Assessment of Ecosystem Services under Land use and Climate Change

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1. Introduction
1.1 Ecosystem services (ES)

The goods and services provided by nature that contribute to the well-being of humans.

Millennium Ecosystem Assessment (MEA) report, 2005 - Milestone in the field

Human actions are depleting Earth's natural capital. Ability of planet’s ecosystem to sustain future generations cannot be taken for granted.

Significance is high on developing nations like Nepal as livelihood of people is highly dependent on these services.

Classification of Ecosystem Services

1. PROVISIONING SERVICES
   Products from ecosystem. Food, timber, freshwater etc.

2. REGULATING SERVICES
   Benefits from regulation of ecosystem processes. Climate regulation, flood regulation etc.

3. CULTURAL SERVICES
   Nonmaterial benefits from ecosystems. Recreation, spiritual, aesthetic etc.

4. SUPPORTING SERVICES
   Underpinning services that enable other services to function. Soil formation, nutrient cycling.
1.2 Objectives of the Study

Why was this study started??

- Developing country are at high risk of ES loss
- Most study in Nepal is focused on small areas and especially on community forest and drinking water.
- Payment of Ecosystem Services – primarily focused on Carbon storage and water provisions.
- Basin wide study – land use and land cover impacts study – are not highlighted.
- Basin wide study – promotes sustainable land use and ensures protection of ES services.

Objectives of the Study

- Water Yield Estimation
- Soil loss Estimation
- Carbon storage Estimation
- Nitrogen export Estimation
- Comparison of ES with land use and land cover change.
2. Methodology
2.1 Study Area

Basin name: Bagmati Basin
Area of Basin : 3,750 sq. km
Area of basin considered on the study : 2,768.97 km²
Elevation: Varies from 78m to as high as 2943 m from sea level.

Figure: LULC map 2000 and 2010

Figure: Location of the Study Basin

Figure: Sub-watershed Used in the Study
2.2 Data Sources

**Land use and Land cover**
- Obtained from the ICIMOD Nepal Geospatial Portal.
- Prepared using public domain landsat TM data.
- Consists 7 attributes: Forest, grassland, shrubland, built-up agriculture, waterbody and barren land.
- Years: 2000 & 2010

**Precipitation Data**
- Purchased from the DHM, Nepal.
- Rainfall map prepared using IDW method in Arc GIS.
- Average rainfall of the basin 1600mm.
- Years: 1987-2016

**Digital Elevation Map (DEM)**
- Obtained from the National Agricultural Research Council, NARC Nepal.
- Resolution: 20m
- Elevation varies from 82.5 m to 2943.68m

**Watersheds and Subwatersheds**
- Based on DEM, generated using ArcSWAT.
- Seven sub-watersheds.
2.2 Data Sources

- Source of data- Various published literatures and InVEST User guidelines
- Kc- Plant evapotranspiration coefficient
- Root depth- maximum root depth(mm) for LULC types
- Carbon pools- mg per ha
- Load_n / Load_p – nutrient loading (kg per ha per year)

### Biophysical table

Table 1 Biophysical attributes used for the InVEST models

<table>
<thead>
<tr>
<th>LULC_desc</th>
<th>Forest</th>
<th>Shrubland</th>
<th>Grassland</th>
<th>Agriculture</th>
<th>Barren</th>
<th>Water</th>
<th>Builtup</th>
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<tbody>
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<td>4</td>
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<td>0.001</td>
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<tr>
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<td>0.5</td>
<td>0.4</td>
<td>0.25</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>
2.3 Evaluation of Ecosystem Services (ES)

Four ES services:

- Water yield (WY) – Regulating Service
- Soil Loss – Regulating Service
- Carbon storage – Regulating Service
- Nutrient delivery – Regulating Service

Mapped based on LULC maps of 2000 and 2010 AD and corresponding climate data.

Soil loss is computed using RUSLE & WY, Carbon, and Nitrogen export are mapped using InVEST model.

(MME) of 12 best GCMs of CMIP5 under scenario RCP 4.5 and RCP 8.5, downscaled by using APCCs’ AIMS software is used to create climate data to study the projection of ES in future.

*Figure InVEST ES Tools Overview*
2.3.1 Water Yield Model

- Determines the amount of water running off each pixel as the precipitation minus the fraction of the water that undergoes evapotranspiration.

- Based on the Budyko curve and annual average precipitation.

\[ Y(x) = (1 - \frac{AET(x)}{P(x)}) \times P(x) \]

- **Y(x)**: Annual water yield for each pixel
- **AET(x)**: the annual actual evapotranspiration
- **P(x)**: annual precipitation on pixel x.

\[ \frac{AET(x)}{P(x)} = 1 + \frac{PET(x)}{P(x)} - \left[ 1 + \left( \frac{PET(x)}{P(x)} \right)^{\omega} \right]^{1/\omega} \]

\[ PET(x) = Kc(l_x) \times ET_o(x) \]

\[ \omega(x) = Z \times AWC(x) + 1.25 \]

- **PET(x)** is potential evapotranspiration
- **ET_o(x)** is the reference evapotranspiration from pixel x
- **Kc(l_x)** is the plant evapotranspiration coefficient
- **ω(x)** is a non-physical parameter that characterizes the natural climatic-soil properties.
- **Z** constant defines local precipitation and hydrogeological characteristics of the basin.
2.3.1 Water Yield Model

Z parameter is calibrated by comparing the model output with observed streamflow at outlet streamflow gauge station.

Figure: Output files

Figure: Model interface
2.3.2 Soil Loss by Revised Universal Soil loss Equation

- RUSLE - Widely used model at large scales
- Well known for data simplicity and its provision of basis for carrying out scenario analysis and taking measures against erosion.
- Uses a combination of geo-physical and land cover factors to estimate the likely annual soil loss from a unit of land.
- The RUSLE equation is as follows:

\[ A = R \times K \times L \times S \times C \times P \]

Where, 
- \( A \) = average annual soil loss amount in (Mg or t/ha/yr)
- \( R \) = Rainfall-runoff erosivity factor (MJ mm/h/ha/yr)
- \( K \) = Soil erodibility factor
- \( L \) = slope length factor
- \( S \) = Slope steepness factor
- \( C \) = Land cover management factor
- \( P \) = Support practice factor

*Figure: RUSLE Data Preparation*
2.3.3 Carbon Storage and Sequestration Model

- The model maps carbon storage densities to LULC rasters.
- It aggregates the amount of carbon stored on four major carbon pools to produce total amount of carbon storage.

(Carbon pools)
- aboveground biomass,
- belowground biomass,
- soil
- dead organic matter

\[ V_{\text{seq}} = V_{\text{sequest}}(X) \sum_{t=0}^{y_{fut}-y_{cur}} \frac{1}{(1 + \frac{r}{100})^t (1 + \frac{c}{100})^t} \]

The output of the model is expressed as million grams per hectare (mg per ha).

Figure: Carbon Model Interface
2.3.4 Nutrient Delivery Ratio Model

- Uses a simple mass balance approach.
- Describes the movement of a mass of nutrient through space and aims to quantify nutrient export.
- Maps the transport of nutrients from watershed sources to the stream network.
- Sources of nutrients are determined based LULC map & associated loading rates.
2.4 Future Climate Projection

- General Circulation Models (GCMs) - serves as useful basis and they are probably the only kind of tool to predict future climate.

- Have inherent problems due to a coarse resolution - difficulty to capture climatic characteristics at regional or local scales.

- Application of downscaling technique – Statistical and Dynamic Downscaling Technique

- Bias Correction is required – Quantile mapping method is used.

- Uncertainties among climate models - many studies recommends use of multiple models.

- Ensemble averaging can improve the accuracy of a climate projection by allowing GCM errors to cancel each other out and GCMs that poorly performed to be down weighted.
2.4 Future Climate Projection – QC

- Observation data for period 1987-2016
- Grid data extraction and comparison / Using R script – R package
- Quality control
  - Grid data by country
    - PERSIANN-CDR: https://www.ncdc.noaa.gov/data/precipitation-persiann/access/
    - ERA-Interim: http://apps.ecmwf.int/datasets/data/interim-full-daily/leveltype=sfc/

After Quality Control(QC), station data is used in AIMS.
2.4 Future Climate Projection – AIMS Module

- AIMS module - free and open source module.
- R script can be exported and run separately.
- Raw GCM analysis results – 12 best GCMS are used.
- Ensemble Averaging for period S1, S2, S3 – using Matlab and Excel.

Figure: AIMS User Module
2.4 Future Climate Projection – Rcp Description

- 29 GCMs of CMIP5 downscaled for Nepal
- For RCP scenarios 4.5 and 8.5
- MME of 12 best GCMs are used for the study.
- Three periods: S1 2010-2039, S2 2040-2069, S3 2070-2099

<table>
<thead>
<tr>
<th>Rcps’</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rcp 8.5</td>
<td>Rising radiative forcing pathway leading to 8.5 W/m² in 2100</td>
</tr>
<tr>
<td>Rcp 6.0</td>
<td>Stabilization without overshoot pathway to 6 W/m² at stabilization after 2100</td>
</tr>
<tr>
<td>Rcp 4.5</td>
<td>Stabilization without overshoot pathway to 4.5 W/m² at stabilization after 2100</td>
</tr>
<tr>
<td>Rcp 2.6</td>
<td>Peak in radiative forcing at ~ 3 W/m² before 2100 and decline.</td>
</tr>
</tbody>
</table>

CMIP Phase 5 Representative Concentration Pathways (RCPs) scenarios (Source: IPCC)

<table>
<thead>
<tr>
<th>Climate Scenarios</th>
<th>RCP</th>
<th>Period</th>
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<tbody>
<tr>
<td>S1RCP4.5</td>
<td>Rcp4.5</td>
<td>2010-2039</td>
</tr>
<tr>
<td>S2RCP4.5</td>
<td>Rcp4.5</td>
<td>2040-2069</td>
</tr>
<tr>
<td>S3RCP4.5</td>
<td>Rcp4.5</td>
<td>2070-2099</td>
</tr>
<tr>
<td>S1RCP8.5</td>
<td>Rcp8.5</td>
<td>2010-2039</td>
</tr>
<tr>
<td>S2RCP8.5</td>
<td>Rcp8.5</td>
<td>2040-2069</td>
</tr>
<tr>
<td>S3RCP8.5</td>
<td>Rcp8.5</td>
<td>2070-2099</td>
</tr>
</tbody>
</table>

Global temperature projections for various RCP scenarios. Source: IPCC, 2013
3. Results and Discussion
3.1 Land use and Land Cover Change Assessment

<table>
<thead>
<tr>
<th>Class</th>
<th>LULC 2000(ha)</th>
<th>LULC 2010(ha)</th>
<th>Change</th>
<th>(%)Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>181246.64</td>
<td>177803.92</td>
<td>-3442.72</td>
<td>-1.90</td>
</tr>
<tr>
<td>Shrubland</td>
<td>2025.96</td>
<td>662.92</td>
<td>-1363.04</td>
<td>-67.28</td>
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<tr>
<td>Grassland</td>
<td>11414.60</td>
<td>5402.48</td>
<td>-6012.12</td>
<td>-52.67</td>
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<tr>
<td>Agriculture</td>
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<tr>
<td>Barren</td>
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<td>5003.60</td>
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<td>-34.64</td>
</tr>
<tr>
<td>Water body</td>
<td>884.20</td>
<td>1034.84</td>
<td>150.64</td>
<td>17.04</td>
</tr>
<tr>
<td>Built-up</td>
<td>13124.52</td>
<td>17211.80</td>
<td>4087.28</td>
<td>31.14</td>
</tr>
<tr>
<td>Total</td>
<td>276897.12</td>
<td>276897.12</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

- Increased population
- Higher demands for food and agriculture
- Urbanization
- Significant change in LULC
- Comparative scenario – high increment on Built-up area and Agriculture and high decrement on Shrubland and Grassland
3.1 Land use and Land Cover Change Assessment

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Forest</th>
<th>Shrubland</th>
<th>Grassland</th>
<th>Agriculture</th>
<th>Barren</th>
<th>Water body</th>
<th>Built-up</th>
<th>Total</th>
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<td>551</td>
<td>473.92</td>
<td>241.2</td>
<td>674.52</td>
<td>42.16</td>
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<td>Grassland</td>
<td>886.04</td>
<td>47.84</td>
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<td>31.48</td>
<td>7.72</td>
<td>47.72</td>
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<td>0</td>
<td>13124.52</td>
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</table>

Conversion from one class to another on LULC of 2000 and 2010

- Rate of conversion to agriculture land from other Land use is highest.
- Also conversion to Built up area is significant from other classes.
- Attributable to increased population and urbanization
- Significant fluctuation on Ecosystem service provisions.
3.2 Future climate projection

- Compared to baseline period: 1987-2016
- Average temperature is expected to increase by 1.62°C by the end of 2030, 2.53°C by the end of 2060 and 2.99°C by 2100 under RCP 4.5 scenario.
- Likewise, under RCP 8.5, average temperature is expected to increase by 1.65°C C by the end of 2030, 3.20°C by the end of 2060 & 4.87°C by 2100

- Under both Rcp scenarios, precipitations is increasing linearly from S1 to S3 periods.
- This increased temperature and precipitation has significant impacts on Ecosystem service provision.
### 3.3 Water Yield

<table>
<thead>
<tr>
<th>Sub basin</th>
<th>Area</th>
<th>Precip (mm)</th>
<th>Precip (mm)</th>
<th>WY (m$^3$/ha)</th>
<th>WY (m$^3$/ha)</th>
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<tbody>
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<td>Avg</td>
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<td></td>
<td>1766.5</td>
<td></td>
</tr>
</tbody>
</table>

- Case 1: 1996-2005 Precipitation data, 2000 LULC,
- Sub-basin 5 has highest water yield in both cases.
- With reduction on Average precipitation, Water yield is reduced on case 2.
- Also, as it is function of reference evapotranspiration, with increment on built-up area on sub-basin 2 on 2010, water yield is increased in contrast to overall reduction of WY in basin.
Urban Flooding

Infrastructural incapability to counteract increased water yield!!

Location: Bhaktapur, Central Nepal

Picture Source: The Himalayan Times daily

Date: Monsoon 2019!!
Under both RCP scenarios, WY is projected to increase – Sub basin 6 having highest yield and sub-basin 2 lowest yield.
### 3.4 Soil loss computation using RUSLE

<table>
<thead>
<tr>
<th>Landuse</th>
<th>Average Rate (t/ha/yr)</th>
<th>Soil Loss (MT/yr)</th>
<th>Average Rate (t/ha/yr)</th>
<th>Soil Loss (MT/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrubland</td>
<td>199.93</td>
<td>0.14</td>
<td>110.65</td>
<td>0.23</td>
</tr>
<tr>
<td>Water</td>
<td>65.83</td>
<td>0.07</td>
<td>51.36</td>
<td>0.05</td>
</tr>
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<td>Barren</td>
<td>225.62</td>
<td>1.12</td>
<td>121.23</td>
<td>0.92</td>
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<tr>
<td>Grass</td>
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<td>Built</td>
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<td>9.22</td>
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<tr>
<td>Forest</td>
<td>35.66</td>
<td>6.30</td>
<td>40.13</td>
<td>7.22</td>
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<tr>
<td>Agriculture</td>
<td>173.58</td>
<td>12.09</td>
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</tr>
<tr>
<td>Total</td>
<td>20.46</td>
<td>21.38</td>
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</table>

- Soil loss (SL) is also highly affected by rainfall-runoff erosivity, factor of rainfall.
- For 2010 LULC, rate of SL is highest on Agriculture, followed by barren and shrubland.
- For 2000 LULC, rate of SL is highest on barren followed by shrubland and agriculture.
- As the upper part of the basin is highly dominated by agriculture, in both cases, total soil loss is highest from Agriculture area.
- Most sensitive issue with increasing trend.
3.4 Soil loss computation using RUSLE

With increasing precipitation, SL is projected to be linearly increasing from S1 period to S3 period in both scenarios in all basins.

Soil loss is highest on sub-basin 3 followed by sub-basin 4 and sub-basin 2.

Baseline 2010 LULC - Lack of proper land use policy and agriculture system further exacerbates the case.
3.5 Carbon Storage mapping

With significant conversion of Land use and land cover from intact natural system to agriculture and built-up, total carbon storage is reduced by 969923Mg.
3.5 Carbon Storage mapping

- Sub-basin 2, incorporates major residential and agricultural area – Kathmandu valley and capital city – has lowest carbon storage.
- On comparative study – reduction is highest on sub-basin 4 followed by sub-basin 2.
- Land use policy – incorporation of map of area of highest/lowest carbon storage – reduces risk of loss of carbon sink - promotes sustainable ES provision.
3.5 Nitrogen export mapping

- Nitrogen load are generated from various point and non-point source pollution.
- Highest on Sub-basin 2 in both cases.
- Highly dependent on LULC
3.6 Relative Comparison of ES on sub-basins and periods (2000-2010)
3.7 Discussion

ES are rescaled on a range on 0 to 1, 0 being lowest provision and 1 being highest when compared on all seven watersheds on LULC of 2000 and 2010 and corresponding climate.

The provision of overall ES service is lowest on sub-basin 2 and highest on sub-basin 7 on both time periods.

Sub-basin 2 has lowest carbon storage and nitrogen retention – attributable to major residential and agricultural area.

Sub-basin 7 has highest Soil retention, nitrogen retention and carbon storage – attributable to intact / undisturbed nature.

Sub-basin 3 has lowest soil retention and Sub-basin 6 has lowest water yield.

Sub-basin 2 demands urgent measures for preservation as ES are on constant decrease.

Ranking of services can be made based on priorities of inhabitants of sub-basin.
4. CONCLUSION
1. Ecosystems provide a range of services, many of which are of fundamental importance to human well being for health, livelihoods, and survival.

2. Conversion of land use from one class to another significantly alters ES.

3. The projection of climate change has indicated the acceleration on the water cycle at a global scale, resulting in more frequent climate events which will impact provision of ecosystem services.

4. Proper plans and mitigation measures are necessary to combat the impacts of climate change.

5. Cost of preservation of ES can be valued as avoided treatment cost or improved quality.

6. ES maps of – where they originate- their storage - their export – on a sub-basin scale – on present and future climatic conditions - helps land use decisions and policy making for sustainable designs and systems.
Any comments and suggestions are highly appreciated!! 😊

Thank you for your attention.

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