CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

This chapter reviews several researches related to capacity estimation of reservoirs that have been carried out using conventional and remote sensing technique. The reviews include catchment soil erosion, classification of remote sensing data using per-pixel and sub-pixel methodologies and spectral analysis studies related to water body and its peripheral landcover.

2.2 SOIL EROSION

This section reviews the works carried out by many authors pertaining to catchment soil erosion.

Choubey and Subramanian (1991) studied the Tawa reservoir, Madhya Pradesh, India using satellite data and synchronous collection of field data. IRS-1A LISS-I satellite data was used for September and October. Suspended sediment samples were collected from 44 locations on the day of satellite overpass from 6am to 7pm. Suspended sediment concentration (SSC) was determined from all sediment samples. For selected samples, mineralogical composition was determined. It was found that SSC was high in the Tawa river segment and the main body of the reservoir. SSC decreases from reservoir tail end to its head. It various between 10 to 50 ppm. DN at sample location were averaged in windows of size 3 x 3. Visible bands were
highly correlated with SSC. Multiple linear regression was fitted using several combinations of bands of October data. The best combination has two variables, namely sum DN from Bands 1, 2 and 3 and sum of DN Band 1 and 3. The relationship was validated using the September data.

Chanson and James (1998) mention that during the 19\textsuperscript{th} and 20\textsuperscript{th} centuries, a series of dams was built in South eastern Australia for water supply, and irrigation purposes. Among these, four dams were silted very rapidly due to sedimentation and were abandoned in less than 25 years. The reason for the same is improper soil conservation practices, streams with heavy sediment load and extreme climatic conditions. They further discuss that although the dams had advanced structural features, their stories reflect a lack of understanding of siltation resulting from sediment transport processes by the designers. The authors hope that this example will serve as a pedagogic example for professionals and students to improve future studies on siltation which reduces the capacity of reservoirs.

Brandts (1999) reviewed the existing literature on reservoir de-siltation. The review is divided into three topics dealing with different aspects of reservoir de-siltation. The first topic treats different hydraulic reservoir de-silting-techniques. The emphases are put on flushing of already deposited sediment and routing of incoming sediments from upstream, through a reservoir, but alternative methods, such as transporting sediment through flexible pipes and siphoning, are also described. The second topic treats resulting reservoir geomorphology after hydraulic reservoir flushings. This includes cross-sectional and longitudinal variations in geomorphology due to flushing, but also the available literature on physical and analytical models. The third topic treats downstream geomorphological and sedimentological effects during and after reservoir flushing operations. Attention is given to
Price et al (2000) explain that the data-based mechanistic (DBM) modelling methodology is applied to the study of reservoir sedimentation. A lumped-parameter, discrete-time model has been developed which directly relates rainfall to suspended sediment load (SSL) at the reservoir outflow from the two years of measured data at Wyresdale Park Reservoir (Lancashire, UK). This nonlinear DBM model comprises two components: a rainfall to SSL model and a second model, relating the SSL at the reservoir inflow to the SSL at the reservoir spillway. Using a daily measured rainfall series as the input, this model is used to reconstruct daily deposition rates between 1911 and 1996. This synthetic sediment accretion sequence is compared with the variations in sand content within sediment cores collected from the reservoir floor. These profiles show good general agreement, reflecting the importance of low reoccurrence, high magnitude events. Though this preliminary study highlights the potential utility of the DBM approach, which could be readily applied to other sites, a lot of field work and ground data input is required.

In another study Yuan Lee et al (2006) discuss that soil erosion in the catchment area of the reservoir is the main source of reservoir sedimentation that affects the reservoir’s lifespan and capacity and is of vital importance for watershed management. Due to the lack of data, empirical formulas are commonly used to estimate reservoir sedimentation. However, these estimations are far from accurate. Field measurements of discharge and suspended sediment were collected by the authors during three typhoon events in Shihmen Reservoir watershed, Taiwan. Temporal variations of water surface elevation, discharge, and concentration of suspended sediment were measured. A numerical model, Hydrological Simulation Program
Fortran HSPF developed by the USEPA was adopted to simulate the sediment yield. However, as calibration and verification data were not always available and the parameter-calibration process is complicated and tedious for novice users of the model, an artificial neural network ANN model was proposed. Significant amount of the synthetic data from the calibrated HSPF model were first generated to train the ANN model, which in turn was used to estimate the sediment yield. Comparisons of the sediment yield using both the HSPF and ANN model give correlation coefficients of 0.96 for training and 0.93 for validation. Without the complicated parameter calibration process, the ANN model was faster and easier to use than the HSPF model.

Villegas and Jerald (2009) define that Trapping efficiency (TE) is the percent of particles that are retained within an impoundment. TE can vary from 0% indicating no sediment is retained to 100% where all the sediment is retained. In this paper a high quality, long-term data set (32 years) was used to demonstrate that annual sediment trap efficiencies. For water years 1973–2005, annual trap efficiencies for Coralville Reservoir ranged from 5.6 to 95.8%. Overall trap efficiency for the entire period was determined as 80.3%. Bathymetric data show that since 1958 the reservoir has lost 11% of its flood storage capacity, and over 62% of its normal pool capacity. For the time studied (1973–2005) the loss of storage is estimated to correspond to 16.9×10^9 kg of sediment deposited in the reservoir, resulting in an annual sedimentation rate of 5.3×10^8 kg year^{-1}.

Garbrech (2011) implies that effectiveness of soil conservation practices at reducing watershed sediment yield and impact on reservoir sedimentation is generally difficult to quantify. In this study the sedimentation survey of the Fort Cobb Reservoir in West - Central Oklahoma and sediment load measurements on contributing tributaries provide an opportunity to address this issue. Sediment and flow observations data for the
pre-conservation time period (1943-1950) and post-conservation time period (2004-2008) were used to compare watershed sediment yield and the rate of reservoir sedimentation. From the analysis the initial sediment yield for pre- and post conservation conditions were estimated as 2,54,900 Mg/yr and 2,47,700 Mg/yr respectively. The results reveals that wetter climate led to increased soil erosion, sediment transport and sediment yield that offset reductions achieved by conservation efforts. About a 60% to 65% reduction in sediment yield would have been achieved by conservation efforts if the climate characteristics had been constant over time.

Van Maren et al (2011) observe that the high sediment load of the Yellow River results in rapid infilling of its reservoirs when sediment is not regularly flushed. Simultaneously, the downstream reaches of the Yellow River experience extremely high siltation rates, which are reduced when sediment is retained in its reservoirs. To minimize siltation in the reservoirs and the downstream river bed, water and sediment are released from the reservoir in a controlled way through flushing experiments. In this paper, the authors analyze the effect of such a flushing event on the downstream river bed through data analysis and numerical modeling. Sedimentation may be minimized by relating the amount of sediment released from the reservoir to the sediment available for release through operational monitoring and by releasing relatively clear water after turbid water. Despite this flushing of sediment, the reservoir will eventually fill up, and more sediment released again into the lower Yellow River. The change in discharge magnitude and frequency brought about by the reservoir will then probably result in increased siltation rates in the lower Yellow River compared to the pre-dam situation.

The above listed reviews clearly indicate that catchment erosion is an important phenomenon to be monitored regularly both in the catchment
and reservoir area. The reduction in the reservoir area due to the erosion in the catchment area and subsequent deposition in the reservoir has also been highlighted in these reviews. The need for an efficient tool such as remote sensing to monitor reservoir capacity is also to be addressed. This is done in the next section.

2.3 OVERVIEW OF REMOTE SENSING FOR RESERVOIR SEDIMENTATION STUDIES

The previous section reviewed the work carried out by several researchers on catchment erosion, which ultimately deposited into the water storage structures such as lakes and reservoirs. The deposition of sedimentation in to the reservoirs reduces its storage capacity which is a major problem for the reservoirs managers. Therefore, it was suggested by many authors (Villegas and Jerald 2009, Garbrech 2011) that the capacity estimation of reservoirs has to be carried out regularly. This section reviews the research work carried out by many researchers pertaining to capacity estimation of reservoirs using remote sensing technique which is cost and time effective.

Garde and Kothyari (1987) carried out the field radiometric and satellite data analysis for Upper Lake, Bhopal. Satellite data used were of TM sensor for the month of February. Synchronous collection of field data was completed starting two days prior to satellite over pass date. The field data were collected before noon on all days. Field radiometric data showed high correlation with Total Suspended Sediment (TSS). TSS was in the range from 38 to 70 ppm. Only one reading was of 110 ppm. Thus, the range of TSS was small for this study. A regression equation was fitted between radiometric Bands 1 and 2 and TSS. TSS was independent variable in the equation. The correlation coefficient and error of estimate were respectively 0.8843 and 5.8
ppm. Satellite data were also classified into five classes using supervised method for TSS concentrations.

Manavalan et al (1993) carried out the storage capacity of the Bhadra and Malaprabha reservoirs in the Krishna river basin using Landsat TM and IRS II digital data respectively. The authors discuss the possible error limit, due to the omission and commission of mixed pixels involved while estimating the water-spread area. Otherwise the discrepancy between the actual water-spread and the satellite water-spread will lead to a misleading conclusion regarding the rate of sedimentation, especially when there is only marginal deposition of sediments.

Bryant et al (1999) studied the Painted Rock Reservoir, southwest of Phoenix, Arizona, which had a storage capacity of about 2.5 million acre-ft in 1959, when dam impoundment was made. When a high flood of record occurred in 1993, it was feared that as much as 500,000 acre-ft of capacity had been lost, and an updated capacity estimate was needed. Because a proposed conventional reservoir survey turned out to be prohibitively expensive, it was decided to investigate the use of Landsat Thematic Mapper remotely sensed data, acquired at multiple reservoir levels, to obtain an updated capacity estimate at a more reasonable cost. Nineteen Landsat Thematic Mapper scenes from 1993 and 1995 were obtained, including reservoir elevations ranging from empty to 5 ft above spillway elevation. Water surface area was determined for each Landsat scene using computer classification of the digital imagery. Investigation results indicate that the reservoir lost approximately 157,000 acre-ft of storage capacity to sedimentation between 1953 and 1993, significantly less than the 500,000 acre-ft previously feared lost.

Sakthivadivel et al (1999) studied multi-date IRS LISS-II data of 1988-89 to map the water spread of Malaprabha reservoir, Karnataka, India at
five different stages, and compared with those of 1972 being adopted by project authorities. At reservoir levels of 620.15m and 623.54m, significant reduction in water spread area was observed while considerable reduction of the order 4 to 9% was observed at levels 626.53m and 629.98m. The overall reduction in the reservoir capacity between levels of 620.15m and 632.98m was estimated at 3.84% in a span of 17 years. Similar study was attempted by Manavalan et al (1984) in Gattaprabha reservoir, Karnataka, India using multi-data IRS, LISS-II data. The overall reduction in capacity of the reservoir between levels 635.24m and 662.94m was computed to be 8.6% in a 16 year period between 1974 and 1990.

Goel et al (2002S) discuss that with the use of remote sensing data in conjunction with a Geographic Information System, the temporal change in water-spread area can be analysed to evaluate the sediment deposition pattern in a reservoir. The reservoir was completed in 1988 and no hydrographie survey has yet been carried out. Under these circumstances, the sedimentation assessment using satellite data guided the authors to update the elevation-area-capacity table of the reservoir. The images for nine dates from the IRS-1C satellite, LISS-III sensor have been analysed using the image processing software, ERDAS. The resulting sedimentation rate in the zone of study was about 229 Mm$^3$/km$^2$ of catchment area per year. This work demonstrates that the capacity survey of reservoir using remote sensing data is in par with field based conventional survey.

In another study Bhakra reservoir located on the Satluj River in the foothills of the Himalayas, Jain et al (2002) carried out a remote-sensing based study of the or the assessment of reduction in capacity. The authors mention that multi-date remote sensing data (IRS-1B, LISS II) provided the information on the water-spread area of the reservoir, which was used for computing the change in storage capacity of the reservoir and in turn the
sedimentation rate. A comparison of the results shows that the reduction in capacity assessed using the remote sensing based approach was close to the results obtained from the hydrographic survey. However, the authors suggest that the water-spread area estimation from the peripheral pixels has to be carefully carried out due to the presence of mixed pixels.

Jeyakanthan et al (2002) et al carried out capacity estimation of Poondi reservoir located in Tamilnadu, India using satellite image data. In this study, the authors utilized IRS-1B & 1C of LISS-II (36 m) and LISS-III (23.5m) sensor data, acquired for seven different water level ranging from 34.67 m and 41.34 m for the period 1999 & 2000. The water-spread area extracted from the satellite data were used in the trapezoidal formula for the estimation of revised capacity of the reservoir. The comparison of the results with the year 1983 show that the loss in capacity, for the Poondi reservoir is 5.09 million cubic metre. If uniform rate of sedimentation is assumed in 16 years of existence of the reservoir, then the sedimentation rate in this zone is 0.318 M Cum per year. The authors observed that comparison of remote sensing results are in agreement with the ground based of hydrographic survey. Thus, this work proves that the remote sensing based capacity survey is economical and time effective.

Peng et al (2005) used MODe-rate-resolution Imaging Spectroradiometer (MODIS) data for the flood disaster monitoring of Dongting Lake, China. The storage curve of Dongting Lake for 1995 was obtained using 1:10,000 topographic map data and then a relationship between water level and the lake area was derived. A new relationship between water level and lake area was obtained by processing MODIS images of Dongting Lake from April 2002 to April 2003 and the influence of lake area variation on water level was analysed with the corresponding flood data. It was found that the water level reduction reached 0.64 m for the 1996 flood
if the original lake area curve was replaced with the area curve of 2002. This illustrates that the flood water level has been considerably reduced as a result of the increased area of Dongting Lake since the Chinese Central Government’s “return land to lake” policy took effect in 1998. In this study, the successful implementation of satellite data for reservoir parameter estimation has been demonstrated. It is opined that coarse resolution of the MODIS data could have resulted in large errors in flood water and land estimation.

Renwick et al (2005) examined recent sedimentation rates in 12 reservoirs in two southwest Ohio counties. One of the two counties is primarily urban with high local relief, while the other is primarily agricultural with low relief. In each case a large range of reservoir sizes was studied (< 1 to > 70 km² drainage area). In the agricultural county sedimentation rates follow the normal pattern of sedimentation per unit drainage area indicating that the channel systems in the area are likely functioning as sediment sinks. In contrast, in the urban county there is no decrease in sedimentation rate with increasing drainage area, indicating that the channels in that landscape are functioning as efficient conduits and/or net sediment sources. These trends highlight that for better management of reservoirs database related to sedimentation has to be updated regularly.

Rathore et al (2006) report that as per the recommendations of working group for National Action for Reservoir Sedimentation Assessment, National Institute of Hydrology (NIH), India has carried out study on sedimentation studies on 25 reservoirs all over India. One among them is Hirakud reservoir in Mahanadhi basin, Orissa studied by the author. Linear Imaging Self Scanning (LISS-III) sensor mounted on the Indian Remote Sensing Satellites (IRS) 1C & 1D data were used to cover the reservoir elevation between 180.69 and 191.89 m. A rule based classification was
applied to water index and radiance of NIR band to extract water-spread area. It was found that during 44 (1956-2001) years of operation, the total live storage capacity loss was 984 Mm$^3$ (which is nearly 17% of the original capacity (5826 Mm$^3$) of the reservoir) at a rate of 0.376% year$^{-1}$. Thus, the satellite data is in immense use for the prediction of rate of sedimentation of reservoirs. Here again, it is opined that the LISS III image being relatively coarse resolution data, computational errors might have crept in.

Peng et al (2006) estimated storage curve of the Fengman reservoir in China based both on traditional and remote sensing approach. They discuss that there are different classification methods or models for extraction of water-spread area of a reservoir such as the density-slicing approach and the normalized difference water index (NDWI) method. The comparison showed that the reservoir storage curve estimation based on RS data is reasonable and economical. The authors also suggest that presence of mixed pixels around the periphery of the reservoir may impose serious errors while estimating the water-spread area of the reservoir, which has to be addressed properly to calculate the capacity of the reservoir more accurately.

All the case studies listed above have been attempted using the per-pixel approach of image analysis. The limitations of the per-pixel approach as suggested by the authors have also been highlighted. Hence, the sub-pixel approach also needs to be reviewed, as done in the next section.

2.4 STUDIES USING SUB-PIXEL CLASSIFICATION APPROACH

The previous section reviewed the work carried out using conventional/per-pixel classification approaches for capacity estimation of reservoirs. The resultant map obtained by per-pixel classifiers may have perhaps produced less accurate results. Also, papers reviewed by various
authors, (eg. Jain 2002, Peng 2006) emphasize on the need for sub-pixel level classification of water-spread area for better estimation of capacity of reservoirs. This section reviews the research work carried out by many researchers pertaining to spectral un-mixing/linear mixture modelling and other sub-pixel classification approaches for different applications.

Quarmby et al (1992) discuss the use of spectral unmixing viz., linear mixture modelling for crop area estimation. Multi-temporal AVHRR dataset of 9 dates of Northern Greece were used and the input to the model was obtained using supervised classification of SPOT HRV images. The proportions of maize, rice, cotton and wheat were correlated with official statistics from 18 village units for comparison of area of each category and the accuracy was 89% showing the performance of the mixture model. The results showed that the linear mixture modelling (LMM) has potential for operational crop area monitoring on a regional scale.

Foody et al (1994) estimated the sub-pixel land cover composition using a LMM and Fuzzy membership function. For both approach, a significant correlation co-efficients, all >0.7, between the actual and predicted proportions of a land cover type within a pixel were obtained.

The mapping of land cover components, vegetation, in particular, with the help of NOAA-AVHRR (Advanced Very High Resolution Radiometer) data was discussed by Shimabukuro et al (1997). Fraction images of vegetation, soil and water/shade were derived from a set of six AVHRR images in the Sao Paulo state, Brazil using linear mixing model. Constrained least squares approach was employed and a global vegetation cover map was available for comparison. In addition, NDVI values were computed and there was a good correlation between the NDVI values and the vegetation fraction obtained through unmixing. This paper gives an insight into the use of linear mixing model for mapping vegetation cover. Though the
aim of the paper was to extract vegetation details, it brings out the importance of soil and shade fraction images, which aid in a better understanding of the spectral response of the other land cover types.

Shimabukuro and Novo (1997) proposed a methodology viz., mixing model for mapping of flood habitats in the Amazon basin. Two adjacent scenes of Landsat TM available in digital format were used for the study. The transformation of digital numbers to spectral reflectance values and radiometric rectification of images was carried out. Assessment of the rectification process and the consequent application of mixing model yielded a classified map of the flood habitats. Three end members were chosen as input for the mixing model and the map thus obtained was compared with a reference map derived from visual interpretation. Flood habitats mapping using mixing model yielded a good classification result. Though accuracy assessment was not carried out, the paper proposes a new methodology namely, mixing model for the purpose of mapping flood habitats to overcome the limitations of per-pixel classification.

Casals-carrasco (2000) applied spectral mixture mixture analysis (SMA) for terrain evaluation using Landsat-TM and Panchromatic images. The author compared the results obtained by traditional supervised rules such as Maximum Likelihood Classifier (MLC) with spectral mixture analysis. The results showed SMA was efficient in deriving more information image data compared to the conventional techniques.

The use of spectral unmixing as a tool for bauxite and laterite mineral targeting and mapping in the Koraput district, Orissa, India was carried out by Das (2002). End members were chosen using the PPI technique. The characteristic laterite cappings in the hills containing bauxite was observed in the Landsat TM image and such region is generally devoid of vegetation cover. MTMF, which performs partial unmixing based on the end
members supplied by the users, was used to unmix the abundances of laterite/bauxite, vegetation and red soil. This study has helped in the discrimination of similar regions in the nearby hills of the Koraput town.

Lu Dengsheng et al (2003) says that many research projects require accurate delineation of different secondary succession (SS) stages over large regions/subregions of the Amazon basin. However, the complexity of vegetation stand structure, abundant vegetation species, and the smooth transition between different SS stages make vegetation classification difficult when using traditional approaches such as the maximum likelihood classifier (MLC). Most of the time, the MLC distinguishes only between forest and non-forest. It has been difficult to accurately distinguish stages of SS. Therefore the authors applied a linear mixture model (LMM) approach to classify successional and mature forests using Thematic Mapper (TM) imagery in the Rondoña region of the Brazilian Amazon. Three endmembers (i.e., shade, soil, and green vegetation or GV) were identified based on the image and a constrained least-squares solution was used to unmix the image. This study indicates that the LMM approach is a promising method for distinguishing successional and mature forests in the Amazon basin using TM data. It improved vegetation classification accuracy over that of the MLC. Initial, intermediate, and advanced successional and mature forests were classified with overall accuracy of 78.2% using a threshold method on the ratio of shade to GV fractions, a 7.4% increase over the MLC. The study implies the LMM approach distinguishes different species in a forest and therefore more promising results can be obtained than the MLC.

Paintera et al (2003) used an automated model that retrieves sub-pixel snow-covered area and effective grain size from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data. The model analyzes multiple end-member spectral mixtures with a spectral library of snow,
vegetation, rock, and soil. They derived the snow spectral end-members of varying grain size from a radiative transfer model. End-member spectra for vegetation, rock, and soil were collected in the field and laboratory. The sub-pixel estimates of snow-covered areas were validated with the fine-resolution aerial photographs. The RMS error for the combined set of fraction images was 4%. This study shows that the authors have used the high resolution data to validate the results of sub-pixel output and such validation proves that un-mixing produces less error.

Fernandes et al (2004) carried out a comparative study using five algorithms for mapping sub-pixel land cover fractions and continuous fields of vegetation properties in their study area (Boreas Ecosystem Atmosphere Experiment (BOREAS) region in Canada). The algorithms include a conventional ‘‘hard’’, per-pixel classifier, a neural network, a clustering/look-up-table approach, multivariate regression, and linear least squares inversion. The comparison reveals that the ‘‘Hard’’ classification performed poorly in estimating proportions or continuous fields. The neural network, look-up-table and multivariate regression algorithms produced good results. However, all three methods exhibited substantial biases with the distant treatment due to the characteristics of the training data. Linear least squares inversion offers a relatively unbiased estimation of sub-pixel proportion and fraction mapping as it avoids calibration to the a priori distribution of land cover in the training data.

Lobell and Asner (2004) says that the knowledge of the distribution of crop types is important for land management and trade decisions, and is needed to constrain remotely sensed estimates of variables, such as crop stress and productivity. The Moderate Resolution Imaging Spectro-radiometer (MODIS) data was used by the authors for large scale crop type mapping. Further the authors say that because of sub-pixel heterogeneity, the
application of traditional hard classification approaches to MODIS data may result in significant errors in crop area estimation. Therefore, they developed and tested a linear un-mixing approach with MODIS that estimates sub-pixel fractions of crop area based on the temporal signature of reflectance throughout the growing season. In this method, the authors used probabilistic temporal un-mixing (PTU), technique for the identification of end-member sets. The results of this study demonstrates the importance of sub-pixel heterogeneity in cropland systems, and the potential of temporal un-mixing to provide accurate and rapid assessments of land cover distributions using coarse resolution sensors, such as MODIS.

Simic et al (2004) carried out a study to address the issues related to spatial scaling of net primary productivity (NPP). The main objective of the study is to develop algorithms for spatial scaling of NPP using sub-pixel information. NPP calculations were performed using the Boreal Ecosystem Productivity Simulator (BEPS). The area of interest is near Fraserdale, Ontario, Canada. It was found from the investigation that lumped (coarse resolution) calculations can be considerably biased (by +14.9% on average) from the distributed (fine resolution) case. Based on these results, algorithms for removing these biases in lumped NPP are developed using sub-pixel land cover type information. The correlation between the distributed NPP and lumped NPP is improved from $r^2=0.16$ to $r^2=0.59$ after the correction. In addition, sub-pixel leaf area index (LAI) information is used to reduce the remaining biases. After the LAI correction, the correlation is further improved to $r^2=0.90$.

Rodrigo sagardia (2005) used sub-pixel classifier for wetland mapping in the Cuitzeo Lake, Mexico and mapped the different communities of plants using MODIS images and linear mixture modeling. It was shown that the fractions present at sub-pixel level could be estimated with a good
degree of accuracy, lying within 25% of the actual values. The performance of the soft classifier is at least three times higher than a hard classification of an artificial image of the same pixel size in areas that show mixed pixels.

Peddle and Smith (2005) used spectral mixture analysis (SMA) to quantify the area abundance of plants, soils and shadows at sub-pixel scales with the aim of improving extraction of plant biophysical and structural information from remote sensing data. Different measurement strategies were tested in the field for acquiring reference end-member spectra of crop vegetation, soil and shadows using a field spectro-radiometer for a set of potato plots in western Canada. End-member fractions derived from excised leaves, cultivated soil and shadowed vegetation spectra showed the best agreement with ground truth data, with differences of only ±3.3%. These sub-pixel scale fractions were used in regression analyses to predict leaf area index, biomass and plant width with an average $r^2$ value of 0.85 from SMA shadow fraction, which was a substantial improvement over the best VI results from NDVI, NGVI and SR (average $r^2 = 0.53$). Perspectives on SMA at different stages in the growing season and for different crop types are provided with a recommendation that further SMA research is warranted for local to regional scale agricultural crop monitoring programmes.

Mertens et al (2006) say that soft classification techniques avoid the loss of information characteristic to hard classification techniques when handling mixed pixels. Sub-pixel mapping is a method incorporating benefits of both hard and soft classification techniques. They developed an algorithm based on sub-pixel/pixel attractions. The design of the algorithm is accomplished using artificial imagery but testing is done on artificial as well as real synthetic imagery. The algorithm was evaluated both visually and quantitatively using established classification accuracy indices. The resulting
images show increased accuracy when compared to hardened soft classifications.

de Asis and Omasa (2007) used models such as Universal Soil Loss Equation (USLE) and its subsequent Revised Universal Soil Loss Equation (RUSLE) to generate the quantitative estimates necessary for designing soil conservation measures. However, large-scale soil erosion model-factor parameterization and quantification is difficult due to the costs, labor and time involved. Among the soil erosion parameters, the vegetative cover or C factor has been one of the most difficult to estimate over broad geographic areas. The C factor represents the effects of vegetation canopy and ground covers in reducing soil loss. Traditional classification techniques and vegetation indices were found to be inaccurate. This study presented a new approach based on Spectral Mixture Analysis (SMA) of Landsat ETM data to map the C factor for use in the modeling of soil erosion. A desirable feature of SMA is that it estimates the fractional abundance of ground cover and bare soils simultaneously, which is appropriate for soil erosion analysis. They used a linear SMA (LSMA) model and performed a minimum noise fraction (MNF) transformation and pixel purity index (PPI) on Landsat ETM image to derive the proportion of ground cover (vegetation and non-photosynthetic materials) and bare soil within a pixel. The end-members were selected based on the purest pixels found using PPI with reference to very high-resolution QuickBird image and actual field data. Results showed that the C factor value estimated using LSMA correlated strongly with the values measured in the field. The correlation coefficient (r) obtained was 0.94. A comparative analysis between NDVI- and LSMA-derived C factors also proved that the latter produced a more detailed spatial variability, as well as generated more accurate erosion estimates when used as input to RUSLE model.
Weng and Lu (2008) carried out a study based upon a spectral unmixing model for characterizing and quantifying urban landscape changes in Indianapolis, Indiana, the United States, and for examining the environmental impact of such changes on land surface temperatures (LST). Three dates of Landsat TM/ETM+ images, acquired in 1991, 1995, and 2000, respectively, were utilized to document the historical morphological changes in impervious surface and vegetation coverage and to analyze the relationship between these changes and those occurred in LST. Three fraction end-members, i.e., impervious surface, green vegetation, and shade, were derived with an unconstrained least-squares solution. Correlation analyses were conducted to investigate the changing relationships of LST with impervious surface and vegetation coverage. Results indicate that multi-temporal fraction images were effective for quantifying the dynamics of urban morphology and for deriving a reliable measurement of environmental variables such as vegetation abundance and impervious surface coverage.

Carola et al (2010) used Landsat overpasses from six different dates and developed a robust linear model to predict sub-pixel fractions of water cover in the Doñana Biological Reserve, Spain. The model was applied to a time series of 174 Landsat TM and ETM+ images to reconstruct the flooding regime of a system of small temporary ponds and to study their spatio-temporal changes in a 23-year period. The authors tried to differentiate natural fluctuations from trends in hydrologic variables (i.e., hydroperiod shortening) that may threaten the preservation of the system. Although medium-resolution remote sensing data have rarely been applied to monitor the small-sized wetlands, this study evidences its utility to understand the hydrology of temporary ponds at a local scale using fraction images.

Ruescas et al (2010) estimated the percentage of burnt land at sub-pixel scale using the Advanced Very High Resolution Radiometer (AVHRR)
through a simple approach. This methodology is based on multi-temporal spectral mixture analysis (MSMA), which uses a normalized difference vegetation index (NDVI) and a land-surface temperature (LST) image as input bands. The area of study is located in the Alcalaten region in Castellon (Spain), a typical semi-arid Mediterranean region. The results have shown an extension of approximately 55 km² affected by fire, which is only 5% lower than the statistic reports provided by the Environmental Ministry of Spain. Further, the authors have included a map of the area showing the percentage of estimated burnt area per pixel and its associated uncertainties. The map was validated through supervised classification of an Airborne Hyperspectral Sensor (AHS) image. Results have shown a high accuracy, with a mean error of 6.5%.

Silván-Cárdenas and Wang (2010) carried out a study using sub-pixel classification techniques based on linear and nonlinear spectral mixture models in order to identify the best possible classification technique for repeatable mapping of saltcedar (Tamarix spp.) canopy cover along the Forgotten River reach of the Rio Grande. The accuracy of sub-pixel canopy cover was assessed through a 1-m spatial-resolution hyper-spectral image and field measurements. Results indicated that the accuracy of the fully constrained linear spectral un-mixing method increased (from 67% to 77%) when the classes were represented with several image spectra.

Hamylton (2011) A staged approach for the application of linear spectral unmixing techniques to airborne hyperspectral remote sensing data of reef communities of the Al Wajh Barrier, Red Sea, is presented. Quantification of the percentage composition of different reef components (live coral, dead coral, macroalgae and carbonate sand) contained within the ground sampling distance associated with an individual pixel is demonstrated. Unmixing is applied to a reduced subset of pre-processed image data to
accurately determine the relative abundance of the reef benthos (R2 > 0.7 for all four components). The result of a phased approach is an increased signal-to-noise ratio for solution of the linear functions and reduction of processing burdens associated with image unmixing.

Since end-members are important inputs of for the process of spectral unmixing, many authors have studied various aspects of the occurrence and selection of end-members. Sanjeevi and Barnsley (2003) introduced the concept of global and regional end-members in the process of spectral unmixing. The author split the entire (global) scene into four quadrants (regional scene). Thus, global and regional end-members were obtained from the scenes. It was observed that the end-members are scene dependent and location specific. Therefore, the use of regional end-members to generate the fraction images rather than the global end-members is suggested to generate accurate fraction maps. The results of this work have been adopted in the present study of reservoir and the only regional or local end-members have been used for unmixing reservoir images.

2.5 STUDIES ON SPECTRAL CHARACTERISTICS OF BIO-PHYSICAL PARAMETERS

Much work on remote sensing and spectral studies of waters has been carried out by the international community. In recent years, there has been increasing interest in utilising remotely sensed data for extracting biophysically important variables, relating observed spectral reflectance to biomass, LAI, vegetation moisture content and many other parameters (Jakubauskas and Price 1997, Card et al 1988, Tong et al 1997, Price 1993). Where the physical basis of the relationship is not fully known, correlation and multiple regression analysis have been used to examine the relationships between spectral response and the biotic factors mentioned above (Franklin 1986, Peterson et al 1986, Danson and Curran 1993).
Rundquist et al (1998) estimated the suspended sediment concentration in water using integrated surface reflectance. They collected the spectral reflectance data for different suspended sediment concentration in 252 discrete spectral bands in a wavelength region between 368 and 1114 nm. The spectroradiometer data between 400 and 900 nm were integrated to spectral bandwidths of Landsat-TM bands. The simulated bands combined with regression techniques were used to examine the relationship between the reflectance and SSC. They concluded that the wavelength range between 700 and 900 nm (NIR) is the best for determining the amount of suspended sediments in surface waters.

Leone and Escadafal (2001) carried out study on differentiating soil types with colour and using TM data. Munsell hue, value and chroma of 69 surface soil samples were both visually estimated by four observers under diffuse daylight and computed from laboratory reflectance spectra by applying the CIE 1931 standard method. Significant relationships were found between ‘observed’ and ‘computed’ colour components. Using a correspondence analysis, soil colour was shown to be important in differentiating between soil types. The results were compared with those obtained using simulated visible Thematic Mapper (TM) bands. Results showed a clear improvement in colour determination.

Tian et al (2001) carried out a study on wheat leaves radiometrically in order to spectrally characterize the water deficiency symptoms. In this study, a FieldSpec-FR was used for measuring wheat leaf spectra. After the spectral analysis using a spectral normalizing technique, the spectral absorption feature parameters: wavelength position (nm), depth and area (relative value) were extracted from each wheat leaf spectrum. The relative water content (RWC) was measured for each wheat leaf sample. A linear regression analysis was conducted between the spectral absorption
feature parameters and corresponding RWCs. The experimental results from 110 samples indicated that reflectance spectra of wheat leaves in the 1650–1850 nm region were dominated by water content. With a decrease in wheat leaf RWC, the 1650-1850 nm spectral absorption features gradually become obvious. The relative errors of predicted RWCs and the absolute error of predicted wavelength positions were calculated from 12 validation samples by established regression equations. The relative errors of predicted RWCs and the absolute error of predicted wavelength position (nm) were both low (<6% for RWCs by the depth and area and <12 nm for the wavelength position, respectively).

Olmanson et al (2002) conducted a study using Landsat multispectral data to determine the procedure for lake water quality assessment. They said that although previous investigations have demonstrated reliable empirical relationships between satellite data and nearly contemporaneous ground observations, satellite imagery has not been incorporated into routine lake monitoring programs. This is due to the fact that efforts to produce a standard prediction equation for SDT applicable to images collected on different dates were not successful. A standard equation was developed in this project which could later be extended to satellite imagery.

Skole et al (2002) conducted a study to test the possible use of Landsat ETM 7+ to measure the water quality over large spatial scales. A regression model was developed between ETM1+ and ETM3+. The results showed that the use of Landsat to measure water clarity is sensitive to the distribution of water clarity in the calibration dataset. They concluded that the ground data need to be combined with the remote sensing data to get better results, since current methods and sensors can effectively measure shallow SDT lakes than lakes with deeper SDT.
Remote sensing technology is a valuable tool in obtaining information on the processes taking place in the surface of waters. The monitoring of water quality using remote sensing technology started in 1970. Since then, the digital evaluation of remotely sensed data onboard both airborne and space-borne platforms has been used to estimate water quality characteristics of rivers, lakes and coastal waters. One major advantage of remote sensing observations over traditional measurements for water quality monitoring provides both spatial and temporal information of surface water characteristics (Lindell et al 1999). With present advanced satellite sensors, a large number of water quality information about chlorophyll-a, suspended sediment, yellow substance, turbidity, Secchi disk depth, wave height, colour index and surface water temperature can be observed on a regular basis (Zhang et al 2002).

Autrey et al (2003) conducted a study using hyperspectral remote sensing to determine water quality parameters for large rivers in Ohio river basin. The study demonstrated that the hyperspectral remote sensing technique is a useful tool for monitoring the distributions of chlorophyll \( a \) concentrations in large rivers. The wavelengths of 675 nm and 705 nm from the Compact Airborne Spectrographic Imager (CASI) data were found to be the most suitable wavelengths for predicting chlorophyll \( a \) concentrations. The methods developed and analyzed in this paper used CASI, but it is predicted that the same information can be revealed using hyperspectral data acquired by a satellite such as the Hyperion satellite. In the future, Hyperion remote sensing data may prove to be the preferable method for the detection of eutrophic water quality indicators over large areas of water.

Pu et al (2003) carried out a study to assess the water status in oak (Quercus agrifolia) leaves. A total of 139 reflectance spectra (between 350 and 2500 nm) from coast live oak (Quercus agrifolia) leaves were measured
in the laboratory with a spectrometer FieldSpecAPro FR. Correlation analysis was conducted between absorption features, three-band ratio indices derived from the spectra and corresponding relative water content (RWC, %) of oak leaves. The experimental results indicate that there exist linear relationships between the RWC of oak leaves and absorption feature parameters: wavelength position (WAVE), absorption feature depth (DEP), width (WID) and the multiplication of DEP and WID (AREA) at the 975 nm, 1200nm and 1750nm positions and two three-band ratio indices: RATIO975 and RATIO1200, derived at 975nm and 1200 nm. AREA has a higher and more stable correlation with RWC compared to other features. It is worthy of noting that the two three-band ratio indices, RATIO975 and RATIO1200, may have potential application in assessing water status in vegetation.

Li and Li (2004) conducted a study on satellite remote sensing technology for lake water quality monitoring. They have discussed the limitations of satellite imagery for the use of water clarity monitoring. The main limitation seems to be the necessity to have site-specific data on the optical properties of locally relevant colour-producing agents. Furthermore, chlorophyll levels exhibit greater short-term variability within lakes than does SDT. They concluded that these limitations can be overcome by combining the ground based spectroradiometric measurements along with the satellite imagery.

Jang et al (2005) compared the water quality parameters estimated with airborne and ground-based hyperspectral sensing. It was observed that using hyperspectral data from either a field spectrometer or aerial images acquired on a single date, it was possible to estimate variations in water quality parameters (i.e., turbidity, chlorophyll, nitrogen and phosphorous concentrations) in Mark Twain Lake in northeast Missourie. They obtained best results ($R^2 > 0.6$ for all parameters) by applying stepwise regression to
field spectrometer data from 117 candidate bands arrayed on 5 nm spacing from 350 to 930 nm. Similar, but slightly less predictive, results were obtained using data from 26 candidate bands, obtained either from a field spectroradiometer or an aerial image. Thus it can be seen that ground based spectroradiometry is of great potential for surface water quality assessment.

Gemperli et al (2005) conducted a study using remote sensing methods to determine the water quality parameters in Indian ponds. They performed the study on five small ponds. Reflectance spectra were measured using a handheld spectroradiometer and concentration of Total Chlorophyll Content, Nutrient Content, Total Organic Content, Dissolved Organic Content and Secchi Disk Depth were determined using laboratory analysis. A comparison of several existing semi-empirical algorithms to determine chlorophyll content was made. All algorithms proved to be of value. They concluded that ground-based remote sensing is of great potential in determining water quality.

Islam and Sado (2005) conducted a study using field spectroradiometer and remote sensing data to monitor water quality of case 2 waters. They described about the technique to develop water quality models for chlorophyll a concentration, turbidity, salinity, conductivity and Secchi disk transparency of Lake Abashiri by using field spectroradiometer data with fluorometer data. The spectroradiometer data were coupled with the fluorometer data to find out the best suited models to monitor the above mentioned parameters. They concluded that the sixth-order polynomial equation with band ratio of wavelength ranges from 670 to 700 nm would be better to monitor the chlorophyll a, band ratio 440, 480 and 600 nm would be better for monitoring turbidity, and 440 and 480 nm for salinity and conductivity, and 560, 660 and 810 nm can be used for the identification Secchi disk depth water clarity for inland and high turbid water.
Karabulut and Ceylan (2005) conducted a study using ground-based remote sensing to determine the effect of increasing suspended sediment concentration containing different levels of organic matter on algal spectral patterns. Distinct differences in reflectance values corresponding to different SSC values were observed between 400 and 900 nm wavelength. They concluded that the above range can be used to monitor a wide variation in turbidity levels in surface water.

Pfitzner et al (2006) imply that spectral signatures represent complex physical and biophysical relationships. Consideration and documentation of potential variables affecting these signatures are essential in obtaining meaningful spectra. A lack of standardized procedures and metadata collection has limited the transfer of spectra from one application to another. The authors have designed and implemented a standard method for the collection of spectral data and associated metadata. A specific application for revegetation assessment and monitoring is described.

Cho and Lu (2010) said that the substantial difference between the reflectance values at the red and the near-infrared (NIR) regions has been used to develop vegetation indices for remote sensing of green plants. These spectral indices, however, may not effectively be used for underwater plants because the overlying water interferes with the upwelling vegetation signals. Therefore, the authors empirically separated the energy absorbed by water and scattered from the water column using an indoor water tank with hypothetical surfaces that either reflect or absorb all the incoming light. Using the experimental data, a function was developed to correct the reflectance measured from a shallow water body for the water effects. When applied to independently measured reflectance of underwater vegetation, the algorithm significantly enhanced vegetation signals, especially in the NIR region. This
experimentally driven algorithm can improve mapping capabilities of seagrass beds and invasive aquatics in shallow water bodies.

2.6 CONCLUSIONS

The principal conclusion of this review is that the work carried out by the researchers cited in section 2.3 implies the need for mixing models in the accurate mapping of any land cover at sub-pixel level is understood. From previous research studies on various hard classification techniques, it is realized that though many techniques like MLC, exist for the classification of the scene, there are certain limiting factors that do not provide accurate estimates. Soft classification can be suggested as an alternate solution in estimating the area of a reservoir, taking into account the boundary pixels thereby finding more accurate estimates.

From section 2.4 it is recognised that the study of bio-physical variables and their nature of reflectance are immensely required to characterise them. Statistical analysis can be used to quantify the relationship between spectral response and biophysical factors. Hence, the reviews have made this author realise the need for a sub-pixel approach for reservoir area estimation and the need to examine the spectral characters of the components of a reservoir system for accurate and enhanced information extraction from remotely sensed image data.