STUDY ON TYPE AND DISTRIBUTION OF WETLANDS OF SIKKIM HIMALAYAS USING SATELLITE IMAGERY WITH REMOTE SENSING & GIS TECHNIQUE

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ABSTRACT
Wetlands are one of the most important and reproductive ecosystems of earth and provides wide array of benefits to mankind. Keeping this in view, the authors made an effort to study the different type of wetlands and their distribution in different geographical regions of Sikkim, a small state in the Himalayas in India with total geographical area as 7096 square kilometres, using satellite data of IRS P6 imagery on 1:50,000 scale. Such studies are first of its kind using IRS P6 and extensive ground truth assessment. The major wetland types in the state are High-altitude lakes (above 3000m), Low-altitude lakes (below 3000m), rivers and major streams. Ground truth data was collected for selected wetland sites and Standard Performa was adopted to record the field data. Field photographs were taken to record the water quality (subjective), status of aquatic vegetation and water spread. GPS was used for locating the features.

During the study, more than 500 lakes (including >2.25 ha and < 2.25 ha) were detected and total area of these wetlands (lakes and rivers/major streams) was found increased in post-monsoon season (2006) from pre-monsoon (2005). High altitude lakes (above 3000m and more than 2.25ha) accounted for 40.79% (3050 ha) of total wetlands area, river/major streams accounting 55.25% (4131 ha) and Low-altitude lake (below 3000m and more than 2.25ha) was 0.20% (15 ha) of total wetland area.

The wetlands of Sikkim were found to be mostly with low and moderate turbidity and High turbidity wetlands were not detected. The state has four districts and North District has highest concentration of wetlands with 63.7% of total wetland area in state and it covers 1.13% of total geographic area of state. The other three districts i.e. West, East and South Districts have 14.3%, 12.1% and 9.88% area under wetlands respectively.

High Altitude Lakes were observed in three districts (North, West and East). The districts with very high concentration of small lakes (<2.25 ha) are North District with 221 followed by East and West Districts with 42 and 16 respectively, while south district has lowest with only 2 such wetlands.

Key: Wetlands, Sikkim, IRS-P6, turbidity

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INTRODUCTION

Sikkim, 22nd state of the Indian Union, is situated in the North Eastern region of India. The state shares its borders with Nepal in the west, China to the north and east, Bhutan in the south east and Indian state of West Bengal to its south. It lies between 27° 04' 46" N to 28° 07' 48" N latitudes and 88° 00' 58" to 88° 55' 25" E longitudes (Risley, 2001). The total geographic area of the state is 7,096 km² (Verma, 2009) occupying an area of 0.22% of the total geographical area of the country. The hilly regions of Sikkim mainly constitutes of two types of rocks—half-schistose and gneissose. These two types of rocks form crucial constituents of the geology. The soil does not have a high content of organic matter and is not rich in minerals. The texture of this soil is coarse. The presence of these two rock types has turned the soil of these regions brown and clayey. Numerous snow-fed streams in Sikkim have carved out river valleys in the west and south of the state. These streams combine into the Teesta and its tributaries. There are two main drainage basins namely Teesta and Rangeet. The Teesta, described as the "lifeline of Sikkim", flows through the state from north to south. There are 84 glaciers mapped in Sikkim (Glacier Atlas of Teesta basin 2001).

The climate ranges from sub-tropical in the south to tundra in the northern parts. The tundra-type region in the north is clad by snow for four months a year, though the temperature drops below 0°C almost every night. Most of the inhabited regions of Sikkim, however, witness a temperate climate, with the temperatures seldom exceeding 28°C in summer or dropping below 0°C in winter (Verma, 2009). The maximum rainfall of the state is recorded in the month of July and August. During the monsoon, heavy rains increase the possibility of landslides.

Along with the mountains, Glaciers and passes, the state of Sikkim also have many lakes though not in very large size. The lakes are both Snow fed as well as river fed. The premier lakes of the state are Changu (Tsongo), Khchodpalri, Gurudongmar, Cholamu, Memenchong, Lampokhari, Samiti etc. The Tsomgo lake covering and area of 24.47 ha is one of the important tourist sites in the state.

Wetlands are one of the crucial natural resources. Wetlands are areas of land that are either temporarily or permanently covered by water. This means that a wetland is neither truly aquatic nor terrestrial; it is possible that wetlands can be both at the same time depending on seasonal variability. Thus, wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry, dominant plants and soil or sediment characteristics. Because of their transitional nature, the boundaries of wetlands are often difficult to define. Wetlands do, however, share a few attributes common to all forms. Of these, hydrological structure (the dynamics of water supply, throughput, storage and loss) is most fundamental to the nature of a wetland system. It is the presence of water for a significant period of time which is principally responsible for the development of a wetland.

One of the difficulties most frequently faced for decision making is lack of scientific data of our natural resources. Often the data are sparse or unconvincing, rarely in the form of geospatial database (map), open to challenges. Thus, the current thrust of every country is to have an appropriate geospatial database of natural resources that is based on unambiguous scientific methods. Keeping in view of above facts an attempt to study on type and distribution of wetlands of Sikkim Himalayas using satellite imagery with Remote Sensing & GIS Technique has been made with the following objective.
- Mapping the wetlands of Sikkim using IRS LISS III digital data following a standard wetland classification system.
- Integration of ancillary theme layers (road, settlements, drainage, administrative boundaries).
- Creation of a seamless database of the states in GIS environment.
- Preparation of wetland atlases of State.

METHODOLOGY

The widely used classifications system, devised by Cowardin et al., (1979), was used during the study. The methodology to create the state level atlas of wetlands is adhered to NWIA (National Wetland Inventory and
Assessment) Technical guidelines and procedure manual (Garg and Patel, 2007). The overview of the steps used is shown in Figure 1. Salient features of methodology adopted are:

- Generation of spatial framework in GIS environment for database creation and organisation:
- Geo-referencing of satellite data
- Identification of wetland classes as per the knowledge based digital classification and onscreen interpretation
- Generation of base layers (road network, settlements, drainage, administrative boundaries) from satellite image and ancillary data.
- Attribute coding of the wetlands following the standard classification system and codification.
- Preparation of map compositions and generation of statistics
  
(Work was carried out using ERDAS Imagine, ArcInfo and ArcGIS software)

**Figure 1: Flow chart of the methodology used**

Data used:
During the study, IRS P6 LISS III Pre-Monsoon (April 13, 2005) and Post-Monsoon (January 26, 2006) and Topographic map of Sikkim (1:50,000 scale) were used. The satellite data were registered by image-image registration process with acceptable RMS (Root Mean Square) error of 0.76 using ERDAS Imagine 9.1 software.

**Accuracy Assessment**

Accuracy assessment was done by the determination of thematic classification as well as location accuracy. GIS database(s) contents have also been evaluated for accuracy and to ensure the reliability of the data. Quality assurance and quality control measures were taken for data collection, analysis, verification and reporting. The study used well established, time-tested, fully documented data collection conventions and employed skilled and trained personnel for image interpretation, processing and digital database creation. All interpreted imagery was reviewed by technical expert for accuracy and code. Quality check includes:
RESULT AND DISCUSSION

Maps and Statistics
Area estimates of various wetland categories for Sikkim have been carried out using GIS layers of wetland boundary, water-spread, aquatic vegetation and turbidity. Total 272 wetlands (greater than 2.25 ha) have been mapped at 1:50,000 scale in the state. In addition, 281 wetlands (smaller than 2.25 ha) have been digitized as point layer. They are named as Small Wetlands (<2.25 ha). Total wetland area estimated is 7477 ha, which comprise around 1.05 per cent of the geographic area of state (Table 1). The major wetland types are High altitude lakes (above 3000m) accounting for 40.79 % (3050 ha) of the total wetland area of state, rivers/streams with area of 4131 ha and Low altitude lakes (below 3000m) which accounted for 15 ha. Graphical distribution of wetland type is shown in Figure 2.

Wetland map of the study area
Table 1: Area estimates of wetlands in Sikkim (Area in hectares)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Wetland Category</th>
<th>No. of wetlands</th>
<th>Wetland Area (ha)</th>
<th>% of wetland area</th>
<th>Open water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Post-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>monsoon 2006 (ha)</td>
</tr>
<tr>
<td>1</td>
<td>Inland Wetlands - Natural</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Low altitude Lakes (below 3000m and more than 2.25ha)</td>
<td>1</td>
<td>15</td>
<td>0.20</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>High altitude Lakes (above 3000m and more than 2.25ha)</td>
<td>259</td>
<td>3050</td>
<td>40.79</td>
<td>3050</td>
</tr>
<tr>
<td>3</td>
<td>Major Rivers/Streams</td>
<td>12</td>
<td>4131</td>
<td>55.25</td>
<td>4131</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>272</td>
<td>7196</td>
<td>96.24</td>
<td>7189</td>
</tr>
<tr>
<td>4</td>
<td>Small Wetlands (&lt;2.25 ha)</td>
<td>281</td>
<td>281*</td>
<td>3.76</td>
<td>281</td>
</tr>
<tr>
<td>5</td>
<td>Total</td>
<td>553</td>
<td>7477</td>
<td>100</td>
<td>7470</td>
</tr>
</tbody>
</table>

* The average area of Small Wetlands (<2.25 ha) has been taken as 1 ha.

Figure 2: Type-wise wetland distribution in Sikkim
District-Wise Wetland Maps and Statistics

District-wise distribution of wetlands showed that 3 districts can be called as wetland rich. North District has highest concentration with 63.7 percent of total wetland area in state and it shares 1.13% of geographic area of state. The other two districts, West and East, have 14.3 and 12.1 per cent area under wetland respectively. South district has the lowest area under wetland (9.88 %) and does not have any High altitude lake (above 3000m). Wetland category of High Altitude Lake (above 3000m) was observed only in three districts. District-wise wetland area estimates is given in Table-2. Figure 3 shows district-wise graphical distribution of wetlands. North district has very high concentration of small wetlands (< 2.25 ha) with 221 followed by East and West District with 42 and 16 respectively, while south district has lowest with 2 such wetlands.

Table-2: District-wise wetland highlights

<table>
<thead>
<tr>
<th>Sl No</th>
<th>District</th>
<th>Geographic Area (ha)</th>
<th>Number of Wetland</th>
<th>Wetland Area (ha)</th>
<th>% of total wetland area</th>
<th>% of geographic area</th>
<th>Major wetland type (total types)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>North</td>
<td>422600</td>
<td>432</td>
<td>4764</td>
<td>63.72</td>
<td>1.13</td>
<td>High Altitude Lake, River/stream, Small Wetlands (&lt;2.25 ha)</td>
</tr>
<tr>
<td>2</td>
<td>West</td>
<td>116600</td>
<td>44</td>
<td>1069</td>
<td>14.30</td>
<td>0.92</td>
<td>River/stream, High Altitude Lake &amp; Low Altitude Lake, Small Wetlands (&lt;2.25ha)</td>
</tr>
<tr>
<td>3</td>
<td>South</td>
<td>75000</td>
<td>5</td>
<td>739</td>
<td>9.88</td>
<td>0.99</td>
<td>River/stream, Small Wetlands (&lt;2.25ha)</td>
</tr>
<tr>
<td>4</td>
<td>East</td>
<td>95400</td>
<td>77</td>
<td>905</td>
<td>12.10</td>
<td>0.95</td>
<td>River/stream &amp; High Altitude Lake, Small Wetlands (&lt;2.25ha)</td>
</tr>
<tr>
<td>5</td>
<td>Total</td>
<td>709600</td>
<td>558*</td>
<td>7477</td>
<td>100</td>
<td>1.05</td>
<td>River/stream, High Altitude Lake &amp; Low Altitude Lake, Small Wetlands (&lt;2.25ha)</td>
</tr>
</tbody>
</table>
* The number of Wetlands may vary in the district-wise allocation because of the confluence of the River/Streams between districts, but the area remains same.

**Figure 3: District-wise graphical distribution of wetlands**

**DATA COMPARISON**

**Table 3: Comparative figure of Area under wetland of Sikkim (excluding river/streams & Small Wetland)**

<table>
<thead>
<tr>
<th>District</th>
<th>North</th>
<th>West</th>
<th>South</th>
<th>East</th>
<th>State (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (in ha)</td>
<td>1807.75</td>
<td>2674</td>
<td>56.50</td>
<td>193</td>
<td>-</td>
</tr>
</tbody>
</table>

Total area increase percentage = 54.4%

**Table 4: Comparative figure of Number of wetland of Sikkim (excluding river and streams)**

<table>
<thead>
<tr>
<th>District</th>
<th>North</th>
<th>West</th>
<th>South</th>
<th>East</th>
<th>State (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands (&gt;2.25ha)</td>
<td>135</td>
<td>207</td>
<td>11</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>Wetlands (&lt;2.25ha)</td>
<td>64</td>
<td>221</td>
<td>-</td>
<td>16</td>
<td>-</td>
</tr>
</tbody>
</table>

Number of wetland increase Percentage = 62.5%
The increase in the number of the wetlands is basically due to the difference in satellite imagery used. The earlier study in the wetland mapping of Sikkim (1998) was done with the help of IRS 1A LISS II data with spatial resolution of 36.25m whereas the present study (2006) was done with the satellite IRS P6 LISS III data having spatial resolution 23.5m.

FINDINGS:

Total 272 wetlands including 1 Low Altitude Lake, 259 High altitude lakes and 12 Major Rivers/streams have been mapped at 1:50,000 scale in the state. In addition, 281 wetlands (<2.25 ha) have also been identified. In all 553 wetlands were detected; pre-monsoon (2005) satellite data accounting 5316 ha and post-monsoon (2006) having an area of 7477 ha.

The total wetland area was found to be 7477 ha, which is 1.05% of the geographic area of state. The major wetland types are High altitude lakes, having area of 3050 ha, accounting 40.7% of the wetlands of state, Major River/streams (4131 ha) and Low Altitude Lake (15 ha). The wetlands of Sikkim have low turbidity (2380 ha in post-monsoon and 885ha in pre-monsoon) and moderate turbidity (4809 ha in post-monsoon and 4151ha in pre-monsoon). High turbidity wetlands were not detected.

Wetland category of High Altitude Lake was observed only in three districts (North, West and East). The district with very high concentration of small wetlands (<2.25 ha) is North with 221 followed by East and West District with 42 and 16 respectively, while south district has lowest with 2 such wetlands.

CONCLUSIONS:

The earlier study in the wetland mapping of Sikkim was done with the help of IRS 1A LISS II satellite data which had the spatial resolution of 36.25m whereas the present study was done with the satellite data of IRS P6 LISS III having spatial resolution 23.5m which is more advance and has higher details of the imagery as compared to LISS II data. As the new imagery has fine details, smaller wetlands can also be detected which the earlier satellite (LISS II) could not detect. Area of various wetland categories for Sikkim has been carried out using GIS layers of wetland boundary, water-spread, aquatic vegetation and turbidity.

The comparative figure of wetland studies carried out in the year 1998 and 2006 suggests that the area under wetland (excluding river/stream and Small Wetland) has been increased in Sikkim in last eight years by 1080ha i.e. 54.4%. The number of wetlands has also increased from 160 (1998) to 260 (2006). Similarly the
The number of wetland (<2.25ha) has increased manifolds from 67 (1998) to 281 (2006). The main reason for increasing the areas as well as number is due to the difference in spatial resolution of IRS 1A LISS II and IRS P6 LISS III data.

North district has the highest concentration with around 63.7 percent of total wetland area in state and it share 1.13% of geographic area of state. This is mainly due to the location of the famous Gurudogmar Lake. West and East districts have 14.3 and 12.1 per cent area under wetland respectively. The south district receives least rainfall in compare with the other district hence regarded as the driest district of Sikkim. South district has the lowest area under wetland (around 9.88 per cent), which is mainly due to the presence of river and streams.

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