Surface Water Monitoring And Evaluation of Indravati Reservoir using the application of Principal Component Analysis using Satellite Remote Sensing Technology

Lakhan Lal Mahato[1], Ajey Kumar Pathak[2], D.Kapoor[3], Nilanchal Patel[4], and M.S.R. Murthy[5]

Research Associate, National Bureau of Fish Genetic Resources, Lucknow.
2&3,National Bureau of Fish Genetic Resources, Lucknow.
Department of Remote Sensing, Birla Institute of Technology, Mesra, Ranchi
Forestry & Ecology Division, National Remote sensing Agency, Balanagar, Hyderabad

Abstract

Over the years, Remote Sensing technology has made great strides and contributed significantly in the management of natural resources, disaster management, environmental monitoring, etc. Operationalisation in many of the application areas including surface water monitoring has been achieved using Indian Remote Sensing satellite data. The remarkable development in space technology currently offers satellite which provide better spatial and spectral resolutions, more frequent revisits, stereo viewing and on board recording capabilities.

Remote sensing techniques can be used to assess several water quality parameters (i.e., suspended sediments (turbidity), chlorophyll, temperature) that are key factors in defining total maximum daily loads (TMDLs). These optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information needed to understand changes in water quality parameters necessary for developing better management practices to improve water quality. With recent and planned launches of satellites with improved spectral and spatial resolution sensors, greater application of remote sensing techniques to assess and monitor water quality parameters will be possible. These remote sensing techniques should improve our abilities to assess the landscape and thus better define TMDLs and then provide monitoring data to follow clean-up efforts.

In the present study, the role of remote sensing in surface water monitoring has been investigated. Principal Component Analysis (PCA) in surface water monitoring of Indravati reservoir have been done to identify the change in the turbidity, loss of water levels resulting in the sinkage of the area along the periphery and loss of water levels resulting in discontinuities of the reservoir.

Introduction

Of all the life sustaining elements water is most fundamental natural resource. It is one of the most important components for photosynthesis and governs the production of any forest ecosystem, efficiency of agricultural system and of course for consumption by human and other living organism and power generation. Thus recharging of the sub-surface and surface water flow depends upon the vegetation cover in addition to geological and geomorphological contours. Thus proper management of the aquifers and conservation of water and soil -a detail information of the watershed is of immense improvement. These would include the large scale mapping, discharge capacity, altitudinal gradient to address prioritization of water run-off and soil conservation of micro- watershed, identification of the species which can help in reducing water loss, improve the soil fertility, prioritization for enrichment or areas for plantation.

Over the years, Remote Sensing technology has made great strides and contributed significantly in the management of natural resources, disaster management, environmental monitoring, etc. Operationalisation in many of the application areas including surface water monitoring has been achieved using Indian Remote Sensing satellite data. The remarkable developments in space technology currently offers satellite which provide better spatial and spectral resolutions, more frequent revisits, stereo viewing and on board recording capabilities. The Indian Remote Sensing satellitelRS-1 C/1 D provides multi spectral data with 23m resolution and panchromatic data with 5.8m resolutions. The high-resolution satellite data not only improves identification of different features but also helps in mapping at cadastral level providing detailed information on 1: 12,500 scale.

Thus, the potential of high-resolution satellite data could be effectively used for surface water monitoring activities at land ownership level with reference to survey numbers. Assessment of the dynamics at the farm level is thus possible with present technology. Frequently coverage of the same area due to repetitive nature of the satellite provides us ample scope to monitor the activities at farm level in the watershed with frequent intervals for tracking the implementation, apply midcourse corrections and for assessing long-term effectiveness of the programme implemented.

Study Area

The area under study lies between the latitude 19° 00’ 00’’ North and 19° 15’ 00’’North and longitude 82° 45’ 00’’ East and 83° 15’ 00’’ East. The study area lies in the southern most portion of Orissa state. It is bounded on the North by Kalahandi and Phulbani districts, on the east by Gajapatti district, on the south by Srikakulum district of Andhra Pradesh state and on the west by Koraput and Kalahandi districts.

The climate of the study area is humid and tropical. It is characterized by a hot and dry summer from March to May, and monsoon or rainy season from June to

September and a good pleasant winter from October to February. However, climatologically, four seasons viz., summer (pre-monsoon), monsoon, post-monsoon and winter could be deciphered as comprising the following months:

- Summer (pre monsoon): March, April and May
- Monsoon: June, July. August and September
- Post Monsoon: October and November
- Winter: December, January and February.

Maximum temperature is recoded during May (mean max. 46.1° C) while minimum is recoded during December (mean min 11.8° C). Humidity is higher during monsoon seasons particularly from July to September and ranges from 79 to 82%. The average rainfall is about 1,100mm. The peak rainfall occurs during the month of August (about 415mm) with the four monsoon months (June to Sep.) contributing almost 85% of the total rainfall. Evaporation rate is maximum (8.00-11.07mm/day) during the dry summer months (March to May) when the relative humidity is the lowest. It is minimum (3.47-4.32mm/day) during the monsoon months, particularly from July to September when the relative humidity is maximum. Wind speed is very low with maximum of 3.5 km/hr being recorded in June. The winter and summer months experience very calm winds with average speed of only about 1km/hr. The mean annual wind
speed is only 1.8km/hr equivalent to less than 0.97m/s.

Data Used

Surface water monitoring and evaluation of Indravati reservoir using the application of Principal Component Analysis (PCA), multi-year (April, 1999 and January, 2000) IRS-LISS-III satellite remote sensing data has been used. After the acquisition of the satellite data in the form of a CD-ROM, it was subjected to various preprocessing techniques in order to obtain geographically referenced data. The data was utilized for the digital classification for identification the surface water monitoring.

Methodology

The study area is covered by the Survey of India (SOI) toposheets number 65 I/16 and 65 M/4 on 1:50,000 scale. The SOI sheets pertaining to the study area were digitally scanned and projected. Common Ground Control Points (GCPs) were selected on the raw satellite data (IRS LISS-III) as well as on the SOI maps with proper spatial distribution covering the entire study area. The coordinates of the GCPs on the reference image and the corresponding coordinates of the similar GCPs on the raw satellite data were used for the geometric correction of the uncorrected satellite data. This was achieved using a first order polynomial transformation fit.

The geometric correction of the satellite data with reference to the SOI topo sheets has been evaluated by superimposing the geometrically corrected satellite data over mosaiced SOI sheets in the digital domain. Using the swipe procedure co-registration of the spatial features on the rectified image with that of the SOI maps was verified. Such geometric rectification of the satellite data facilitates overlaying different administrative (district, taluk etc.) and infrastructure (forest block/compartment) boundaries to extract and analyze the information at different functional units/levels.

Various steps followed for land use/land cover mapping are given below.

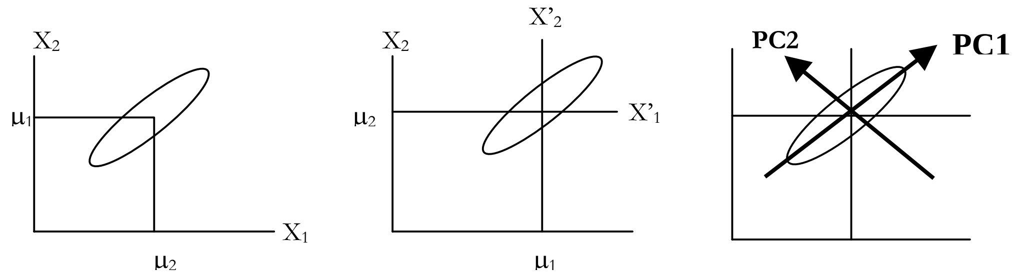
1. Pre-interpretation field visits for getting information about land cover classes, crop types, crop condition, extent of salinity, water logging, etc following standard methodology (Lillesand and Kieffer, 1986).
2. Preparation of base maps on 1:50,000 scale using Survey of India toposheets.
3. Visual interpretation of multi-season geocoded paper print using light table.
4. Correction of interpreted maps using field information, Cartography and finally, scanning of final land use/land cover maps.

Principal Components Analysis

Principal component analysis (often called PCA, or Karhunen- Loeve analysis) has proved to be of value in the analysis of multispectral remotely sensed data (Press et al., 1992; Wang, 1993). The transformation of the raw remote sensor data using PCA can result in new principal component images that may be more interpretable than the original data (Singh and Harrison, 1985). PCA analysis may also be used to compress the information content of a number of bands of imagery (e.g., seven Thematic Mapper bands) into just two or three transformed principal component images. The ability to reduce the dimensionality (i.e., the number of bands in the data set that must be analyzed to produce usable results) from n to two or three bands in an Important economic consideration, especially if the potential information recoverable from the transformed data is just as good as the original remote sensor data. A form of PCA may also be useful for reducing the dimensionality of the hyperspectral data set. Satellite remote sensing data sets of the future may be hyperspectral; containing hundred of bands (e.g., MODIS). For example, Lee et al. (1990) used a modified PCA transformation (i.e., the maximum noise fraction, or MNF) for data compression and noise deduction of 64-channel hyper spectral scanner data in Australia. Noise was removed from the multispectral data by transforming to the MNF space, smoothing or rejecting the most noisy components, and then retransforming to the original space.

To perform principal component analysis we apply a transformation to a correlated set of multispectral data. The application of the transformation to the correlated remote sensor data will result in another correlated multispectral dataset that has certain ordered variance properties (Singh and Harrison, 1985). This transformation is conceptualized by considering the two-dimensional distribution of pixel values obtained in two TM bands, which we will label simply X1 and X2. A scatter plot of all the brightness values associated with each pixel in each band is shown in figure- 1a, along with the location of the respective means, μ_1 and μ_2. The spread or variance of the distribution of points is an indication of the correlation and quality of information associated with both bands. If all the data points clustered in an extremely tight zone in the two-dimensional space, these data would probably provide very little information.

The initial measurement coordinates axes (X1 and X2 may not be the best arrangement in multispectral feature space to analyze the remote sensor data associated with these two bands. The goal is to use PCA to translate and *lor* rotate the original axes so that the original brightness values on axes X1 and X2 are redistributed (reprojected) into a new set of axes or dimensions, X'1 and X'2 (Wang, 1993). For example, the best translation for the original data points from X1 to X'1 and from X2 to X'2 coordinate systems might be the simple relationship $X'1=X1-\mu_1$ and $X'2=X2-\mu_2$.Thus, the origin of the new coordinate system (X'1 and X'2) now lies at the location of both means in the original scatter of the points (fig 1b).



Brightness Value 1(a) 1 b 1 c

Figure 1 Diagrammatic representation of the spatial resolution ship between the first two principal component: (a) Scatterplot of data points collected from two remotely bands labeled X_1 and X_2 with the means of the distribution labeled μ_1 and μ_2. (b) A new coordinate system is created by shifting the axes to an X' system. The values for the new data points are found by the relationship X'1 = X1 -μ_1 and X'2 = X2 -μ_2. (c) The X' axis system is then rotated about its origin ($\mu_{1,}$ μ_2) so that PC1 is projected through the semimajor axis of the distribution of points and the variance of PC1 is a maximum. PC2 must be perpendicular to PC1. The PC axes are the principal component of this two-dimensional data space. Component 1 usually accounts for approximately 90% of the variance, with component 2 accounting for approximately 50%.

The X' coordinate system might then be rotated about its new origin ($\mu_{1,}$ μ_2) in the new coordinate system some Φ degree so that the first axis X'1 is associated with the maximum amount of variance in the scatter of point (figure 1c). This new axis is called the first principal component ($PC_1=\lambda_1$). The second principal component ($PC_1=\lambda_1$) is perpendicular (orthogonal) to PC1. Thus, the major and minor axes of the ellipsoid of points in bands X1 and X2 are called the principal components. The third, fourth, fifth and so on, components contain decreasing amounts of the variance found in the data set.

To transform (reproject) the original data on the X1 and X2 axes onto the PC1 and PC2 axes, we must obtain certain transformation coefficients that we can apply in a linear fashion to the original pixel values. The linear transformation required is derived from the covariance matrix of the original data set. Thus, this is a data-dependent process with each new data set yielding different transformation coefficients.

The transformation is computed from the original spectral statistics as follows (Short, 1982).

1. The n x n covariance matrix, Cov, of the n-dimensional remote sensing data set to be transformed is computed (Table 1). Use of the covariance matrix results in an unstandardized PCA, where as use of the correlation matrix results in a standardized PCA (Eastman and Fulk, 1993).

2. The eigen values, E=[$\lambda_{1,1}$, $\lambda_{2,2}$, $\lambda_{3,3}$,….. $\lambda_{n,n}$], and eigen vectors EV=[a_{kp}… ..for k=1 to n bands, and p=1 to n components] of the

Covariance matrix are computed such that:

Covariance matrix are computed such that:

$$EV\ Con\ EV^T = \begin{matrix} \lambda_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda_{2,2} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \lambda_{3,3} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda_{4,4} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \lambda_{5,5} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \lambda_{n,n} & 0 \end{matrix}$$

Where EV^T is the transpose of the eigenvector matrix, EV, and E is a diagonal covariance matrix whose elements λii , called eigenvalues, are the variance of the p^{th} principal components, where p= 1 to n components. The nondiagonal eigenvalues, λij are equal to zero and therefore can be ignored. The number of nonzero eigenvalues in an n x n covariance matrix always equals n, the number of bands examined. The eigenvalues are often called components (i.e., eigenvalue 1 may be referred to s principal component 1).

Table: 1

1.1.1 Eigen Values Computed for the Covariance Matrix

Bands	Eigen Values	Percentage	Difference	Total Variance
1	701.54	57.2	401.74	1226.32
2	299.80	24.4	155.36	
3	144.44	11.8	95.62	
4	48.82	3.98	21.92	
5	26.90	2.19	22.08	
6	4.82	0.39	----	

Table: 2
Eigenvectors (akp) (Factors Scores) computed for the Covariance Matrix

Bands	1	2	3	4	5	6
1	0.34	-0.26	0.11	-0.52	-0.50	0.52
2	0.55	-0.23	0.15	-0.42	0.55	-0.39
3	0.54	0.43	0.55	0.42	-0.20	-0.02
4	0.22	-0.35	-0.31	0.19	-0.57	-0.61
5	0.39	-0.38	-0.37	0.54	0.29	0.45

6	0.32	0.65	-0.65	-0.22	-0.02	0.02

Percentage of total variance in the data explained by each component:

$$\text{Computed as } \% = \frac{\text{Eigenvalues } (\lambda p) \times 100}{\sum_{p=1}^{n} \text{Eigenvalues } (\lambda p)}$$

Results And Discussion

Using Principal component analysis the changes of Indravati reservoir studied in the following: -

1. Change in the turbidity

2. Loss of water levels resulting in the sinkage of the area along the periphery, and

3. Loss of water levels resulting in discontinuities of the reservoir.

The reflection properties of different bands depict in the above changes can be seen in the figure No. 2 (Principal Component Analysis).

The turbidity levels or better reflectance in band -2 (Green) data and the compared evaluation showed the turbidity levels relatively higher the northern parts of the reservoir. This should be viewed in terms of not only characteristics of the watersheds contributing to the northern part of the reservoir, but also the depth levels of the reservoir. On the other hand the band -4 (NIR) data because of the use water absorption characteristics, the discontinuities of the reservoir or clearly seen in the band -4 in April data. The total reservoir area is well exhibited in band -4 of January data.

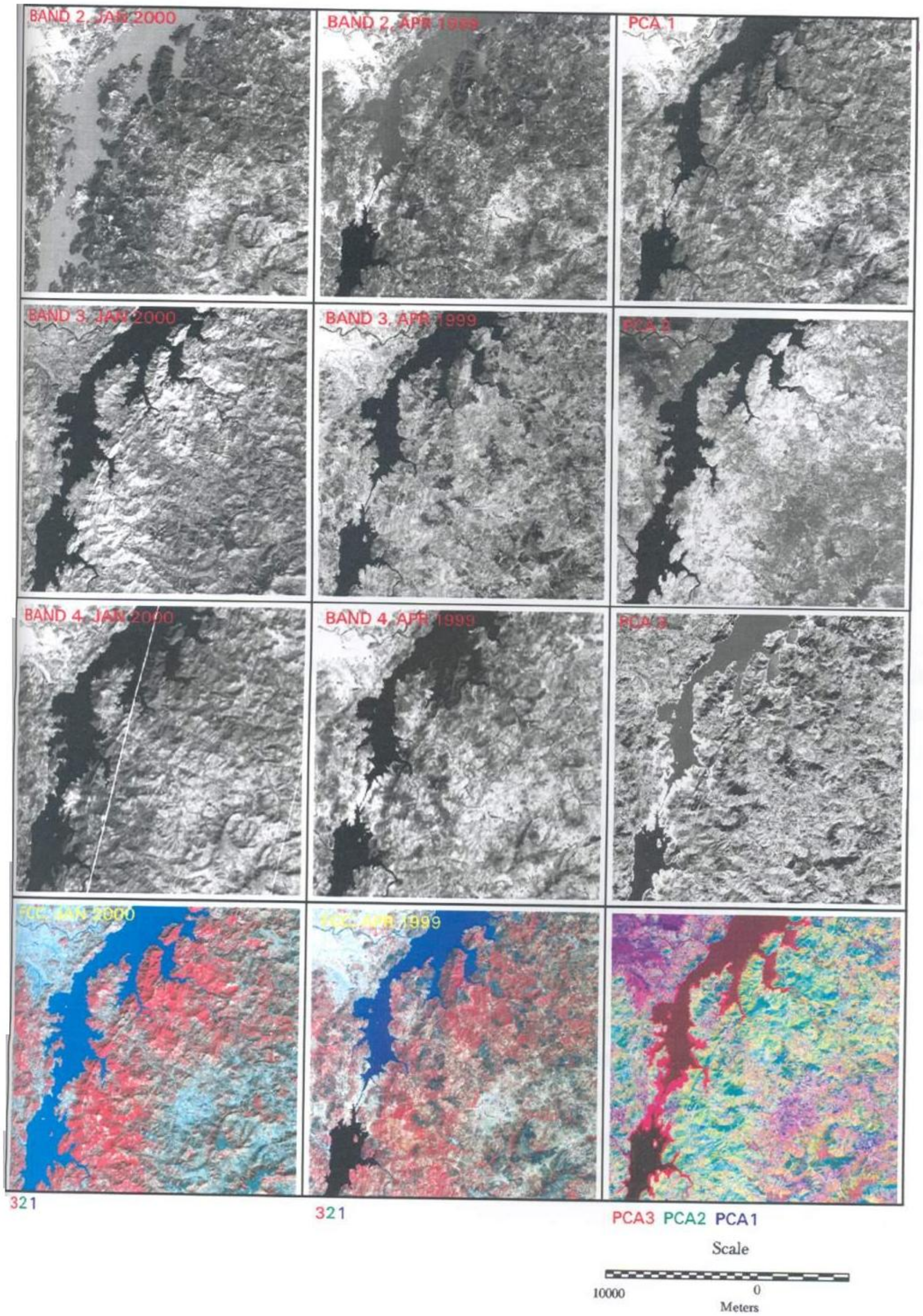
In order to bring out all these temporal characteristics to study the reservoir changes,the *Principal Component Analysis* was done.

It can be seen from the table (eigen2) the band -4 data of both the season contributed to large variability of PC -2 and PC -3 where in predominantly in the temporal changes described above were reflected.

Predominantly the changes in water land along the periphery another hand PC -3 component exhibited the changes both from turbidity levels and also the total loss of water resulting in discontinuing.

Hence, the False color composite (FCC) of PCA -3, PCA -2 and PCA -1 was made to brought the total reservoir area and the temporal changes in different color tones. In this way the surface water monitoring using Remote Sensing data analysis will be useful to understand the surface water bodies different characteristics area.

Surface Water Monitoring Using Multi-Temporal Satellite Data



References

John R. Jensen, "Introductory Digital Image Processing"- A Remote Sensing Perspective, Second edition.

Jensen. S.K and J.O.Domingue, 1988, Extraction topographic structure from digital elevation data for geographic system analysis, Photogrametry Engineering and Remote Sensing, vol.54, No.11, pp.1593-1600.

Manual of Procedure for preparation of wastelands digital data base using Remote Sensing & GIS techniques, prepared by NRSA, Dept. of Space, Govt. of India, Balanagar, Hyderabad-37.

Remote Sensing Application in Water Resources, The Indian Society for Technical Education, Lecture Notes, May 15-June4, 1985, Dept of Civil Engineering, Anna University, Madras-25.

Thomas M. Lillesand and Raiph W. Kiffer "Remote Sensing and Image Interpretation", second edition, 1986.

Tanji K.K. and B. Yaron (Eels), Management of water use in Agriculture, Springer-Verlag, Berlin Heidelberg, New York.