IMPACTS OF LCLUC ON WATER MANAGEMENT IN INDIA

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International Regional Science Meeting
Land cover and land use changes dynamics
and their impacts in South Asia
10-12 January 2013
The global situation

Less than 3% of the world’s water is fresh – the rest is seawater and undrinkable.

Of this 3% over 2.5% is frozen, locked up in Antarctica, the Arctic and glaciers, and not available to man.

- Thus humanity must rely on this 0.5% for all of man’s and ecosystem’s fresh water needs.
## India’s Land Resources

<table>
<thead>
<tr>
<th>Geographical Area</th>
<th>329 mha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-cultivated Area</td>
<td>7%</td>
</tr>
<tr>
<td>Barren/Waste Land</td>
<td>23%</td>
</tr>
<tr>
<td>Forested Area</td>
<td>23%</td>
</tr>
<tr>
<td>Cultivated Area (CA)</td>
<td>47%</td>
</tr>
<tr>
<td>Irrigated Area (produces 55%)</td>
<td>37% of CA</td>
</tr>
<tr>
<td>Rainfed Area (produces 45%)</td>
<td>63% of CA</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td><strong>India’s Land Resources</strong></td>
<td>2% of the World</td>
</tr>
<tr>
<td><strong>India’s Freshwater Resource</strong></td>
<td>4% of the World</td>
</tr>
<tr>
<td><strong>India’s Population</strong></td>
<td>16% of the World</td>
</tr>
<tr>
<td><strong>India’s Cattle Population</strong></td>
<td>10% of the World</td>
</tr>
</tbody>
</table>
Spatial Variation of Rainfall in India

Average Annual Rainfall
- 116 cm
RAINFALL PATTERNS IN INDIA

Long-term average annual rainfall: 116 cm.

Highly Variable in space (about 11,69 cm at Mousinram near Cherrapunji in Meghalaya and 15 cm at Jaisalmer)

Highly Variable in time (Three-quarters of the rain in less than 120 days during June to September)

Average number of rainy days in a year: 40
## Temporal Variation of Rainfall

<table>
<thead>
<tr>
<th>Month</th>
<th>Percent of Annual Average Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.24</td>
</tr>
<tr>
<td>Feb</td>
<td>1.33</td>
</tr>
<tr>
<td>Mar</td>
<td>2.12</td>
</tr>
<tr>
<td>Apr</td>
<td>3.46</td>
</tr>
<tr>
<td>May</td>
<td>6.03</td>
</tr>
<tr>
<td>Jun</td>
<td>15.42</td>
</tr>
<tr>
<td>Jul</td>
<td>23.76</td>
</tr>
<tr>
<td>Aug</td>
<td>19.89</td>
</tr>
<tr>
<td>Sep</td>
<td>14.19</td>
</tr>
<tr>
<td>Oct</td>
<td>7.69</td>
</tr>
<tr>
<td>Nov</td>
<td>3.45</td>
</tr>
<tr>
<td>Dec</td>
<td>1.42</td>
</tr>
</tbody>
</table>
## Annual Water Availability in India

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity (BCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total precipitation</strong></td>
<td>4000</td>
</tr>
<tr>
<td><strong>Annual water availability</strong> (after accounting for losses in the form of evaporation etc.)</td>
<td>1869</td>
</tr>
<tr>
<td><strong>Utilizable water</strong></td>
<td>1123</td>
</tr>
<tr>
<td>- <strong>Surface water</strong></td>
<td>690</td>
</tr>
<tr>
<td>- <strong>Ground water</strong></td>
<td>433</td>
</tr>
</tbody>
</table>
Major River Basins of India
Basin-wise Groundwater Development
### Per Capita Water Availability with Time

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (in millions)</th>
<th>Per Capita water availability (in cubic meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>361</td>
<td>5177</td>
</tr>
<tr>
<td>2001</td>
<td>1027</td>
<td>1820</td>
</tr>
<tr>
<td>2025 (projected)</td>
<td>1394</td>
<td>1341</td>
</tr>
<tr>
<td>2050 (projected)</td>
<td>1640</td>
<td>1140</td>
</tr>
</tbody>
</table>
Water Stressed

Per Capita Availability < 1700 Cubic Meter per year

Water Scarce

Per Capita Availability < 1000 Cubic Meter per year
<table>
<thead>
<tr>
<th>Use</th>
<th>Year 2010</th>
<th>Year 2025</th>
<th>Year 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Demand (BCM)</td>
<td>% of total demand</td>
<td>Projected Demand (BCM)</td>
</tr>
<tr>
<td>Irrigation</td>
<td>557</td>
<td>78%</td>
<td>611</td>
</tr>
<tr>
<td>Domestic</td>
<td>43</td>
<td>6%</td>
<td>62</td>
</tr>
<tr>
<td>Industries</td>
<td>37</td>
<td>5%</td>
<td>67</td>
</tr>
<tr>
<td>Environment</td>
<td>5</td>
<td>1%</td>
<td>10</td>
</tr>
<tr>
<td>Others</td>
<td>68</td>
<td>10%</td>
<td>93</td>
</tr>
<tr>
<td>Total</td>
<td>710</td>
<td>100%</td>
<td>843</td>
</tr>
</tbody>
</table>
SOURCES OF POLLUTION

- **Point Sources**
  - Municipal & industrial wastes
  - Pollution measured directly

- **Non-point Sources**
  - Agricultural sources
  - No single outlet
<table>
<thead>
<tr>
<th>Major sources of water pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban and domestic waste</td>
</tr>
<tr>
<td>Industrial waste</td>
</tr>
<tr>
<td>Agricultural sources</td>
</tr>
<tr>
<td>Mining wastes</td>
</tr>
<tr>
<td>Induced contaminated sources</td>
</tr>
<tr>
<td>Radioactive substances etc.</td>
</tr>
<tr>
<td>Washoff from landfill sites</td>
</tr>
</tbody>
</table>
Major Water Quality Issues

Common issues of Surface and Ground water
- Pathogenic (Bacteriological) Pollution
- Salinity
- Toxicity (micro-pollutants and other industrial pollutants)

Surface Water
- Eutrophication
- Oxygen depletion
- Ecological health

Ground Water
- Fluoride
- Nitrate
- Arsenic
- Iron
- Sea water intrusion
The Indian situation

- Groundwater [Depleted]
- Surface water [Polluted]
- Rainfall [Wasted]
- Population
- Demand
- Consumption
- Industrial Growth
- Economy-Industry
- Water Business
- Agriculture
- Health & Environment
- Future

SCARCITY
Land cover is the physical material at the surface of the earth.

Land Cover refers to the vegetation, structures, or other features that cover the land. For example, the land covered by grass, by trees, by water, or by large buildings surrounded by a lawn.
Land use is the human use of land

Land use involves the management and modification of natural environment or wilderness into built environment such as fields, pastures, and settlements.

Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.
Relation between Land use and Land Cover

- Land use – defined by economic terms
- Land cover – visible features
- Both are important and are really inseparable
- Depend on accurate LU/LC data for scientific and administrative purposes
Impact of Climate Change

- Sea Level Rise
- Temperature increase
- Change in Monsoon Pattern
- Increase in Rain Fall Intensity
- Increase in Extreme Events
- Decrease in No. of Rainy Days
- Increase in Ground water Recharge
- Decrease in Snow Fall
- Change in Runoff Pattern
- Decrease in No. of Rainy Days
- Increase in Glacier retreat
- Increase in Evaporation rate
Key questions about the climate system and its relation to human kind

What changes have occurred? How well are the past and present climates understood? What changes could lie ahead?

Observations:
- temperatures
- precipitation
- snow / ice cover
- sea level
- circulation
- extremes

Simulations:
- natural variation
- forcing agents
- global climate
- regional climate
- high impact events
- stabilisation

Observations vis-à-vis Simulations

Timeline: Palaeo & Instrumental Periods The Present The Future

WG1 - TS FIGURE 1
Projecting Climate Change Impacts on Hydrology

Climate Change Projections (precipitation, temperature, radiation, humidity)

Topography, Land-use Patterns; soil characteristics;

Downscaling

Hydrologic Model

Possible Future Hydrologic Scenarios on Basin Scale

(Streamflow, Evapotranspiration, Soil Moisture, Infiltration, Groundwater Recharge, etc.)
The LULC change is central to climate change as both the processes are linked with each other in a complex way at multiple spatial and temporal scales.

The changes in LULC alter the energy fluxes thereby affecting the climate, while climatic variability and change in turn affect the LULC patterns through the feedback mechanism.

The cause-and-effect relation between these two processes has significant environmental implications, such as biodiversity loss, alterations in hydrological processes, changes in biogeochemical cycles, land degradation and its impact on agriculture, etc.
The relationship between landuse/landcover (LULC) change and hydrology is complex, with linkages existing at a wide variety of spatial and temporal scales; LULC change unquestionably has a strong influence on global water yield. LULC directly impact the amount of evaporation, groundwater infiltration and overland runoff that occurs during and after precipitation events. These factors control the water yields of surface streams and groundwater aquifers and thus the amount of water available for both ecosystem function and human use.
The impacts of LULC and climate changes on hydrology can be best handled through a physical-based, distributed hydrological model capable of simulating hydrological processes.

Such a treatment is essential since the hydrological response of river basin is a highly complex process which is governed by a large number of biophysical variables of the land surface and climatic forcing.

Thus, the water resources management requires a systems approach that includes not only all of the hydrological components, but also the links, relations, interactions, consequences, and implications among these components.

A thorough knowledge and understanding of the different hydrological phenomena and hydrological cycle as a whole is required in studying the implications of these changes.
Land-use changes

Hydrologic Impacts
- Water Quantity
- Water Quality

Environmental Impacts
- Greater (M&F) of Flooding events with smaller lead times
- River channel erosion
- River channel widening
- Negative impacts on human health & welfare
- Degrade of riparian & wetland habitats
- Decline on aquatic community populations
- Reduced ecological diversity
Effect of Deforestation on Hydrologic cycle

- Decreased interception of rainfall by the tree canopy
- Decreased Evapo-transpiration
- Decreased rainfall interception by surface litter
- Increased runoff volumes.
- Decrease in base flow
Effect of Deforestation on Hydrologic cycle

Partial or complete removal of the forest canopy decreases interception (precipitation captured by leaves and branches) and increases net precipitation arriving at the soil surface.

Reduces transpiration (water lost from plants to the atmosphere).

Reductions in interception and transpiration increase soil moisture, water availability to plants, and water yield.

Increased soil moisture and loss of root strength reduces slope stability.
Water cycle feedbacks between tropical vegetation and the atmosphere. Deforestation reduces evapotranspiration with potential impacts on downwind rainfall.
Effect of Urbanisation on Hydrologic Cycle

- Reduced interception of rainfall due to removal of trees and other vegetation;
- Removal of natural vegetation and drainage patterns;
- Loss of natural depressions which temporarily store surface water (i.e. re-grading of areas results in a change in topography)
Urbanization affects the roughness and imperviousness of the land surface, which increases the runoff volume. As surface roughness is decreased, the stream exhibits a faster response time and increased peak flows.

Excessive stream channel erosion (bed and bank)
Reduced infiltration and hence groundwater recharge
Increased runoff and magnitude of floods
Decreased movement of groundwater to surface water
Loss of stream bank tree cover
Increased contaminants in water
Overall degradation of the aquatic habitat
Hydrologic effects of urbanization

- Paving prevents water from soaking in - increases runoff
- Storm sewers move water to river faster
- Increased peak discharge, shortened lag time
Urban Flooding

Urbanisation alters the hydrology of a region; rainfall – runoff relationships get affected; quicker and higher peak flows; more runoff.
How do the short term intensities of rainfall respond to the climate change?

**Urban Flooding**

Bangalore Floods

Likely changes in IDF (Intensity-Duration-Frequency) relationships due to climate change
Humans have impacted the Hydrological process in many ways. Population increases, rising living standards and industrial and economic growth have put a lot more stress on the environment. Some activities can change the hydrologic equation and can affect the quantity and quality of natural water resources available to current and future generations.

The water used by households, industries, and farms has increased and people demand it to be clean. The amount of fresh water is limited and the easily accessible sources have been developed. As the population increases, so will our need to withdraw more water from rivers, lakes and aquifers, threatening local resources and future water supplies.
A larger population will not only use more water but will discharge more wastewater from domestic, agricultural, and industrial wastes. Poor irrigation practices also raise soil salinity and evaporation rates. All of these factors place far more pressure on existing water resources.

Drainage of water through road drains and city sewer systems alters the rates of infiltration, evaporation, and transpiration. All of these various effects determine the amount of water in the water system and can result in negative consequences for river watersheds, lake levels, aquifers, and the environment as a whole.
CASE STUDY

Effect of land use change on runoff in Panjhara basin

PANJHRA BASIN

TAPI BASIN

Tapi River

Panjhra River

74°30’
19°55’

78°30’
22°05’
Data

Survey of India toposheets (Nos. 46L/1, 46L/5, 46L/9, 46L/13, 46K/4, 46K/8, 46K/12, 46H/13, 46G/16, Scale 1:50,000)

Satellite data of Indian Remote Sensing (IRS)

- Pre and Post monsoon LISS III satellite images of 1997
- Pre and Post monsoon LISS III satellite image of 2003

Ground truth data using GPS at various locations in the Panjhra basin

Daily stage & discharge data at Morane (CWC G&D site) for 1978-2004

Daily Rainfall data at three rain gauge stations for 1990-2004
The catchment boundary and drainage of the basin have been delineated from Survey of India toposheets at a scale of 1:50,000. For creation of data base in GIS, Integrated Land and Water Information System (ILWIS) GIS Software has been used.

From raingauge location map, thessien polygons were drawn. From this map weight of each raingauge have been calculated for computation of average rainfall in the catchment.

The land use/cover map have been prepared using IRS LISS III data of 1997 and 2003. The change of land use have been computed between these years.

The Soil map of the study area has been prepared from the information available in the NBULS&S map of Gujarat state. SCS-CN method has been applied for estimation of surface runoff for rainfall event.
Runoff (mm) in the study area for 1996 and 1997

August 1996

Morane

Runoff (mm)
- < 5
- 5-10
- 10-15
- 15-20
- 20-25
- >25

August 1997

Morane

Runoff (mm)
- < 15
- 15-20
- 20-25
- 25-30
- 30-35
- 35-40
- >40
Runoff (mm) in the study area for 2002 and 2003.
## LAND USE CHANGES

<table>
<thead>
<tr>
<th>LAND USE</th>
<th>AREA (%) 1996</th>
<th>AREA(%) 2003</th>
<th>% CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOREST</td>
<td>5.16</td>
<td>3.25</td>
<td>-1.9</td>
</tr>
<tr>
<td>AGRICULTURAL</td>
<td>31.46</td>
<td>27.13</td>
<td>-4.3</td>
</tr>
<tr>
<td>BARREN</td>
<td>8.22</td>
<td>10.29</td>
<td>+2.1</td>
</tr>
<tr>
<td>PASTURE</td>
<td>46.36</td>
<td>47.20</td>
<td>+0.8</td>
</tr>
<tr>
<td>ROCK OUTCROP</td>
<td>0.34</td>
<td>2.55</td>
<td>+2.2</td>
</tr>
<tr>
<td>BUILT-UP</td>
<td>7.99</td>
<td>8.62</td>
<td>+0.62</td>
</tr>
<tr>
<td>WATER</td>
<td>0.46</td>
<td>0.95</td>
<td>+0.49</td>
</tr>
<tr>
<td>Year</td>
<td>Month</td>
<td>Rainfall (mm)</td>
<td>Runoff (C ) mm</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>--------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1996</td>
<td>June</td>
<td>70</td>
<td>6.625</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>130</td>
<td>18.380</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>97.5</td>
<td>10.760</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>111.25</td>
<td>6.705</td>
</tr>
<tr>
<td>2003</td>
<td>June</td>
<td>223.7</td>
<td>5.600</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>177.05</td>
<td>29.320</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>173.4</td>
<td>26.930</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>157.4</td>
<td>31.460</td>
</tr>
</tbody>
</table>

It is observed that the runoff coefficient has increased as a result of deforestation and reduction in agricultural land showing that land use/ land cover has an impact on the hydrological regime.
Runoff Coefficients for monsoon period
It is also observed that the runoff coefficient has increased over the years (from 0.06 in September 1997 to 0.2 in September 2003) which means more surface runoff during monsoon months and less in non-monsoon as infiltration becomes less. This is due to the result of deforestation and reduction in agricultural land.

From the analysis of these results, it can be concluded that runoff of the Panjhra River is sensitive to landuse/landcover.

However, more multi-date satellite data is required for better assessment of the changes in runoff due to the landuse/landcover changes.
IMPACT ASSESSMENT OF LANDUSE ON THE HYDROLOGIC REGIME IN THE SELECTED MICRO-WATERSHEDS IN LESSER HIMALAYAS, UTTARAKHAND
OBJECTIVES

To assess the impact of forest cover on stream discharge pattern (FRI).

To separate surface runoff and base flow components in stream discharge (NIH).

Soil erosion modelling under different forest covers (FRI-NIH).

Identification of recharge zones of springs (NIH).
LAND USE DETAILS OF WATERSHED

<table>
<thead>
<tr>
<th>LAND</th>
<th>BANSIGAD</th>
<th>ARNIGAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.03 (2%)</td>
<td>Nil</td>
</tr>
<tr>
<td>Barren</td>
<td>0.36 (28%)</td>
<td>0.15 (5%)</td>
</tr>
<tr>
<td>Forest</td>
<td>0.86 (65%)</td>
<td>2.35 (83%)</td>
</tr>
<tr>
<td>Habitation</td>
<td>0.07 (5%)</td>
<td>0.35 (12%)</td>
</tr>
</tbody>
</table>
SEASONAL RUNOFF PATTERN

Dense Forest Watershed
- 2008-2009:
  - Monsoon Period: 60%
  - Winter: 15%
  - Pre-monsoon: 18%
  - Post Monsoon: 7%

Degraded Forest Watershed
- 2008-2009:
  - Monsoon Period: 85%
  - Winter: 11%
  - Pre-monsoon: 4%
  - Post Monsoon: 1%

- 2009-2010:
  - Monsoon Period: 84%
  - Winter: 15%
  - Pre-monsoon: 1%
  - Post Monsoon: 24%
# Annual and Direct Runoff in Both the Watershed

<table>
<thead>
<tr>
<th>Study Period</th>
<th>Arnigad (Dense Forest)</th>
<th>Bansigad (Degraded Forest)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual Runoff Coefficient</td>
<td>Direct Runoff</td>
</tr>
<tr>
<td>2008-2009</td>
<td>0.6 (1627 mm)</td>
<td>0.23 (689 mm)</td>
</tr>
<tr>
<td>2009-2010</td>
<td>0.5</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Soil moisture under dense forest cover was higher than the degraded forest during all the seasons. The values during monsoon, winter and summer seasons were obtained as 40.33, 29.29 and 25.95% respectively under dense forest; and 39.34, 25.50 and 22.58% respectively under degraded forest.

Degraded w/s exhibited larger spatial variation in soil moisture than the dense w/s which has comparative a uniform distribution of trees across the watershed.
Many hydrologic models have been developed in the past and more are being developed and they are used to determine the performance of watersheds under inevitable land use changes, climate change, and increased climate variability.

This is done in the form of sensitivity analysis where baseline conditions of climate, land cover and streamflow are established, and then used to compare the effect on streamflow due to changes in precipitation, temperature, land cover and other climate variables.

These analyses provide information on the direction and magnitude of streamflow changes and insight into which variables are most significant in predicting these changes.

This would be very important for decision makers who require such information to evaluate management alternatives or the effects of different climate scenarios, as well as to support policies about water allocations between various sectors such as agriculture, ecosystems, domestic and industry.
The Soil and Water Assessment Tool (SWAT) has been applied in various studies to assess watershed response to land-use changes.

SWAT model developed by USDA, beginning in 1995, as a distributed, physically based model designed to: “predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, landuse and management conditions over long periods of time.”
INTEGRATED WATER RESOURCES MANAGEMENT

Defined as a process which promotes the co-ordinated development and management of water, land and related resources in the river basin in order to maximize the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems.
Why Integrated Water Resources Management?

Agriculture Department
Livestock Department
Forest Department

Rural Water Supply Department
Urban Water Supply Department
Irrigation Department
Power Department
Industry Department

Fisheries Department
Environment Department
Transport Department
Tourism Department

Groundwater Department
Surface Water Department
Ocean Development/CZM Department

...this is why we need IWRM in a basin context!!!
Water Management

Water management under hydrological extremes

- Flood
- Drought
- Drainage Congestion
- Cross drainage works, rails, roads and other infrastructures

Estimation of Surface & Ground water resources under changing Climate & LULC (Adaptation strategies)

Enhancement of water supply/availability

Reductions in water demands
Computer based model together with their interactive interfaces are typically called decision support systems (DSSs).

Computer-based systems integrating tools and databases that assist a decision-maker in making informed decisions and analyse consequences.
Why Do We Need a DSS?

- Semi-structured approach to problem solving
- Large volume of information
- Integrate many information sources
- Models are difficult to use
- Deal with trade-offs: social, economic, biophysical, legislation
- Identify preferred options for further follow up
Components of a DSS

- Databases – Temporal, spatial, relational, attribute
- GIS for spatial data
- Mathematical models
- Expert systems
- Statistical, graphical software, spreadsheets
- User interface
A DSS under Development at NIH
For
Integrated Water Resources (Planning)

- Surface water planning
- Integrated operation of reservoirs
- Conjunctive surface water and ground water planning
- Drought monitoring, assessment and management
- Management of surface water and ground water quality
Population growth and human-induced development have accelerated the speed of LULC changes, which in turn influence interception, infiltration, and evaporation processes in the hydrological cycle, and thus water availability and demand.

The second most populous country, India, is comprised of diverse climatic zones and bio-diversity.

Moreover, it is a fast developing country and in order to cater huge population, vast infrastructure developmental activities are going on. However, such developmental activities are imposing huge pressure on its LULC pattern, biodiversity and climate.
Thank You