TERRESTRIAL CARBON BUDGET OF INDIA

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GCP WORKSHOP
REGIONAL CARBON BUDGETS: FROM METHODOLOGIES TO QUANTIFICATION

BEIJING, CHINA
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OUTLINE

- Introduction

- Terrestrial Carbon Cycle: India
  - National Circumstances
  - Preliminary Assessments
  - Agroecosystem C Cycle
  - Forest Ecosystem C cycle
  - Estimation of Net Primary Productivity and Burnt Area detection
  - Anthropogenic C Emissions

- Uncertainties in C stock Estimates vis-à-vis LU/LC related C Emissions

- Conclusion
INTRODUCTION

- Carbon (C) Cycle is central to the ‘Earth System’

- National-level C budgets are needed under UNFCCC
  --to assess national contributions to sources and sinks of CO$_2$
  --evaluate the processes that control CO$_2$ accumulation in atmosphere

- Terrestrial C is the most uncertain but very important component of ‘C budgets’

- Factors affecting terrestrial C storage includes:
  changes in LU, CO$_2$ fertilization, N deposition, Climate, natural disturbances
**Atmosphere ~ 760**
Accumulations 3.3 ± 0.2

- Fossil fuels and cement production 6.3 ± 0.6
- Net Terrestrial Uptake 0.7 ± 1.0
- Net Ocean Uptake 2.3 ± 0.8

**Global Net Primary Productivity, Respiration and Fire ~ 60**

- Vegetation ~ 500
- Soils and Detritus ~ 2,000
- ~ 2,500

**Ocean ~ 39,000**

- Runoff ~ 0.8

**Net Terrestrial Uptake**

- Net Terrestrial Uptake 0.7 ± 1.0

**Net Ocean Uptake**

- Net Ocean Uptake 2.3 ± 0.8

**Air/Sea Exchange ~ 90**

**Vegetation**

- Vegetation ~ 500
- Soils and Detritus ~ 2,000
- ~ 2,500

**Fossil Fuel Reserves: 4000**

**Carbonate Rocks: 65x10^6**

C pools in PgC = 10^{15} gC, C fluxes: PgC/yr

*(IPCC, 2000)*

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NATIONAL CIRCUMSTANCES

-- 7th largest country covering ~329 Mha (2.4%) of world’s total land area
-- Supports 16.4% of world’s human population
-- Largest livestock population with only 0.5% of the world’s grazing area
-- Agricultural land use is major land utilization followed by forest area

<table>
<thead>
<tr>
<th>Parameters</th>
<th>India</th>
<th>World</th>
<th>India's Share</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Land Area (Mha)</td>
<td>329</td>
<td>14930</td>
<td>2.4</td>
<td>Seventh</td>
</tr>
<tr>
<td>Human Population (Million) 2001</td>
<td>1035</td>
<td>6300</td>
<td>16.4</td>
<td>Second</td>
</tr>
<tr>
<td>Cattle Livestock (Million Head)</td>
<td>196</td>
<td>1320</td>
<td>14.8</td>
<td>First</td>
</tr>
<tr>
<td>Arable Land</td>
<td>166</td>
<td>1362</td>
<td>12.2</td>
<td>Second</td>
</tr>
<tr>
<td>Irrigated Land</td>
<td>50</td>
<td>255</td>
<td>19.6</td>
<td>First</td>
</tr>
<tr>
<td>Forest &amp; Woodland (Mha)</td>
<td>67.55</td>
<td>4081.5</td>
<td>2.3</td>
<td>Fifteenth</td>
</tr>
</tbody>
</table>

Land and available Natural Resources are under stress

With diverse physiographical features, India is endowed with varied soils, climate, biodiversity & ecological regions
• Few attempts made at national level, based on different approaches

❖ Preliminary Assessments of major pools & fluxes of C

[USING BOOK-KEEPING APPROACH]

---For 1980  Hingane (1991)
Total phytomass pool*: 3.02 PgC  (*estimate refer to 284.9 Mha of land surface only)
NPP : 1.24 PgC/yr

---For 1985  Dadhwal and Nayak (1993)
Using RS-based LU/LC inventories and regional /global C densities & fluxes

Total Biospheric pool# : 32.3-39.0 PgC
Soil Organic C : 23.5-27.1 PgC
Total Phytomass : 8.3-10.9 PgC
Forest Phytomass : 2.9-3.3 PgC
NPP : 1.3-1.6 PgC/yr
Litterfall : 0.8-0.9 PgC/yr

# including phytomass, litter, SOC
AGROECOSYSTEM C CYCLE

- Significant role as ~half of the total land area is arable

DETAILED ASSESSMENT (1950-1990)

[Included crop, human and livestock (including poultry) biomass C-pools]

Used book-keeping approach and secondary data on crop production, human and livestock census and trade (export/import) statistics for India

- ~2.4 times increase in Crop NPP with large Inter-state variations

- Significant linear relationship of crop NPP with irrigated fraction ($R^2 = 0.92$)

- Improved Crop biomass partitioning into EP, AGR and BGR pools

- Human and livestock biomass C pools increased by 83% & 64%, respectively between 1951-1981/82

Dadhwal et al. (1994, 1996)
MAJOR POOLS & FLUXES OF AGROECOSYSTEM C CYCLE 1950-51/1989-90

AGRO Ecosystem

CROPS

BGR

12.4/34.4

AGR

89.8/243.9

ECB

40.3/129

INSIDE INDIA

OUTSIDE

INSIDE INDIA

OUTSIDE

IMP

EXP

1. FEED & FODDER, GRAZING

2. FUEL WOOD PRODUCTS

3. STORAGE

4. HUMAN CONSUP. FISH CATCH

5. SOIL

OTHER ECOSYSTEMS

ATMOSPHERE

SOIL POOL

BIOME. CULT. HUMANS

STOR FUEL

^TgC = 10^{12} gC
RELATIONSHIP BETWEEN NPP & IRRIGATED FRACTION, INDIA (1951-1990)

\[ y = 0.1886x - 0.1977 \]

\[ R^2 = 0.92 \]
AGRICULTURAL LANDUSE AND C CYCLE IN INDO-GANGETIC PLAINS (IGP)

BACKGROUND
- IGP Region: Pakistan, India, Nepal, Bangladesh
- IGP Region: Food-bowl of Indian subcontinent, important for food security of South Asia
- IGP (India): length 1600 km, width 320 km, Total Geog. area 9.57 Mha, 5 major states: (Bihar, Haryana, Punjab, Uttar Pradesh, West Bengal)
- Agriculture: Dominant landuse

AGROECOSYSTEM INPUTS
- Cropping Intensity (1901-1991)
- Irrigation Intensity (1901-1991)
- Energy use in intensive agriculture
- Chemical Fertilizer consumption (1955-1995)

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INFLUENCE OF AGRICULTURAL INTENSIFICATION ON AGROECOSYSTEM CROP NPP

- Crop biomass and NPP estimated using crop area, production, moisture fraction, and harvest index (Dadhwal et al., 1995)

- Increase of 435.6 Mt crop biomass (1901-1991)
  6 fold increase in crop NPP

- Crop NPP range: ~1 t/ha/yr (1901) in Bihar–
  ~17 t/ha/yr in Punjab (1991)

- Intensification of crop NPP due to increased irrigation, cropping intensity & fertilizer application

Dadhwal and Chhabra (2002)
FOREST ECOSYSTEM C CYCLE

- Major Pools: Phytomass C, Soil Organic C
- Major Fluxes: NPP, Litterfall

Different estimates based on different approaches:

- Point ecological studies based on destructive sampling

- Growing stock volume ground inventory over large sample areas (based on stratified sampling)
  
  Approach more realistic although estimates are lower than ecological studies based

- Remote Sensing based approach

  RS help to quantify and monitor vegetation dynamics over large spatial scales, at high spatial resolutions, and with well-defined temporal sampling
Space-borne Remote Sensing

Economically feasible solution to collect relevant information at Regional to Global scales with relatively high spatial resolution.

Sensors (Optical, Radars) on board satellite platforms.
Extent of Indian forest cover studied by:
- Historical data: long-term changes in forest area (Richards and Flint, 1994)
- RS-based biennial Forest cover assessment (since 1987)

RS-based FSI inventory provides information
- Area by forest types (FSI, 1987)
- Crown density based area (Dense, Open, forest)
- Forest area (deforested/afforested) Change matrices
- Small scale afforestation studies

Indian forests range from ETRF in A&N islands, Western Ghats & NE states to dry alpine scrub in Himalayas in North

Average GS 74 cum/ha, compared to global average of 110 cum/ha

Estimated forest phytomass C densities & stocks for recent period are in range of 50–68 tha⁻¹ and 2.0–4.4 PgC, respectively (Chhabra and Dadhwal, 2004)
SPATIAL DISTRIBUTION OF PHYTOMASS C
(DISTRICT-LEVEL)

Data Used

• RS-based district level forest area (FSI, 1991, 1997)
• Crown density-based biomass expansion factors

Methodology

PD = GS × DEN × CC × RC × EF

PD : Forest phytomass C density (t/ha)
GS : Growing Stock (m³/ha)
DEN : Density of Wood (g/cc) = 0.62
CC : Carbon Content of wood = 0.5
RC : Root Correction factor (TDM/AGDM) = 1.16 (Hall and Uhlig, 1991)
EF : Expansion Factor = (1.9 × D + 2.5 × (O + M)) / (D + O + M)

• District phytomass C pool = PD × total forest area of the district

• Estimated district-wise forest area (as % G.A.), PD, Phytomass C pool linked to digitized district coverage of India using GIS ARC/INFO
FOREST SOIL ORGANIC C POOL

Data Used
--RS-based forest area by major forest types (FSI, 1987)
--Indian forest studies
  location, forest type, soil type, depth of profile, Organic C %,
  soil texture (sand & clay %), soil bulk density (if reported)

Methodology

\[
\text{Soil Bulk Density} = \frac{100}{(X/\rho_0) + (100-X/\rho_m)}
\]

\[X: \text{ } \% \text{ by weight of organic matter}\]
\[\rho_0: \text{ average bulk density of organic matter (0.224 g/ cm}^3)\]
\[\rho_m: \text{ mineral bulk density (g/ cm}^3)\]

[Adams, 1973] [Rawls, 1983]

✓ Soil OC density = OC% x soil BD x thickness of horizon

[Batjes, 1996]

- Estimated Soil OC densities added for top 50 cm, and top 1m soil
- Database classified into 16 major forest types [Champion & Seth, 1968]
grouped into 7 major forest types.
### Soil organic C pool = Estimated Soil OC densities x Forest area

#### SOIL ORGANIC C POOL BY MAJOR FOREST TYPES

**(in top 50 cm & 1m soil depths)**

<table>
<thead>
<tr>
<th>Forest Type*</th>
<th>Area (Mha)</th>
<th>Soil C density (tC/ha)</th>
<th>Soil OC pool (PgC)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (+ S.E.)</td>
<td>Mean (+ S.E.)</td>
<td>Mean (+ S.E.)</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Top 50 cm</td>
<td>N</td>
</tr>
<tr>
<td>T-Ever.</td>
<td>7.77</td>
<td>36</td>
<td>90.7(±7.7)</td>
</tr>
<tr>
<td>Mon.Temp.</td>
<td>6.43</td>
<td>25</td>
<td>73.4(±10.4)</td>
</tr>
<tr>
<td>T-M. Dec.</td>
<td>23.7</td>
<td>34</td>
<td>73.2(± 5)</td>
</tr>
<tr>
<td>T.D. Dec.</td>
<td>20.0</td>
<td>35</td>
<td>37.5(± 3.4)</td>
</tr>
<tr>
<td>Lit &amp; Swamp</td>
<td>0.40</td>
<td>15</td>
<td>92.1(±9.4)</td>
</tr>
<tr>
<td>T-D. Ever.</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST-Mont.</td>
<td>5.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>64.20</strong></td>
<td><strong>175</strong></td>
<td><strong>136</strong></td>
</tr>
</tbody>
</table>

*Tropical Evergreen, Montane Temperate, Tropical Moist Deciduous, Tropical Dry Deciduous, Littoral and Swamp, Tropical Dry Evergreen, Subtropical Montane

*N* = number of observations
FOREST LITTERFALL C FLUX

Data Used
--RS-based forest area by major forest types [FSI, 1987]
--Indian forest studies (location, forest type, total and leaf litterfall)

Methodology
--Database classified into 16 forest types [Champion and Seth, 1968]
--Grouped into 7 major forest types
--Litterfall C flux = Mean litterfall x forest area x 0.45

Results
Mean Litterfall : 5.7 (T), 3.9 (L) t/ha/yr (MTF)–8.9 (T), 6.4 (L) t/ha/yr (TMDF)

Estimated Total Litterfall C flux (TgC/yr): 208.8 (± 18.5) N= 122
Estimated Leaf Litterfall C flux (TgC/yr): 153.1 (± 13.2) N= 114

MTF: Montane Temperate Forest, TMDF: Tropical Moist Deciduous Forest

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N: number of observations, T: Total, L: Leaf
Phytomass C density (1988)

Phytomass Density range:
4.3 (Birbhum, West Bengal)-207 (Lahul & Spiti, Himachal Pradesh) t/ha

NF: non-forested district

FOREST PHYTOMASS C POOL (INDIA): 3.8 PgC

Phytomass Density range:
4.3 (Birbhum, West Bengal)-207 (Lahul & Spiti, Himachal Pradesh)

Spatial Distribution of Forest Phytomass C Density

Chhabra et al., 2002

RS-based forest area by types + point field measurements (n = 122)

Chhabra and Dadhwal, 2004

TOTAL LITTERFALL C FLUX: $209 \pm 18.5$ TgC/yr

TOTAL SOIL ORGANIC C: $6816 \pm 680$ TgC

RS-based forest area by types + estimated soil organic C densities (n = 136)

estimates for 1982 (n: no. of observations)

Chhabra et al., 2003

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$^\text{PgC} = 10^{15}$gC, $^\text{TgC} = 10^{12}$gC
Spatial modeling of annual net C flux from Indian forests (1880-1995)

C-CYCLE MODEL : FOR -> AG TRANSFORMATION

(Total biomass per ha)

Biomass removed per ha

Decay pools

Atmosphere

Land area cleared

Vegetation response

Soil response

(Biomass left/ha)

Dead

Live

Total biomass per ha

Regional net C flux (MtC) due to deforestation

Central: 1145, East: 417, NE: 556, NW: 380, South: 761, India: 3259

Cumulative C emission due to Deforestation & Phytomass degradation: 5.5 PgC

Regional net C flux (MtC) due to deforestation & phytomass degradation


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Chhabra & Dadhwal (2004)
ESTIMATION AND VALIDATION OF REMOTE SENSING DERIVED TERRESTRIAL NET PRIMARY PRODUCTIVITY

• SPOT–VEGETATION 1-km derived and C-Fix (a PEM) based 10-day NPP composites used for computing terrestrial NPP over India (1998-99)

• Characterize spatial, seasonal, land cover related variations and inter-annual variability in terrestrial NPP over different geographical regions of India

• Attempt at validation of RS-based NPP using ground-based crop NPP estimates at district level

Net Primary Productivity Image over Indian sub-continent (June 1998–May 1999)

NET PRIMARY PRODUCTION: 2.18 PgC

Regional contributions:
Central: 543.8 (24.9%), East: 314.6 (14.4%), Islands: 5.62 (0.3%), Northwest: 131.2 (6.0%), Northeast: 276.7 (12.7%), Peninsular: 483.9 (22.2%), Western Region-1: 109.4 (5.0%), and Western Region-2: 317.9 (14.6%) TgC
**INTER-ANNUAL VARIABILITY**

Year 2000-01  
Total NPP : 1.88 PgC

~14% decrease in NPP (drought year 2000-01)  
Max. decrease 84.3 TgC Central India

**VALIDATION AT DISTRICT-LEVEL**

Four-fold difference at low NPP level of ground-based method.  
H.I. method underestimate crop NPP in low productivity districts. Both methods provide nearly similar estimates in districts with moderate to high NPP (R= 0.6).

**LAND COVER RELATED VARIATIONS**

With rainfall decrease by 11 cm in Kharif season (July-Oct 2000), Crop NPP dropped ~41 TgC.  
No significant change in Forest NPP

Monthly patterns of SPOT- VGT NPP and NDVI for  
NW (Agroecosystem), NE(Forest)  
Punjab(Agriculture state), Total India

Punjab : NPP vs NDVI (9: 3.5 fold variations)
RS-DERIVED BURNT AREA AND ACTIVE FIRE DETECTION OVER INDIA USING SPOT4-VGT AND ATSR-2 DATA

Data Used: Coarse resolution 1-Km SPOT 4-VGT monthly data for year 2000

(Data Source: European Commission JRC, Global Burnt Area – 2000)
ANTHROPOGENIC C EMISSIONS

India is a party to UNFCCC as a non-annex I country

Recent estimate

- Using Revised 1996 IPCC guidelines, national GHG inventory was estimated for year 1994 [NATCOM, 2004]

**Aggregate emissions**

793 Tg CO$_2$, 18.1 Tg CH$_4$, 0.17 Tg N$_2$O or total 1228 Tg (CO$_2$ equivalent)

Per-capita CO$_2$ emissions 0.87 tCO$_2$ (23% of global average)

**Sectoral Contributions**

- Energy sector (61%), Agriculture sector (28%), Industrial sector (8%), Waste disposal (2%), LU/LUCF (1%)

Coal combustion dominant source (~64%) among energy emissions
LONG-TERM C-RELEASE DUE TO FOSSIL FUEL BURNING & CEMENT PRODUCTION IN INDIA (1860-1990)

- COAL: Predominant source of C, accounts for 75% of cumulative release from total fossil fuel burning and industrial activity emissions
- Only 8.7% release before 1930
- Annual C emissions increasing rapidly:
  - 23.2 TgC (1951)
  - 60.5 (1971)
  - 172.7 TgC (1990)
- Long-term C release (1901-1990):
  - India: 3.45 PgC
  - Global: 201.5 PgC

(Dadhwal et al., 1996)
LU/LC changes are important controls of C storage, responsible for large C fluxes ~20% of anthropogenic C emissions (Schimel et al., 2001).

Uncertainties due to variations:
- Rates of deforestation
- Fate of deforested land
- Phytomass and Soil OC stocks

Land utilization statistics (govt. records) in India reflect only legal status, no categories having bearing on C stocks.

LU changes dominated by losses of fertile land, forest conversion to croplands towards increasing demand of agricultural products for growing population, forest degradation.

- Forestry & LU change emissions: 0.40 TgC for 1990 (ALGAS, 1999)
- Cumulative emissions: 5.4 PgC (1880-1996) (Chhabra et al., 2004)
• Reforestation of wastelands and Agroforestry practices may be considered as strong options for terrestrial C sequestration

• RS technique helpful in uncertainty reduction:
  • Identifying potential lands
  • Potential C sequestration at different land types
  • Monitoring current C sequestration in forest biomass
  • NPP estimation of different forest types

• Improved forest biomass assessments by developing models between canopy cover and RS observations

• New and emerging RS tools widely explored for vegetation studies:
  • Hyper spectral RS (MODIS, AVIRIS, etc.)
  • LIDAR
  • Multiband/ Polarimetric & Interferometric MW Radar systems
WASTELAND MAPPING IN INDIA

- 1:50000 scale
  entire country
- Digital database
- Input to MRD for development

MRD: Ministry of Rural Development
CURRENT & FUTURE ......

EO SYSTEM OF INDIA

RISAT
C-band SAR; 3-50 m
Multi-Pol; Multi mode

MEGHA-TROPIQUES
SAPHIR, SCARAB & MADRAS

OCEANSAT-II
SCAT, OCM

CARTOSAT-2
PAN – 1.0 m, 11km

IRS-P5(Cartosat-1)
PAN-2.5M, 30 km, F/A

MEGHA-TROPIQUES
SAPHIR, SCARAB & MADRAS

OCEANSAT-II
SCAT, OCM

CARTOSAT-2
PAN – 1.0 m, 11km

IRS-P5(Cartosat-1)
PAN-2.5M, 30 km, F/A

MEGHA-TROPIQUES
SAPHIR, SCARAB & MADRAS

OCEANSAT-II
SCAT, OCM

IRS-P6(Resourcetsat-1)
LISS III - 23M ; 140 Km; 4Xs
LISS IV - 5.8M ; 3Xs
Multi-Spectral high resolution data useful for resource monitoring
AWiFS - 60M; 740 Km
Regional landcover mapping and monitoring, Vegetation Index

METSAT-1
VHRR – 2 Km(vis); 8 Km(IR & WV)

INSAT-3A
VHRR – 2 Km(vis); 8 Km(IR & WV)
CCD – 1 Km

INSAT-3D
19 Ch. Sounder
6 Ch. Imager

INSAT-3D
19 Ch. Sounder
6 Ch. Imager
Current Understanding of Terrestrial C Cycle In India (1990s)

**ENERGY USE & INDUSTRY**

Cumulative C emission (1901-1990) : 3.5 PgC

Energy & industry flux 173 Tg C/yr

**FOREST ECOSYSTEM**

Net C flux (deforestation & degradation) 0.05 Pg C/yr

NPP: 465-543 Tg C/yr

Phytomass 3871-4342 TgC

Leaf Litterfall flux 153±13 Tg C/yr

Litter pool 390-410 TgC

Total Litterfall flux 209 ± 18 TgC/yr

Forest soil organic C : 6816 TgC (top 1m soil)

**AGRO-ECOSYSTEM**

Cumulative C emission (1880-1996) : 5.5 PgC

NPP 142.5/407 Tg C (1950-51/1989-90)

Phytomass 3871-4342 TgC

Crop biomass production (MtC)

Crop NPP (tC/ha/yr)

Year

Crop biomass production (MtC)

Biomass

NPP

0  100  200  300  400  500  600


Cumulative C emission (1880-1996) : 5.5 PgC

Cumulative C emission (1901-1990) : 3.5 PgC

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CONCLUSION

- Major estimates for India:
  - Total phytomass (3.8-4.3 PgC), Soil Organic Carbon (6.8 PgC)
  - Litterfall C flux (209 ± 18 TgC/yr)

- Cumulative C emissions 5.5 PgC (LU change & phytomass degradation) from Indian forests dominated over cumulative fossil fuel use & industrial activity C emissions of 3.45 Pg C over the 20th century

- RS combined with appropriate field studies and Ecological Modeling improves understanding of terrestrial vegetation C stocks and their related stock changes
DATA GAPS AND RESEARCH NEEDS

To Predict Future C Stocks

✓ Need to clearly define different LU categories/forest types

✓ Update country’s forest resources inventory to include specific forest plantations

✓ Use of combined ground-based data and satellite data

A FULL C ACCOUNTING FOR INDIA IS THE FUTURE RESEARCH NEED


“Coming Together is a Beginning
Keeping Together is Progress
Working Together is Success”

- Anonymous

THANK YOU

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