•Complex and irregular urban shapes show significantly higher per-capita emissions compared to compact urban forms.

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Dimensions of Compact Urban Form and CO_2 emissions from Transport in Indian Cities

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INTRODUCTION & AIM

Urban form is increasingly recognised as a determinant of transport-sector CO_2 emissions in fast-urbanizing economies, and is accordingly a focal concern of low-carbon urban planning.

Compact urban development is preferred as a central strategy for promoting sustainable urbanisation worldwide. It is widely associated with lower transport CO_2 emissions by facilitating:

i. **Shorter trip lengths**

ii. **Reduced travel demand**

iii. **Viable public transit**

➢ However, urban compactness has been mostly equated with high density, overlooking other spatial characteristics of compactness that shape travel patterns and emission outcomes.

AIM : This study revisits the compact city paradigm by defining compactness through multiple spatial dimensions and examining their association with per-capita transport CO_2 emissions across 27 Indian cities. Specifically, the study seeks to:

i. Test whether the relationship between five distinct urban form metrics and per-capita transport CO_2 emissions is non-linear in Indian cities; and

ii. Identify threshold values where present.

METHODOLOGY

The methodology proceeds in four steps:

Step 1 - **Defining Compactness through five Spatial Dimensions**

i. Population Intensity ii. Shape Complexity iii. Contiguity
iv. Spatial Concentration v. Landscape Fragmentation

Step 2 - **Calculation of CO_2 emission per capita**

Using Modified IPCC formula and India specific emission factors

Step 3 - **Computing spatial metrics**

Using FRAGSTATS on Landsat 8/9 imagery

Step 4 - **Test for non-linearity and thresholds**

Three statistical methods applied independently, then triangulated.

Quadratic regression
with Lind–Mehlum U-test
Detects smooth curvature

Generalised Additive Model (GAM)
Penalized cubic spline
No functional-form assumption

Segmented regression
with Davies' test
Detects sharp breakpoints

Why three methods?

The three methods differ in the kind of non-linearity they detect — smooth curves, sharp breaks, or shapes left unspecified. Quadratic regression assumes a symmetric U or inverted-U; segmented regression locates a discrete breakpoint; the GAM relaxes both assumptions and lets the data dictate the shape. Convergence across them is therefore taken as evidence of a **robust** finding.

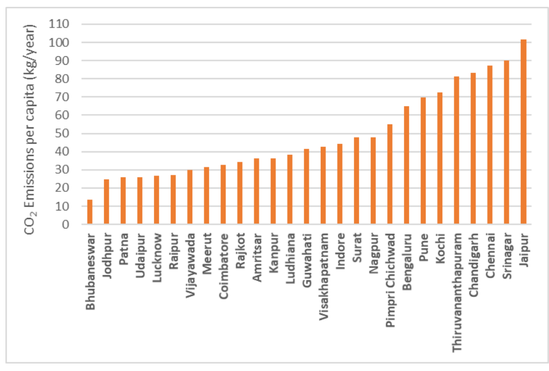
RESULTS & DISCUSSION

The five spatial dimensions defining compactness were measured using five spatial metrics:

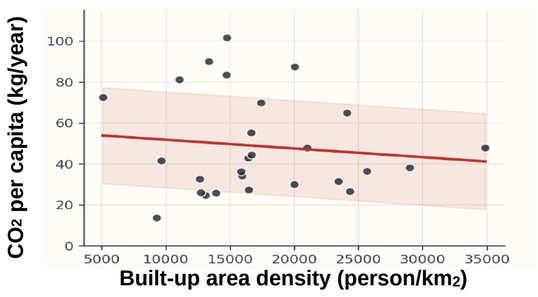
i. Population Intensity - Built-up Area Density
ii. Shape Complexity - SHAPE_AM (Area weighted mean patch shape index)
iii. Contiguity - PLADJ (Percentage of Like Adjacencies)
iv. Spatial Concentration - LPI (Largest Patch Index)
v. Landscape Fragmentation - DIVISION (Landscape Division Index)

➢ Per-capita transport CO_2 emissions across the 27 city sample ranges from:

- 13.75 kg/year (Bhubaneswar) to
- 101.64 kg/year (Jaipur), with 41.49 kg/year as median.



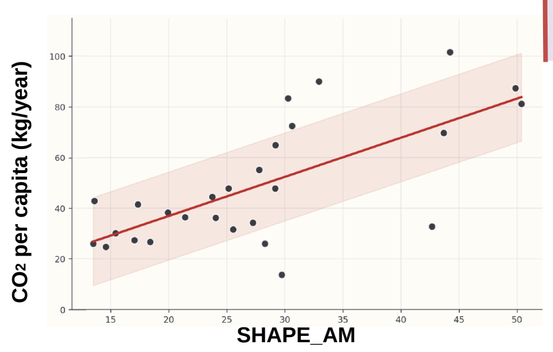
Population Intensity



➢ Higher built-up density is associated with lower per-capita transport emissions, supporting the compact city hypothesis.

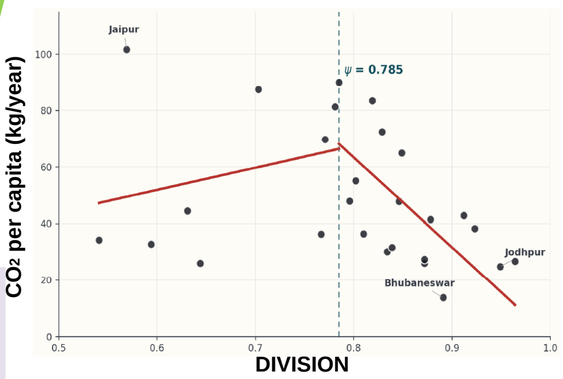
➢ Complex and irregular urban shapes show significantly higher per-capita emissions compared to compact urban forms.

Shape Complexity



Landscape Fragmentation

LOW CO_2



➢ CO_2 emissions peak at moderate fragmentation and decline beyond the threshold.

CONCLUSION

The compact-city idea holds — but compactness is a multi-dimensional construct, not a single attribute.

Continuous mechanism

✓ **Increase Population intensity**
✓ **Decrease Shape complexity**

Threshold mechanism

✓ **Landscape Fragmentation**
(threshold at 0.785)

Below threshold
Integrated cities,
Contain sprawl

Above threshold
Strengthen clusters,
Short range mobility

Low Carbon Urban Development in Indian Cities

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