Trends and Drivers of Land Use/Cover Change in India

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Background

• Three principal objectives
  – To understand the major LCLUC transition activities in the study region.
  – To advance our understanding of the causes of LCLUC.
  – To improve our understanding of the historical effects of LCLUC dynamics on the quantities and pathways of terrestrial carbon and nitrogen fluxes.
SSEA Region

- Covers about 16% of earth’s land surface
- Characterized by a long history of LCLUC activities
- the home for over 50% of the world’s population
- Study LCLUC dynamics country-by-country basis
Carbon Budget for SSEA countries
(2000s)

\[ \text{NBP} = \text{NEP} - \text{FIRE} - \text{LUC} \]

-ve is C Source
+ve is C Sink

Cervarich et al. 2016
Quantification of LCLUC in India – Reviewed Literature

• We reviewed literature for LCLUC studies covering India published between 1980 and May 2015.

• Overall, the literature review resulted in more than 630 articles that we studied in detail.
  – About 72% of all articles focused on LCLUC processes and rest on causes of LCLUC
Quantification of LCLUC Dynamics & Causes - Reviewed Literature

Dynamics

• Studies are carried out small regions
• Studies are carried out using coarse resolution remote-sensing products
  – tend to mask highly fragmented land
• Data is not available at regular time interval

Causes of LCLUC

• No geospatial socioeconomic data available at national scale
• Data collection efforts (e.g., social surveys) are focused on small regions
• Biophysical variables are compiled based on courser resolution global scale data sets
Dynamics

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All these constraints are hindering effective national level planning and policy-making.

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Dynamics & Causes of LCLUC in India –
Our Approach

• Quantified land-cover conversion (~30m resolution) at national scales using Landsat-MSS/TM imageries (30m) at decadal time interval (1985, 1995, and 2005)

• Quantified the causes by estimating spatial logistic regressions between land-cover conversion estimates and socioeconomic and biophysical factors
  – used village level (>630,000 administrative units) socioeconomic data (>200 variables) at national scale
  – evaluated our regression results through collective evidence from synthesis of 102 case studies
We studied the causes (spatial determinants as opposed to aggregate) of three broad LCLUC that are central to land use planning in India:
- Underutilization of land area (non-productive land specifically fallow land and wasteland)
- Deforestation and forest degradation, and
- Increase in forest area.
Studied Causes for Three LCLUC Types

• We studied the causes (spatial determinants as opposed to aggregate) of three broad LCLUC that are central to land use planning in India
  – Underutilization of land area (non-productive land specifically fallow land and wasteland)
  – Deforestation and forest degradation, and
  – Increase in forest area.

Approach for LULUC change mapping
Wall-to-wall Landsat Analysis (30m)

- Uniform Classification Scheme: IGBP
- Patch to Patch Land Dynamics
- Ground Validation (>12000 points)

Roy et al. (Remote Sensing, 2015)
LCLUC Dynamics at National Scale

Meiyappan et al. (2016)
LCLUC Dynamics at National Scale

Meiyappan et al. (2016)
LCLUC Dynamics at National Scale

Meiyappan et al. (2016)
Regional LCLUC Dynamics

Meiyappan et al. (2016)
Socioeconomic Causes of LCLUC

• A key aspect of our study is the compilation and usage of the most detailed, national level spatial database
  – over 80 socioeconomic factors at village/town level (~630,000 administrative units) for two consecutive census years (1991 and 2001).
Data - Administrative Hierarchy

Village (~630,000 units)

- Captures the high granularity in socioeconomics
- Used village specific qualitative variables that reflect the base of the socio-economic culture prevalent in rural parts of India
Socioeconomics: Illustration with example

Best Res. Data (Currently Available) > 100x improvement Our Database
**Broder Cluster and Explanatory Factors - Examples**

<table>
<thead>
<tr>
<th>Irrigation Infrastructure</th>
<th>Proportion of cropland irrigated</th>
<th>Proportion of area irrigated by government canal</th>
<th>Proportion of area irrigated by private canal</th>
<th>Proportion of area irrigated by well without electricity</th>
<th>Proportion of area irrigated by well with electricity</th>
<th>Proportion of area irrigated by tube well without electricity</th>
<th>Proportion of area irrigated by tube well with electricity</th>
<th>Proportion of area irrigated by tanks</th>
<th>Proportion of area irrigated by rivers</th>
<th>Proportion of area irrigated by lakes</th>
<th>Proportion of crop area irrigated by other means</th>
<th>Availability of well irrigation with electricity</th>
<th>Availability of tube well irrigation with electricity</th>
<th>Availability of irrigation facility</th>
<th>Availability of well irrigation without electricity</th>
<th>Availability of tube well irrigation without electricity</th>
<th>Availability of tank irrigation</th>
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**Income dependency: Binary variables coded to indicate primary occupations of each village.**

<table>
<thead>
<tr>
<th>Building/mining Materials</th>
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<tbody>
<tr>
<td>Dairy/cattle/leather</td>
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<tr>
<td>Wool/Woollen Blankets</td>
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<tr>
<td>Poultry</td>
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<td>Coffee Production</td>
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<tr>
<td>Tea production</td>
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<tr>
<td>Coconut Production</td>
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<tr>
<td>Rubber production</td>
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<tr>
<td>Forestry-related Products</td>
</tr>
<tr>
<td>Making of Wooden Furniture’s/timber</td>
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<tr>
<td>Manufacturing of wooden agricultural implements</td>
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<tr>
<td>Prawn harvesting</td>
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<tr>
<td>80+ other binary-coded variables to capture the other common primary occupations in India relevant to the three landcover conversions investigated in this analysis.</td>
</tr>
</tbody>
</table>
Underlying Causes: Examples of Biophysical Data

Soil data (NBSS - ~30 variables)  Terrain (SRTM)
Statistical Estimation: Causes of LCLUC

Example: Forest loss

Key Points

- **Model Technique**: Fractional Binomial Logit Model
- **Modeling Resolution**: 1km x 1km lat/long
- **Spatial Domain**: National & by regional hotspots
- **Temporal Domain**: Separate estimation by decade (1985-95, 1995-05)
- **Scaling of predictors**: Z-score standardization
- **Multicollinearity**: Elastic-net regularization
- **Parameter selection**: k-fold cross validation
- **Confidence Intervals & Spatial autocorrelation**: Bootstrap with 500 replicates
Causes of Forest Loss: National Scale

### 1985-1995
- Occupation (Dairy/Cattle/Leather)
- Occupation (Wooden/Agricultural implements)
- Occupation (Building/mining Material)
- Availability of Power Supply
- Annual Mean Temperature
- Protected Area
- Cation Exchange Capacity
- Step Slope (>50%) Slope
- Occupation (Wooden Furniture/timber)
- Proportion of Cropland irrigation

### 1995-2005
- Availability of Power Supply
- Indus. & Construction worker density
- Precip. For the Wettest Month
- Occupation (Building/mining Material)
- Occupation (Dairy/Cattle/Leather)
- Severe Soil Erosion
- Protected Area
- Occupation (Wooden/Agricultural implements)
- Steep Slope (>50%)
- Proportion of Cropland irrigation
Summary of model findings (regional hotspots)
Evaluation: Meta-synthesis of 102 case studies
Evaluation: Case-study results (national aggregates)

- Poor Land Management (e.g. forest fire)
- Climate Change
- Faulty Land Reforms
- Local Market Demands (tourism, medicines)
- Natural Factors (insects, wildlife grazing, fires, diseases)
- Shifting Cultivation
- Government-aided Deforestation (e.g. for landless people)
- Higher Income Dependency on Forests
- Livestock (Overgrazing, fodder)
- Industrial Exploitation
- Human Pressure (dams, roads, settlements)
- Domestic Use/Subsistence
- Illeagal Forest Encroachment (weak management)

Number of studies

Deforestation & forest degradation (N=42)
Extended efforts: 1km reconstruction (1950-2011)

India’s changing land cover: 1950 to 2011

Data from: Melyappan et al (2015); Estimating India’s land change from 1950 to 2011 at 1km resolution. Global Change Biology
Validation: How good are the reconstructed maps?

Pattern validation: an example

Topographic Map (1950) → Digitized Topographic Map (1950) → Reconstruction Data (1950)

Data Clean-up + Digitization

Ground truthing at over 12000 locations for year 1950
Prevailing uncertainties in LULCC over India
Three distinct global estimates of historical land-cover change and land-use conversions for over 200 years

Prashanth MEIYAPPAN, Atul K. JAIN


Spatial modeling of agricultural land use change at global scale

Prasanth Meiyappan, Michael Dalton, Brian C. O’Neill, Atul K. Jain

CO₂ emissions from land-use change affected more by nitrogen cycle, than by the choice of land-cover data

ATUL K. JAIN*, PRASANTH MEIYAPPAN*, YANG SONG* and JOANNA I. HOUSE†
Three distinct global estimates of historical land-cover change and land-use conversions for over 200 years

Prasanth MEIYAPPAN, Atul K. JAIN (✉)
University of Illinois, Urbana, IL 61801, USA

Global Biogeochemical Cycles

Increased influence of nitrogen limitation on CO₂ emissions from future land use and land use change

Prasanth Meiyappan¹, Atul K. Jain¹, and Joanna I. House²

Spatial modeling of agricultural land use change at global scale
Prasanth Meiyappan³, Michael Dalton⁴, Brian C. O’Neill⁵, Atul K. Jain⁶,⁷

CO₂ emissions from land-use change affected more by nitrogen cycle, than by the choice of land-cover data
Atul K. Jain*, Prasanth Meiyappan*, Yang Song* and Joanna I. House†
Historical Land-Cover Change and Land-Use Conversions Global Dataset

Updated: Feb 02, 2015

A set of three estimates of land-cover types and annual transformations of land use are provided on a global 0.5 x 0.5 degree lat/lon grid at annual time steps. The longest of the three estimates spans 1770-2010. The dataset presented here takes into account land-cover change due to four major land-use/management activities: (1) cropland expansion and abandonment, (2) pastureland expansion and abandonment, (3) urbanization, and (4) secondary forest regrowth due to wood harvest. Due to uncertainties associated with estimating historical agricultural (crops and pastures) land use, the study uses three widely accepted global reconstruction of cropland and pastureland in combination with common wood harvest and urban land data set to provide three distinct estimates of historical land-cover change and underlying land-use management history.
Data Product: Village level socioeconomic database for India

Illustrating the new data product with population density as example (notice the high granularity captured in the new data)

Data currently available  >100x improvement in resolution  My new data product
Key collaborators

Yeshu Sharma

Prasanth Meiyappan

Parth Roy

Jing Gao

Pawan Joshi

Acknowledgement: NASA LCLUC Program
Thank You
LCLUC Dynamics and Causes – Overall Challenges

• Spatiotemporal dynamics and causes of LCLUC over larger regions of India are limited

• It is hard to generalize and quantify the causes of LCLUC by studying small regions (e.g., few villages)
  – Note that India has 630,000 villages with diverse agro-ecological and socio-cultural environment.

All these constraints are hindering effective national level planning and policy-making.