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Capacity Estimation of Singoor Reservoir, Andhra Pradesh Using Sub-pixel Classification Approach.

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NATIONAL INSTITUTE OF HYDROLOGY,

JAL VIGYAN BHAVAN

ROORKEE – 247 667 (UTTARANCHAL)

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PREFACE

Efficient reservoir management calls for periodic assessment of its capacity. Capacity surveys of reservoirs are important to study patterns and rate of sedimentation for defining appropriate measures for controlling sediment inflow, for managing the available storage in the reservoir and for optimum reservoir operation schedule based on realistic assessment of available storage. Data from space platforms can play a significant role in reservoir capacity surveys. In the recent past, satellite remote sensing has emerged as an important tool in carrying out reservoir capacity surveys rapidly, frequently and economically. Multi-temporal satellite data provide information on elevation contour areas directly in the form of water spread areas. The traditional methodology involves per-pixel classification approach to delineate the water-spread. One of the limitations of the per-pixel approach is that the border pixels, containing water with soil and vegetation, are also classified entirely as water pixels, thereby giving inaccurate estimate of the water-spread area. The error induced by per-pixel classification approach can be minimized by utilizing the efficacy of the novel methodology known as the sub-pixel classification or linear mixture model (LMM) approach.

In this report data from Indian Remote Sensing satellites such IRS-1C & 1D have been used to classify the water-spread areas of Singoor reservoir located in Andhra Pradesh using per-pixel and sub-pixel classification approaches. The sub-pixel approach was validated using high resolution panchromatic data. The validation proved that the accuracy of sub-pixel classification is in the higher side than the per-pixel classification approach.

This report was prepared by Mr.V.S.Jeyakanthan, Sc-E1 and Dr.Y.R.Satyaji Rao, Sc-E2 of Deltaic Regional Centre of the Institute.

(Raj Dev Singh)
Director

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ABSTRACT

Satellite data has long been in use to estimate the water-spread area at different elevations of a reservoir. The delineated water-spread is used to quantify the capacity of a reservoir. The traditional methodology involves per-pixel classification approach to delineate the water-spread, which is the only thematic information required to estimate the capacity of a reservoir. One of the limitations of the per-pixel approach is that the border pixels, containing water with soil and vegetation, are also classified entirely as water pixels, thereby giving inaccurate estimate of the water-spread area. To accurately compute the water-spread area to the maximum possible extent, the sub-pixel classification or linear mixture model (LMM) approach has been used in this study for classifying the water-spread areas of Singoor reservoir, Andhra Pradesh.

IRS-1C & 1D (LISS-III) satellites were used to extract the water-spread area for the period 2005 using per-pixel and sub-pixel classification approaches. MLC and band threshold methods have been adopted in the per-pixel classification approach. The estimated capacity of the reservoir from MLC, band threshold and sub-pixel approaches are 688.48 Mm^3, 727.75 Mm^3 and 716.11 Mm^3 respectively. The per-pixel and sub-pixel classification was validated using high resolution PAN (5m) data. The validation shows that sub-pixel classification produced very less error (1.07%) than the MLC (6.1%) and band threshold method (3.77%).

1997 hydrographic survey (791.22 Mm^3) and the capacity estimated (2005) using sub-pixel approach (716.11 Mm^3) were used to estimate the rate of sedimentation. Based on these results, if uniform rate of sedimentation is assumed from 1997 to 2005, the reservoir sedimentation rate is 9.39 Mm^3

Apart from this a preliminary study on the three satellite pass of 56m (IRS-P6, AWiFS) resolution data, was carried out for the extraction of water-spread area using sub-pixel classification methodology. The sub-pixel approach applied on the 56 m satellite data produced an average accuracy of 97.84% when compared with the 24 m resolution data. This indicates that the 56 m resolution data with sub-pixel methodology can be used to get results comparable with the 24 m resolution data.

CHAPTER-1

INTRODUCTION

The natural process like erosion in the catchment area, movement of sediment and its deposition in various parts of the reservoir require careful consideration in the planning of major reservoir projects. The silt which gets deposited in different levels, reduces the storage capacity of the reservoir. Reduction in the storage capacity beyond a limit prevents the reservoir from the fulfillment of the purpose for which it is designed. Periodical capacity surveys of the reservoir help in assessing the rate of sedimentation and reduction in storage capacity. With the correct knowledge of the sedimentation processes going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedule can be planned for optimum utilization of water. The conventional technique such as hydrographic survey and inflow-outflow approaches are cumbersome, time consuming, expensive and involve more man power. An alternate to conventional methods, remote sensing technique provides cost and time effective estimation of live capacity of a reservoir. Multi-date satellite remote sensing data provide information on elevation contours in the form of water spread area, at different water levels of a reservoir. Water-spread area thus interpreted from the satellite data is used as an input in a simple volume estimation formula to calculate the revised capacity of a reservoir. Comparison of previous and revised capacity estimation yields the loss in storage volume of the reservoir due to sediment deposition.

For the quantification of volume of sediments deposited in the reservoir, the only thematic information that has to be extracted from the satellite data is the water spread area of the reservoir at different water levels of the reservoir. The most widely used traditional approach to delineate different thematic information from the remote sensing digital data is the maximum-likelihood classification (MLC) technique which adopts the per-pixel based methodology and assigns a pixel to a single land cover type, whereas in reality a single pixel may contain more than one land cover type and known as a mixed pixel. Mixed pixels are common especially near the boundaries of two or more discrete classes (Campbell 1996). One of the limitations of the per-pixel approach in classifying water spread area is that the border pixels that are mixed in nature, representing soil, vegetation class with moisture are also classified as water pixels, thereby giving inaccurate estimate of the water-spread area. To accurately compute the water-spread area to the maximum possible extent, thereby reducing the error in the estimation of capacity of a reservoir, a sub-pixel classification or linear mixture model (LMM) approach has been chosen for classifying the water-spread areas of Singoor reservoir, Andhra Pradesh.

1.1 OBJECTIVE:

It is proposed to adopt both the per-pixel and sub-pixel approaches to classify the water-spread area of a reservoir. The results of these approaches would be compared and the methodology which produces higher accuracy would be suggested for the accurate capacity estimation of the reservoir.

CHAPTER-2

STUDY AREA

2.1 GENERAL

The river Manjira takes its origin near Bhir in Maharastra State in Balaghat hills and joins Godavari river about 54 kms upstream of Sriramsagar Dam. The Singoor dam is constructed across Manjira at its 490^{th} km.

The river flows in general east and south easterly direction for about 512 kms through the Bhir and Osmanabad districts of Maharastra and Bidar district of Karnataka and Medak district of Andhra Pradesh until it changes its direction north side near Sangareddy after flowing 75 kms, further it enters in the Nizamabad district of A.P. and for 107 kms lower down it falls in the Godavari between Maharastra and Andhra Pradesh. The total length of the river from its origin to its confluence with Godavari is 720 kms. The location of the reservoir is shown in Figure 2.1.

The catchment area of Singoor reservoir lies in three states of Maharashtra, Karnataka and Andhra Pradesh and the break up of the catchment is as follows.

Sl.No.	State	Area in Sq.Km
1	Maharashtra	6,474
2	Karnataka	4,014
3	Andhra Pradesh	1,608
	Total	12,096

Major portion of the catchment area consists of flat cultivated black cotton soil track of Maratwada, which is destitute of forests and jungle and not intercepted by any tanks or reservoirs. The part of the catchment that lies in Medak and Nizamabad district is however slightly undulating mixed soil track having some jungle in it and is intercepted by tanks and reservoirs and anicuts for irrigation.

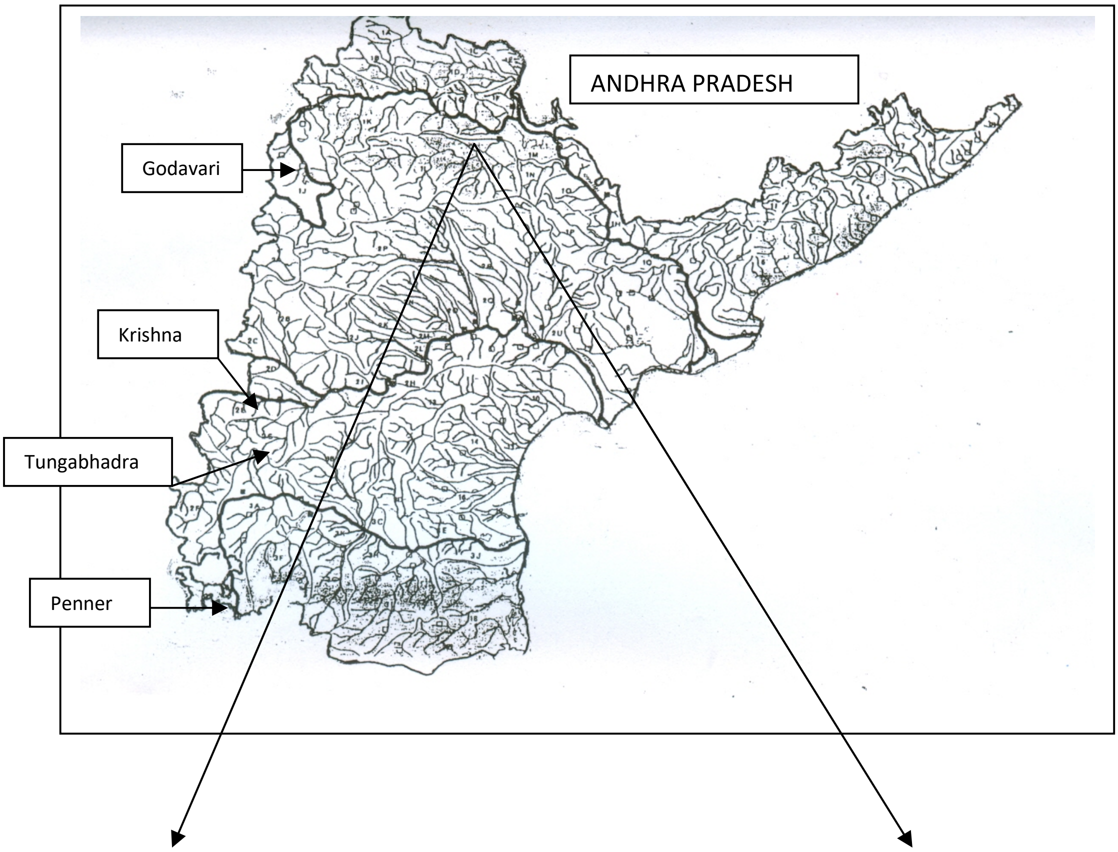


Fig.2.1 Location of study area – Singoor Reservoir

2.2 CLIMATE

The climate of the sub-basin is characterized by hot summer and mild winter. The monsoon sets early in June and continues upto October. Winter is from November to mid February and summer is from mid February to end of May.

2.3 GEOLOGY AND SOILS

The soils differ in their capacity for crop production and stability for irrigation. The behaviour of sub-soil, water plays an important role in the conversion of soil nature. The principal types of soils in the catchment and sub-basin area are medium black cotton mixed soils, red soils, red earth mixed with disintegrated rock and loam. As the soil in the catchment area is mainly black cotton which gets eroded very easily much silt is carried into the stream that drain into Manjeera which eventually has resulted in the silting up of Nizamsagar reservoir. After construction of Singoor reservoir the rate of siltation at Nizamsagar reservoir has reduced comparatively.

Many irrigation projects were constructed in the upstream of Singoor reservoir on Manjeera river. These projects will intercept about 28.25% of the catchment. The balance 71.75% is free catchment, which is immediately above the foreshore of the Singoor reservoir that contribute major portion of the silt into the reservoir. The free catchment area is covered in two states of Karnataka and Andhra Pradesh. Even in these catchment areas there are several minor irrigation sources that contribute in arresting silt.

2.4 SINGOOR RESERVOIR

The Singoor reservoir is a major irrigation project built across the river Manjira at its 490th km from its origin. This reservoir is located 24 km in the upstream of Manjira Barrage. The project is located near Singoor village, Medak District which is at a distance of 100 kms from Hyderabad. The geographical location of the dam site is 17^{o} 45' N Latitude and 77^{0} 56' E Longitude. The total length of dam is 7.52 kms which consists of 327 m long over flow masonry dam, in the river gorge portion and 81 m non over flow masonry dam, flanked on both sides by earthen embankments. The maximum height of earth dam is 27.60 m and that of masonry dam is 33.5 m, radial gates 17 nos. of each 15 x 13 m size are provided at crest level + 510.6m. The spillway is designed to dispose off a maximum flood of 7,80,000 cusses.

Singoor project is primarily proposed for providing additional water supply requirements to the twin cities of Hyderabad and Secunderabad to the extent of 62.50 million gallons per day. In addition, the project will provide the following the benefits.

1) regulated releases in the river for lower down irrigation systems including Nizamsagar to stabilise the existing irrigation.
2) arresting the silt in Manjira river down into Nizamsagar reservoir
3) provide irrigation facilities for 40,000 acres of Kharif I.

The gross storage of the reservoir up to FRL + 523.60 m is 847 M.cum (30 TMC) and the first impounding of reservoir was during 1987. The sill levels of right flank and left flank are fixed at + 320.00m. Consequently the siltation in the reservoir also started in 1987. At the planning stage of the reservoir a provision of dead storage to an extent of 10 TMC assuming the life of reservoir as 100 years has been made to accommodate the silt deposition.

The Dam Review Panel observed in the second meeting that the rate of sedimentation at Nizamsagar was about 1 acre ft/1.sq.mile/year and that provision has been made that at the rate of 1.2 acre-feet/sq.mile/year (5.71 ha m/100sq km/yr) for the Singoor reservoir. The panel was informed that there was a drastic reduction in the rate of sedimentation at Nizamsagar after the Singoor dam was built on the upstream. This indicates that high interception of sedimentation at Singoor reservoir.

CHAPTER – 3

METHODOLOGY

3.1 INTRODUCTION

Periodic surveys of reservoirs are essential to monitor the decrease in storage capacity and useful life due to inflow and deposition of sediment. Hydrographic survey and inflow-outflow approaches are the common direct and indirect conventional methods used to estimate the sediment deposition in a reservoir, but these methods are cumbersome, time consuming and expensive. An alternate to conventional methods, remote sensing technique provides cost and time effective estimation of live capacity of a reservoir. Multi-date satellite remote sensing data provide information on elevation contours in the form of water spread area, at different water levels of a reservoir. Water-spread area thus interpreted from the satellite data is used as an input in a simple volume estimation formula to calculate the revised capacity of a reservoir. Comparison of previous and revised capacity estimation yields the loss in storage volume of the reservoir due to sediment deposition.

For the quantification of volume of sediments deposited in the reservoir, the only thematic information that has to be extracted from the satellite data is the water spread area of the reservoir at different water levels of the reservoir. The most widely used traditional approach to delineate different thematic information from the remote sensing digital data is the maximum-likelihood classification (MLC) technique which adopts the per-pixel based methodology and assigns a pixel to a single landcover type, whereas in reality a single pixel may contain more than one land cover type and known as a mixed pixel. Mixed pixels are common especially near the boundaries of two or more discrete classes (Campbell 1996). One of the limitations of the per-pixel approach in classifying water spread area is that the border pixels that are mixed in nature, representing soil, vegetation class with moisture are also classified as water pixels, thereby giving inaccurate estimate of the water-spread area. To accurately compute the water-spread area to the maximum possible extent, thereby reducing the error in the estimation of capacity of a reservoir, a linear mixture model (LMM) approach has been applied for classifying the water-spread area of South Indian reservoirs. Five such reservoirs were identified for this research work. The per-pixel and the sub-pixel based methodology that has been applied to extract the water-spread area and computation of capacity loss of the reservoirs due to sedimentation are explained in the following sections of this chapter.

3.2 PRE-PROCESSING OF REMOTE SENSING DATA

The steps such as selection of data product, selection of period for analysis, sensor selection, and geo-referencing of digital data are to be carefully adopted prior to the extraction of water-spread area from the satellite data.

3.2.1 SELECTION OF SATELLITE DATA PRODUCT

The choice of interpretation technique determines the type of data product. Visual interpretation can be carried out if the satellite imagery is in the form of black and white or false colour composite (FCC) transparency (to be used in PROCOM and other optical equipment) or paper prints of suitable scale (typically in 1:50,000 scale or larger). These are directly used to delineate land/water boundary and to estimate the water spread area. Standard photographic products have inherent positional errors and need to be adjusted while transferring information to the base map, or alternately require precision correction before interpretation. Visual techniques are based purely on the interpretive capability of the analyst and it is not possible to use the rich information content of different bands, after the visual product is generated. While adopting visual techniques around the periphery of the water spread area, the wet land appears very similar to the water pixels and it becomes very difficult for the eye to decide whether a pixel near the periphery is to be classified as water or land. Moreover, in case of clouds or noise in the scene around the periphery, it is not visually possible to demarcate the water spread area. Therefore the visual techniques are rarely used now. Whereas, if digital techniques are used, the information of different bands can be utilized to the maximum extent and consistent analysis can be carried out over the entire range of the reservoir. It is also easy to calculate the water spread area using digitally processed satellite data. The increased accuracy in water spread estimation is also due to the improved geometric correction, image to image registration and image enhancement capabilities possible in the digital environment.

3.2.2 SENSOR SELECTION

Selection of optical satellite sensors used in reservoir study is mainly based on the extent of water-spread area of the reservoir. Depending on the size of the reservoir, the water-spread varies from small to large. If the extent of water-spread area of the reservoir is between small to medium, sensor's that have high spatial resolution (5 to 10 m) are generally used. In this case of reservoirs (small to medium), the percentage of error would increase if lesser resolution data is used due to the considerable coverage of soil and vegetated area along the periphery of the reservoir. The larger reservoirs are monitored with medium resolution data such as IRS-LISS III or Landsat-TM which have spatial resolution of 23 to 30 m. Some times due to the large extent of water-spread area it may not be possible to get the data of one water level of the reservoir in a single scene of the satellite (i.e the single scene may contain only part of the reservoir). In such cases the sensor resolution has to be compromised and the resolution of the data is selected in such a way to accommodate the full water-spread area of the reservoir in a single satellite pass.

3.2.3 SELECTION OF PERIOD FOR ANALYSIS

The period between onset and offset of monsoon season known as the hydrologic year or water year is best suited for the analysis of sedimentation in a reservoir. The onset and offset of the monsoon seasons are the water accumulation and water depletion periods respectively i.e the reservoir attains its full reservoir level (FRL) during the water accumulation period and reaches the minimum draw down level (MDDL) during the water depletion period. This pattern of wet year followed by dry year is usually adopted in the sedimentation analysis study since such a sequence will largely cover the entire operable range of the reservoir. During this period the satellite overpass dates has to be selected which corresponds to the different water levels of the reservoir. The water levels are selected in such a way that it covers full reservoir level to minimum draw down level and can have unequal intervals taking note of the shape of the existing capacity curve. However, in practice it may not be possible to include MDDL and FRL due to non-availability of cloud free satellite data. Also sometimes remote sensing data cannot be obtained throughout the year due to various satellite functioning conditions. In such cases where FRL and MDDL are not reached or could not be included the possible near FRL and near MDDL should be considered for the analysis. The FRL and MDDL occupying conditions of Indian reservoirs are explained below.

India is confined with two different monsoon periods known as Southwest monsoon (June to September) and Northeast monsoon (October to December). Except Tamilnadu and Southern part of Andhra Pradesh Indian reservoirs receive more than 80% of the rainfall during the four monsoon months of Southwest monsoon (Jayarami Reddy 1989). The geographical area which is not covered in the Southwest monsoon receives rainfall during the Northeast monsoon season. Hence during these monsoon seasons, depending on the amount of rainfall, water level in a reservoir can be expected to be at higher elevation. And the water level in a reservoir gradually depletes to lower levels towards the offset of the monsoon (May/June) season. During this period typically 7 to 10 dates of satellite pass, over the reservoir can be selected to adequately cover the range of observed water stages. Selection of range of water level should also be contained to one or utmost two hydrologic years, so that the sedimentation of different hydrologic years is not combined in a single study.

3.2.4 GEOMETRIC CORRECTION OF SATELLITE DATA

It is a pre-requisite to geo-reference the satellite data which contains various lanuse/landcover classes of different time periods of the same area. In fact the determination of water-spread area in a reservoir does not require geo-referencing due to water-spread area is the only information that is to be extracted from the satellite data. However, using the geo-referenced images, it is possible to overlay the remote sensing data of different dates. Comparison and analysis of the change in water-spread area and shrinkage in the water-spread area with time, particularly for the tail end of the reservoir, are made possible using geo-referenced data.

The raw satellite data received may be full or part of the path and row of the sensor in such cases the area occupied by the reservoir in the scene may be very less, carrying out the classification for the full path and row will take enormous time and occupy a large memory of the computer. To save time and computer memory, classification has to be carried out only for the water-spread area of the reservoir which has been segmented out from the raw satellite data. Segmenting the images has to be carried out after completion of geo-referencing of the scene so that the change detection among the sub-images could be carried out without any error.

3.3 ESTIMATION OF WATER-SPREAD AREA USING PER-PIXEL APPROACH

The only reason for the reduction, in capacity of a reservoir is deposition of sediments. The reduction in capacity actually means the water holding capacity of the reservoir is reduced. This indicates that the original water-spread area of the reservoir which was at the time of impound is going on reducing at every water level of the reservoir. The reduction in water-spread area at different water level of the reservoir could be vividly estimated by analyzing the satellite data over a period of time. The information on the water-spread area of the reservoir gathered by satellites which is in the form of digital data can be classified using different classification techniques. The following section explains the per-pixel based classification approach of water-spread area of the reservoir.

Per-pixel approach denotes that the classification of satellite digital data is performed on pixel-to-pixel basis i.e a single pixel is assigned to only one landcover type. The traditional classifiers which uses the per-pixel approach is based on the statistical descriptions of the class samples or training sets to map image data into categories or classes of land cover (Foschi, P.G, 1994). To achieve this following assumption were incorporated in the statistical models. The per-pixel model assumes that for a given pixel, there is a homogeneous land cover and the land cover corresponds to one of a number of pre-defined land cover classes. Another assumption made in hard classification is that there is only one class per pixel i.e., only one label is given to a single pixel. Besides these assumptions, it is believed that the image scene is comprised of pure pixels.

Classification of remote sensing data is based on the reflected energy received from the objects on the earth surface and stored as digital numbers. Water reflects most of its energy in the blue region of electromagnetic spectrum. It is less reflective in the green and red bands and is absorptive in the near infrared wavelength and the longer wavelengths. Thus, there is a marked contrast between land and water due to the strong absorption of water and high reflectance of vegetation and soil in the near infrared wavelengths. Such a contrast helps in extracting the water-spread area from the surrounding land. The most widely used method for extracting information from the remotely sensed data is image classification. Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands and attempts to classify each individual pixel based on this spectral information. The objective is to assign all pixels in the image to particular classes or themes (e.g. water, mangroves, forest, soil, paddy etc). The resulting classified image is comprised of a mosaic of pixels, each of which belongs to a particular theme, and is essentially a thematic map of the original image. Common classification procedures can be broken into two broad subdivisions based on the method used: unsupervised classification and supervised classification (Jensen 1996).

Unsupervised classification

This requires only a minimal amount of input from the analyst. It is a process whereby numerical computations are performed to combine the similar spectral information of the pixels in the data. Unsupervised classification does not utilize training data as the basis for classification. Two types of this classification include K-means and ISODATA (Iterative Self-Organizing Data Analysis Technique) classifiers. The only advantage of unsupervised classification is that the classifier identifies the distinct spectral classes present in the image data. Several researches were carried out using unsupervised classification technique for landuse/landcover mapping (Irvin et al 1997, Ricketts 1992, Ertep 1992 and Anderson 1992).

Supervised Classification

In Supervised classification, the image analyst 'supervises' the pixel categorization process by specifying, to the computer algorithm, the numerical description of the various landcover types present in a scene. Then each category is labeled on comparing with "interpretation key". A number of commonly used spectral classifiers exist including the maximum likelihood, the minimum distance to mean and the parallelepiped classifiers. A detailed account of these and the other classifiers can be found in Mather (1987), Swain and Davis (1978), Lillesand and Kiefer (1994) and Schowengerdt (1997).

While performing supervised classification approach, the user trains the system to classify the image, based on the spectral reflectance of various features. Certain features such as black soil, moist soil, burnt land etc. have the same spectral signature as that of water in the NIR wavelength. Such a similarity makes it difficult to distinguish these features. To overcome this problem a generalized algorithm based on the information of different bands was adopted. Each pixel has a numerical value called a digital number (DN) that records the intensity of electromagnetic energy measured for the ground resolution cell represented by that pixel. Using the spectral information, the algorithm matches the signatures of the pixel with the standard signatures of water and identifies whether a pixel represents water or not. The spectral signature shows the reflectance /remittances pattern of any object at different wavelengths.

The following model equation has been used to extract the water spread area of the reservoir:

$$\text{if } P_{V4} > T_{L4} \text{ and } P_{V4} < T_{H4} \text{ then} \quad (1)$$

the pixel is in the water spread area; where, P_{V4} is pixel value in NIR band. T_{L4} and T_{H4} are lower and higher thresholds for the NIR band. Since the absorption of electromagnetic radiation by water is maximum in the NIR spectral region, the digital number (DN) of water pixels is considerably lower than that corresponding to other land uses. Even if the water depth is very shallow the increased absorption in NIR band will restrict the DN value to be less than the blue band and red band. If the soil is exposed (possibly saturated) at the surface, the reflectance will be as per the signature of the soil, which increases with wavelength in this spectral range. Thus following this algorithm water pixels that belongs to single satellite pass or a single contour area (or water level) of the reservoir were identified.

3.4 ESTIMATION OF WATER-SPREAD AREA USING SUB-PIXEL APPROACH

The sub-pixel classifier uses the linear unmixing technique, that allows in identifying the "material of interest" and determine its "material part fraction" or cover percentage, within a pixel.

Linear spectral unmixing is an excellent approximation for calculating the abundance or fraction of an end-member in an image pixel. This technique aims at estimating the proportions of specific classes that occur within each pixel using linear mixing approach (Youngim et al 1997, Smith et al 1999, Bryant 1996, Pddele et al 1995, Bajjouk et al. 1998) or the non-linear mixing approach (Carlotto 1995, Tomkins et al. 1997, Foody *et al.* 1997). In this study the reservoir water-spread area would be estimated using linear mixing model approach only.

The basic assumption of linear mixture model is that the measured reflectance of a pixel is the linear sum of the reflectance of the components that make up the pixel. The basic hypothesis is also that the image spectra are the result of mixtures of surface materials, shade and clouds, and that each of these components is linearly independent of the other (Adams et al 1995, Roberts et al 1998). Linear unmixing also assumes that all materials within the image have sufficient spectral contrast to allow their separation. In soft classifications, the estimated variables (the fractions or proportions of each land cover class) are continuous, ranging from 0 to 100 percent coverage within a pixel. Linear spectral unmixing is a reliable method to resolve the mixed pixel problem. Settle and Drake (1993) and Foody and Cox (1994), proposed a mathematical expression for linear spectral unmixing. The theory behind this is the contribution of a series of end-members present within a pixel to its spectral signature. Hence, the spectral signature of a pixel would be derived from the sum of the products of the single spectrum of the end-members it contains, each weighted by a fraction plus a residue which would be explained by the following mathematical model.

$$R_i = \sum f_k R_{ik} + E_i \qquad (2)$$

where $$\sum f_k = 1 \qquad (3)$$

and $$0 \leq f_k \leq 1 \qquad (4)$$

$i = 1, \ldots, m$ (number of spectral bands)
$k = 1, \ldots, n$ (number of endmembers)
R_i = Spectral reflectance of band i of a pixel which contains one or more endmembers
f_k = Proportion of endmember k within the pixel
R_{ik} = Known spectral reflectance of endmember k within the pixel on band i
E_i = Error for band i.

Equations 2 and 3 introduce the constraints that the sum of the fractions are equal to one and they are non-negative. To solve f_k, the following conditions must be satisfied:

(i) selected endmembers should be independent of each other, (ii) the number of endmembers should be less than or equal to the spectral bands used, and (iii) selected spectral bands should not be highly correlated.

In this study, the linear spectral unmixing is adopted based on the equations described below to segregate the actual information within a pixel of an image

$$R1 = F_{water} * R1_{water} + F_{Veg} * R1_{Veg} + F_{Soil} * R1_{Soil} + \varepsilon 1$$
$$R2 = F_{water} * R2_{water} + F_{Veg} * R2_{Veg} + F_{Soil} * R2_{Soil} + \varepsilon 2 \quad (5)$$
$$R3 = F_{water} * R3_{water} + F_{Veg} * R3_{Veg} + F_{Soil} * R3_{Soil} + \varepsilon 3$$

Where,

→R1, R2 and R3 represent the signal recorded at the satellite in the green, red and NIR bands of the LISS-III sensor.

→F_{water}, F_{Veg} and F_{Soil} are the fraction of the pixel covered by water, vegetation, and soil.

→$R1_{water}$, $R2_{water}$ and $R3_{water}$ represent the reflectance of water in each of the three spectral bands.

→$R1_{Veg}$, $R2_{Veg}$ and $R3_{Veg}$ represent the reflectance of vegetation in each of the three spectral bands.

→$R1_{Soil}$, $R2_{Soil}$ and $R3_{Soil}$ represent the reflectance of soil in each of the three spectral bands.

→ε1, ε2 and ε3 are the error components of band 1, 2, and 3.

The system of linear equation shown above can be solved by a least square solution which minimizes the sum of squares of errors. The accuracy of the unmixing is based on ε_n of equation.

3.5 REMOVAL OF DISCONTINUOUS PIXEL EXTENDED TAIL AND CHANNELS

The contour area represents only the continuous water-spread area at any elevation. Due to the presence of local depressions within the islands in the reservoir and around the periphery of the reservoir, a considerable number of pixels in these depressions appear as water pixels. These pixels do not form part of the continuous water-spread and need to be removed. The water image is edited manually to remove these discontinuous pixels.

In addition to the main river at the tail end, numerous channels usually join the reservoir from different directions. The elevation of water in these channels and main river remains at higher than that of reservoir water surface. So, the extended tail and channels must be removed from the point of termination of spread. The selection of truncation point is subjective and can be based on the difference between the water levels in the subsequent date imageries. The water pixels beyond the truncation point are removed by manual editing. Similarly, the water pixels in the downstream of the dam are not part of reservoir water-spread and need to be removed.

3.6 CONVERTING WATER PIXELS INTO WATER-SPREAD AREA

3.6.1 Per-pixel approach

The continuous water pixels were converted into water-spread area by multiplying the number of pixels that has been extracted using the above methodology, with the area (24m X 24m) of a pixel. All the satellite data used in this study is from IRS-1C and 1D (LISS III & LISS IV) which is having a pixel size of 23.5m X 23.5m. Likewise for reservoir sedimentation estimation a minimum of 7 to 10 water-spread areas has estimated, which various according to the storage level of the reservoir.

3.6.2 Sub-pixel approach

The fraction images obtained by sub-pixel approach are in shades of gray scale. The brighter pixels of water fraction image shows that it consists of high proportions of water and the dark pixels shows that lesser proportions of water. The proportions of pixels various from 0 to 1 and non-negative i.e a pixel from water fraction image having a value 0 indicates that there is no water at all in that pixel, whereas a pixel having a value of 0.3 indicates that 30% of the area of the pixel is occupied by water. Therefore for IRS-1C and 1D (LISS-III) data area of water in that pixel is 172.80 m^2 (0.3 X 24m X 24m). The border pixels which have minimum value of upto 0.05 (i.e a pixel contains a minimum 5% of area of water) are isolated from the water fraction image and the area covered by water in these border pixels are estimated. The number of pixels that contains 100% of water are also found out. By summing up the area occupied by these two types of pixels, the total water-spread area of the reservoir is estimated.

3.7 COMPUTATION OF VOLUME BETWEEN SUCCESSIVE WATER LEVELS

The water-spread area estimated by per-pixel and sub-pixel approaches is used separately to find out the reservoir volume at different water levels. In this study the volume between two consecutive reservoir water levels was computed using the trapezoidal formula. The other formula that can be used to estimate the volume are Prismoidal and Cone formula:

Trapezoidal Formula : $V = H/3 \, (A1 + A2 + \sqrt{A1 * A2})$

Prismoidal Formula : $V = H/3 \, (A1+4A2+A3)$

Cone Formula : $V = H/3 \, (A1+A2)$

Where V is the volume between two consecutive levels; A1 is the water-spread area at elevation1, A2 is the water-spread area at elevation 2 and H is the difference between the elevations A1 and A2, A3 is the water-spread area at elevation 3.

3.8 COMPUTATION OF CUMULATIVE CAPACITY OF THE RESERVOIR

The volume computed between different water levels (i.e from MMDL to FRL) was added up to calculate the cumulative capacity of the reservoir.

3.9 ESTIMATION OF LOSS IN STORAGE DUE TO SEDIMENTATION

Above computed cumulative capacity of the reservoir is compared with the impoundment capacity of the reservoir, the difference between these two capacities yields the loss in storage due to sedimentation of the reservoir.

CHAPTER-4

RESULTS AND DISCUSSION

Capacity of singoor reservoir for the period 2005 was estimated using per-pixel and sub-pixel classification approaches. To estimate the capacity, six different water levels of the reservoir which varies from MDDL (Minimum Draw Down Level) to FRL (Full Reservoir Level) have been selected based on the economic elevation interval and the availability of cloud free data. Digital data pertaining to these water levels were acquired from IRS-1C & 1D (LISS-III) satellites and its water-spread areas were extracted using the above said two different classification approaches. In the case of per-pixel approach Maximum Likelihood Classification (MLC) and band threshold method have been adopted. The results of the per-pixel and sub-pixel approaches have been compared and validated with the higher resolution data (5m) obtained from IRS-P6. Rate of sedimentation between the period 1997 and 2005 have been estimated. The results of the above said classification methods are summarized in two sections part-I and part-II. Part-I deals with the application of per-pixel and sub-pixel classification methodology over the medium resolution (24m) data. Part-II is devoted for the application of sub-pixel classification approach on the low resolution (56m) data obtained from AWiFS sensor for the extraction of water-spread area on reconnaissance basis.

PART-I: APPLICATION OF PER-PIXEL AND SUB-PIXEL CLASSIFICATION APPROACH FOR RESERVOIR CAPACITY ESTIMATION USING MEDIUM (24m) RESOLUTION SATELLITE DATA:

4.1 Capacity Estimation Using Per-pixel Classification approach.

Six different water levels or elevations of the reservoir have been selected (Table 4.1) to estimate the capacity of the reservoir which varies from 512.51 m to 523.49 m (The impoundment MDDL and FRL of the reservoir is 510.6 m and 523.6 m respectively). The satellite data pertaining to these water levels were procured and their corresponding water-spread areas were extracted using two different per-pixel classification approaches viz. Maximum Likelihood Classification (MLC) and band threshold method.

MLC is the most used methodology to classify the satellite digital data. MLC was tried initially with a single, water training set for classifying the water-spread area. But it was found that, single training sample could not classify the tail end and peripheral portions of the water-spread area. Therefore as many numbers of training sets has been used until all the water pixels are classified. To minimise the error in MLC, the calculation was carried out for three times, every classification used different sets of samples selected from different parts of the water-spread area. Average of these three results was used for the finial MLC calculation.

Table-4.1 Selected water levels and their corresponding date of satellite pass over the Singoor Reservoir.

Sl.No.	Date of Satellite Pass	Reservoir Elevation (m)	Satellite Sensor
1.	12.11.2005	523.49	IRS 1D LISS III
2.	06.10.2005	522.10	IRS 1C LISS III
3.	29.08.2005	517.10	IRS 1D LISS III
4.	01.04.2005	514.92	IRS 1D LISS III
5.	15.05.2005	513.71	IRS 1C LISS III
6.	15.06.2005	512.51	IRS 1D LISS III

Apart from MLC, band threshold method is also used to classify the water-spread area. In this method only Near-infra red (NIR) band of satellite data was used. Being the reason that, waterbody absorbs the NIR band and other landuse classes (vegetation, soil, etc.) surrounding the water body highly reflects the electromagnetic radiation (EMR) and this makes the water pixels easily separable from the land classes. To separate the water pixels from the adjoining land cover class a mathematical expression is used, it requires minimum and maximum digital number (DN) of the water body. The pixels which have DN values between the given minimum and maximum value are classified as water pixels. Due to the water body absorbs NIR wavelength their digital values are be very less, in this study it ranged between 5 to 10. During summer season it increased to 20. The minimum pixel value is at the deeper and central portion of the water-spread area. The pixel value increases towards the periphery of the water body and the border pixels contain maximum digital number. In selecting the maximum value of the water-spread area, it may look just finding out the value of pixels along the periphery. But it is not an easy task to select a maximum threshold value along the border of the reservoir area. For example at one place of the border area, one may be satisfied with a pixel value of 43 but in another palace he may fix up a DN value of 40. The change in pixel value, over a large range consumes enormous time to come to a conclusion on the maximum threshold of DN value that has to fixed-up to extract the water-spread area. The periphery pixels digital number of the reservoir ranged from 30 to 44. Thus the water-spread areas of Singoor reservoir delineated from the satellite data using band threshold method is shown in Figure 4.1

The water-spread areas delineated using two different per-pixel classification approaches have been used as an input in the trapezoidal formula to calculate the consecutive and cumulative volumes of the reservoir. The cumulative capacity (37.47 Mm^3) of the reservoir, at the lowest observed level (512.51 m) was drawn from the 1997 capacity-area table, obtained from the dam authority. The cumulative capacity of the reservoir at 523.49 m (Near FRL) using MLC and band threshold method are 688.48Mm^3 and 727.75 Mm^3 respectively. The capacity estimated using MLC and band threshold methods are given in Table.4.2.

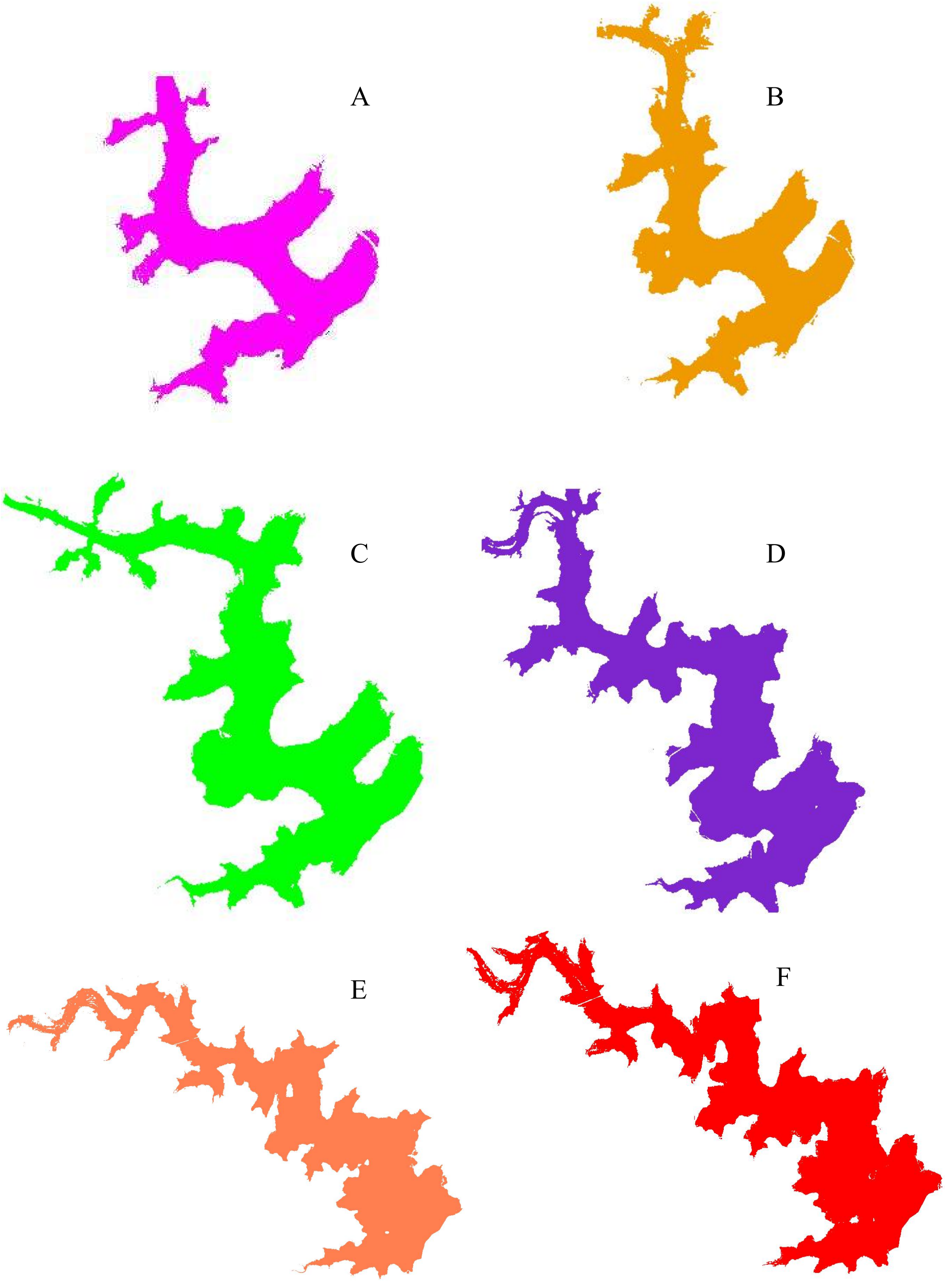


Figure 4.1. Water-spread area of Singoor reservoir delineated using band threshold method from the satellite data: A (512.51m – 10.32Mm^2), B (513.71m – 17.28 Mm^2), C (514.92m – 22.36 Mm^2), D (517.10m – 52.01 Mm^2), E (522.10m – 110.96 Mm^2), F (523.49m – 138.37 Mm^2)

4.2 Capacity Estimation Using Sub-pixel Classification approach.

Sub-pixel classification approach was applied to find out the proportion or fraction of water class exits in a pixel. The first step involved in sub-pixel classification approach is, identification of end members. The end members were identified using scatter plot method. The identified end members were supplied as input to the linear mixture model (LMM), explained through equation number (5), in the chapter 3. The equation has been solved and the output of the equation is the fraction images. The output contains three images known as water fraction image, soil fraction image and vegetation fraction image. The value of the pixels in the fraction image ranges from 0 to 1. Each fraction image corresponds to a single landcover only, for example the pixels in the water fraction image gives the proportion or amount of water it contains. From the water fraction image one would get only the details of water, it will not give the details of other classes such as vegetation and soil. Likewise if one wants to know about the amount of vegetation present in a pixel he has to switch over to the vegetation fraction image. Like the same, soil fraction image contains details about the soil class only. However in this study we are interested to know about only the amount of water present in the border pixels of the reservoir. Therefore we are concerned about only the water fraction image. In the water fraction image, for example a periphery pixel value is 0.35, it means that the particular pixel contains 35% of water. Therefore the area cover by water by this periphery pixel is 201.6 m^2 (0.35 x 24 x 24). The water fraction value of the pixel is multiplied by the pixel size, which is 24 m. The spatial resolution of LISS-III data is 23.5m, but it was reported by the supplier of satellite data (NRSC, Hyderabad) that the pixel size is 24m after re-sampling the data by them. The border pixels have been identified and the water-spread areas in the periphery pixels have been estimated as said above. Apart from this the pixel contains 100% of water is identified and their water-spread area is calculated separately. Water-spread area of periphery pixels and the pixels which have 100% water are summed-up to get the water-spread area of a single reservoir elevation. Likewise the sub-pixel approach was applied to all the six satellite data used in this study. The water-spread area estimated thus is used to calculate the capacity of the Singoor reservoir using sub-pixel classification approach. The water-spread area estimated from the linear mixture model is given in Table No.4.2. Here it is worth to mention that if a pixel containing 35% of water is classified as 100% of water in per-pixel calculation, it increases the water-spread area thereby over estimating and if it is not included the water-spread area is under estimated. Therefore the sub-pixel classification approach reduces the error imposed by the per-pixel classification approach. The capacity estimation of both per-pixel and sub-pixel approaches are given in Table No. 4.2. From the table it can be ascertained that the estimated capacity of the reservoir from MLC, band threshold and sub-pixel approaches are 688.48 Mm^3, 727.75 Mm^3 and 716.11 Mm^3 respectively. The MLC is underestimating whereas the band threshold method is over estimating when compared with the sub-pixel classification approach.

Table 4.2 Capacity estimation using per-pixel and sub-pixel classification approaches of Singoor Reservoir.

Date of Satellite Pass	Reservoir Elevation (m)	Water-spread area - Per-pixel (Mm^2)		Water-spread area sub-pixel (Mm^2)	Cumulative Volume per-pixel (Mm^3)		Cumulative Volume sub-pixel (Mm^3)
		MLC	Band Threshold		MLC	Band Threshold	
12.11.05	523.49	132.67	138.37	**136.37**	688.48	727.75	**716.11**
06.10.05	522.10	106.19	110.96	**110.36**	522.81	554.82	**544.95**
29.08.05	517.10	48.04	52.01	**50.51**	146.72	156.59	**152.40**
01.04.05	514.92	20.60	22.36	**21.59**	73.98	77.67	**76.01**
15.05.05	513.71	15.50	17.28	**16.46**	52.21	53.85	**53.06**
15.06.05	512.51	9.32	10.32	**9.82**	37.47	37.47	**37.47**

4.3 Validation of Sub-pixel classification Approach

Several investigations (Foody, 2002; Oleson K.W., et al, 1995; Quaramby et al, 1992; Hlavka et al, 1995) have shown that the recovery of sub-pixel information from medium resolution data is feasible and this information can be directly compared to that obtained at higher scales. In line with the above findings the result of sub-pixel classification approach which was carried out using 24m data was validated using high resolution data with a spatial resolution of 5m (IRS 1C-PAN). The validation would be meaning full if the both the data (24m & 5m) belongs to same satellite pass, being the reason that data acquired on different time period would have different water-spread area. But this condition could not be fulfilled for the dates on which sub-pixel classification was carried out, due to non-availability of high resolution data. Therefore three new sets of data were procured in such a way that both the 24m and 5m data have the same date of satellite pass. The MLC, band threshold and sub-pixel classification was again carried out on the new data sets. Fraction images obtained from sub-pixel classification approach for the validation set are shown in Fig 4.2 (a) to 4.2 (c). PAN data was classified using band threshold method. The details of the results are given in the Table 4.3 and Fig 4.3. By analyzing all the three sets of validation it can be ascertained that MLC, under estimates whereas band threshold method over estimates when compared with the high resolution data. The error result reveals that (Table 4.4 and Fig. 4.3) the sub-pixel classification produced very less error (1.07%) than the MLC (6.1%) and band threshold method (3.77%). This shows that the sub-pixel classification approach can be applied to estimate the capacity of the Singoor reservoir with high accuracy than the per-pixel approaches.

Table 4.3 Validation of sub-Pixel classification approach

Satellite/Sensor	IRS-P6 / LISS-III (24 m)			IRS-1C/PAN (5m)
Date of Satellite Pass	Water-spread area Per-Pixel (Mm^2)		Water-spread area Sub-Pixel (Mm^2)	Water-spread area (Mm^2)
	MLC	Band Threshold		
03 Feb 2006 (Validation-1)	113.29	123.73	118.69	119.82
23 Mar 2006 (Validation-2)	100.29	107.89	104.50	105.97
15 Jan 2005 (Validation-3)	35.73	41.09	39.01	38.67

Table 4.4 Percentage (%) of error between different classification methods.

No. of Validation	Classification Methods		
	MLC	Band Threshold	Sub-pixel
Validation-1	5.36%	1.81%	1.39%
Validation-2	5.45%	3.26%	0.94%
Validation-3	7.6%	6.25%	0.88%
Average	**6.1%**	**3.77%**	**1.07%**

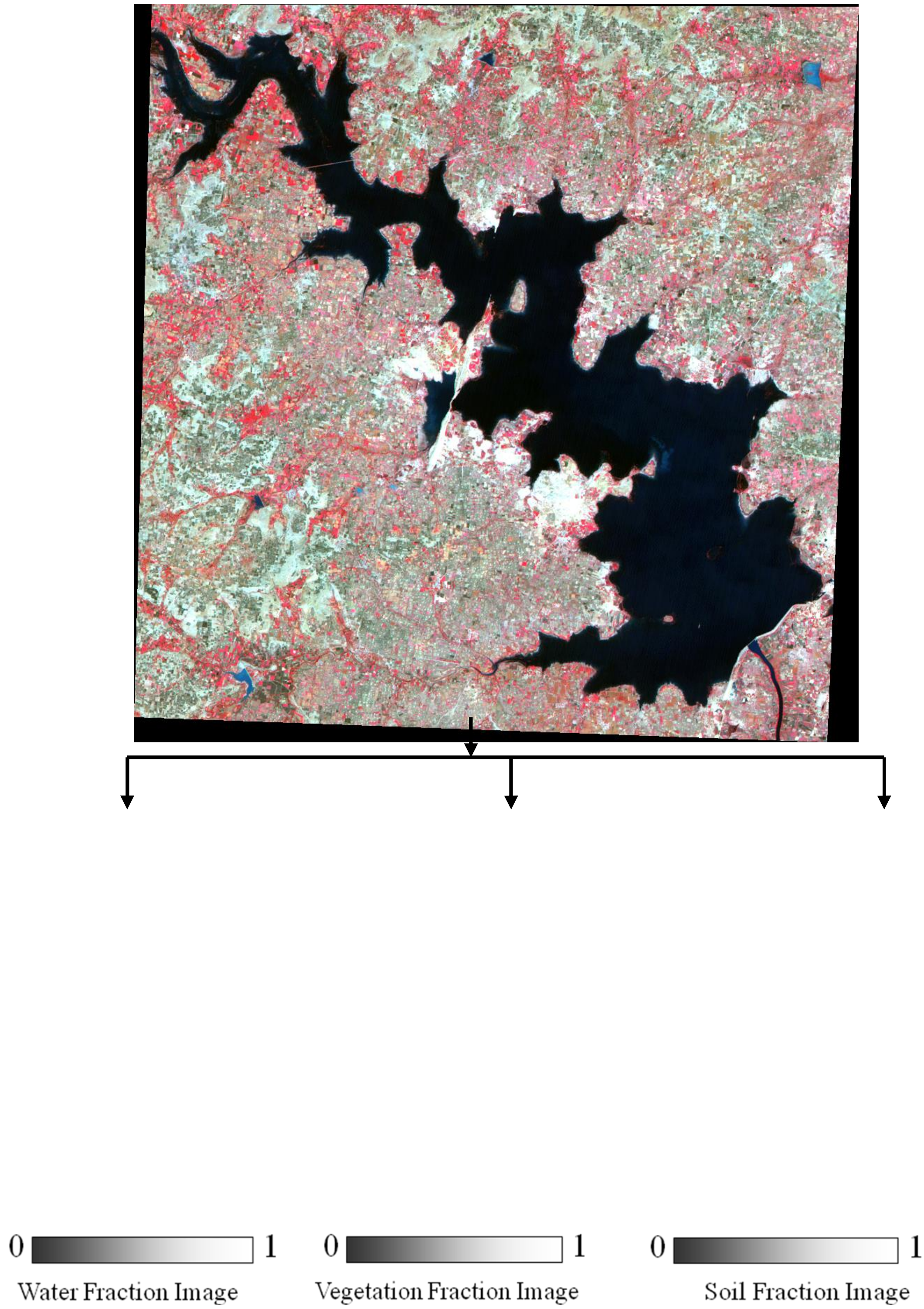


Fig 4.2 (a) Fraction images obtained from sub-pixel classification approach for the validation date 03 Feb 2006.

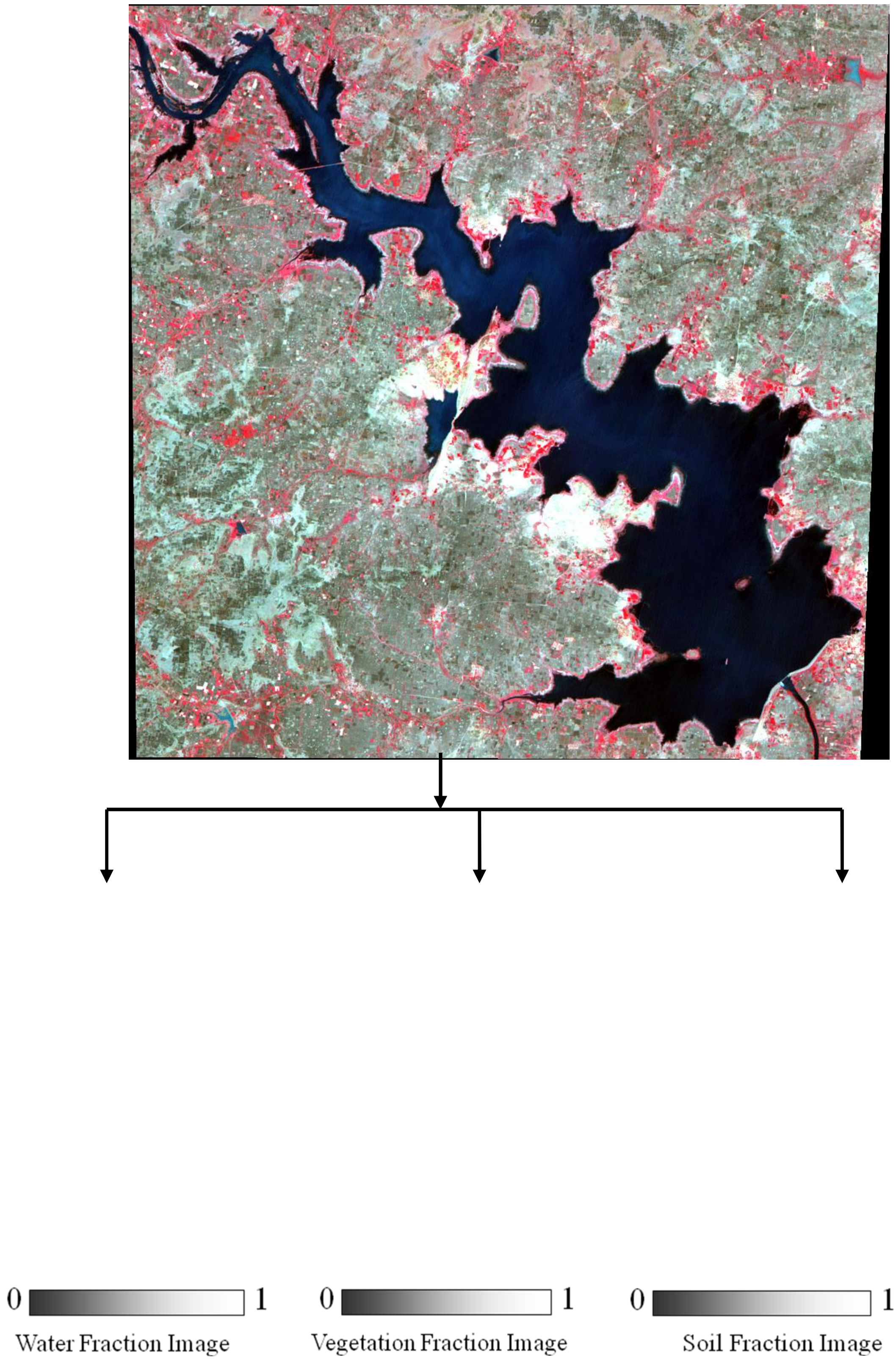


Fig 4.2 (b) Fraction images obtained from sub-pixel classification approach for the validation date 23 Mar 2006.

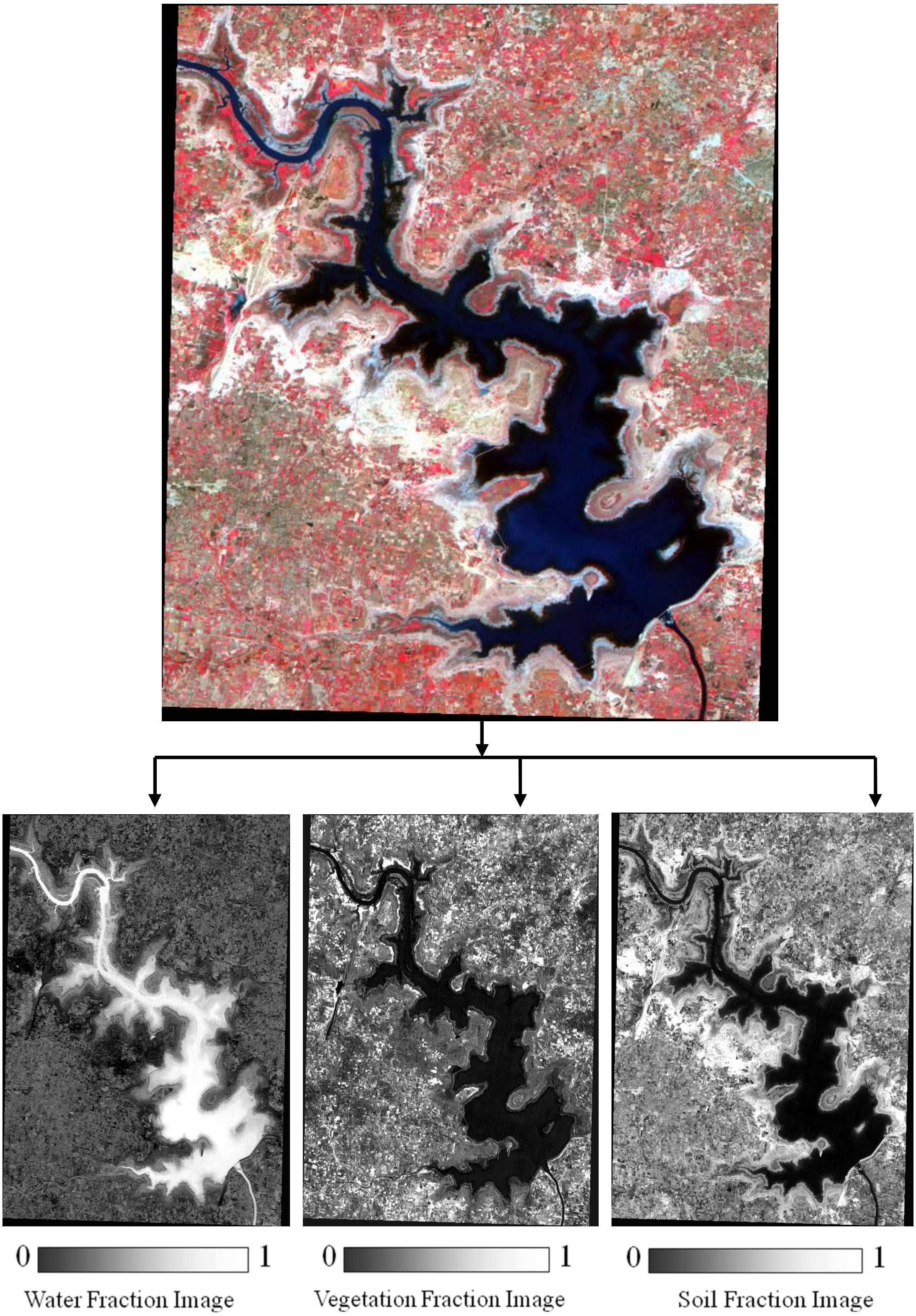
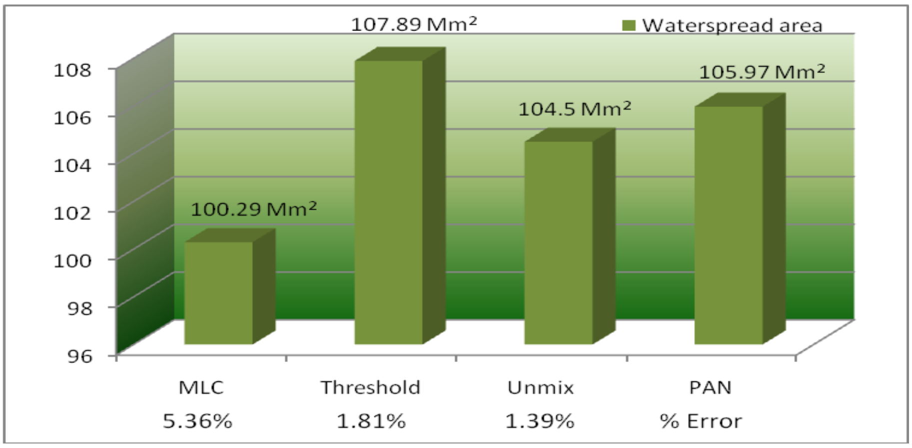
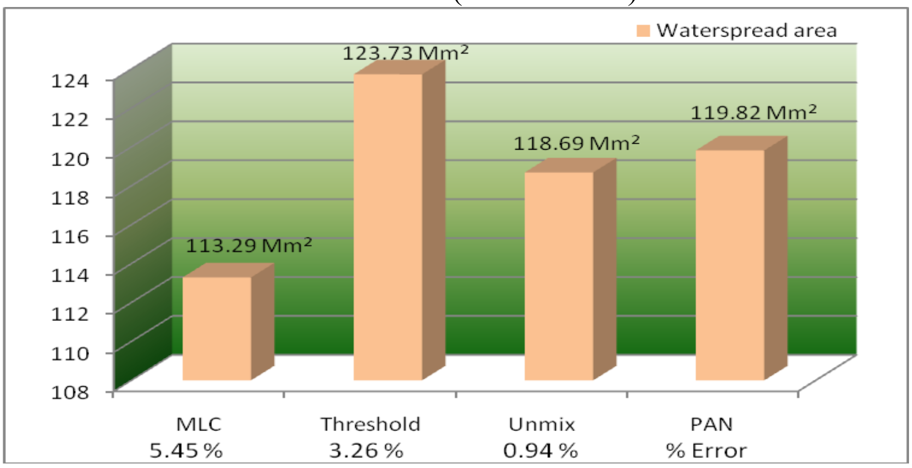


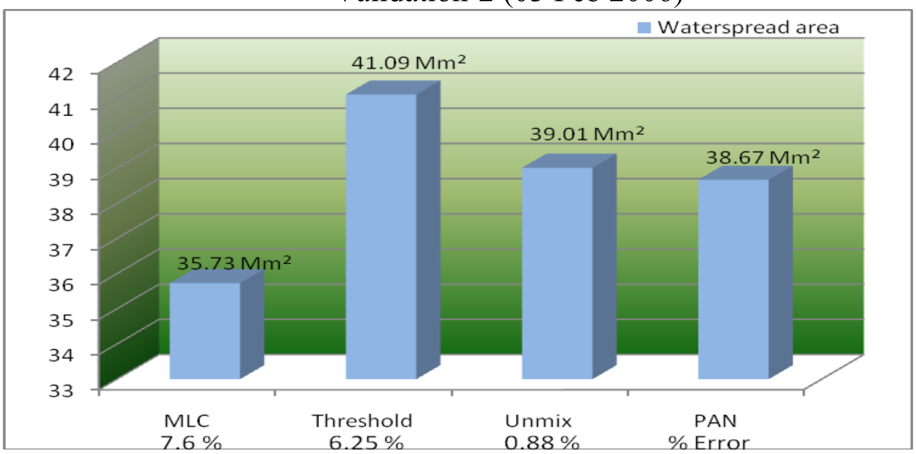
Fig 4.2 (c) Fraction images obtained from sub-pixel classification approach for the validation date 15 Jan 2005.



Validation-1 (23 Mar 2006)



Validation-2 (03 Feb 2006)



Validation-3 (15 Jan 2005)

Fig.4.3 Accuracy assessment of per-pixel and sub-pixel classification approaches.

4.4 Estimation of loss in storage due to sedimentation

The loss in storage can be estimated by subtracting the impoundment volume or any recently estimated hydrographic survey and the present volume estimated using satellite data. The recent hydrographic survey conducted at Singoor reservoir was during 1997. Therefore the loss in storage between the period 1997 and 2005 is calculated. Subtracting the volume 791.22 Mm^3 (1997) and 716.11 Mm^3 (2005) yields a result of 75.11 Mm^3. This shows that during a period of eight years from 1997 to 2005, sediment of volume 75.11 Mm^3 has been deposited in the singoor reservoir. If a uniform rate of sedimentation is assumed from 1997 to 2005 the reservoir sedimentation rate is 9.39 Mm^3 (75.11/8). The volumes of the reservoir against each water level, pertaining to hydrographic survey conducted during the period 1997 are given in Table No.4.5. and Fig.4.4.

Table 4.5 Comparison between sediment deposition in Singoor reservoir during the period 1997 and 2005.

Date of Satellite Pass	Reservoir Elevation (m)	Original Volume (1997) (Mm^3)	Cumulative Volume (2005) sub-pixel (Mm^3)
12.11.05	523.49	791.22	716.11
06.10.05	522.10	591.67	544.95
29.08.05	517.10	171.40	152.40
01.04.05	514.92	89.08	76.01
15.05.05	513.71	59.54	53.06
15.06.05	512.51	37.47	37.47

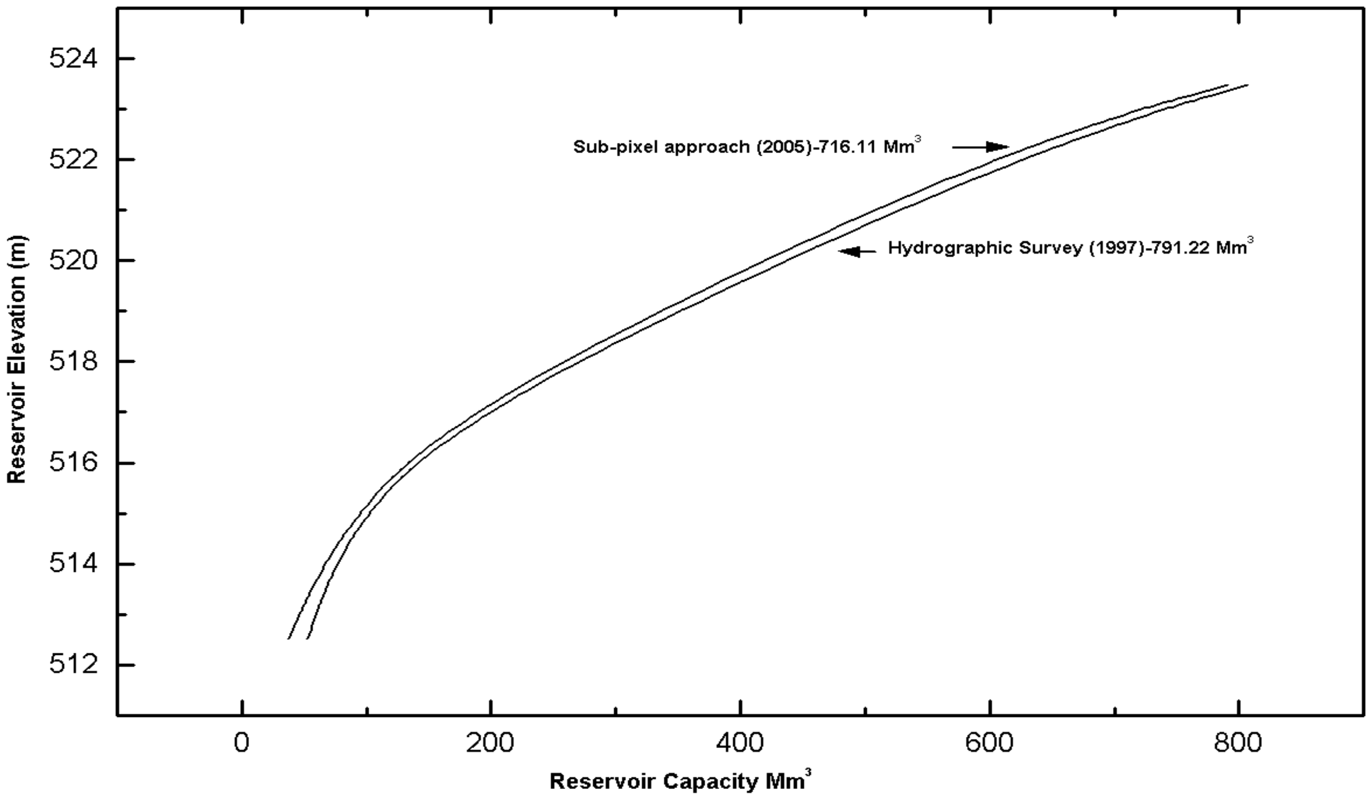


Fig.4.4 Elevation capacity curve of Singoor reservoir for the period 1997-2005

PART-II: APPLICATION OF SUB-PIXEL CLASSIFICATION APPROACH FOR THE EXTRACTION OF WATER-SPREAD AREA USING LOW RESOLUTION (56m) SATELLITE DATA:

The AWiFS (Advanced Wide Field Sensor) sensor of Indian satellite IRS-P6 have a spatial resolution of 56 m, it covers nearly 40% of India tertiary in its 740 km swath. In this wide area there are nearly 15 large reservoirs are located. From the 56m data, if the sub-pixel approach yields considerable results, it would be highly economical for the capacity estimation of the reservoirs. In this context it was decided to carry out a preliminary study on the AWiFS, data for the extraction of water-spread area using sub-pixel classification methodology. Three set of satellite pass was selected which have both 56m and 24m in the single pass over singoor reservoir. Coherence 5m data is not available for the 56m pass. Per-pixel and sub-pixel classification was applied to the 56m data. 24 m data has been used to validate the results of sub-pixel methodology and this data has been classified using band threshold method. Due to the low resolution in nature only band threshold method was applied. The results are given in the following Table No.4.6. It is evident from the table that the sub-pixel approach applied on the 56 m satellite data produces an average accuracy of 97.84% when compared with the 24 m resolution data. This indicates that the 56 m resolution data with sub-pixel methodology can be used to get results comparable with the 24 m resolution data. The results show that more number of reservoir capacities can be estimated economically.

Table 4.6 Accuracy Estimation between Per-pixel and Sub-pixel Approaches.

Sl.No.	Water-spread area (Mm^2) delineated Using Per-pixel Approach		Water-spread area (Mm^2) delineated Using Sub-pixel Approach	Accuracy
	56 m	24 m	56 m	
1.	81.59	86.82	85.34	**98.29%**
2.	124.98	130.02	127.78	**96.84%**
3.	141.56	148.61	143.91	**98.39%**
			Average	**97.84%**

CHAPTER-5

CONCLUSIONS

The thematic information that has to be extracted from the satellite data for the estimation of capacity of a reservoir is the water spread-area, at different water levels of the reservoir. The most widely used traditional approach to delineate the thematic information from the remote sensing, digital data is the maximum-likelihood classification (MLC) technique. The MLC adopts the per-pixel based methodology and assigns a pixel to a single land cover type, whereas in reality a single pixel may contain more than one land cover type and known as a mixed pixel. The mixed pixels contain different proportion of soil, vegetation and moisture are also classified as water pixels, thereby giving inaccurate estimate of the water-spread area. To accurately compute the water-spread area to the maximum possible extent, thereby reducing the error in the estimation of capacity of a reservoir, a sub-pixel classification or linear mixture model (LMM) approach has been adopted in this study for classifying the water-spread areas of Singoor reservoir, Andhra Pradesh.

Based on the availability of cloud free data six different, reservoir water levels have been selected to estimate the capacity (2005) of the reservoir. Digital data pertaining to these water levels were acquired from IRS-1C & 1D (LISS-III) satellites and its water-spread areas were extracted using per-pixel and sub-pixel classification approaches. MLC and band threshold methods have been adopted in the per-pixel classification approach. The estimated capacity of the reservoir from MLC, band threshold and sub-pixel approaches are 688.48 Mm^3, 727.75 Mm^3 and 716.11 Mm^3 respectively. The per-pixel and sub-pixel classification was validated using high resolution PAN (5m) data. The validation shows that sub-pixel classification produced very less error (1.07%) than the MLC (6.1%) and band threshold method (3.77%). This shows that the sub-pixel classification approach can be applied to estimate the capacity of the Singoor reservoir with high accuracy than the per-pixel classification approaches. To estimate the rate of sedimentation of singoor reservoir the capacity of 1997 hydrographic survey (791.22 Mm^3) and the capacity estimated (2005) using sub-pixel approach (716.11 Mm^3) was used. Based on these results, if uniform rate of sedimentation is assumed from 1997 to 2005 the reservoir sedimentation rate is 9.39 Mm^3

Apart from this a preliminary study on the three satellite pass of 56m (IRS-P6, AWiFS) resolution data, was carried out for the extraction of water-spread area using sub-pixel classification methodology. The sub-pixel approach applied on the 56 m satellite data produced an average accuracy of 97.84% when compared with the 24 m resolution data. This indicates that the 56 m resolution data with sub-pixel methodology can be used to get results comparable with the 24 m resolution data. The 56 m data accommodates nearly 15 large reservoirs in its 740 km swath. This shows that more number of reservoir capacities can be estimated economically.

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DIRECTOR: Dr. Raj Dev Singh

COORDINATOR: Dr. Bhishm Kumar

HEAD: Dr. Y. R. Satyaji Rao

STUDY GROUP

V. S. Jeyakanthan, Scientist-E1

Y. R. Satyaji Rao, Scientist-E2