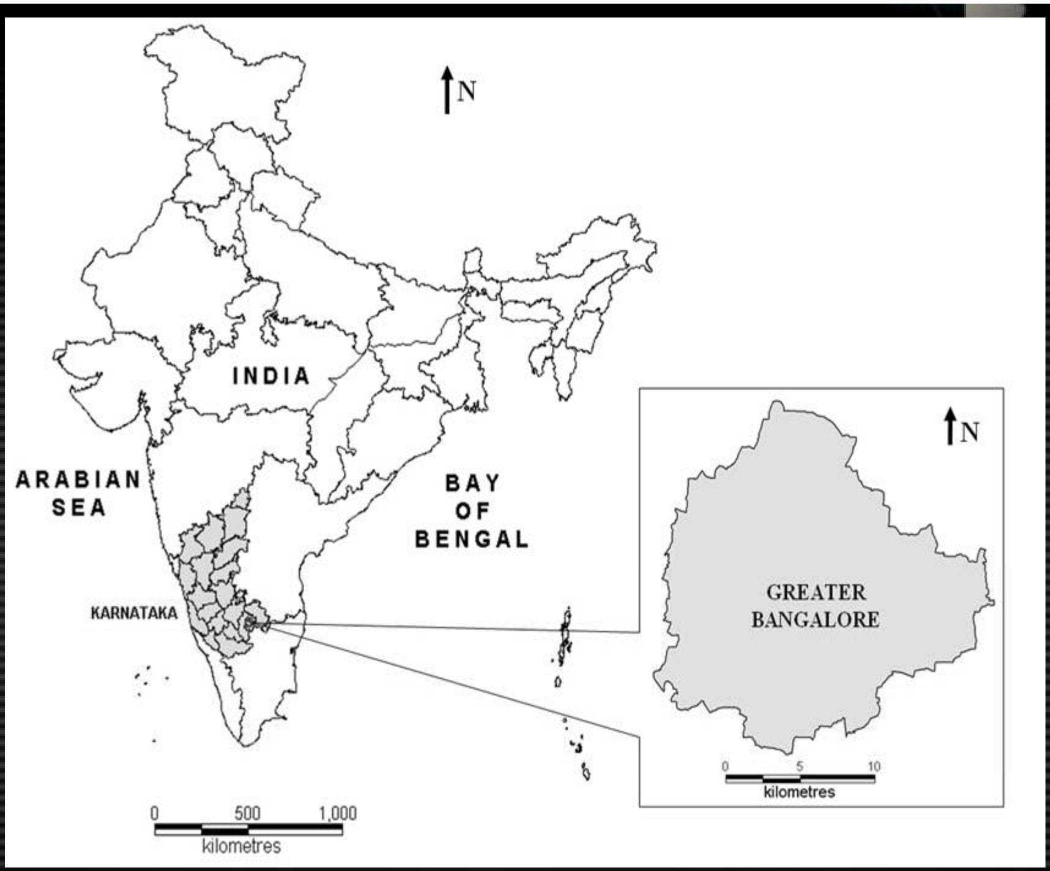
- Remote sensing data (IKONOS, IRS, Landsat, MODIS) provides spatial data (on temporal scale).

- These data are in multi-resolution
  - Spatial (1m, 4m, 5.8m, 23.5 m, 30m , 250,m.....1Km)
  - Spectral [B, G, R, NIR, Superspectral (MODIS), Hyperspectral (Hyperion)]
  - Temporal (1 day, 8 days, 21 days, 24 days .....)

- Analysis of these data (multi resolution) help in capturing urban dynamics.

- Mapping landscapes on temporal scale provide an opportunity to inventory and also to understand changes.

Greater Bangalore, India-Study area



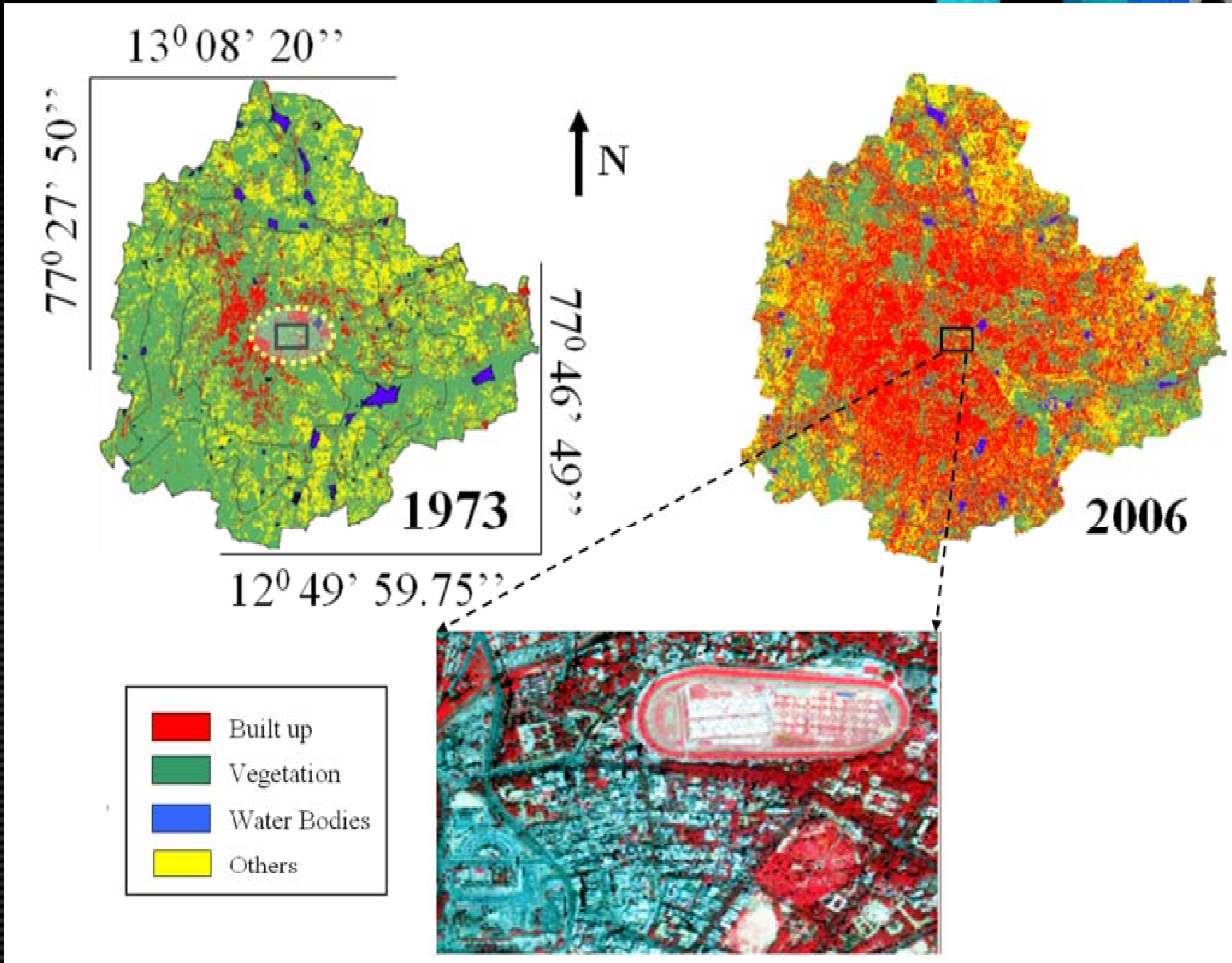
- Area - 741 sq. km.
- Grown spatially more than 10 times since 1949 to 2006 (from 69 km^2 ≈ 700 km^2).
- Fifth largest metropolis in India.

Growth of Bangalore – Consequent land use changes (1973 - 2006)

Year ↓	Class →	Built up	Vegetation	Water	Others
1973	Ha	5448	46639	2324	13903
	%	7.97	68.27	3.40	20.35
2006	Ha	29535	19696	1073	18017
	%	43.23	28.83	1.57	26.37

- **466% increase in built up area from 1973 to 2006.**
- **54% decline in area of water bodies.**
- **65% decline in vegetation.**

1973 – 2006 Land use change



Multi-resolution data

- High Spatial resolution with low Spectral resolution (very expensive).
- Low Spatial resolution with high Spectral resolution (not expensive, some are in public domain as at GLCF website).
- Fusion of these data provide high spatial with high spectral resolution – economical.

Fusion

- Fusion permits identification of objects on the Earth's surface,
  - especially useful in urban areas because the characteristic of urban objects are determined not only by their spectra but also by their structure.
- Objective: to optimise multi-resolution data through fusion
  - to analyse and understand landscape dynamics in Greater Bangalore.

Data used

- Low spatial with Multispectral Data (4m)

  (MSS - IKONOS)

- High Spatial with Single Spectral Data (1m)

  (PANCHROMATIC - IKONOS)

- Ancillary Data

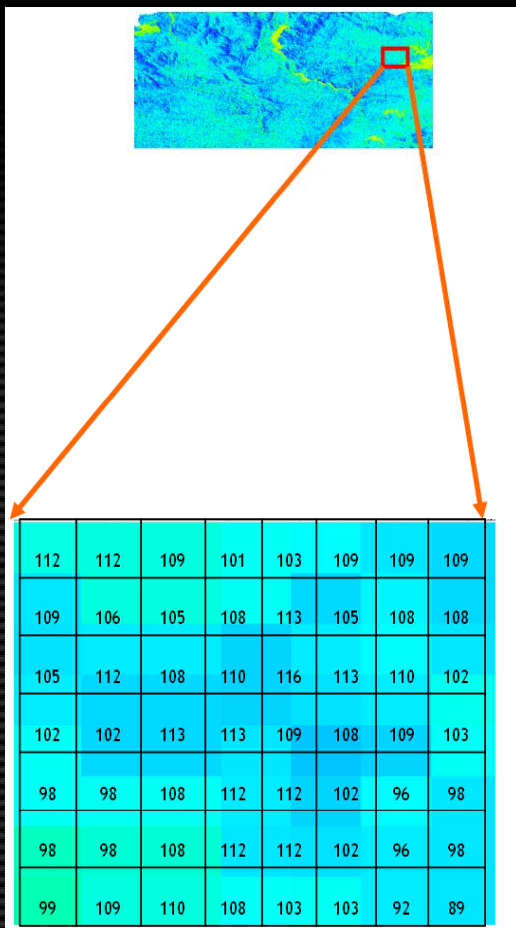
  - Landsat and IRS MSS bands
  - Google Earth images
  - Survey of India Toposheets

Method

- Adoption of SFIM (Smoothing Filter-based Intensity Modulation) for fusion of co-registered multi-resolution images.
- SFIM (Liu, 2000) is a general spectral preserve image fusion technique applicable to co-registered multi -resolution images .
  - based on a simplified solar radiation and land surface reflection model.

Liu, J. U., (2000), Smoothing Filter-based Intensity Modulation: a spectral preserve image fusion technique for improving spatial details, International Journal of Remote Sensing, 21 (18):3461-3472.

Solar radiation and land surface reflection model



$$DN(\lambda)=r(\lambda)\ E(\lambda) \quad \text{……….(1)}$$

where DN is digital number, λ – Band, E(λ) - irradiance, r(λ) - spectral reflectance .

Let

$DN(\lambda)_{low}$ - DN value in a lower resolution image of spectral band λ,

$DN(\gamma)_{high}$ - DN value of the corresponding pixel in a higher resolution image of spectral band γ

and the two images are taken in similar solar illumination conditions,

$$DN(\lambda)_{low} = r(\lambda)_{low}\ E(\lambda)_{low} \quad \text{…………. (2)}$$
$$DN(\gamma)_{high} = r(\gamma)_{high}\ E(\gamma)_{high} \ \text{……………..(3)}$$

Technique - SFIM

Defined as,

$$DN(\lambda)_{sfim} = DN(\lambda)_{low}\, DN(\gamma)_{high} \;/\; DN(\gamma)_{mean}$$

$$= \frac{r(\lambda)_{low}\, E(\lambda)_{low}\, r(\gamma)_{high}\, E(\gamma)_{high}}{r(\gamma)_{low}\, E(\gamma)_{low}}$$

If the two images are quantified to the same DN range and with no significant spectral variation within the neighbourhood, we can presume $E(\lambda)_{low} \approx E(\gamma)_{low}$ $r(\gamma)_{low} = r(\gamma)_{high}$, for any given resolution because the both vary with topography in the same way.

$$= r(\lambda)_{low}\, E(\gamma)_{high} \qquad \text{………} \; (4)$$

- In General SFIM can be written as

$$IMAGE_{SFIM} = \frac{IMAGE_{low} IMAGE_{high}}{IMAGE_{mean}}$$

where,

- $IMAGE_{low}$ is a pixel of a lower resolution image co- registered to a higher resolution image of $IMAGE_{high}$
- $IMAGE_{mean}$ a smoothed pixel of $IMAGE_{high}$ using averaging filter over a neighbourhood equivalent to the actual resolution of $IMAGE_{low}$

Technique – RGB-HIS

- RGB bands are transformed to HIS (Carper et al., 1990)

(hue – dominant or average wavelength of light contributing to a colour,
intensity – total brightness of the colour,
saturation – purity of colour relative to gray)

$$\begin{pmatrix} DN^{l}_{PAN} \\ V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ \frac{-1}{\sqrt{6}} & \frac{-1}{\sqrt{6}} & \frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{6}} & \frac{-1}{\sqrt{6}} & 0 \end{pmatrix} \begin{pmatrix} DN^{l}_{MS1} \\ DN^{l}_{MS2} \\ DN^{l}_{MS3} \end{pmatrix}$$

where DN^{l}_{MS1}, DN^{l}_{MS2}, DN^{l}_{MS3} are the low resolution bands

V_1, V_2 *are the intermediate variables.*

Carper, W. J., Lillesand, T. M., and Kieffer, R. W., 1990, The use of Intensity-Hue-Saturation transformations for merging SPOT Panchromatic and multispectral image data. *Photogrammetric Engineering and Remote Sensing, 56, 459-467.*

Technique – RGB-HIS

$$I = DN^{l}_{PAN} \qquad H = \tan^{-1}\left(\frac{V_2}{V_1}\right) \qquad S = \sqrt{V_1^2 + V_2^2}$$

- *I is replaced with high spatial resolution image – $DN^{h'}_{PAN}$ (contrast stretched to I) which is to be integrated.*

$$DN_{new\_image} = \frac{\sigma_{ref}}{\sigma_{old}}(DN_{old} - \mu_{old}) + \mu_{ref}$$

$$\begin{pmatrix} DN^{h}_{MS1} \\ DN^{h}_{MS2} \\ DN^{h}_{MS3} \end{pmatrix} = \begin{pmatrix} 1 & \frac{-1}{\sqrt{6}} & \frac{3}{\sqrt{6}} \\ 1 & \frac{-1}{\sqrt{6}} & \frac{-3}{\sqrt{6}} \\ 1 & \frac{2}{\sqrt{6}} & 0 \end{pmatrix} \begin{pmatrix} DN^{h'}_{PAN} \\ V_1 \\ V_2 \end{pmatrix}$$

where DN^h_{MS1}, DN^h_{MS2}, DN^h_{MS3} are the fused high resolution multispectral bands.

Technique – Brovey Transform

(Pohl, 1996)

$$\begin{pmatrix} DN^{h}_{MS1} \\ DN^{h}_{MS2} \\ DN^{h}_{MS3} \end{pmatrix} = \begin{pmatrix} DN^{l}_{MS1} \\ DN^{l}_{MS2} \\ DN^{l}_{MS3} \end{pmatrix} + \left(DN^{h}_{PAN} - DN^{l}_{PAN}\right) \begin{bmatrix} \dfrac{DN^{l}_{MS1}}{DN^{l}_{PAN}} \\ \dfrac{DN^{l}_{MS2}}{DN^{l}_{PAN}} \\ \dfrac{DN^{l}_{MS3}}{DN^{l}_{PAN}} \end{bmatrix}$$

where

$$DN^{l}_{PAN} = (1/3)(DN^{l}_{MS1} + DN^{l}_{MS2} + DN^{l}_{MS3})$$

DN^{l}_{MS1}, DN^{l}_{MS2}, DN^{l}_{MS3} are the low resolution bands

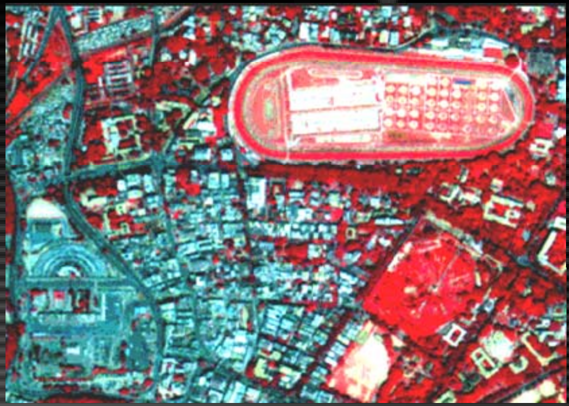
DN^{h}_{MS1}, DN^{h}_{MS2}, DN^{h}_{MS3} are the fused high resolution multispectral bands

Pohl, C., 1996, Geometric aspects of multisensor image fusion for topographic map updating in the humid Tropics. *ITC publication No. 39 (Enschede: ITC), ISBN 90 6164 121 7.*

Results and Discussion

- SFIM, RGB-HIS, Brovey Output –
  - Based on the fusion of IKONOS MSS and PAN data

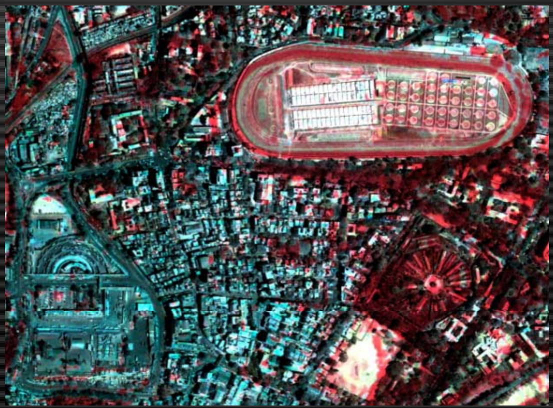
IKONOS PAN 1m



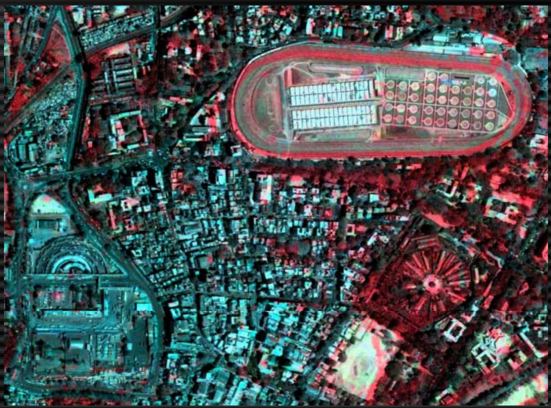
Original bands at 4m

Fused bands at 1m

SFIM



RGB-HIS



Brovey

Performance analysis

- Quantitatively - Correlation Coefficient.

Fusion techniques	Original Band 2	Original Band 3	Original Band 4
HIS	0.22	0.32	0.17
Brovey	0.99	0.98	0.67
SFIM	0.96	0.98	0.97

- Universal Image Quality Index (UIQI) (Wang et al., 2005)

$$Q = \frac{\sigma_{AB}}{\sigma_A \sigma_B} \cdot \frac{2\mu_A \mu_B}{\mu_A^2 + \mu_B^2} \cdot \frac{2\sigma_A \sigma_B}{\sigma_A^2 + \sigma_B^2}$$

The 1st component is the CC for A (original band) and B (fused).
The 2nd component measures how close the mean DN of A and B is.
The 3rd measures the similarity between A and B.
Range is [-1, 1]. If two images are identical, Q = 1.

Fusion techniques	Original Band 2	Original Band 3	Original Band 4
HIS	0.17	0.27	0.11
Brovey	1.00	0.97	0.63
SFIM	0.97	0.97	0.97

Wang, Z., Ziou, D., Armenakis, C., Li, D., and Li, Q., (2005), A Comparative Analysis of Image Fusion Methods. IEEE Transactions of Geoscience and Remote Sensing, vol. 43 (6), pp. 1391-1402.

Conclusion

- SFIM compared to HIS and Brovey transform fusion techniques - Improves spatial details with the fidelity to the image spectral properties and contrast.
- This technique can be used to perform Image fusion for better visualisation of sprawl regions.
- However, the SFIM is not applicable for fusing images that are fundamentally different in illumination conditions or physical properties (optical and radar images).

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