Spatiotemporal Assessment of Ecosystem Services in a Tier-II Indian City: A Case Study of Visakhapatnam (1995–2022)

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Contents:-

Introduction:-

- An **ecosystem** is a community of living organisms (plants, animals, and microorganisms) interacting with each other and with their non-living environment (like air, water, and soil) in a specific area. These interactions create a system where energy flows and nutrients are cycled.
- **Provisioning and Regulating Services:** These are the essential goods we consume and the environmental processes that keep our world habitable.
- **Cultural and Supporting Services:** These are the non-material and fundamental benefits provided by nature.

Motivation:

- Tier-2 cities in India are growing rapidly, with expanding urban areas replacing forests, farmland, wetlands, and other natural landscapes. While this growth brings development opportunities, it also causes the loss of valuable ecosystem services that support human well-being and environmental balance. The ecological and economic consequences of these changes are often overlooked and rarely measured in a systematic way. Therefore, assessing Ecosystem Service Value (ESV) is essential to understand these impacts and to guide sustainable planning for the future.

Research Gap:

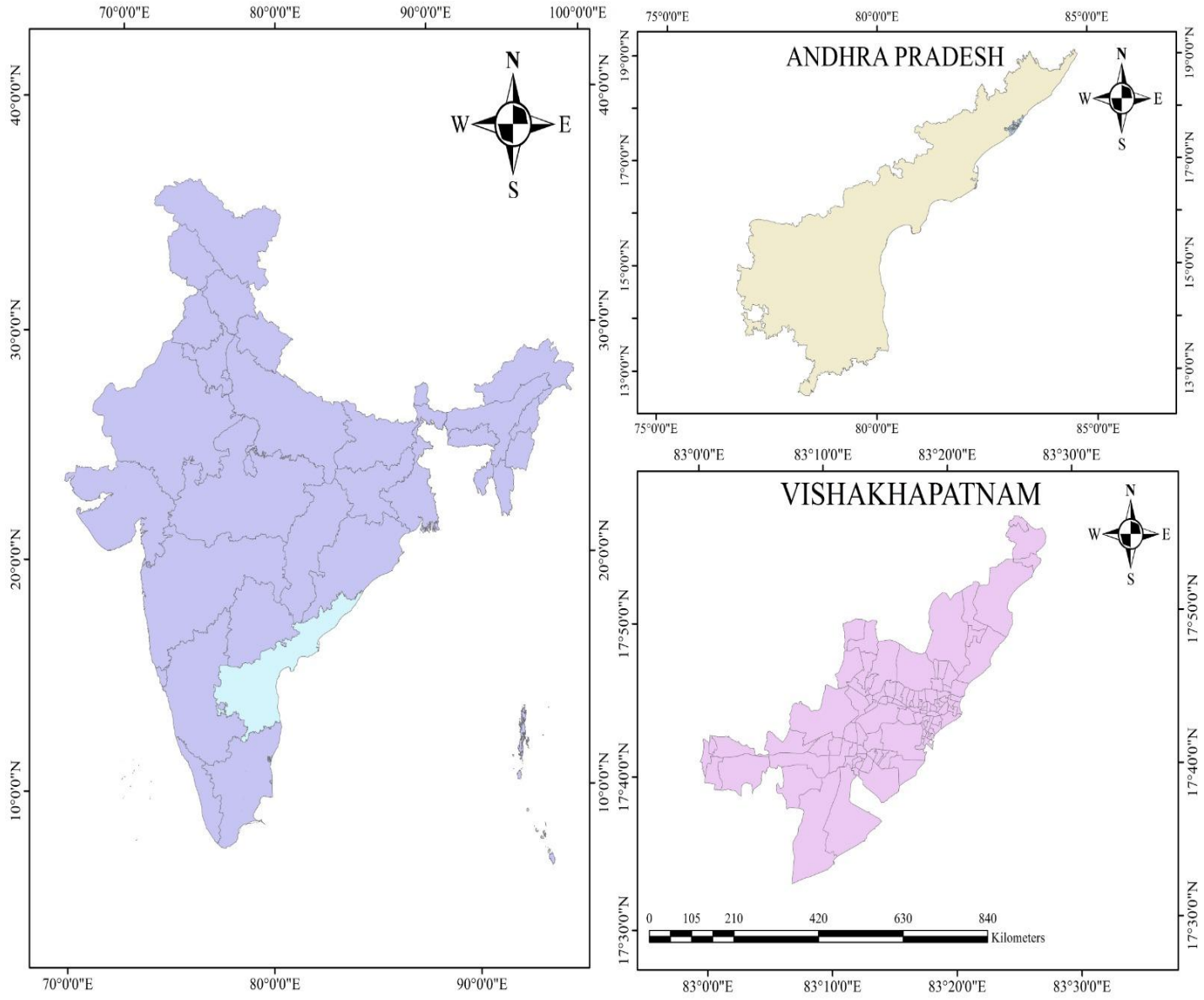
- ESV assessments for Tier-2 cities in India, where urbanization is transforming natural landscapes, but the resulting ecological and economic implications are yet to be systematically quantified.

Objective:

- To assess and quantify the ecosystem services value (ESV) by integrating ecosystem services valuation methods with land use and land cover (LULC) analysis.
- The study aims to evaluate how different land use patterns contribute to various ecosystem services such as provisioning, regulating, supporting, and cultural services.

Study Area:-

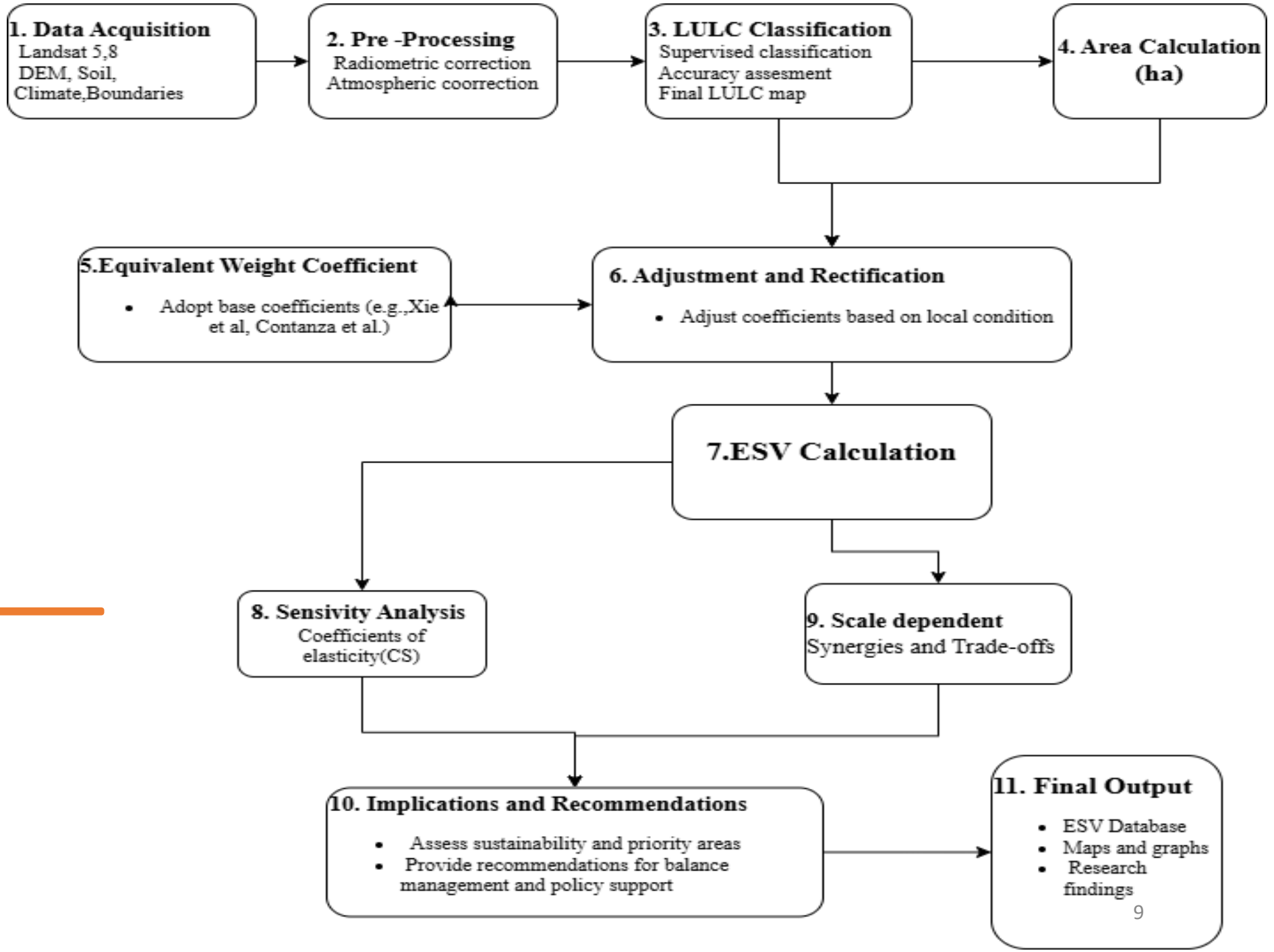
- Visakhapatnam is a major coastal city along the Bay of Bengal on India's eastern coast.
- Located between **17°15'–18°32' N latitude** and **82°54'–83°30' E longitude**.
- Supports diverse ecosystems: forests, agriculture, wetlands, and urban areas.
- Experiences a tropical climate with **1000–1200 mm annual rainfall**.
- Major rivers include the Gosthani River and Sarada River, enhancing regional hydrology



Data Source:

- Landsat DATA ("LANDSAT/LC08/C02/T1_TOA")
- India State Boundary map
- India district boundary map (https://onlinemaps.surveyofindia.gov.in/Login.aspx)
- Precipitation & Climate Data (https://www.climatologylab.org/terraclimate.html)
- Digital Elevation Model (DEM) (https://earthexplorer.usgs.gov/)
- Soil Data https://soilgrids.org/
- Crop Yield Data https://data.gov.in/

Methodology:



Methodology:

- Land Use Land Classification
- Accuracy assessment of thematic layer
- Using dynamic correction factor method for adjusting the ESVs of different land classes in the study region.

- Net Primary Productivity (NPP) – proxy for biomass and ecosystem productivity.
- Normalized Difference Vegetation Index (NDVI) – vegetation health and density
- Precipitation (R) – linked to water-related services
- Fractional Vegetation Cover (FVC) – vegetation extent
- Crop Yield (Y) – indicator of provisioning services

Methodology:

- Dynamic equivalent factors for ecosystem services are calculated as

$$EFij = Bj \times Fn1$$

$$EF_{ij} = P_j \times F_{n2}$$
$$EF_{ij} = V_j \times F_{n3}$$
$$EF_{ij} = Y_j \times F_{n4}$$

- $\mathbf{EF_{ij}}$ → Dynamic equivalent factor
- $\mathbf{B_j}$ → Biomass correction factor (derived from NPP / NDVI)
- $\mathbf{P_j}$ → Precipitation correction factor
- $\mathbf{V_j}$ → Fractional vegetation cover correction factor
- $\mathbf{Y_j}$ → Crop yield correction factor

Methodology:

- Estimating of ecosystem services values using Benefit Transfer Method

- Ecosystem-wise Ecosystem Service Value (ESV):

$$ESV_j = \Sigma (E \times EF_{ij} \times A_j)$$

- Service-wise Ecosystem Service Value (ESV):

$$ESV_i = \Sigma (E \times EF_{ij} \times A_j)$$

- Total Ecosystem Service Value (ESV):

$$ESV = \Sigma \Sigma (E \times EF_{ij} \times A_j)$$

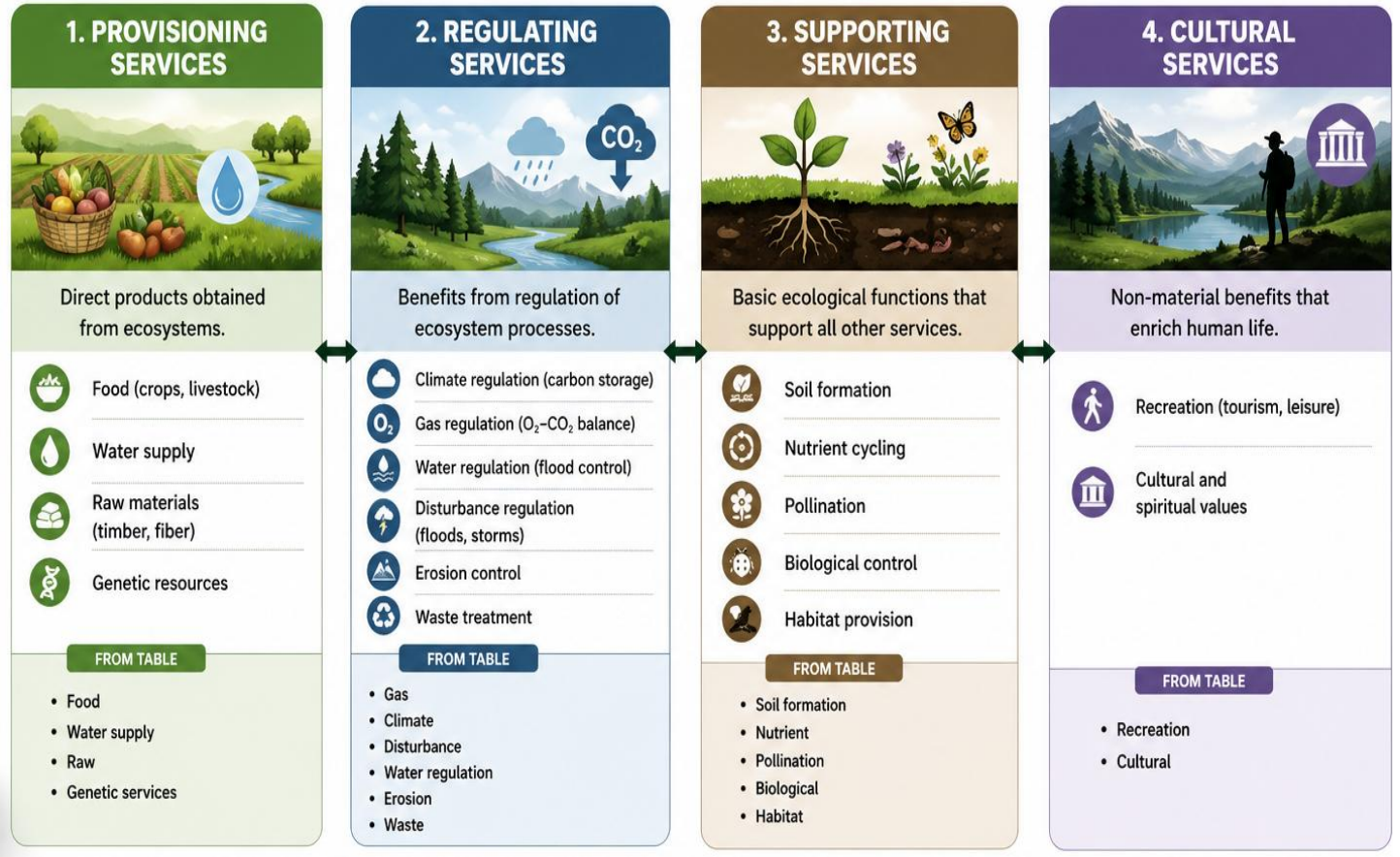
- Percentage Change in Ecosystem Service Value:

$$ESV\_change\ (\%) = ((ESV\_end - ESV\_start) / ESV\_start) \times 100$$

- Evaluating special scale dependents synergies and trade offs of ecosystem services.

Methodology:

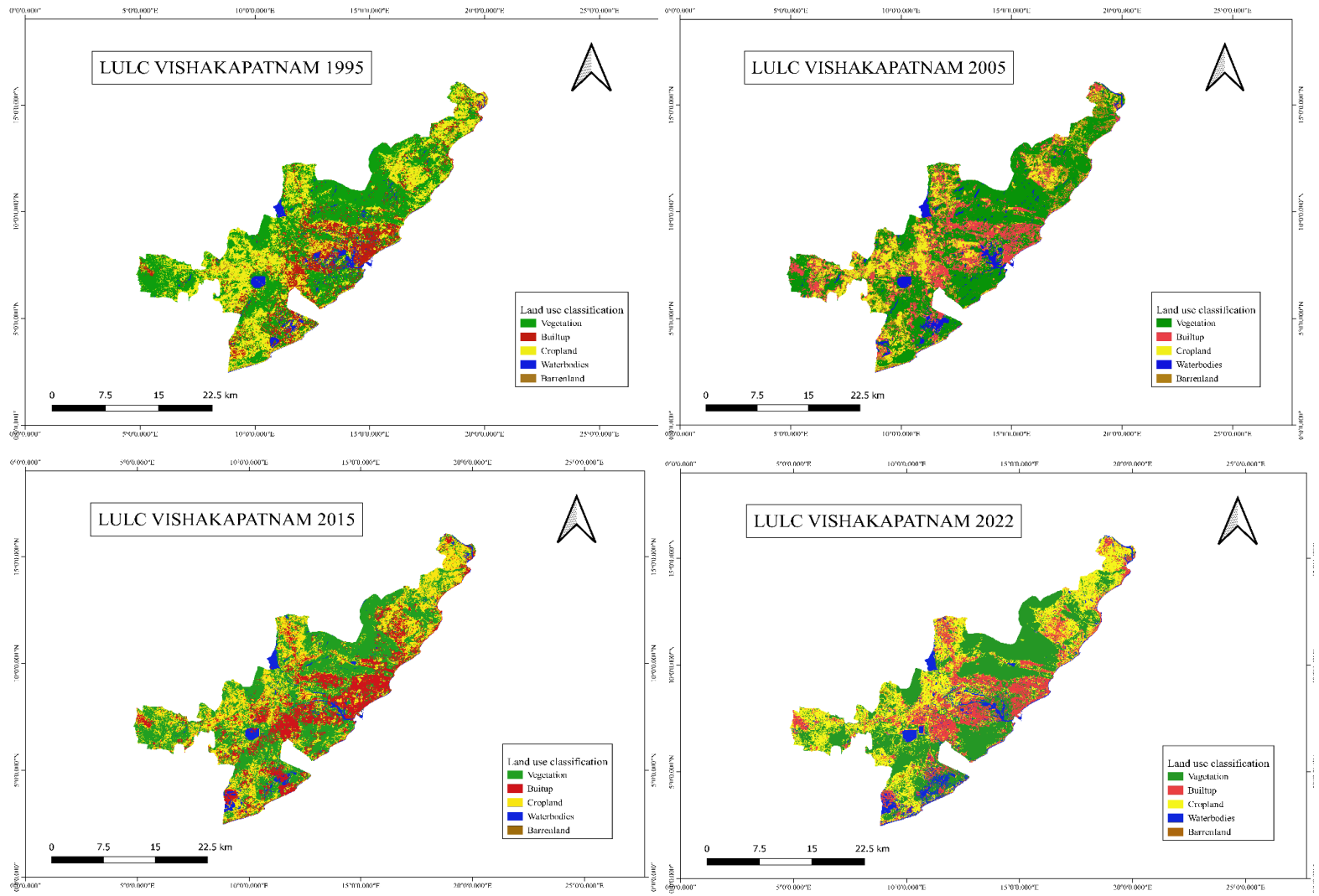
- **Synergies and Trade-offs evaluation**
- **Synergies** occur when multiple services increase together (e.g., vegetation improves climate regulation + habitat + soil).
- **Trade-offs** occur when one service increases at the cost of another (e.g., cropland expansion ↑ food but ↓ biodiversity & regulation).
- Understanding these helps in balanced ecosystem management and sustainable planning



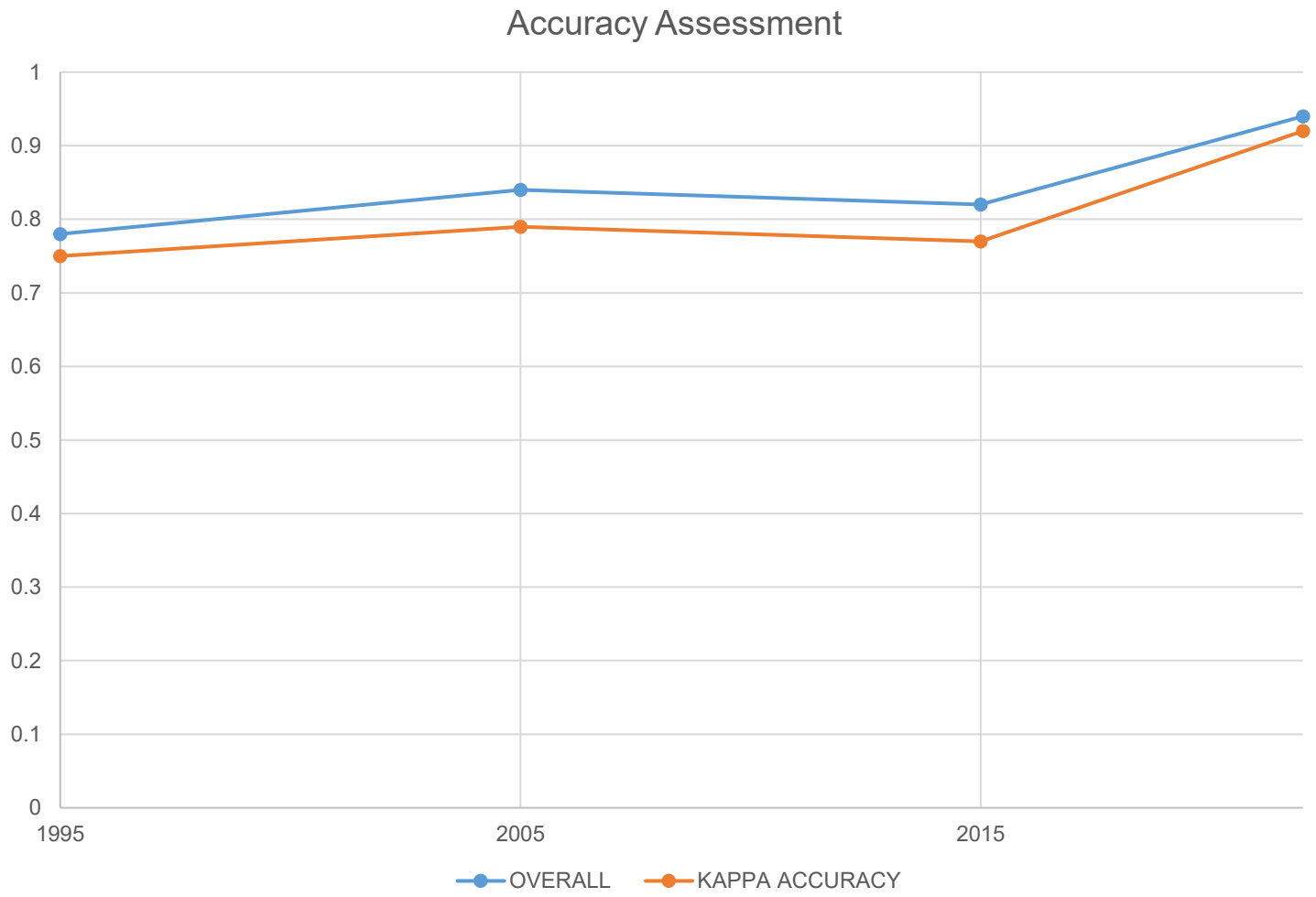
Results:-

- Classification and spatiotemporal changes of LULC of Vishakapatnam (1995-2022).
- Calculated area for each class vegetation, built-up, cropland, waterbodies, barren land in hectares.
- Accuracy assessment of model over all accuracy and kappa accuracy.
- ESV calculation.
- ESV Map and change map.
- ESs Map of Vishakapatnam.
- Spatial association between the four ESs bundles Map.

LULC Map of Vishakapatnam:

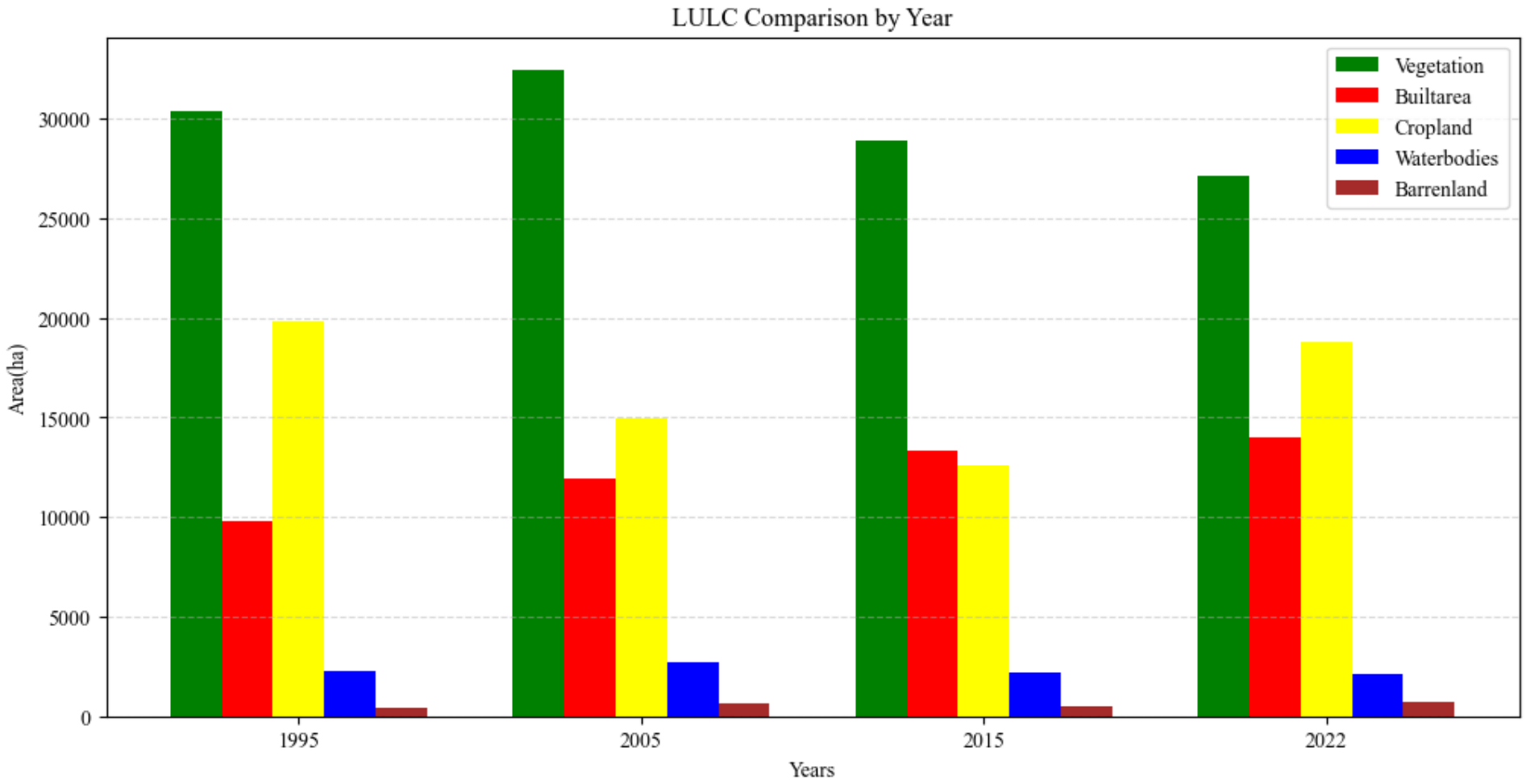


Accuracy Assessment of Vishakapatnam LULC:



YEAR	OVERALL ACCURACY	KAPPA ACCURACY
2022	0.94	0.92
2015	0.82	0.77
2005	0.84	0.79
1995	0.78	0.75

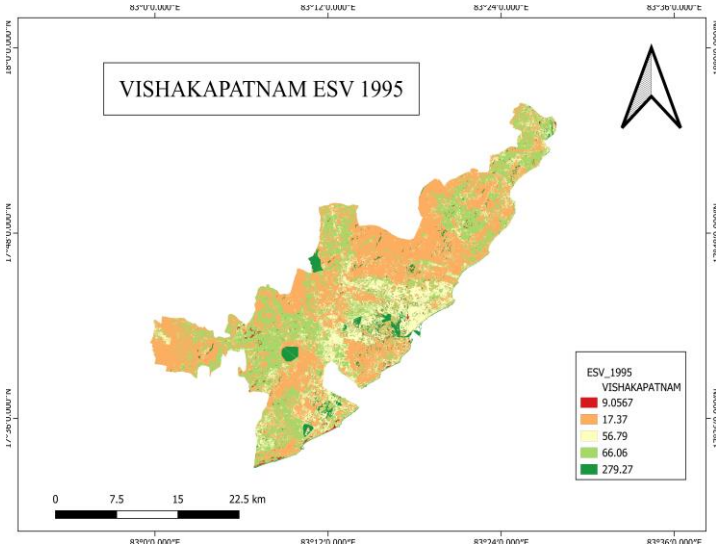
Area in(ha) of each class:

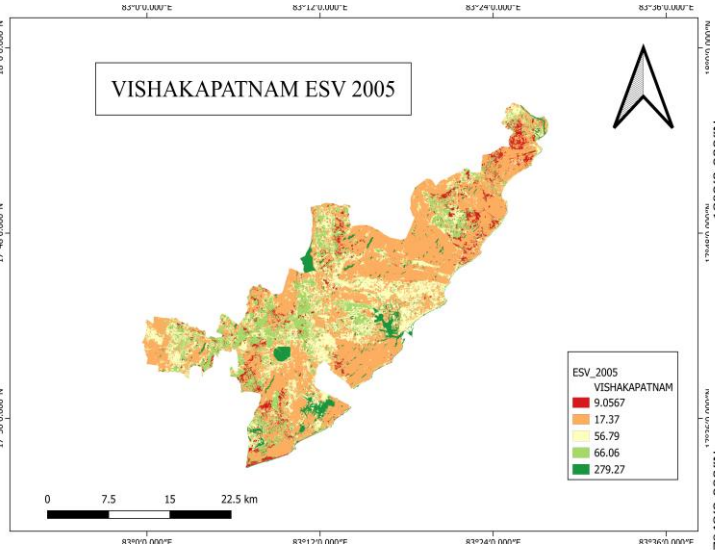


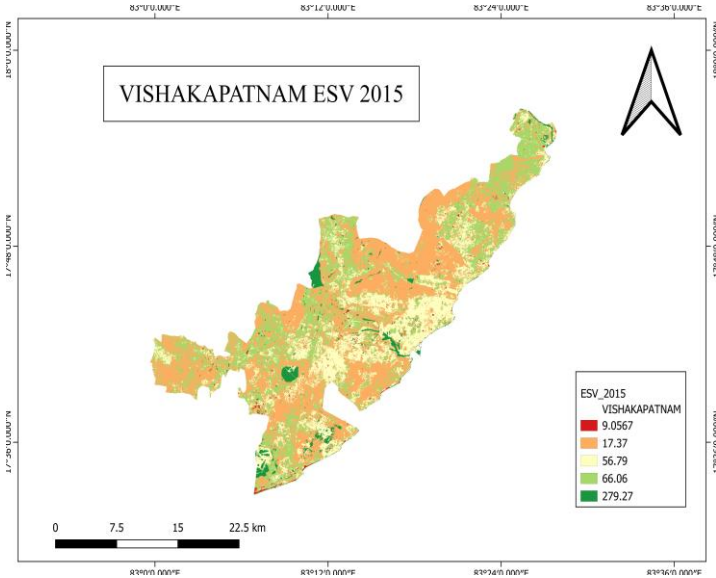
Adjusted ESVs Coefficient of different land classes in the study region

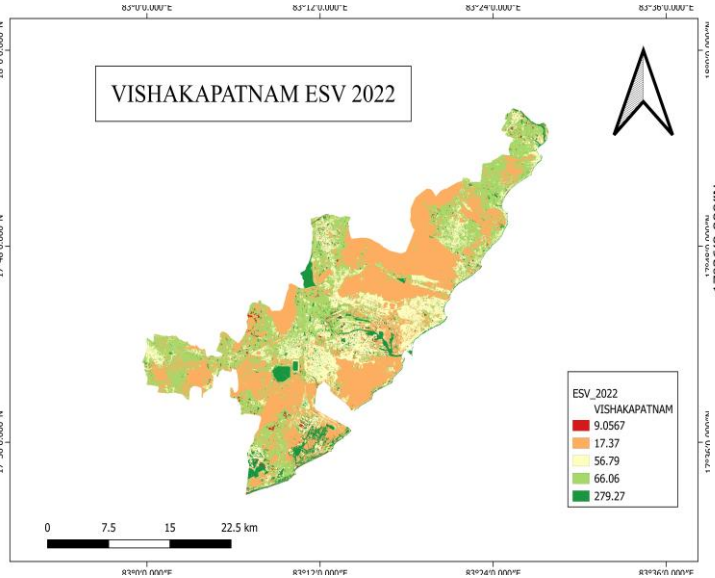
Services	Vegetation	Builtup	Cropland	Water	BarrenLand
Gas	0	0	0	0	10.06
Climate	6	26	215	13	0
Disturbance	0	0	0	81	0
Water reg	0	1	0	166	15.1
Water supply	10	0	234	12	0
Erosion	8	0	74	88	10.06
Soil formation	0	0	370	0	0
Nutrient	0	0	0	51	0
Waste	11	0	208	82	50.32
Pollination	5	0	12	0	0
Biological	5	0	17	26	0
Habitat	184	0	0	66	10.06
Food	181	0	1269	17	0
Raw	8	0	115	15	0
Genetic services	184	0	546	3	0
Recreation	4	166	43	60	0
Cultural	25	0	0	54	5.03
Total	631	193	3103	734	100.63

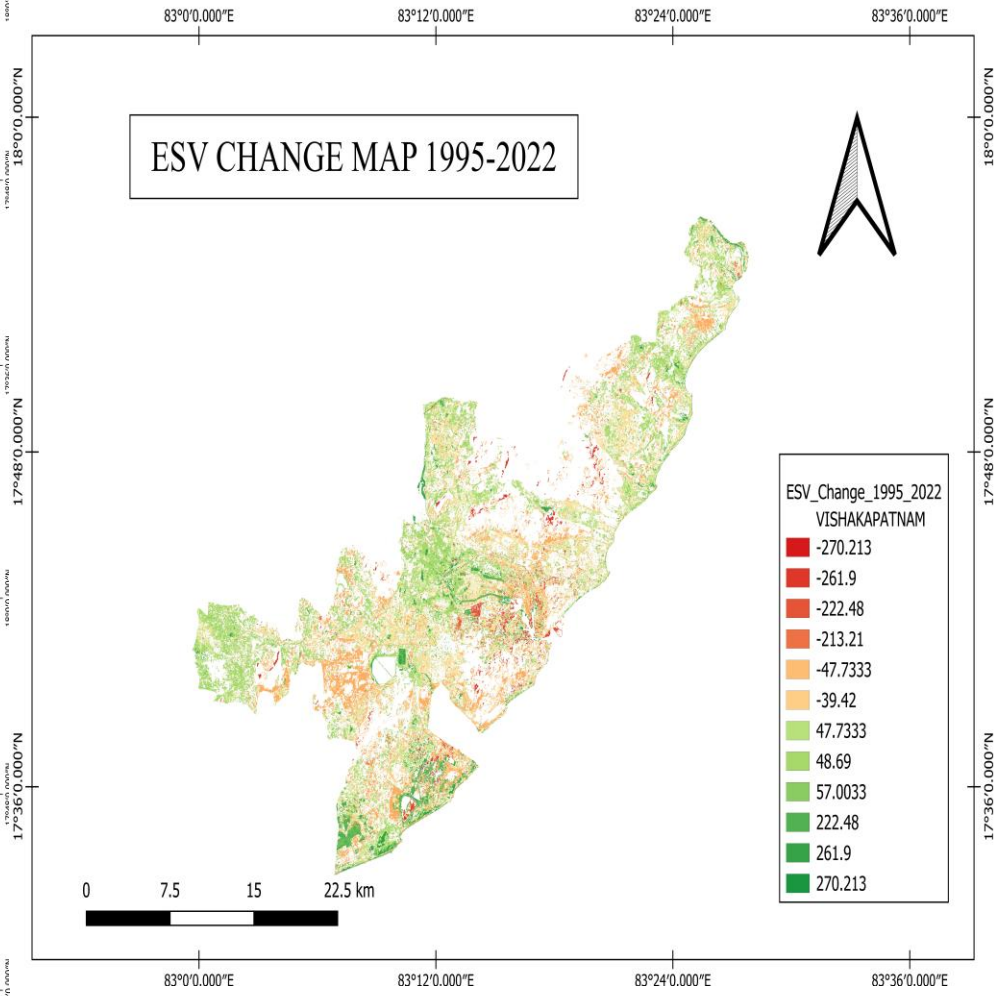
ESV IN Million US$ Per Year



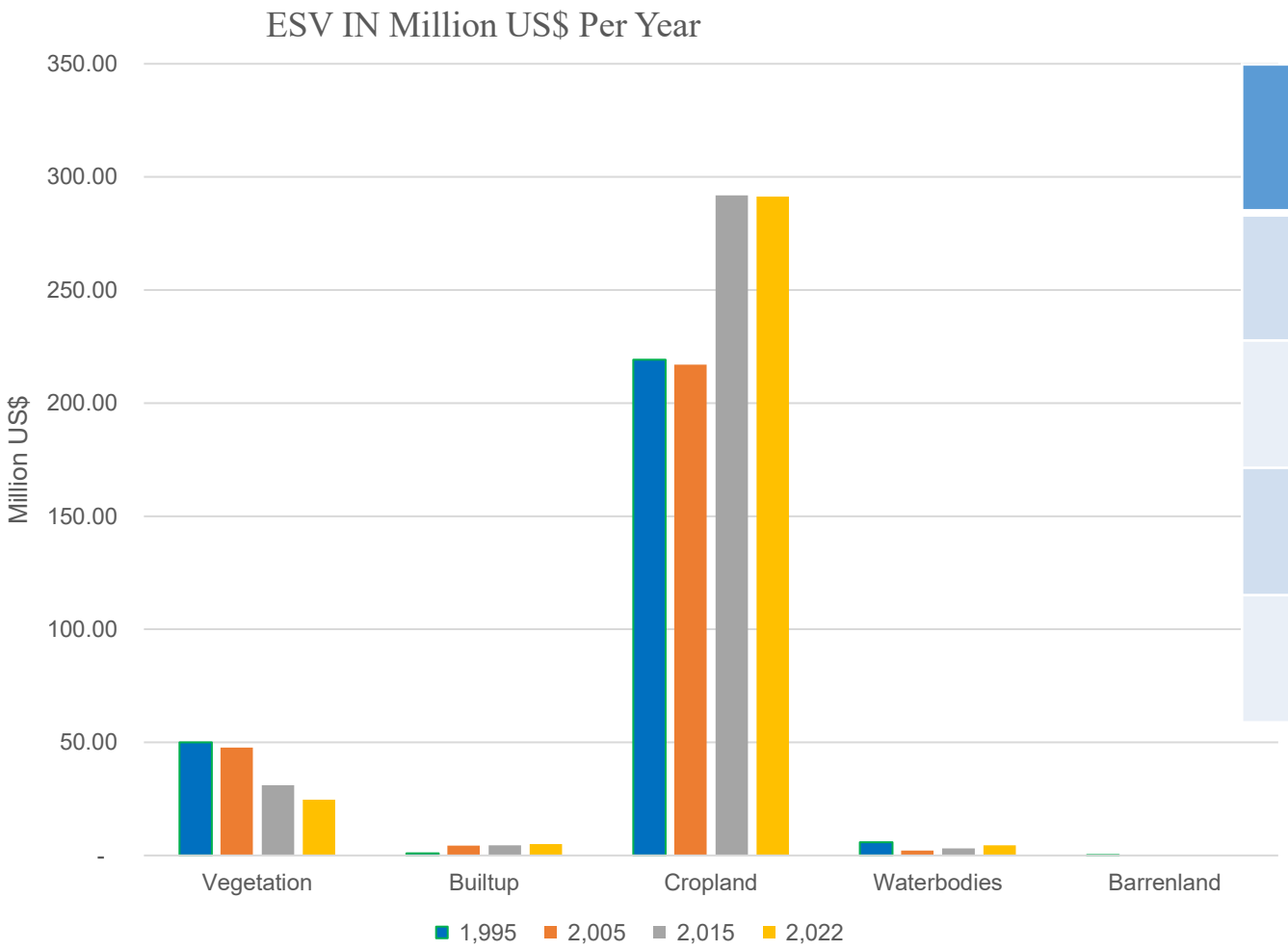






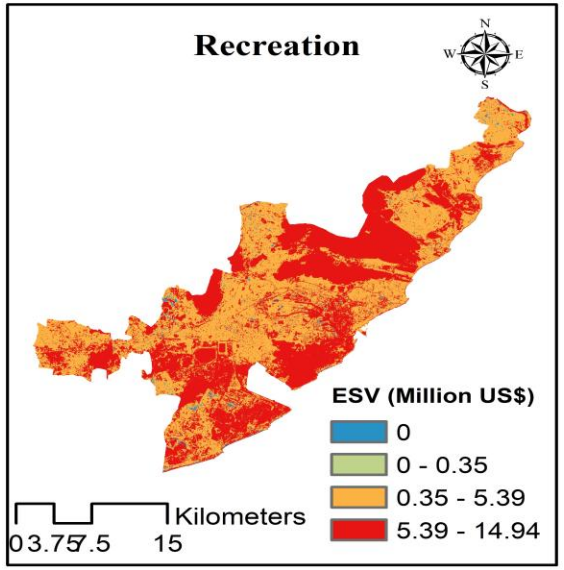


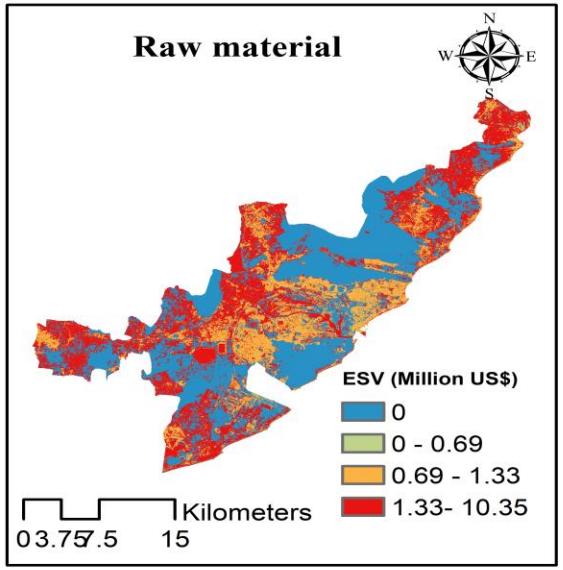
ESV IN Million US$ Per Year:

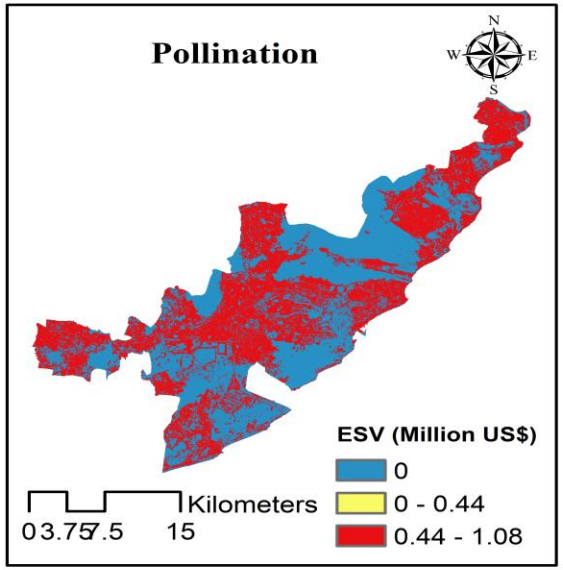


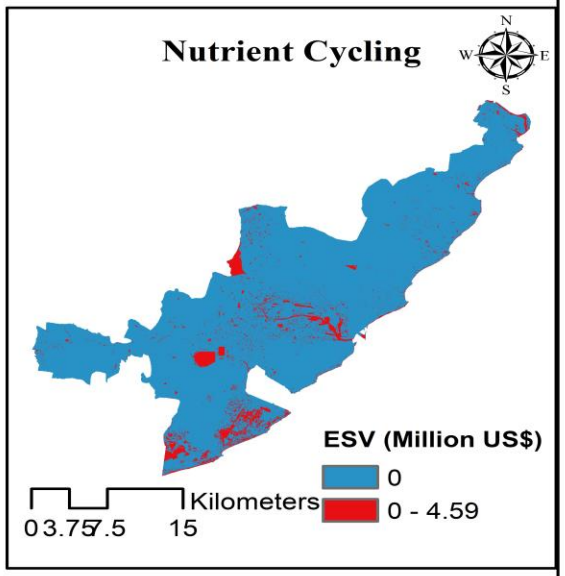
Year	Vegetation	Builtup	Cropland	Waterbodies	Barrenland
1995	50.06	0.89	219.16	5.90	0.01
2005	47.65	4.29	217.02	2.23	0.00
2015	31.09	4.44	291.79	3.17	0.00
2022	24.62	5.08	291.34	4.52	0.01

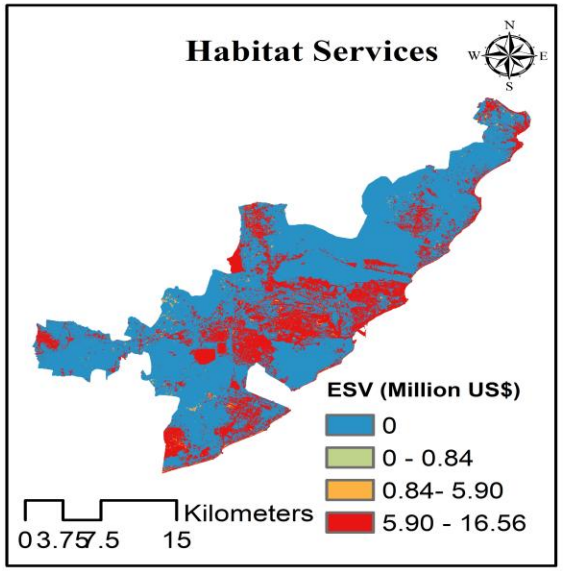
Vishakapatnam Ecosystem Service values (Million US$)

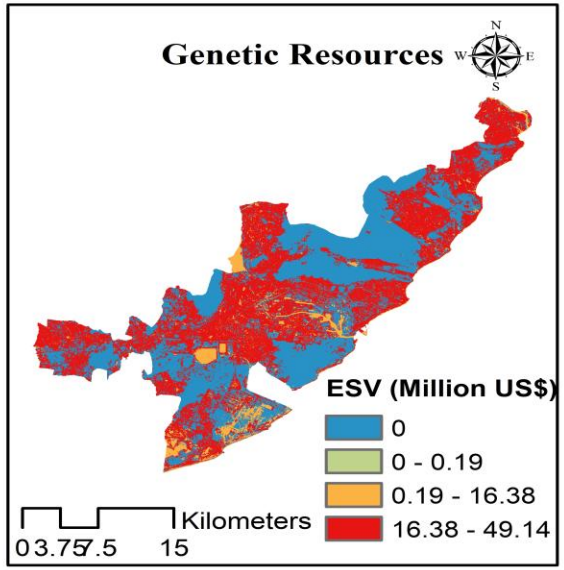


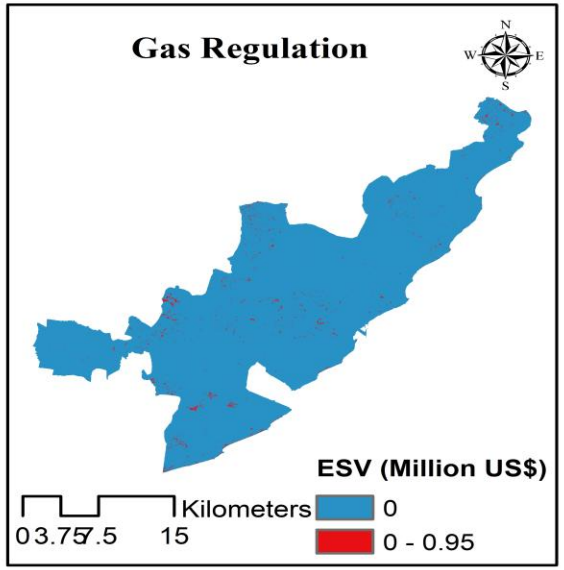


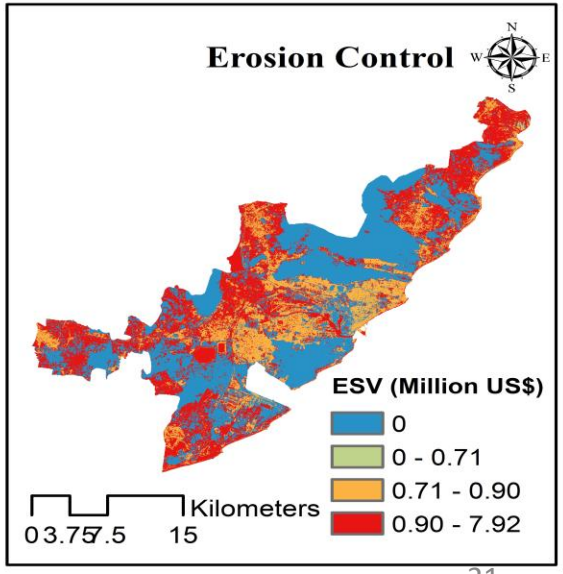




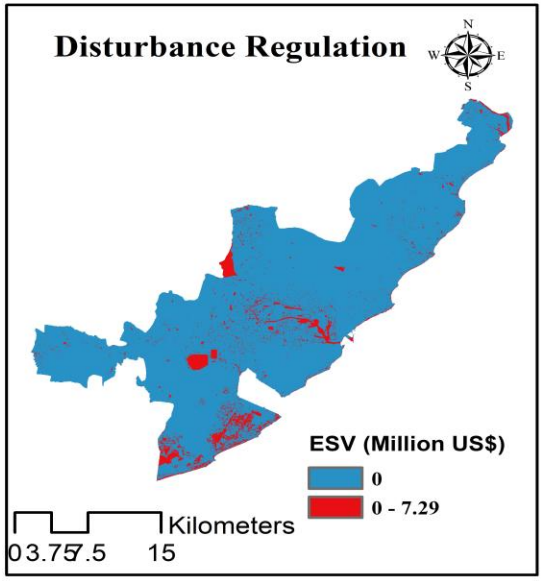


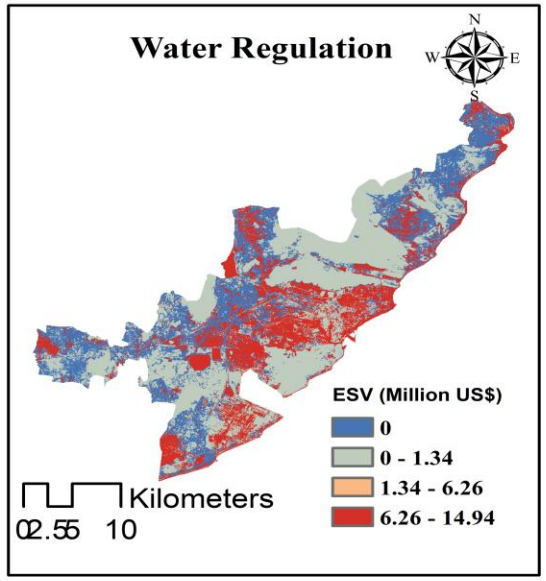


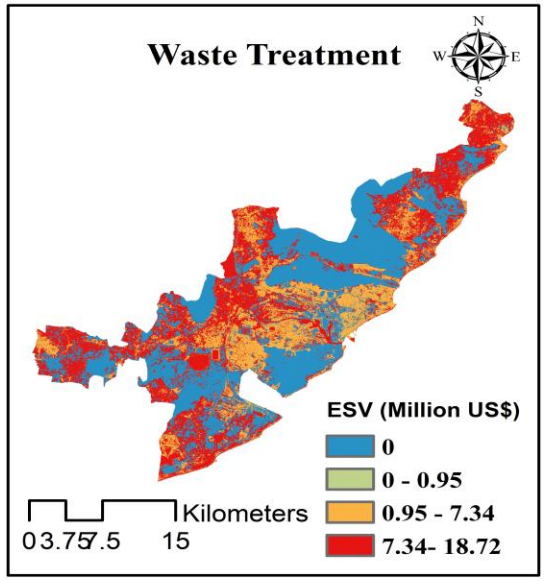


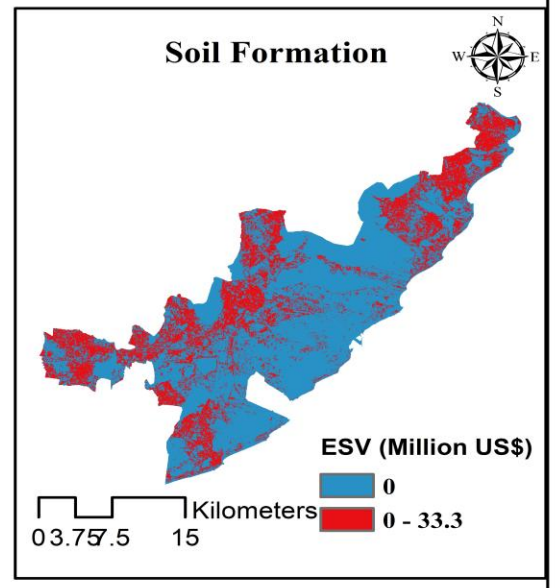


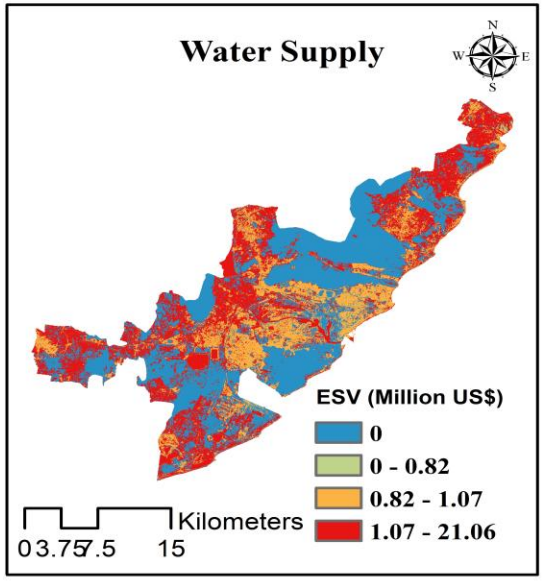
Vishakapatnam Ecosystem Service values (Million US$)

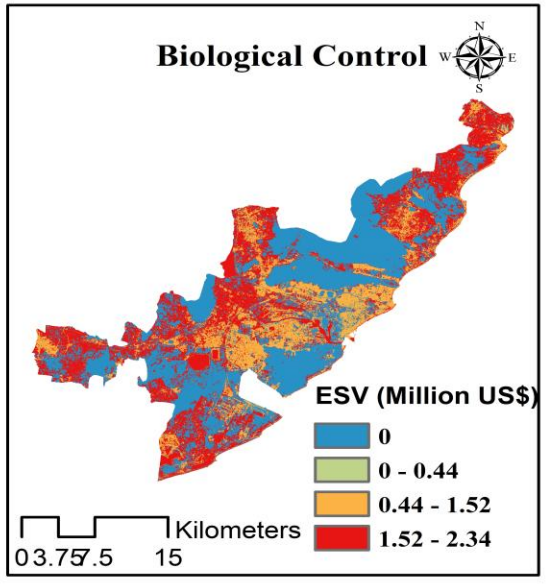


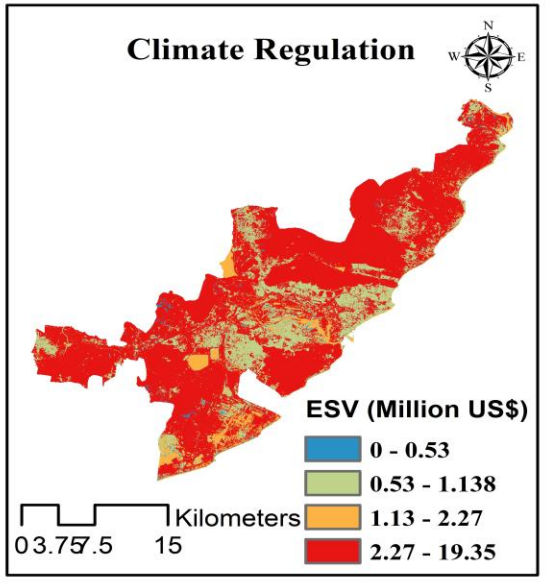


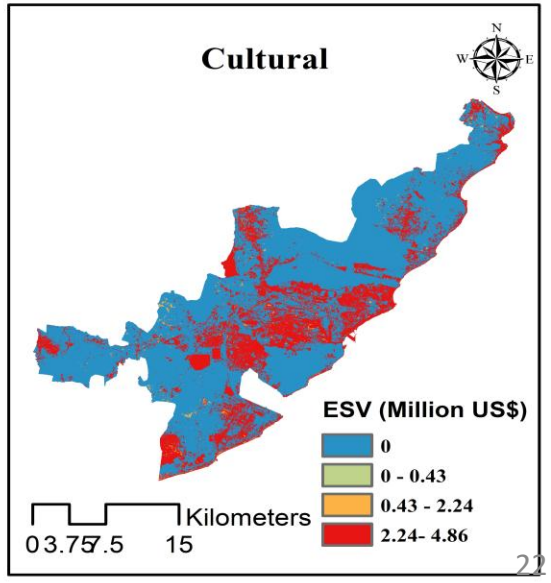




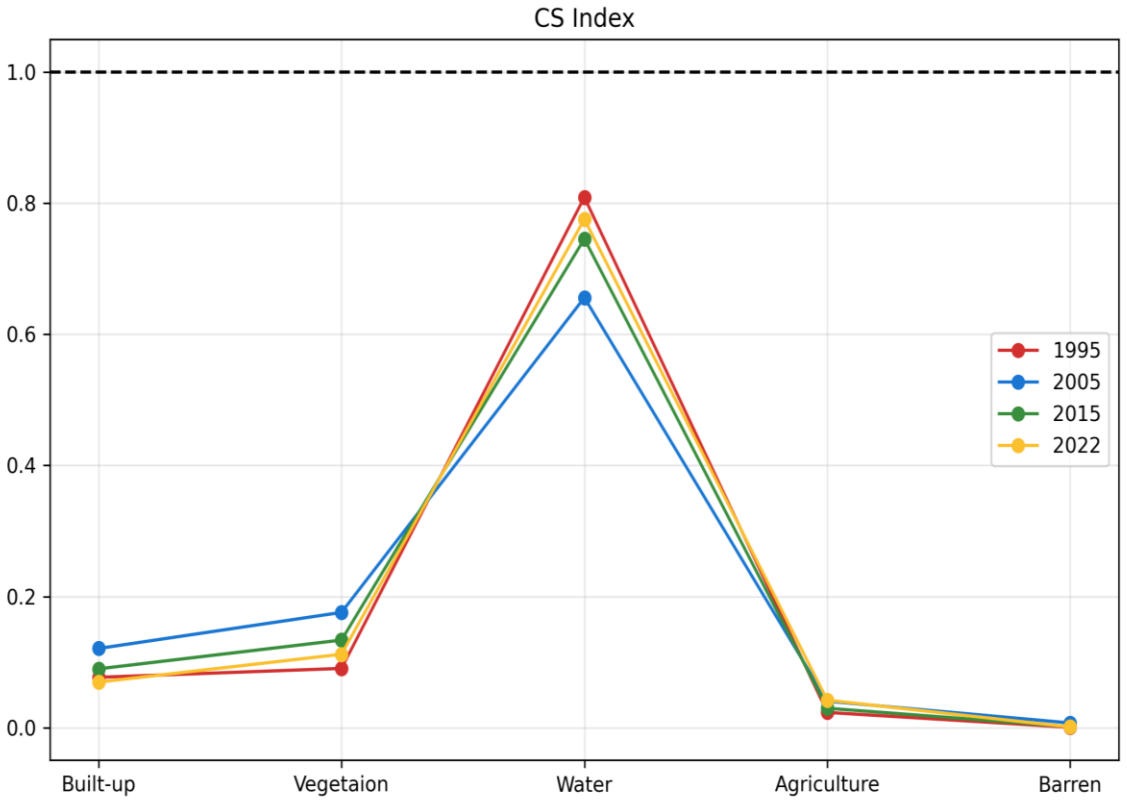


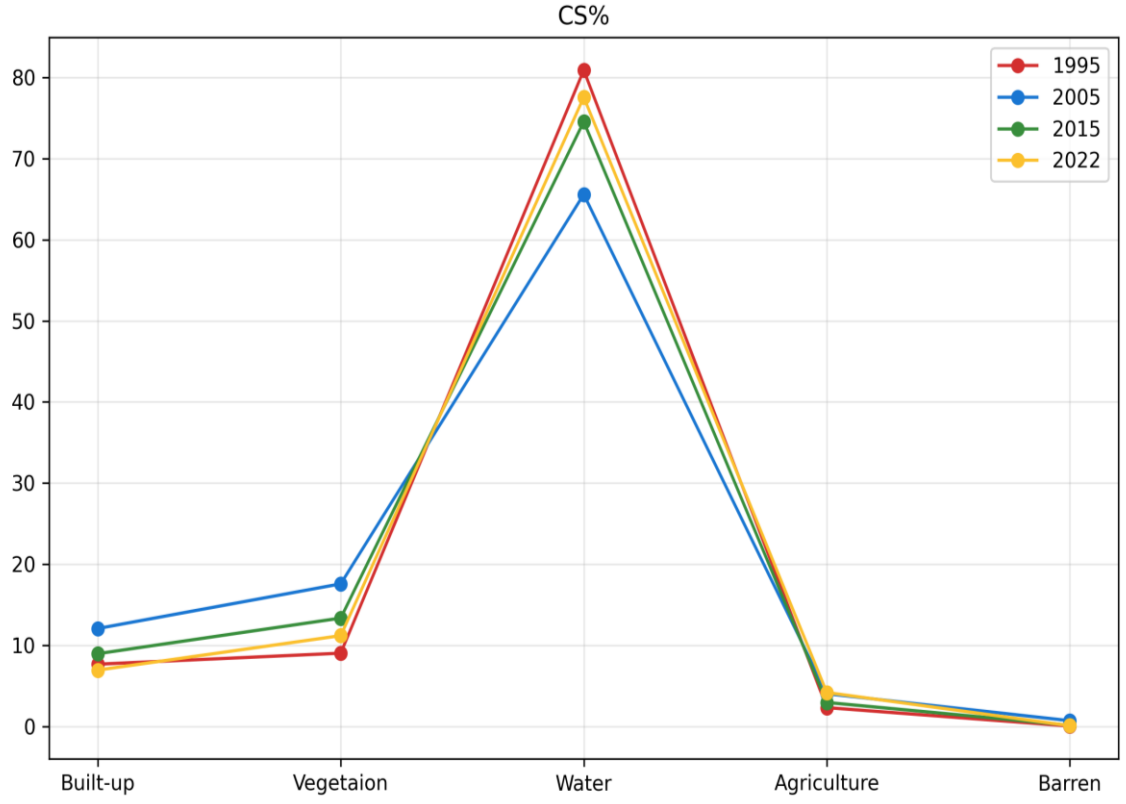






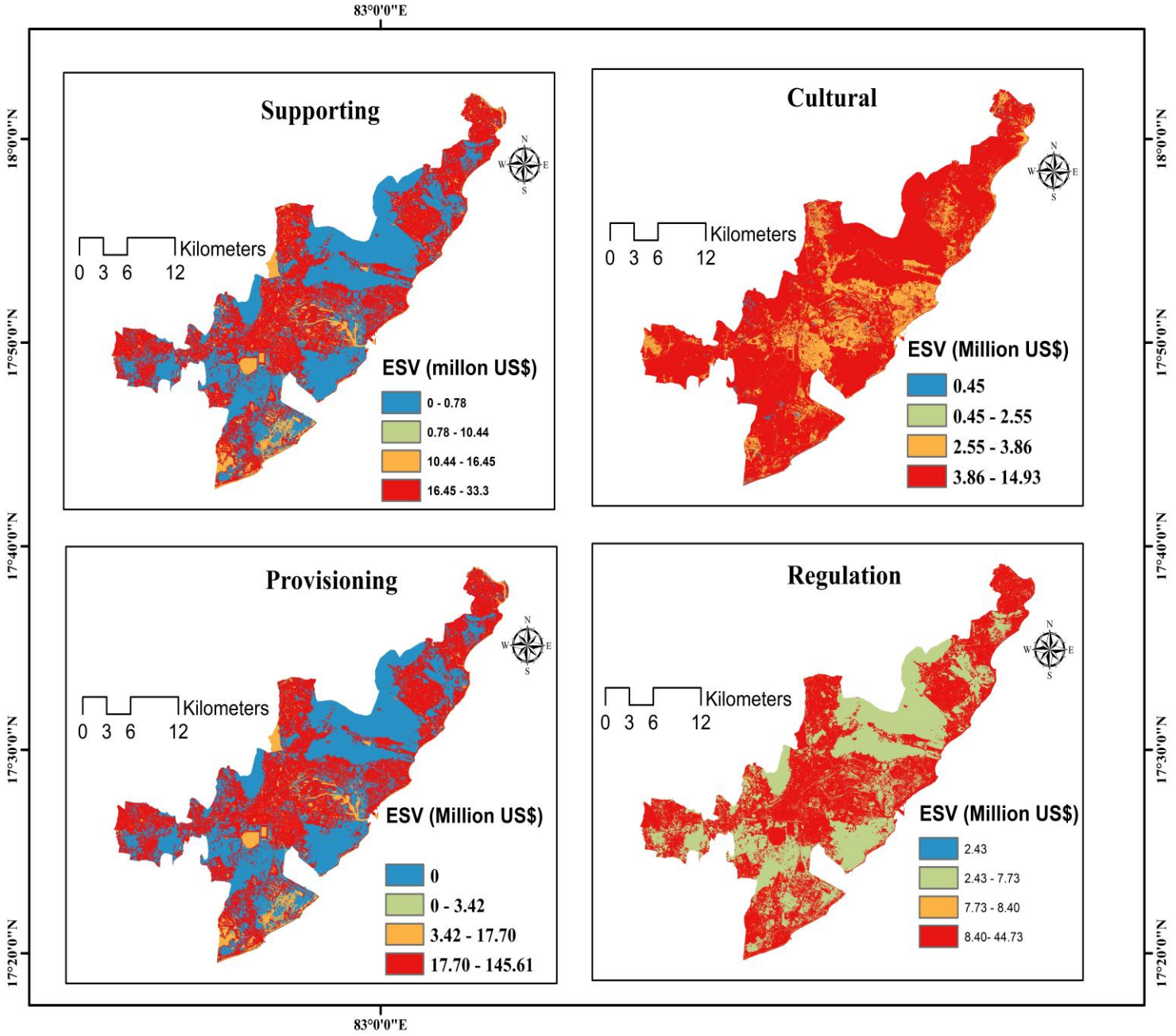
Coefficient of Sensitivity:





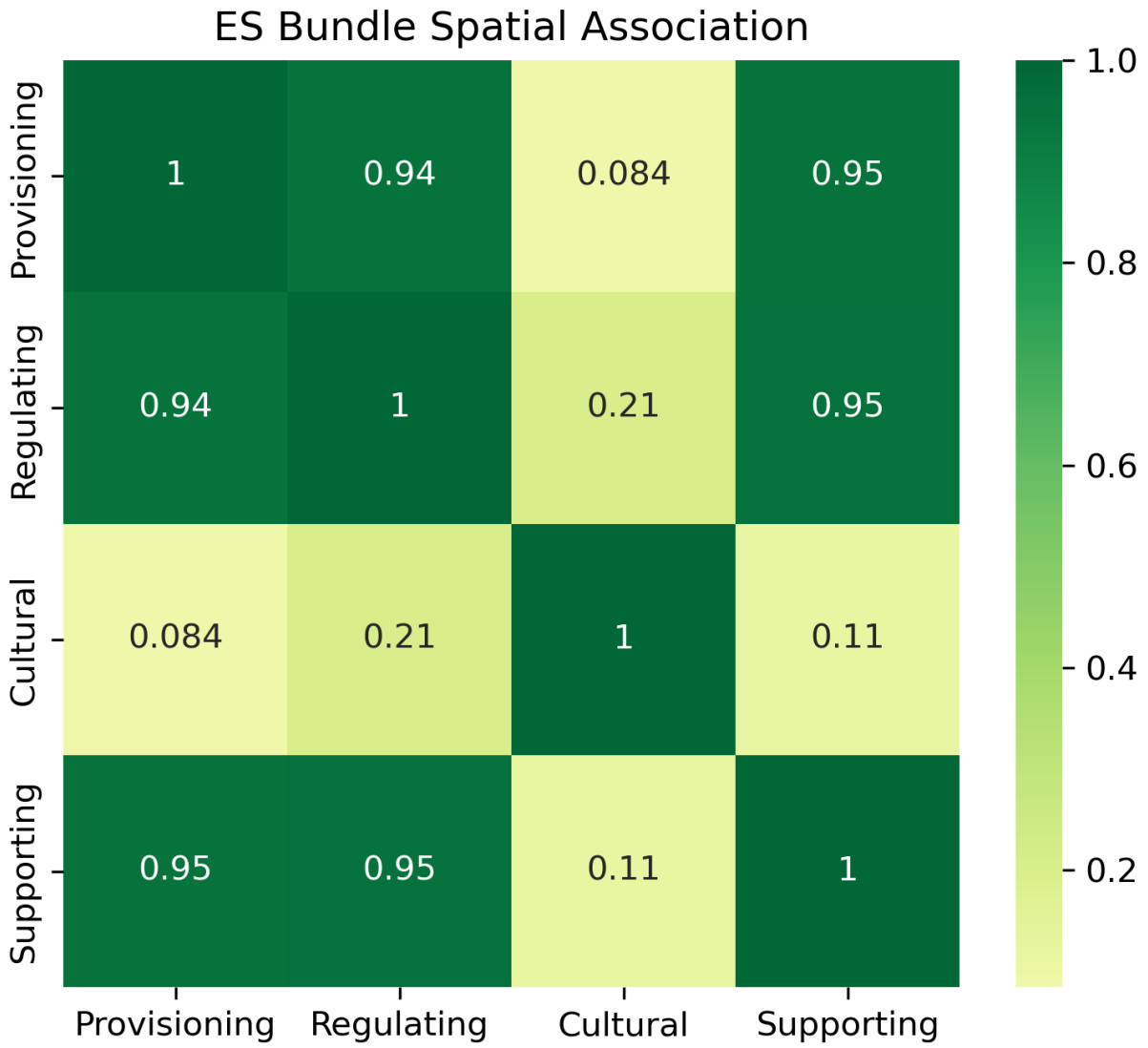
The coefficient of sensitivity (CS) of ESVs for five ecoregions and 16ES at four scenarios (±50%,±40%,±30%,±20%,±10%), Fig shows the percentage of CS at five scenarios.

Spatial association between the four ESs bundles:



Spatial correlation between the four ESs bundles:

- Provisioning, regulating, and supporting services show **strong positive relationships (around 0.94–0.95)**, meaning they mostly occur together.
- Cultural services have **weak connections** with other services, especially provisioning and supporting.
- This suggests cultural benefits are **located separately**, often in urban or coastal/tourism areas.
- Overall, the region shows **strong ecological synergy**, but planning is needed to balance development and ecosystem health.



Summary:

- Total 5ESs were chosen, and their monetary values are estimated using the adjusted equivalent value coefficient.
- Vegetation is the dominant land use type in the study region Vishakapatnam, and contributes 43.23% to the total geographical extent, followed by Cropland (30.01%), Built-up area(22.28%), Waterbodies(3.34%), Barren land(0.11%).
- Change in ESV in Vishakapatnam from 1995-2022 is 5.50%.
- Provisioning, regulating, and supporting services show strong positive relationships (~0.94–0.95), indicating they occur together, whereas cultural services have weak associations with other services, especially provisioning and supporting.

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