

## MONITORING OF STRUCTURAL COMPONENTS AND WATER BALANCE AS AN AID TO WETLAND MANAGEMENT USING GEOSPATIAL TECHNIQUES – A CASE STUDY FOR NALSAROVAR LAKE, GUJARAT

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### ABSTRACT:

The hydrologic variability greatly influences the structural components of wetlands that have a great bearing on habitats for avifauna, aquatic fauna including fish *etc.* This paper highlights the results of a study carried out to derive changes in open-water and vegetation, and also water balance for Nalsarovar Lake, Gujarat. MODIS 8-day composite data for three consecutive years viz 2002/03, 2003/04 and 2004/05 were used to study the seasonal and inter annual dynamics of water regime in the lake. Digital elevation model derived using Shuttle Radar Topographic Mission data with interpolated bottom topography was used to generate elevation contours and compute water volume from water spread data. The reference data of 2002 (drought year) shows the maximum extent of wetland to be 8.06 km<sup>2</sup> with emergent vegetation of recorded as 2.36 km<sup>2</sup> and open-water as 5.70 km<sup>2</sup>. The rainfall has an impact on the preferred habitat availability for various species of avifauna and it is noted that emergent vegetation present in the lake completely dried up by summer 2002, a rainfall deficit year but revived again in the preceding year i.e. 2003 which was a good rainfall year with 46.68 km<sup>2</sup> under emergent vegetation and 61.96 km<sup>2</sup> under open-water. The 2002 being a drought year has shown very low reference storage (0.256 MCM), which has shown a gradual decrease in the storage to 0.00019 MCM in March 2003. The reference storage also registered a steep increase to 18.165 MCM in October 2003 and decreased 1.264 MCM in March 2004. From this study it is evident that water level of about 9 m elevation at the end of the rainy season is found to be optimal for maintaining various habitats that in turn support the avifauna for the rest of the lean period.

### 1. INTRODUCTION

Wetlands are among the most productive ecosystems of the world. The interactions of physical, chemical and biological components of wetlands enable them perform multiple functions like water storage, storm protection and flood mitigation (Mitsch and Gosselink, 2000). The wetlands like natural lakes, swamps, waterlogged area play very crucial role in avifauna life cycle. Thus, wetland management though requires many parameters, hydrology is the key factor. Remote sensing data has been widely used for mapping and monitoring of various structural components of wetland like water spread, aquatic vegetation, water quality etc (Prigent *et al*, 2001, Ndirima, 2007). Modelling of hydrological fluctuations, water balance of wetlands like lakes, eservoirs is also being attempted with advances in satellite remote sensing. This paper highlights the use of multi temporal remote sensing data and satellite derived digital elevation model to study the surface hydrological condition and its influence on various habitat types of avifauna in an important inland lake, which is a notified bird sanctuary in India.

### 2. STUDY AREA

Nalsarovar situated between 22°40'00"–22°52'00"N latitudes and 71°55'00"–72°06'00" E longitudes located amidst the semi-arid lands of Ahmedabad and Surendranagar districts of Gujarat, India is the study site (Fig.1). It falls in the 4B Gujarat-Rajwara biotic province of the semi arid biogeographical zone. Nalsarovar notified as a sanctuary under Wildlife (Protection) Act, 1972; is the largest wetland bird sanctuary in Gujarat. The avi-fauna habitat formation is highly

dynamic due to changes in the water level and based on this water level and vegetation, eight habitat types have been identified (Anon., 1998, Tatu, 1995), the important ones being i) Deep open-water, ii) Shallow open-water, iii) Emergent-aquatic vegetation and iv. Mud habitat.

### 3. DATA USED

The remote sensing data comprised cloud-free IRS LISS-III data closest to the last rainfall event of the season for 2002, 2003 and 2004 were used as reference. The eight-day composite reflectance data of MODIS Aqua pertaining to green, red, NIR, SWIR bands (500 m) from October 31 to March 30 for 2002-03, 2003-04 and 2004-05 were used to monitor the temporal changes in the wetland structural components. Actual Evapotranspiration (AET) products based on MODIS data of same period were also used.

The digital elevation data of Shuttle Radar Topographic Mission (SRTM) of NASA was used for elevation contour generation. The data is of 90 m resolution at the equator, with reported vertical error of less than 16 m (downloaded from USGS ftp site). These are available in both ArcInfo GRID and GeoTiff format to facilitate their ease of use in a variety of image processing and GIS applications. The version 4 available from August 2009 is used for this study. Field data was collected on various classes for thematic classification of remote sensing data. Sampled locations on water depth were also collected. Ancillary information on rainfall data, lake water use etc. were also collected.

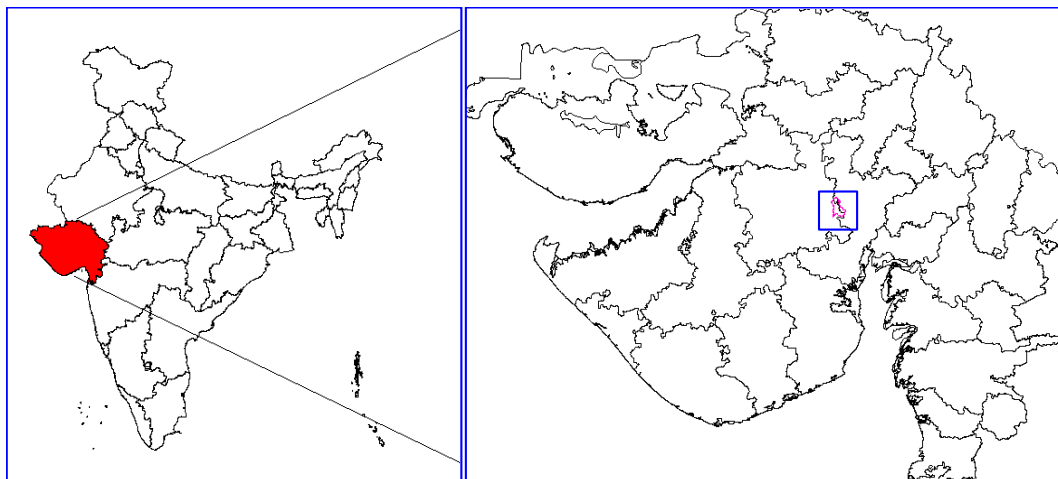


Figure 1: Location of Nalsarovar Lake (Gujarat, India)

#### 4. METHODOLOGY

##### 4.1 Derivation of Wetland Structural Components

Pre-processing of remote sensing data was done following standard techniques of geometric correction, reprojection to a standard coordinate system (Anon., 2005), multi-date data registration, conversion of digital number to radiance. This was followed by generation of various indices images such as Normalised Difference Water Index (McFeeters, 1996), Modified Normalised Difference Water Index (Hanque, 2002), Normalised Difference Pond Index (Lacaux *et al.*, 2007) and Normalised Difference Vegetation Index (Tucker and Sellers, 1986; Townshend and Justice, 1986). These indices were then used to map the open-water spread, aquatic vegetation, terrestrial vegetation, muddy area *etc* as demonstrated by Murthy *et al.*, 2009. The work was carried out using ERDAS 9.2 image processing software.

##### 4.2 Water Volume and Balance Estimation

For the computation of volume of the water in the lake, one requires the aerial extent and depth. Depth was derived in an indirect way using SRTM-DEM. First the Digital elevation of the land area surrounding the lake using SRTM-DEM was calibrated using linear regression between corresponding values of elevation for the common points in the SRTM-DEM and ground data (collected from various survey maps). Since, a very good linear relationship ( $R^2 = 0.901$ ) was obtained the SRTM data was used for the generation of elevation contours of the area.

Since, the SRTM-DEM does not give the elevation of water surface (shows no-data), the temporal change in the water spread boundary as derived from satellite data was used as elevation contour line, based on the assumption that the surface of water reaches the same height everywhere within the lake. GPS based point measurements for depth of the water were collected (during November 2005 to October 06, regularly for each month corresponding to water spread boundary) and used for the surface interpolation of bottom topography.

To account for the loss of water while computing the change in storage for water balance, actual evapotranspiration (AET) was computed using MODIS (Aqua) noontime optical and thermal data (Bhattacharya *et al.*, 2007).

Change in storage is calculated as:

$$\Delta S_1 = S_r - (ET + \text{Other losses}) \text{ for Date}_1$$

$$\Delta S_2 = \Delta S_1 - (ET_1 + \text{Other losses}_1) \text{ for Date}_2 \dots \text{Date}_n$$

Where,

$$\Delta S_1 = \text{Change in storage for date 1}$$

$$S_r = \text{Reference Storage}$$

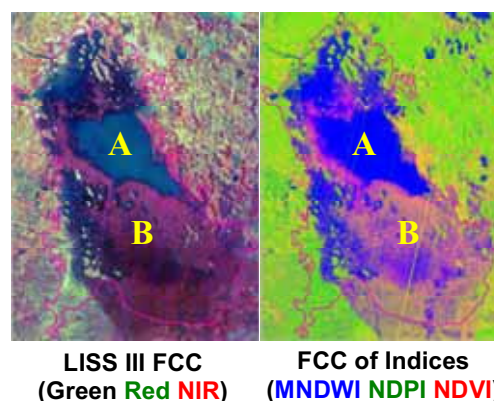
$$\Delta S_2 = \text{Change in storage for date 2}$$

$$ET_1 = \text{Evapotranspiration for date 1}$$

The volume of the water is computed for each dataset using the elevation information. Water balance ( $\Delta S$ ) is computed by subtracting the volume of  $S_1$  from the reference volume ( $S_r$ ) and also accounting losses due to actual evapotranspiration (AET). As other losses like use of water for irrigation, surface/subsurface flow were not physically measured in this study, the difference barring the AET is considered as other losses.

#### 5. RESULTS AND DISCUSSION

The wetland boundary, open-water spread and aquatic vegetation (emergent) could be delineated using combinations of indices images (Fig. 2).



A: Open-water B: Emergent Vegetation

Figure 2: IRS LISS III FCC of the Nalsarovar Lake area along with FCC of indices highlighting accurate detection of open-water and emergent vegetation areas

Nalsarovar Lake being fed through surface runoff exhibit wide fluctuations in the water spread and consequently vegetation

spread, both seasonally and annually. Annual fluctuations are due to the change in rainfall quantity received during monsoon. Figure-3 shows the LISS III FCC corresponding to post-monsoon season (October) of the lake during a drought year (2002), and a normal monsoon year (2004). One can observe the complete drying of emergent vegetation in the drought year and revival of the same in the next year- a normal monsoon year. Similar observations have been made in other studies (Anon, 1998).

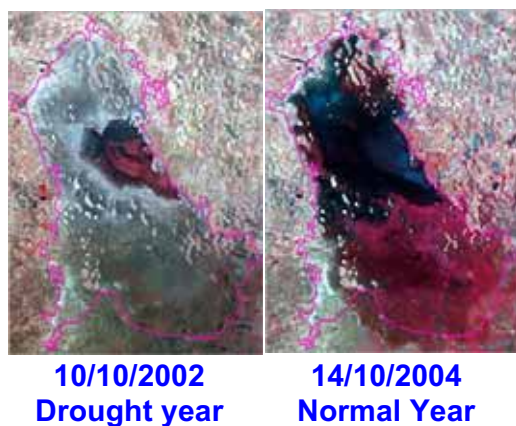


Figure 3: IRS LISS III FCC of Nalsarovar Lake area showing status of open-water and emergent vegetation areas during post-monsoon month of October in a drought year (2002) and a normal year (2003)

It can be inferred that the flooding/inundation gradient influences the vegetation composition, distribution and growth

patterns, as well as the extent of suitable foraging habitats for avifauna. Further, hydrology influences the physico-chemical and biological properties of the lake as well as macrophytes along with the fish and other animals that could be a source of food to certain avifauna. Hence, modelling the water balance is the best aid in the management of this rain fed natural Lake.

### 5.1 Inter- annual Changes

The water balance derived in this study for three years using LISS III data (2002, 2003 and 2004) of post-monsoon month (October) showed significant change from normal year to a monsoon deficit year. The year 2002 was a drought year with 240.70 mm of season's total rainfall. The extent of open-water and emergent vegetation in the lake during 2002 October was found to be 5.70 km<sup>2</sup> and 2.26 km<sup>2</sup> respectively (Table 1). The years 2003 and 2004 were normal-to-good rainfall years with 780 mm and 832 mm rain fall respectively. The extent of open-water and emergent vegetation in the lake during 2003 and 2004 October was 61.96 km<sup>2</sup> and 66.04 km<sup>2</sup> respectively, while the emergent vegetation was 46.68 km<sup>2</sup> and 49.76 km<sup>2</sup> respectively. Thus, one can observe that the extents of open-water and emergent vegetation have been drastically reduced during a drought year compared to a normal/good monsoon year.

### 5.2 Seasonal Changes

Lakes also are known to show seasonal dynamics. Since, this lake is a natural rain-fed lake; its water storage is in its peak during monsoon period (June-September).

| MODIS Data | Area (km <sup>2</sup> ) 2002-03 |                     |            | Area (km <sup>2</sup> ) 2003-04 |                     |            | Area(km <sup>2</sup> ) 2004-05 |                     |            |
|------------|---------------------------------|---------------------|------------|---------------------------------|---------------------|------------|--------------------------------|---------------------|------------|
|            | Wetland                         | Emergent Vegetation | Open Water | Wetland                         | Emergent Vegetation | Open Water | Wetland                        | Emergent Vegetation | Open Water |
| 31-Oct.    | 7.40                            | 2.26                | 5.14       | 108.43                          | 48.14               | 60.30      | 115.59                         | 51.31               | 64.27      |
| 08-Nov.    | 7.18                            | 2.15                | 5.03       | 107.74                          | 48.16               | 59.58      | 114.85                         | 51.33               | 63.52      |
| 16-Nov.    | 6.82                            | 1.91                | 4.91       | 107.45                          | 48.57               | 58.88      | 114.54                         | 51.78               | 62.76      |
| 22-Nov.    | 6.36                            | 1.67                | 4.69       | 107.14                          | 49.23               | 57.91      | 114.21                         | 52.48               | 61.73      |
| 02-Dec.    | 6.09                            | 1.63                | 4.46       | 107.11                          | 49.26               | 57.85      | 114.18                         | 52.51               | 61.67      |
| 10-Dec.    | 5.85                            | 1.62                | 4.23       | 106.81                          | 50.93               | 55.87      | 113.85                         | 54.29               | 59.56      |
| 18-Dec.    | 5.51                            | 1.51                | 4.00       | 105.42                          | 51.00               | 54.43      | 112.38                         | 54.36               | 58.02      |
| 26-Dec.    | 4.83                            | 1.39                | 3.44       | 104.91                          | 50.93               | 53.97      | 111.83                         | 54.30               | 57.53      |
| 01-Jan.    | 4.55                            | 1.39                | 3.15       | 104.63                          | 50.69               | 53.95      | 111.53                         | 54.03               | 57.50      |
| 09-Jan.    | 4.06                            | 1.16                | 2.90       | 104.23                          | 50.63               | 53.60      | 111.11                         | 53.97               | 57.14      |
| 17-Jan.    | 3.71                            | 1.04                | 2.67       | 103.15                          | 49.91               | 53.24      | 109.95                         | 53.20               | 56.75      |
| 25-Jan.    | 3.25                            | 0.93                | 2.33       | 102.27                          | 49.36               | 52.91      | 109.01                         | 52.61               | 56.40      |
| 02-Feb.    | 2.89                            | 0.80                | 2.09       | 99.86                           | 48.04               | 51.83      | 106.45                         | 51.21               | 55.25      |
| 10-Feb.    | 2.67                            | 0.69                | 1.98       | 98.37                           | 47.54               | 50.83      | 104.86                         | 50.67               | 54.18      |
| 18-Feb.    | 2.22                            | 0.47                | 1.75       | 95.23                           | 45.53               | 49.70      | 101.52                         | 48.54               | 52.98      |
| 26-Feb.    | 1.74                            | 0.24                | 1.51       | 91.80                           | 43.98               | 47.82      | 97.86                          | 46.88               | 50.98      |
| 06-Mar.    | 1.36                            | 0.23                | 1.14       | 89.06                           | 43.83               | 45.22      | 95.93                          | 46.73               | 49.21      |
| 14-Mar.    | 1.23                            | 0.22                | 1.02       | 86.87                           | 41.87               | 45.00      | 93.50                          | 44.63               | 48.87      |
| 22-Mar.    | 0.89                            | 0.21                | 0.67       | 85.16                           | 40.52               | 44.64      | 91.33                          | 43.19               | 48.14      |
| 30-Mar.    | 0.82                            | 0.21                | 0.60       | 83.76                           | 40.05               | 43.71      | 89.45                          | 42.69               | 46.75      |

Table-1. Seasonal changes in the extent of open-water and emergent vegetation (from October to March) derived from MODIS 8 day composite data for 3-years.

Thus September-October in general is the peak water storage period. There after, it starts declining, and the lowest storage period is attained during May-June. High temporal 8 day composite MODIS data is thus very suitable to study the

seasonal dynamics of this lake. Results showed significant seasonal fluctuation in the extent wetland extent, open-water and emergent vegetation in the lake. The total wetland area shows a gradual decrease from October to March in all the

years (normal as well as rainfall deficit year) as shown in Table-1. Similar trend was observed with extent of open-water. However, in case of emergent vegetation, in normal years (2003, 2004) one observes a gradual increase from October early January and decrease there after. This was mainly due to the fact that the vegetation growth takes place in areas with receded water, and as the saturated areas start drying up after January with increase in temperature, the vegetation declines and reaches its minima by March end. However, in rainfall deficit year (2002), one observes gradual decrease of vegetation also.

### 5.3 Water balance

Relation between the elevation and water spread area of the lake was found to be best explained by the logarithmic fit with  $R^2 = 0.9489$ . The volume of water thus computed was converted to storage accounting for the AET and other losses. Results showed gradual decrease of water storage from October to March during all the years. However, the peak storage of the lake registered very significant reduction in the drought year. During 2002-03, which is one of the worst monsoon years, the storage during October (2002) was 0.256 million cubic meters (MCM) got reduced to 0.00019 MCM (Table 2) by March

(2003). During 2003-04, the storage in October was 18.165 MCM and reduced to 10.724 MCM by March. During 2004-05, which received maximum rainfall, the storage in October was 20.936 MCM that was reduced to 1.997 MCM by March.

Thus, one can infer that drastic seasonal reduction of water storage in the lake from post-monsoon to summer, strongly characterising the rain-fed water balance of this shallow lake. Since, the amount as well as depth gradient of water available in the lake is decisive in the modelling of optimal habitats of species of avifauna. Simulation of water spread using elevation contour of the lake was carried out. The results showed that beyond 10.5 m elevation, the lake water overflows into the Bhogava River through surface drainage present in the southern part of lake. Thus, water storage at **about 9 m** elevation at the end of the rainy season is optimal to sustain various habitats that support the avifauna for the rest of the season. If a canal is envisaged to join Nalsarovar Lake with the Sardar Sarovar Project Canal passing through the catchment is expected to bring certain positive impacts on the wetland i) Reduction in the salinity of lake water, ii) part of the lake would become perennial and iii) Increase in submergence area leading to conducive for prolonged development of habitats for certain species of waterfowl.

| MODIS<br>8-day<br>Composite | 2002-03 (Drought year) |             |                | 2003-04 (Normal year) |             |                | 2004-05 (Normal year) |             |                |
|-----------------------------|------------------------|-------------|----------------|-----------------------|-------------|----------------|-----------------------|-------------|----------------|
|                             | AET<br>(MCM)           | OL<br>(MCM) | C S T<br>(MCM) | AET<br>(MCM)          | OL<br>(MCM) | C S T<br>(MCM) | AET<br>(MCM)          | OL<br>(MCM) | C S T<br>(MCM) |
| 1, 2, 3                     |                        |             | 0.256          |                       |             | 18.165         |                       |             | 20.936         |
| 31-Oct                      | 0.04                   | 0.19        | 0.215          | 1.64                  | 16.37       | 18.009         | 2.32                  | 18.44       | 20.761         |
| 08-Nov                      | 0.04                   | 0.18        | 0.202          | 1.58                  | 15.91       | 17.488         | 1.86                  | 18.32       | 20.174         |
| 16-Nov                      | 0.04                   | 0.16        | 0.182          | 1.67                  | 15.60       | 17.271         | 1.67                  | 18.26       | 19.931         |
| 22-Nov                      | 0.04                   | 0.13        | 0.158          | 1.51                  | 15.53       | 17.037         | 1.77                  | 17.90       | 19.667         |
| 02-Dec                      | 0.04                   | 0.12        | 0.145          | 1.31                  | 15.71       | 17.018         | 1.78                  | 17.87       | 19.645         |
| 10-Dec                      | 0.02                   | 0.12        | 0.134          | 1.69                  | 15.10       | 16.789         | 1.84                  | 17.54       | 19.388         |
| 18-Dec                      | 0.02                   | 0.10        | 0.118          | 1.52                  | 14.25       | 15.767         | 1.99                  | 16.25       | 18.237         |
| 26-Dec                      | 0.03                   | 0.07        | 0.091          | 1.77                  | 13.62       | 15.388         | 2.10                  | 15.72       | 17.811         |
| 01-Jan                      | 0.03                   | 0.06        | 0.080          | 1.62                  | 13.57       | 15.185         | 2.59                  | 14.99       | 17.583         |
| 09-Jan                      | 0.02                   | 0.05        | 0.063          | 1.43                  | 13.46       | 14.894         | 2.85                  | 14.40       | 17.254         |
| 17-Jan                      | 0.01                   | 0.04        | 0.052          | 1.53                  | 12.57       | 14.106         | 2.52                  | 13.85       | 16.367         |
| 25-Jan                      | 0.02                   | 0.03        | 0.040          | 1.59                  | 11.89       | 13.473         | 2.65                  | 13.01       | 15.654         |
| 02-Feb                      | 0.02                   | 0.02        | 0.031          | 1.83                  | 9.93        | 11.769         | 2.07                  | 11.66       | 13.735         |
| 10-Feb                      | 0.02                   | 0.01        | 0.026          | 1.85                  | 8.87        | 10.724         | 2.41                  | 10.15       | 12.559         |
| 18-Feb                      | 0.02                   | 0.00        | 0.017          | 1.81                  | 6.78        | 8.584          | 2.65                  | 7.49        | 10.147         |
| 26-Feb                      | 0.02                   | 0.00        | 0.010          | 1.60                  | 4.71        | 6.308          | 2.95                  | 4.63        | 7.582          |
| 06-Mar                      | 0.01                   | 0.00        | 0.005          | 1.94                  | 2.60        | 4.541          | 2.18                  | 4.09        | 6.265          |
| 14-Mar                      | 0.01                   | 0.00        | 0.004          | 1.44                  | 1.73        | 3.165          | 2.12                  | 2.51        | 4.634          |
| 22-Mar                      | 0.00                   | 0.00        | 0.00066        | 1.70                  | 0.41        | 2.110          | 2.02                  | 1.19        | 3.212          |
| 30-Mar                      | 0.00                   | 0.00        | 0.00019        | 0.89                  | 0.37        | 1.264          | 1.71                  | 0.28        | 1.997          |

Table-2 Change in storage, actual evapotranspiration and other losses in the Nalsarovar Lake

**Note:** AET = Actual Evapotranspiration, OL = Other Loses, CST = Change in Storage, MCM = Million Cubic Meter, LISS-III data of 1 = 10/10/2002, 2 = 20/10/2003 and 3 = 14/10/2004 as reference storage

## 6 CONCLUSIONS

Following conclusions are drawn from the present study.

- The present study shows that various indices derived using multi spectral data can be used to map lake structural components like open-water, emergent vegetation with good accuracy.
- This paper highlights a methodology to derive depth contours of the lake using limited GPS based observation based on water spread extent observed in remote sensing data.
- SRTM DEM calibrated with known elevation points was useful in assessing the optimum storage requirement of the lake for avifauna habitat.
- High temporal MODIS data is useful in monitoring two important structural components viz open-water and emergent vegetation, which show a strong relationship to avifauna habitat of the Nalsarovar lake.
- The lake registered a significant change in the extent of open-water and emergent vegetation due to seasonal change within a year.
- Water extent at about 9 m elevation at the end of the rainy season is found to be optimal for maintaining various habitats that in turn support the avifauna for the rest of the lean period.

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