



ESTIMATION OF REVISED CAPACITY IN RESERVOIRS OF CHHATTISGARH STATE USING DIGITAL IMAGE PROCESSING TECHNIQUE

Part-I

(Ravishankar Sagar, Tandula, Maramsilli, Dudhawa and Gondli Reservoirs)



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PREFACE

The soil erosion, transportation and subsequent deposition are natural processes reduce useful storage, availability of water, operation and overall benefits from reservoir. The sediment also influences downstream water quality, conveyance capacity of canals, biotic life and ecosystem. The assessment of revised capacity indicative of sediment deposition at regular interval is essential to determine present availability of water, modification in reservoir operation, necessity and intensity of soil conservation in the catchment. To estimate reservoir sedimentation conventional techniques like hydrographic survey, inflow-outflow method, bathymetric survey are used which are time consuming, laborious, risky and cumbersome. An alternative of traditional methods, the digital image analysis of remote sensing data is commonly used which is less time consuming, needs less manpower, less risky and economical. The remote sensing (RS) based technique of revised capacity estimation is essentially based on principle that the deposition of sediment reduces the water spread at any level which can be demarcated with the help of image processing of multi-band RS data in geographic information system (GIS) software. The revised water-spread areas determined from image analysis and elevation data are used to compute reduced volume of water which ultimately provides revised cumulative capacities on these levels. The computed revised capacities can be compared with the original capacities to find out changes in capacity and percentage losses between these levels.

In the present study, an attempt has been made to compute the loss of storage capacity and sedimentation in Ravishankar Sagar, Tandula, Maramsilli, Dudhawa and Gondli reservoirs of Chhattisgarh state in India by digital image processing approach of remote sensing data. The study is being carried out jointly by Central India Hydrology Regional Centre (CIHRC), National Institute of Hydrology, Bhopal and State Water Data Centre (SWDC), Water Resources Department (WRD), Govt. of Chhattisgarh, Raipur. This report is prepared by Sri R. K. Jaiswal, Sc-D, as P.I., with Co-P.I. as Dr. T. R. Nayak, Sc-E & Head, Sri R. V. Galkate, Sc-E, Sri T. Thomas, Sc-D and Sashi P. Indwar, Sc-C from CIHRC, Bhopal and Sri Akhilesh Verma, Deputy Director as P.I. and Sri Rishi Chandrakar, S.D.O, Sri J. N. Vishwakarma, A.E., Sri S. K. Verma, Sub Engineer, Sri S. K. Shukla, Sub Engineer, Sri T. L. Chandrakar, Sub Engineer as Co-P.I. from SWDC, WRD Raipur under the guidance of Dr. N.C. Ghosh, Coordinator & Sc-G, NIH Roorkee is the first part of sedimentation report.

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ABSTRACT

The soil eroded from different parts of catchment flow through channels and rivers deposited in dead as well as live storage zones of reservoir due to reduced velocity of flowing water under natural hydrological process. But, the rate of sedimentation in reservoirs and lakes is accelerated due to environmental degradation, lack of conservation measures, change in land use, deforestation etc. Presently, the live storage capacity of large dams in India is 225.14 billion m³ out of which 1.95 billion m³ capacity of reservoirs is being lost annually. Reservoir surveys are necessary to get more realistic data/estimate regarding the rate of siltation and to provide reliable criteria for studying the implication of annual loss of storage over a definite period of time with particular reference to reduction of intended benefits in the form of irrigation potential, hydropower, flood absorption capacity and water supply for domestic, industrial and other uses and periodic reallocation of available storage for various pool levels.

With the introduction of remote sensing techniques in the recent past, it has become convenient and far less expensive to quantify sedimentation in reservoirs and to assess its distribution and deposition pattern. Advantages of using remote sensing data are that it is highly cost effective, easy to use and requires lesser time in analysis as compared to conventional methods. The spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information regarding the revised area after the occurrence of sedimentation and sediment distribution pattern in the reservoir. The digital image analysis of multi date remote sensing data have been used to determine revised water spreads at different water levels of reservoir which in turn compute revised capacities and cumulative capacities in these levels.

The present report is the first part of the study in which Ravishankar Sagar, Tandula, Maramsilli, Dudhawa and Gondli reservoir in Chhattisgarh state were chosen for assessment of revised capacities using remote sensing data. The normalized difference water index (NDWI), band ratio (BR) and false color composite (FCC) along with field truth verification were used to differentiate water pixels from rest of image. The reservoirs seldom go below dead storage level (DSL), due to which remote sensing technique is generally used to determine loss in storage in live storage zone only. This weakness was overcome in this study by backward extension of best-fit curve between reservoir levels and revised water spreads to get revised river bed. This method was verified with the help of revised capacity curves obtained from conventional and optimized empirical area reduction method. In the optimization method, the parameters C , m and n of this method were optimized using Latin Hypercube, one at time (LH-OAT) technique.

The results of analysis showed that 69.11 Mm³ storage from 909 Mm³ original capacity in Ravishankar Sagar reservoir during 37 years, 24.75 Mm³ from 308.66 Mm³ original storage in Tandula reservoir during 93 years, 29.75 Mm³ from 163.06 Mm³ original storage in Maramsilli reservoir during 92 years, 19.33 Mm³ from 284.49 Mm³ original capacity in Dudhawa reservoir

during 52 years and 7.21 Mm³ from 99.31 Mm³ of gross storage in Gondli reservoir during 60 years have been lost due to deposition of sediment in different zones. The rate of sedimentation in these reservoirs vary between 0.032 Mm³/100 km²/yr in Tandula reservoir and 0.076 Mm³/100 km²/yr in Dudhawa reservoir where size of catchment vary approximately from 175 km² to 3335 km². In the present study, the parameters C , m and n of empirical area reduction method were optimized using Latin hypercube, one parameter at time (LH-OAT) technique to determine sediment profile and revised river bed for Ravishankar Sagar and Tandula reservoir. The profile obtained from conventional and optimized methods were compared with the profile obtained from remote sensing (RS) technique and establish the application of this method for determination of revised river bed and loss of storage in dead storage zone of reservoir.

CHAPTER -1: INTRODUCTION

1.0 General

Water resources are very vital renewable resources essential for the survival and development of any society and necessitate assessment and management of the quality and quantity both spatially and temporally. The precipitation is the main source of water in India but uneven spatial and temporal distribution compels water resource managers to collect surface water flowing through the rivers by constructing a barrier across the river by forming reservoir. The capacity of reservoir reduces continuously due to entry of eroded soil carried by water, wind, ice and movement of particles due to gravity force. A huge quantity of sediment is deposited annually by Indian rivers in lakes, reservoirs, estuaries, bays and oceans. Loss of storage capacity due to reservoir sedimentation affects both obtains ability of water and operation schedules (Biswas et al 1999). Sedimentation process in reservoir is a natural phenomenon. Almost every reservoir is bound to suffer a loss in their storage capacity potential because of silt load, for long period of time.

The continuous sediments deposition reduces the reservoir storage and channel conveyance (canals) for water supply, irrigation, cover fish spawning grounds and reduce downstream water quality and cause extensive disturbance to streams. The suspended sediments makes water turbid and reduce sunlight penetration affects biotic life. The sediments settlement to the bottom of water bodies buries and kills the vegetation and changes the ecosystem. When a size of reservoir is relatively small compared to the mean annual runoff (MAR) (less than 10%) and the sediment yield is value is higher, then siltation of reservoir will occur in a short period of time as compared to large reservoirs which requires more time to filled with sediment. The sedimentation rate and ultimate storage capacity of small reservoirs will then be controlled by flushing or sluicing of sediment through wide low level outlets at the time of floods or the rainy season (ICOLD 2009). The dam construction can vary the flow regime and sedimentation load of the river at downstream by changing flood peaks and durations, also by trapping large amounts of sediment. It is of uttermost significance to be aware of yield, composition and rate of sediment in reservoir. These information allow water resource managers to estimate approximate lifespan of a reservoir and decide future course of action against reservoir sedimentation, water shortage and river bank breaches.

1.1 Factors Influencing Sedimentation Process

The sediments come from the fluvial channel system primarily settle in reservoir due to the lowering water speed near the obstruction in the form of dam. The sedimentation deposition process derived from drainage channels is largely affected by vegetated area, soil erosion, floods

and storms, rain water runoff carrying sedimentation and the properties of sediment transported along the water (Sreenivasulu et al 2012). The factors affecting the sedimentation yield process in drainage are given below:

- Topography (geomorphology);
- Type of soil and its geological formation.
- Soil coverage (like vegetation, apparent rocks and open soil area).
- Soil management (cultivation process, grazing of grass by animals, forest cutting, building constructions etc).
- Climatic factor like precipitation quantity, frequency and intensity.
- Topography of the area.
- Nature of the drainage channel network like density, slope, shape, size and the configuration of channels.
- Surface runoff, Sediments features like granulometric, mineralogical etc and channels hydraulics.

All the sediment brought down by river water to the dam does not settle in the water spread and periphery of reservoir. A significant part of it flows down the reservoir while distribution of remaining part depends on topography of water spread, reservoir capacity and inflows, catchment characteristics, reservoir operation and types of structures including arrangement and operation of sluices etc.

1.2 Effects of Reservoir Sedimentation

Sediment storage in reservoir behind dams can have large presumption for ecosystem and coastal growth downstream of large river systems, as inferior sediments are deposited which will influence river and coastal geomorphic functions (Syvitski, 2003; Vorosmarty et al., 2003; WCD, 2000; Woodward, 1995). The main adverse impact of reservoir sedimentation is reduction of capacities that lead to reduction of availability of water for designated uses and reduction of crop production, power generation, domestic water supply and ultimately the overall economics of the region and cost benefit ratio of reservoir. The reduced capacity may cause increased flood risks in the downstream of reservoir due to less absorption of water in live storage and flood zones. When the sediment laden water enters into the dam's intake like penstock, river sluice and gates etc, it impedes navigation and swimming and clogs electromechanical equipment at dams and increase corrosion of equipment.

The sedimentation of reservoir also has environmental, quality and ecological ill effects also. The sedimentation process in reservoir may cause serious water quality deterioration which is

not fully explained or surveyed yet. The floods and torrents derives large amount of water which may contain nutrients, agro-toxic, bacteria, algae human and industrial waste etc. When these substances enter in the reservoir undergoes several changes, which leads to affect the downstream water quality resulting underwater decay and reservoir stratification. Such effects must be previewed, assessed and conciliated at the time of planning, execution, construction and reservoir operation time. The sedimentation entering into the bed of reservoir form delta along the river coarse which leads to the deformation of river channel that becomes strangled. In narrow channels delta gradually increases, which increases reservoir backwater and increases floods in areas surrounding to reservoir. The deposits of the sedimentation in reservoirs modify the bed level thus lead to the degradation of habitats for most fishes and other aquatic species, which causes loss of some species and strong one survives only. It also modified breeding grounds for mosquitoes and other nuisance species and disease vectors. The suspended sediment load in reservoir reduces the penetration of sunlight, thus retarded the photosynthesis process that reduces the oxygen level in water body. The greenhouse gasses are released into the atmosphere from reservoirs after that biomass decomposes through aerobic and anaerobic vegetation in reservoir occurs, either slowly or rapidly. These greenhouse gasses are widely consulted as the main reason of human-induced global climate change, which contribute to retrograde the thermal heating of low terrestrial atmosphere known as greenhouse effect (UNEP, 1997).

1.3 Techniques for Measurement of Reservoir Sedimentation

The reservoir sedimentation is natural process for all reservoirs whether big or small but remains invisible in the significant part of its life. The regular monitoring of sediment deposition is necessary to know current available capacity, loss in storages and need assessment of soil conservation measures in the catchment. The state of sediment deposition may allow to determine the probable lifespan of a reservoir and to take proper measures against reservoir sedimentation, shortage of water, river bank and coastal erosion. The reservoir sediment or assessment of revised capacities can be grouped in two broad categories i.e. conventional and non-conventioanal techniques.

1.3.1 Conventional techniques

The conventional techniques include inflow-outflow technique and hydrographic survey, are cumbersome, clumsy, time consuming, uneconomical and involve huge manpower. Sometimes these conventional methods approximately take up to three years to complete just one survey of a major reservoir (like Hirakud, Sardar Sarivar, Bhakra etc.) so cannot be done frequently . Some of the conventional methods are life threatening but able to give detail sediment pattern in different zones and their location also. In the inflow-outflow method, the measurement of sediment inflows

from different streams to the reservoir and outflow from reservoir are computed with the help of continuous monitoring of discharges and sediment sampling. The mass balance equation is used to determine the amount of sediment deposited in the reservoir. The measurement location should be sufficiently nearer to the reservoir periphery and proper care must be handled to execute the inflows and outflow sample analysis before it meets the tenable channel downstream.

The hydrographic survey is done with the help of echo sounder with transducer, differential geographic positioning system (GPS), field computer and reliable power supply (Munir et al 2014). Two methods are commonly used for hydrographic surveys includes (1) the contour method and (2) the range line method. The contour method involves making of suitable scale contour map of the reservoir and contour interval similar to the contours at the time of survey. The difference in capacity between two studies presents the loss of capacity due to sediment deposition during that period. In range method, survey is performed in the selected limits across the reservoir and this gives the basis for the estimation of cubic contents between ranges. The contour method of survey is universal type which is applicable for all types of reservoir (small or large) while range method is limited to relatively straight reaches.

1.3.2 Non-conventional technique

The substitute of lengthy, cumbersome and time consuming conventional methods is the latest techniques of digital image analysis of multi temporal remote sensing data. This method requires less time, need less manpower and economical than other conventional methods but having disadvantage of not providing sediment deposit in dead storage zones. The synoptic and repetitive viewing capability of remote sensing data is used for determination of revised water spreads at different levels of reservoir which in turn provides revised capacities at different levels. The image analysis capability of GIS software can be used effectively for differentiating water pixels from rest of the images.

1.4 Distribution of Sediment

The reservoir elevation-area-capacity is basically used for determination of storage in reservoir, irrigation planning and reservoir operation. The understanding of the distribution of sediment in a reservoir is essential for fixing sill levels of the outlets and the penstock gate levels to dodge inopportune loss of services when sediment load is eloquent factor. The revised distribution can also be used to modify reservoir operation plan and assess need of soil conservation measures in the light of sediment entry in to the reservoir. The distribution of the deposits should be determined to permits the assessment of the limit to which various allocations of the storage is disturbed by sediment accumulation. The distribution pattern of various reservoirs depends on lots

of factors like valley slope, reservoir length, and size of particles in suspended sediment, ratio of capacity-inflow and reservoir operation. The main river tributaries also influence the distribution pattern depending on their magnitude of inflow, shape and location.

Two methods namely the empirical area reduction and area incremental methods are commonly used for approximate estimation of the sediment distribution pattern. Borland and Miller (1958) categorize the distribution pattern of sediment in a various reservoirs into four standard classes. The data presented by them shows that there is a definite relationship between percent of total depth of a reservoir to the percent of total volume of reservoir sediment presents for each of the four different reservoir types depends on physical shape. The type of the reservoir is classified by plotting the reservoir depth on ordinate and capacity on abscissa in logarithmic coordinates or log-log scales. The plotted curve draws as a straight line, wherever some reservoirs may have a shape responsible in two straight lines. The reciprocal of the slope of the line presented the reservoir type. The curve indicating a rapid increase in capacity compared to depth signify large basin type reservoir, whereas a less increase in the relationship signifies gorge type reservoirs.

1.5 Objectives

As sedimentation deposited in dead as well as live storage zones of reservoir affects normal reservoir operations and intended benefits taken into consideration during design, it is necessary to monitor reservoir sediment, resultant profile and revised capacities at regular intervals. The present study for estimation of revised capacities of reservoirs in Chhattisgarh state to determine present rate of siltation with the following objectives:

- Collection and analysis of detailed information and elevations of reservoirs.
- Selection, procurement and digital image processing of remote sensing data
- Estimation of revised capacities of reservoirs and trend assessment in selected reservoirs
- Sediment profile for selected reservoirs using conventional as well as optimization technique
- Knowledge dissemination and development of awareness

In the part I of reservoir sedimentation study, the Ravishanke Sagar, Tandula, Maramsilli, Gondli and Dudhawa reservoirs were selected for sedimentation study using remote sensing data.

CHAPTER- 2: REVIEW OF LITERATURE

The review for present study consists of reservoir sediment and its impact, assessment of reservoir capacity and techniques for sediment profiling. A detailed review on all these aspects have been carried out and outlined here.

2.1 Reservoir Sedimentation and its Impacts

The problems of reservoir are wide and varied including Loss of storage, blocking of outlets, over flowing, delta deposition, channel aggradation, interference in navigation, earthquake, abrasion, shoreline erosion, ecological problem, downstream consequences of bank erosion, increase of bank height, increase in scouring, environmental issues etc (Rao et al 2014). The gradual loss of storage volume which results in reduced capability to provide water for irrigation, hydropower production and other uses, as well as to intercept floods and regulate the flow. When the sediment deposits near to structure, it may block the outlets or even compromise the safety of the dam. The sediment passing through the turbines causes abrasion of mechanical equipment, decreasing its power generating efficiency and ultimately loss of production time during its repair (Petkovsek & Roca, 2014). The total control on sediment deposition in reservoir is not possible as it is a universal phenomenon (Jain and Kothyari, 2000). But, the rate of sedimentation in reservoirs and lakes is accelerated due to environmental degradation, lack of conservation measures in catchment, change in land use, deforestation, urbanization and industrialization (Jaiswal et al 2010).

The life of a reservoir starts reducing soon after its commissioning due to continuous deposition of water-born sediments eroded/washed from all parts of watershed (Jaiswal et al 2009). The range of problems caused by reservoir sedimentation is varied and wide. Apart from loss of capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance lead to increase in their associated cost (Kothyari et al., 2002). A broad estimate of soil erosion in India showed that about 5334 million tones of soil is being lost every year, which means, soil erosion is taking place at the rate of 16.35 tones/ha/year (Narayana and Ram Babu, 1983), which is more than the permissible soil loss tolerance value of 4.5 - 11.2 tones/ha/year (Singh et al, 1981). As a result, it is widely viewed that, nearly 20 % of the live storage capacity of major and medium sized reservoirs of India have been silted up by the end of the year 2000, which means a loss of irrigation potential of about 60,000 ha every year due to silting. An analysis of sedimentation survey in respect of 43 major, medium and minor reservoirs in India indicated the variation of sedimentation rate between 0.003–0.28 Mm³/100 km²/year for major reservoirs, 0.002–0.11 Mm³/100 km²/year for medium and 0.01–0.02 Mm³/100 km²/year for

minor reservoirs (Shangle, 1991). The results of a survey in the year 2012 from 122 reservoirs in India indicated that 0.44% of storage is being lost every year due to sediment which accumulates in dead as well as live storage zones of reservoir (Rao et al 2014)

2.2 Revised Capacity Assessment

The reservoir sediment or loss in capacities of a reservoir can be determined with the help of conventional methods such as hydrographic survey and inflow-outflow method or advance technique of digital image classification of remote sensing data. The conventional method of reservoir sedimentation survey has been in practice for quite long time in India and elsewhere. The conventional methods of reservoir sedimentation are time consuming, costly, cumbersome and require lot off manpower, therefore cannot be used frequently. But the synoptic and repetitive viewing capacity of remote sensing sensors and the ability of image processing with geographic information system (GIS) can be used to model bathymetry and the spatial distribution of sediments (Evans et al 2002). The data obtained from the remote sensing platforms by virtue of their repetitive and synoptic coverage and computer aided analysis make significant contributions in understanding and monitoring the environmental processes. Basically, multi-date satellite remote sensing data provide information on elevation contour areas directly in the form of water-spread areas. Any reduction in reservoir water-spread area at a specified elevation estimated from the satellite data is indicative of sediment deposition.

The ability to map and estimate water spread from satellite data is well understood and commonly used techniques include visual interpretation of satellite imagery, density slicing, and digital classification of water from other land uses for delineation of water bodies (Work and Gilmer 1976; Thiruvengadachari et. al 1980; Thiruvengadachari and Manavalan 1983; Jain & Goel 1993; Goel & Jain 1996; Narasayya et al 2005; Mukherjee et al 2007; Rathor et al 2006; Thomas et al 2009; Jaiswal et al 2008; Jaiswal et al 2011; Ninja Merina et al 2016 etc.). Hanumantha Rao et al (1985) adopted visual interpretation of enlarged MSS images to estimate the water spread at eight different levels of the Sriramsagar reservoir. Suvit et al (1988) used digital image analysis technique in which density slicing of Landsat MSS near-IR (0.8- 1.1 μm) data were used to extract the water spreads of the Ubolratana Reservoir of five different dates. Singh et al (2010) used digital image processing technique of remote sensing data to assess the loss in reservoir capacity & sedimentation of Ujjani reservoir (also named as Yashavant Sagar reservoir) on river Bhima, in Sholapur district of Maharashtra state, India having catchment in of 14, 856 km^2 . It was found that there was loss of gross storage of 498.38 Mm^3 from 1977 to 2004 (i.e. 27 years). Bhatti et al (2011) carried out research work for computation of suspended sediment engrossment in surface waters using of ALOS and ASTER satellite data. They combined the multispectral data and optical modeling to minimize the lack of ground truth data.

2.3 Sediment Profiling in Reservoir

The deposition of sediment in reservoir is not uniform at all the storage zones and remote sensing technique has limitation of not capable to assess deposition in dead storage zone because reservoirs seldom emptied below dead storage level. The hydrologic size is a primary factor influencing the rate of sediment accumulation (Brune, 1953) primarily responsible for determination of types of sediment management techniques required for a particular reservoir. The sediment profile can be determined by different conventional methods like empirical area reduction method (Borland & Miller, 1958; Lara, 1962) and area incremental method by Christophano in 1953 also several optimization methods were proposed by different researchers (Amini et al 2010). Issa et al. (2015) studied four empirical and semi-empirical techniques proposed by Mohammadzadeh Habili et al. 2009, Mohammadzadeh Habili & Heidarpour 2010 and Kaveh et al. 2013 along with area reduction method. For assessment, these methods were reviewed and used to compute sedimentation depth and establishing the ASC curves for the Mosul dam reservoir (MDR), which is the biggest hydraulic structure, build on the River Tigris in northern Iraq. The results were compared with bathymetric survey data carried out in 2011 after 25 years of functioning of MDR. The comparison of the results for establishing the ASC curves presented that the method proposed by Kaveh et al. (2013) gave good relation with bathymetric output.

Mohammadiha & Emadi (2011) used conventional area reduction method for Golestan dam and adjudged a reduction of 10% on error estimation. Fendreski et al (2014) applied area reduction and incremental area methods for computation of sediment profile using conventional as well as optimized parameters which were then compared with hydrographic survey using error rate and standard error as goodness of fit criterions. From the analysis, it has been observed that error rate can be reduced from 34 to 23 percent by optimizing in area reduction method. Rahamanian & Banihashemi (2012) introduced a new shape function in the form of depth factor which is the ratio of volume of pyramid to the actual volume of water in the reservoir at that level based on the analysis of 42 dams in Iran. On the basis of analysis, it has been observed that these dams can be classified into three groups and cumulative sediment deposition was inversely related to variations of depth factor in height. To determine sediment distribution two empirical functions called depth shape function (DSF) and relative depth shape function (RDSF) were introduced to determine sediment pattern in nine reservoirs. From the analysis, it has been observed that the sediment pattern observed from new developed functions RDSF can predict relative sediment deposition and sediment deposition in a wide variety of reservoir geometries.

CHAPTER- 3: STUDY AREA AND DATA USED

The sedimentation analysis using remote sensing data has been carried out for Ravishankar Sagar, Tandula, Maramsilli, Dudhawa and Gondli reservoirs of Chhattisgarh state as Part-I of the study.

3.1 Chhattisgarh State

The Chhattisgarh state is rich in water resources and large numbers of medium and major water resources projects have been created to harness extra surface water to cater irrigation, industrial and domestic demands. In the present study, some important reservoirs of Chhattisgarh state have been considered for reservoir sedimentation study using digital image analysis of remote sensing data. The total geographic area of Chhattisgarh state is about 1, 35, 194 km² formed on Nov 01, 2000 by partitioning from Madhya Pradesh state of India. The average rainfall in the state is around 1400 mm and about 90% of the total rainfall falls in the monsoon season. The Mahanadi, Godavari, Ganga, Narmada and Brahmani basins drain out the state and Mahanadi, Seonath, Hasdeo, Arpa, Indravati, Sabari, Leelagar, Hasdeo, Kelo, Son, Rehar, Kanhar, Pairi, Sondur, Sabari, Mand, Narangi etc. are important rivers which have a torrential regime characterized by high flow of water for three to four months during monsoon (June to September) during which around 80% of the annual runoff flows. The paddy in rabi and kharif season is the main crop of the state demands more storage of surface water due to large scale variability of rainfall and large demands of crops.

The state is called as rice bowl of India and surface water is prime source of irrigation to meet demands of paddy crop, industrial and domestic water requirement. In order to meet various water demands of state, several major, medium and minor irrigation projects are commissioned and serving the state. Some of the important reservoirs of the state are Ravishankar Sagar, Tandula, Hasdeo –Bango, Sondure, Maramsilli, Kharkhara, Gondli, Dudhawa, Minimata etc. For the first part of the project, Ravishankar Sagar, Tandula, Maramsilli, Dudhawa and Gondli reservoirs were selected by joint research group of NIH RC Bhopal and State Water Data Centre, Raipur for estimation of revised capacity using digital image analysis of remote sensing in GIS environment. The base map of study area is given in the Fig. 3.1. All the reservoirs selected for first part of the study are situated on main Mahanadi river or its tributaries which is called life line of Chhattisgarh

state covers 50% of land in the state and supplies water for irrigation, drinking, industrial and other purposes.

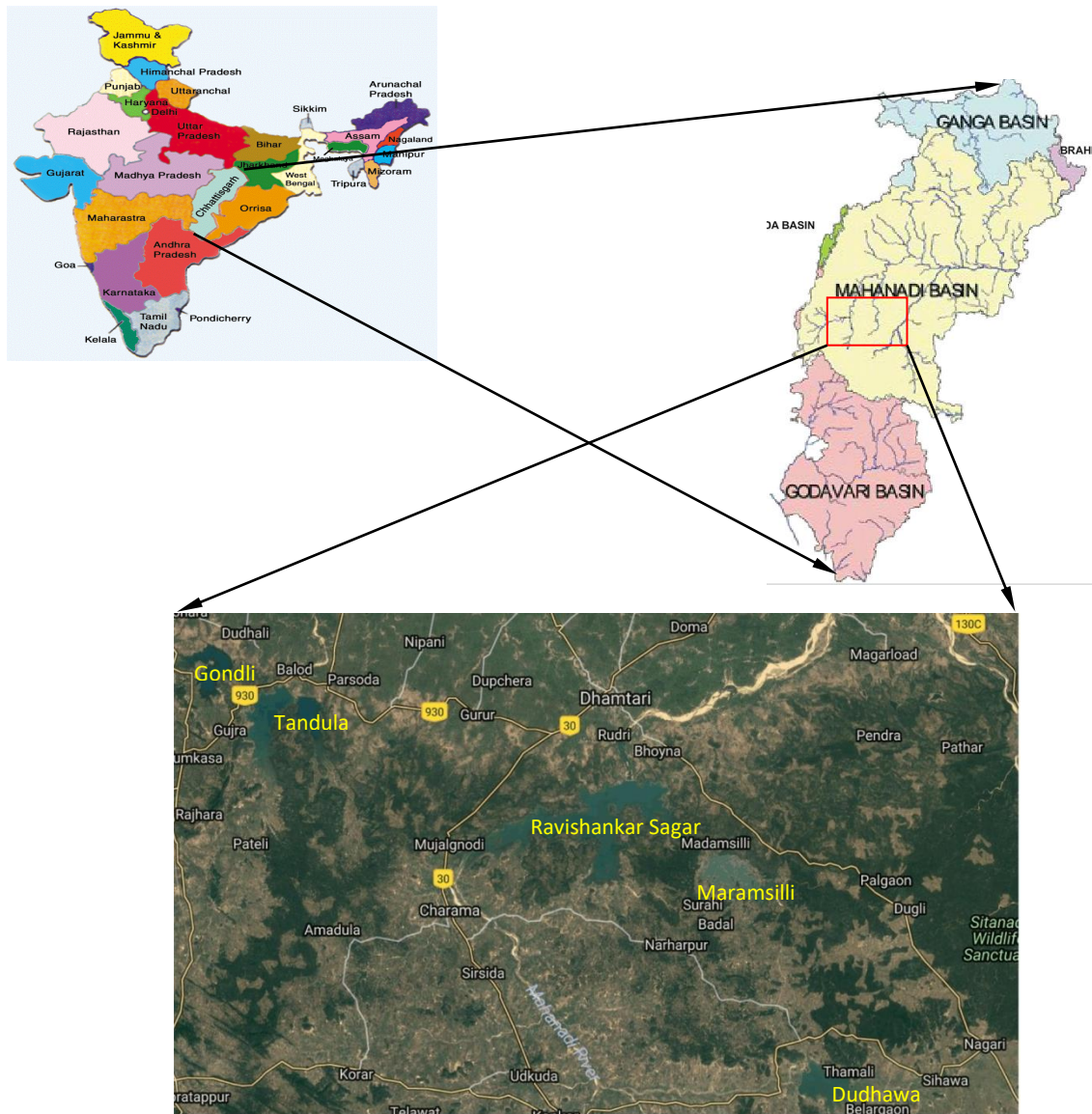


Fig. 3.1 Location map of Study Area

3.1.1 Ravishankar Sagar Reservoir

Ravishankar Sagar reservoir is situated on river Mahanadi near Dhamtari at 20°37' N latitude and 81° 34' E longitude is one of the important reservoirs in Chhattisgarh. It is an earthen dam including masonry spillway and rock-fill dam having gross storage and live storage capacity of as 909.32 Mm³ and 766.32 Mm³ respectively. The dead storage level (DSL) and the full supply level (FSL) of the Ravishankar Sagar reservoir are 336.21 m and 348.70 m respectively. The total catchment area of river Mahanadi up to Ravishankar Sagar dam is about 3620 km² out of which upstream Dudhawa and Maramsilli reservoirs intercepted 625 km² and 486 km² areas respectively.

The Ravishankar Sagar dam started its functioning in 1979 and is designed to irrigate kharif paddy in about 1,82,500 hectares, provide drinking water to Raipur and Dhamtari, power generation and industrial water supply to Bhilai Steel Plant through Tandula canal. A view of Ravishankar Sagar reservoir has been presented in Fig. 3.2. The original elevation-area-capacity curve of Ravishankar Sagar reservoir is presented in Table 3.1.



Fig. 3.2 Pictorial view of Ravishankar Sagar reservoir

3.1.2 Tandula reservoir

Tandula reservoir is one of the oldest reservoirs situated on the confluence of river Tandula and Sukha nala at $20^{\circ} 37' N$ latitude and $81^{\circ} 34' E$ longitude in Balod district. The Tandula dam is an earthen dam, started and commissioned in the year 1922. The catchment area of Tandula dam is about 827 km^2 with dead storage and full reservoir levels are 320.45 m and 332.18 m respectively. The gross and live storage capacities are 312.25 Mm^3 and 302.28 Mm^3 respectively, designed to irrigate 68,219 hectares of cropped area during the kharif season. The original area-elevation-capacity table of Tandula reservoir has been presented in Table 3.2 and reservoir view in Fig. 3.3.

3.1.3 Maramsilli Reservoir

Maramsilli Reservoir is constructed across river Silliyari, a tributary of river Mahanadi upstream of Ravishankar Sagar reservoir during the years 1914-1923 at coordinates of $20^{\circ}32'17'' N$ and $81^{\circ}39'82'' E$. It is the first dam in Asia which has siphon spillways with a gross storage capacity of 165.34 Mm^3 , a water spread of 25 km^2 and a live storage capacity of 161.91 Mm^3 . The dam

height and length are 34.15 m 2.591 km respectively with spillway capacity of 1132 m³/s. The original elevation-capacity table of Maramsilli reservoir has been depicted in Table 3.3.



Fig. 3.3 Pictorial view of Tandula reservoir

3.1.4 Dudhawa Reservoir

Dudhawa dam (Fig. 3.4) is situated in Dhamtari district of Chhattisgarh. It is constructed on the Mahanadi River in the village of Dudhawa, which is 29 Km from Kanker started its operation in 1964. The location of Dudhawa dam can be represented by 20°18'28''N longitude and 81°46'18'' E latitude. The height and length of dam is 24.53 m 2.90 km respectively with catchment area of 625.27 Km². The original elevation-capacity table of Dudhawa reservoir is given in Table 3.4.



Fig. 3.4 Pictorial view of Dudhawa reservoir

3.1.5 Gondli Reservoir

The Gondli reservoir is situated on Tujra nala in Balod city of Chhattisgarh state. The Gondli dam is an earthen dam completed in the year 1956 having gross and dead storage capacities of 101.48 Mm³ and 0.78 Mm³ respectively. The Gondli reservoir has culturable command area of 4980 ha with paddy is the only crop grown in the region. The original elevation-capacity table of Gondli reservoir has been presented in Table 3.5.

3.2 Data Used

The original elevation-capacity table of all reservoirs, characteristics values of reservoirs and reservoir elevations during the period 2013 to 2015 were used in the analysis. The dates of pass of path 102 and row 58 of IRS satellite were identified and procured different LISS 3 data of IRD 1D/P6 satellite to cover the whole range of live storage of reservoirs at regular intervals. The different remote sensing scenes for reservoirs selected for sediment analysis in the study are presented in Table 3.6 (a) to Table 3.6 (e).

CHAPTER- 4: METHODOLOGY

4.1 General

The construction of barrier in the form of dam for storage of water causes siltation of reservoir due to reduction of speed of flowing water. The periodical assessment of capacity of reservoirs is necessary for determination of extent of degradation in the catchment areas, allocation of existing water for different purposes, determination of useful life of reservoir and rate of siltation etc. The basic principle of revised capacity estimation using remote sensing and GIS is that when the sediment deposits in a reservoir, its water spread get reduced with respect to its original area before impoundment (Fig. 4.1). The multi-date remote sensing data and capability of GIS software to delineate water pixels can be used to extract revised water spreads from rest of the image at different reservoir levels. The digital images of different dates are required to cover the whole range of live storage. The methodology for assessment of sediment through remote sensing and GIS is indirect method in which revised water spread at different reservoir levels are computed with the help of remote sensing data which in turn are used for estimation of revised capacities, cumulative capacities and loss of storages. The synoptic viewing and repetitive movement of satellite data are helpful in this regard.

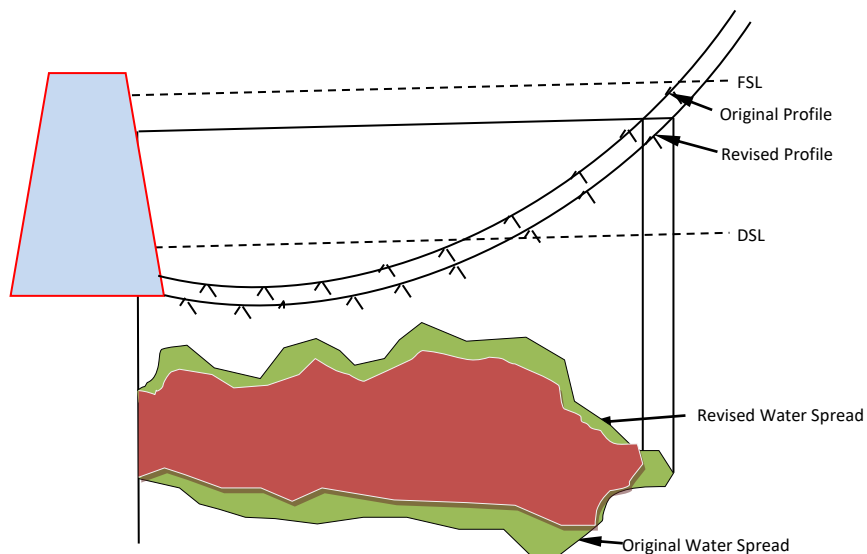


Fig. 4.1 Principle of assessment of sediment in digital image classification technique

The method of remote sensing does not directly compute the silt in the reservoir. It helps to determine the present storage capacity, which is compared with the original or designed capacity and the reduction in capacity over a period of time is attributed to silt deposition. The correctness of silt computation by this method was fully dependant of the rectification of the original area capacity table. If the accuracy of original survey is not of high quality and contained errors, then results of silt assessment based on comparison of outputs of original survey with satellite remote sensing

(SRS) base or hydrographic survey may not give correct results of siltation in reservoir, hence it is suggested that SRS based sedimentation surveys be frequently carried out at regular intervals of 3 to 5 years. The methodology for digital image analysis of remote sensing data based technique of reservoir sediment assessment consists of preparation of GIS based base map, selection, procurement and import of satellite data, estimation of revised water spread, determination of revised capacities and losses from reservoir.

4.2 Preparation of Base Map in GIS

The satellite image scene in raw form are supplied either in raw format or geo-referenced with limited ground control points require atmospheric and earth curvature corrections. For using the images for any meaningful results and determine areas of different land features after image classification, it is necessary to geo-reference the images with survey of India toposheets and other cadastral maps of the corresponding area with the help of standard image processing software. This phenomenon is known as image rectification. The base map consisting drainage, roads, rail, canal network and important points based on topo-sheets and other reliable maps need to be prepared which subsequently used for geo-referencing of remote sensing data procured from National Remote Sensing Centre Hyderabad, the sole supplier of RS data in India. The ground control points should be easily identified on remote sensing image and of permanent nature.

4.3 Selection of Remote Sending Data

The IRS LISS III data of Indian satellite were used in this study and therefore, the different date of passes based on their temporal resolution and quality of scene were finalized from web site of NRSC. With the close look on reservoir levels and corresponding availability and quality RS data, seven to ten remote sensing scenes were selected for each reservoir in such a way so that these data can cover whole range of live storage at nearly equal interval. These selected data were procured from NRSC and used in the analysis. After importing, all the images need to be geo-referenced with the help of topo-sheets/maps so that they can be overlaid and linked with the latitude and longitude and the geographical area also can be determined. After geo-referencing, all the images can be cut down to small sizes to cover the water spread area of the reservoir and its surroundings.

4.4 Image Analysis

The remote sensing images represent information regarding the vegetations cover on the ground including agricultural surface, forest land, natural vegetation, waste land etc. and other features such as water bodies, road/rail network, built up land etc. Two methods of remote sensing

data interpretation including visual and digital image analysis are commonly used for classification of image. The visual techniques are purely dependent on the interpretative capability of the analyst. In the digital image analysis, the, multi band data are processed in GIS software to get some known indices with the help of raster operation which ultimately distinguished water pixels from rest of the image.

4.4.1 Visual technique

It is purely based on the explicate capability of the analyst and this technique provide a facility of not using the information of different band (as in case LISS-III sensor data shows four band), after the visual result is obtained. Wet land around the periphery of the water spread area seems to very similar to water pixels & which makes very complicated for eyes to analysis whether the pixel near the periphery is to be named as land or water. The presence of clouds or noise in the scene near the periphery make difficult to compute actual water spread area.

4.4.2 Digital image analysis techniques

Remote sensing provides land resource data in the form of digital magnetic types and in different bands of the electromagnetic spectrum. For any given material, the amount of solar radiation that it reflects, absorbs, transmits, or emits varies with wavelength. This important property of matter makes it possible to identify different substances or classes and to separate them by their individual spectral signatures. In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorption and reflectance are low. The reflectance of water in the visible region scarcely rises above 5%. The absorption of water rises rapidly in the near-infrared (NIR) band where both, the reflectance and transmittance are low. The reflectance of various objects present on the earth is different than water and this reflectance recorded in digital format by the sensors mounted on satellite. The digital data obtained from the sensors can be used to extract water spreads at different levels. The normalized difference water index (NDWI), band ratio and slicing has been used to identify the water pixels in the images. The *NDWI* and band ratio (*BR*) for identification of water pixels can be written as:

$$NDWI = \left[\frac{GREEN - NIR}{GREEN + NIR} \right] \quad (4.1)$$

where, GREEN = Band-II data of IRS 1D/P6 satellite, NIR = Band IV data of IRS 1D/P6 satellite.

$$BR = \frac{NIR}{GREEN} \quad (4.2)$$

The slicing operation of the NDWI and band ratio images is carried out to extract water pixels from the rest of the image. In the slicing operation, the FCC, NDWI and BR images should be examined carefully where knowledge of spectral characteristics and ground truth information play an important role to decide the upper limit above which all the pixels can be classified as water.

4.5 Discarding of Extended Tail and Channels

The main river at the tail end of the reservoir and numerous small channels joining the reservoir from distinct directions around its periphery are also classified as water during digital image classification. However, the elevation of water in these channels and the main river can slightly higher than the water surface of a reservoir receiving inflow through perennial streams inflow. So, these extended tail and channels must be separated from the point of termination of spread. The choice of truncation point is subjective and may be depend on the difference between the water levels in the subsequent date scenes.

4.6 Computation of Revised Capacity

After extracting water spread area from rest of the image, the histograms were built to determined revised water spread directly. As water level in the reservoir seldom goes below dead storage level (DSL), in the present study a graph has been plotted between revised water spreads and reservoir levels. A curve has been fitted and extended backward to determine revised bed of reservoir. The reservoir capacity between two consecutive reservoir elevations was calculated using the prismatic formula.

$$V = \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 * A_2}) \quad (4.3)$$

where, V is the volume between two sequential elevations, A_1 and A_2 are the water spread areas at sequential elevations and h is the difference in the elevations. The revised cumulative capacities can be computed by adding the revised volumes between consecutive intervals which in turns used to estimate losses in revised capacities.

4.7 Comparison with Empirical Formulae

In the present study, the rate of sediment from reservoir has been compared with two following equations given by Khosla and Jogelkar (Mutreja, 1986 & Subramanya, 2008).

$$\text{Khosla's Equation: } V_s = \frac{0.323}{A^{0.28}} \quad (4.4)$$

$$\text{Joglekar's Equation: } V_s = \frac{0.597}{A^{0.24}} \quad (4.5)$$

where, V_s is the rate of sedimentation in $\text{Mm}^3/100 \text{ km}^2/\text{yr}$ and A is the catchment area in km^2 .

4. Sediment Profiling

The empirical area reduction method proposed by Borland & Miller in 1959 and later on modified by several researchers. Conventionally, three parameters (C , m , and n) based on slope of elevation capacity best-fit line is determined which in turn provide sediment distribution for trial and error based revised river bed called zero elevation. The parameters of this method were suggested based on results of study from reservoirs situated in USA which sometimes may not be useful in other part of world. In the present study, the sediment profiles of few reservoirs were determined conventional as well as optimization techniques for deposition of sediment obtained from remote sensing analysis.

4.7.1 Conventional empirical area reduction method

When the total sediment deposition in the reservoir is known, the profile can be determined by empirical area reduction method and area incremental method. The empirical are-reduction method is based on principle that the accumulation and distribution of sediment has specific relationship with the shape of reservoir. The main equation suggested in this method can be written as:

$$S = \int_0^{y_0} A dy + \int_{y_0}^H Ka dy \quad (4.6)$$

where, S is the total sediment distribution, A is the reservoir area at height y , dy is a small height increment, a is the approximate area of sediment, H is the total height of reservoir, y_0 is the new zero elevation and K is a proportionality coefficient can be expressed by the following equation.

$$K = \frac{A_0}{A_p} \quad (4.7)$$

where, A_0 is the original area and A_p is the relative area at new zero elevation y_0 . The methodology of empirical area reduction method consists of determination of reservoir's shape. The shape of reservoir is determined by plotting gross capacities on X-axis and respective reservoir depths on Y-axis in a log-log plot. The reciprocal of slope (m) is used to determine type of reservoir as given in Table 4.1 or Fig 4.2.

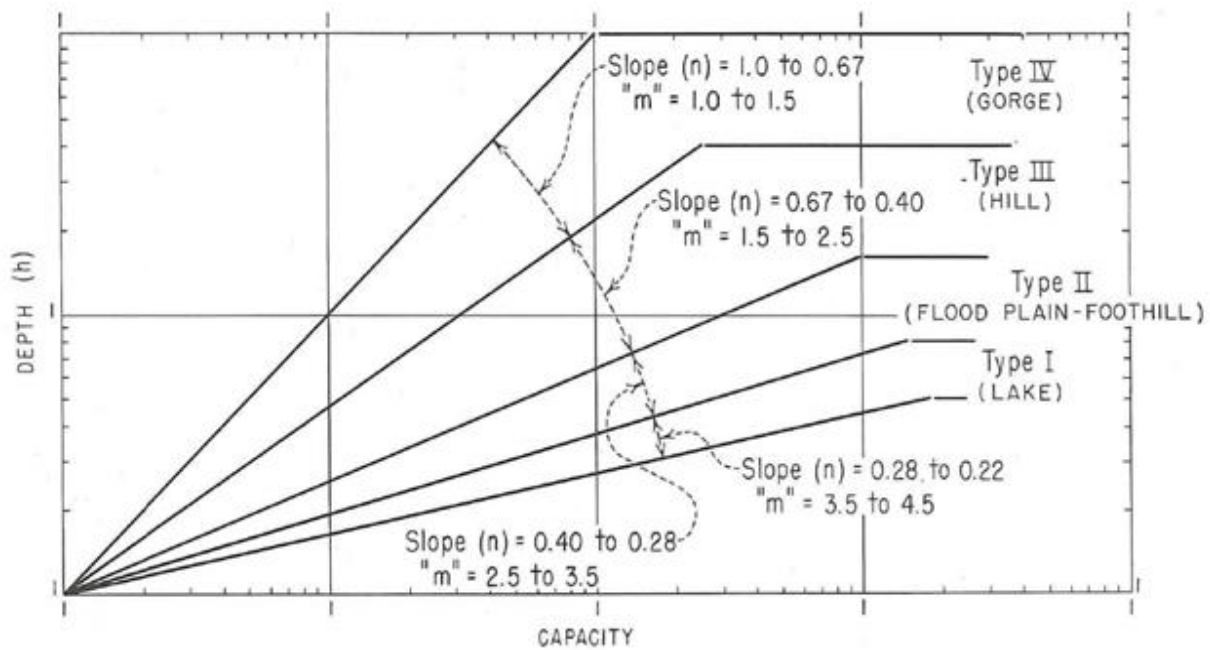


Fig. 4.2 Determination of type of reservoir (reproduced from Borland & Miller 1960)

The constants C , m and n of empirical area reduction method may be determined using Table 4.1. After determination of constants, a new zero elevation is assumed for a given sediment deposit and relative depths (p) for different elevations can be computed as the ratio of depth to total depth of reservoir. The relative areas (A_p) at different elevations are computed using following equation or Fig 4.3.

$$A_p = Cp^m(1 - p)^n \quad (4.8)$$

Now, constant K is computed using equation 4.7. By multiplying K and A_p at different depths, the sediment areas can be determined which subsequently used to compute sediment volume between the levels using trapezoidal formula. The total sediment volume at HFL is then computed by adding subsequent sediment volumes between the elevations and compared with total desired sediment deposit. If computed volume is not near to the total sediment need to be deposited, the next new zero elevation is assumed and whole process is repeated again till difference between computed and needed sediment deposit come within the limit (Generally 10% or as decided). In the present study, an attempt has been made to apply conventional and optimization approach where total sediment deposit obtained from remote sensing approach for Ravishankar Sagar and Tandula reservoirs. With the help of optimization where Latin Hypercube one parameter at a time (LH-OAT) were used to verify the use of revised water spread curve for determination of revised river bed and sediment deposit in dead storage zone in remote sensing approach.

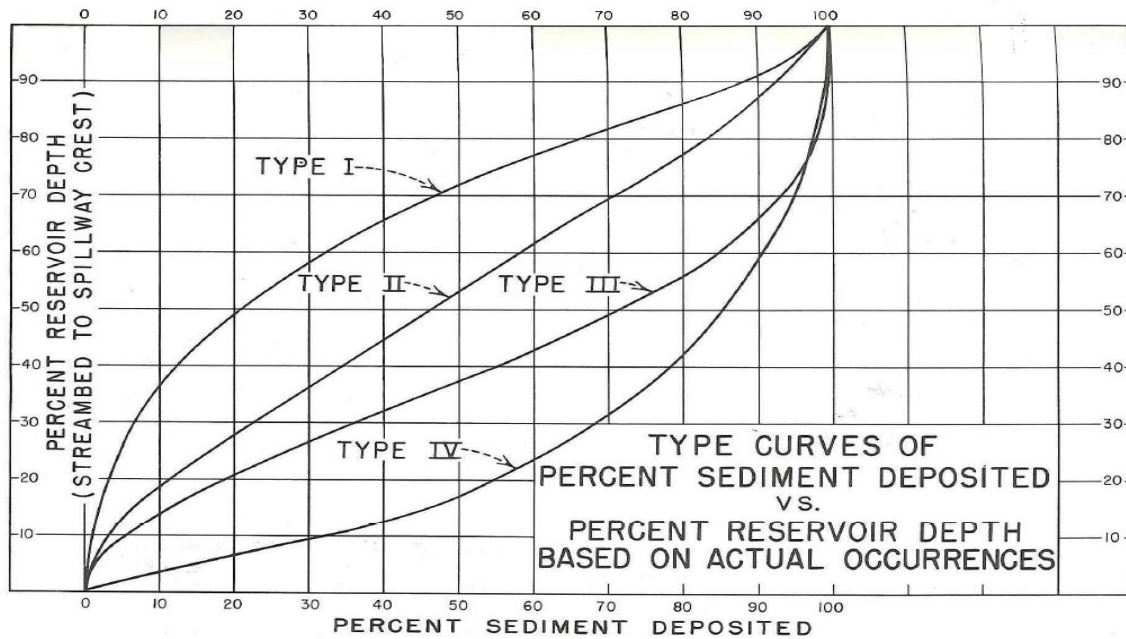


Fig. 4.3 Sediment distribution in different types of reservoirs (reproduced from Borland & Miller 1960)

4.7.2 LH-OAT optimization technique

The Latin Hypercube Sampling was first presented and explained by McKay et al in 1979 (McKey et al 1979) and used for solving the problem of uncertainty for a particular class of problems (Wyss and Jorgensen, 1998) and generating a reasonable sample from a collection of distributed multidimensional field. McKay et al (2000) has compared random, stratified and Latin Hypercube sampling random variables in Monto Carlo studies. Zhang and Pinder (2003) applied Lattice sampling which is a special case of Latin Hypercube sampling (LHS) for groundwater flow and transport and found that LHS realization is not affected by seed and reduces the computational effort. Flores et al (2010) compared Latin Hypercube and random sampling techniques to sample soil hydraulic and thermal properties and concluded that LH based approach yielded less variance in the estimate of ensemble moments of all sizes. In the LH sampling, whole space or probability distribution was split into x numbers of intervals or probabilities in such a way so that exactly one observation laid in each interval (Hung 2013). The one at a time method has been used in optimization where the value of one parameter is changed as per LHS keeping other parameters constant to examine all combinations that may prevail in the system.

For determination of sediment profile, the original elevation and capacities were plotted on log-log paper to determine the type and parameters C , m and n for a reservoir. The profile of revised bed was then determined using conventional methodology proposed in this method. Now, considering the normal distribution of parameters, the LH-OAT method has been applied in which one parameter was considered for optimization keeping other constants and revised profile of

sediments was obtained. A computer program was developed in FORTRAN, where, the parameters C , m , n were changed one-by one and revised profile were determined considering appropriate new zero elevation using trial and error method. For doing this, each time for value of C , m and n , a revised bed level was assumed and taking these, revised sediment volume at highest flood level was computed and compared with actual sediment volume obtained from hydrographic/remote sensing survey. If the difference between actual sediment volume and computed sediment volume was within limit (0.5 Mm^3 in this case), the sediment profile was computed else next revised level was considered. If the computed revised sediment did not converge with actual sediment, then next combination of C , m and n were used as per LH-OAT sampling and best selection which gave the minimum difference between observed and computed total computed sediment has been selected for that reservoir.

CHAPTER- 5: ANALYSIS OF RESULTS

The digital image classification of remote sensing data has been used to determine revised water spreads which in turn used for estimation of revised capacities and losses at various levels of reservoir. For determination of revised water spreads at regular intervals, eight to ten different remote sensing LISS3 scenes were procured from NRSC, Hyderabad, imported and geo-referenced with the help of index map/topo-sheets in ARC GIS software. The digital image analysis has been performed to estimate the revised water spread. The normalized deviation water indexes (NDWI), image ratio and then slicing of image classification have been used to differentiate the water pixels from other land uses. The revised water spreads computed in this way were used to estimate revised capacities between the levels and revised gross capacities at different levels of reservoir. The levels of reservoir generally do not go below dead storage level due to revised water spreads and thus capacities below DSL and revised bed level cannot be determined by RS technique. This limitation of RS was overcome by graphical representation of revised water spreads and extending the best-fit curve backward to get revised bed level. The sediment profile of total sediment deposition was computed by conventional empirical area reduction method and LH-OAT optimization based approach for few selected reservoir. The results of estimation of revised capacities, loss in storages and sediment profiling for selected reservoirs are presented below.

5.1 Ravishankar Sagar Reservoir

To determine revised capacities of Ravishankar Sagar reservoir, eight different remote sensing scenes were analyzed and revised water spreads were computed. The false color composite (FCC), NDWI and extracted water spread for different dates of Ravishankar Sagar reservoir have been depicted in Fig. 5.1 (a) & 5.1 (b) As water level seldom goes below dead storage level and some time it is not possible to get a scene on full reservoir level, a scatter graph was plotted between reservoir elevation and revised water spread area and a best-fit curve was fitted to evaluate revised water spreads on these levels. The best-fit curve for revised water spreads suggested that the revised bed of Ravishankar Sagar reservoir can be considered as 331.68 m against its original bed as 323.50 m. With the help of revised spread areas, the revised cumulative capacity and percentage loss in cumulative storages at different levels have been estimated and presented in Table 5.1 (a) and 5.1 (b). The graphical representation of original capacities in the year 1979 and revised cumulative capacity in the year 2015 for Ravishankar Sagar reservoir has been presented in Fig. 5.1 (c). The result of remote sensing analysis confirmed that 69.11 Mm³ of gross storage has been lost due to deposition of sediment in 37 years (1979 to 2015) and if the uniform rate is considered, the sedimentation in this reservoir comes out to be 1.87 Mm³/ year. It can also be confirmed that nearly 26.7 % dead storage and 9% of live storage of this reservoir have been lost in the last 37 years of operation of reservoir.

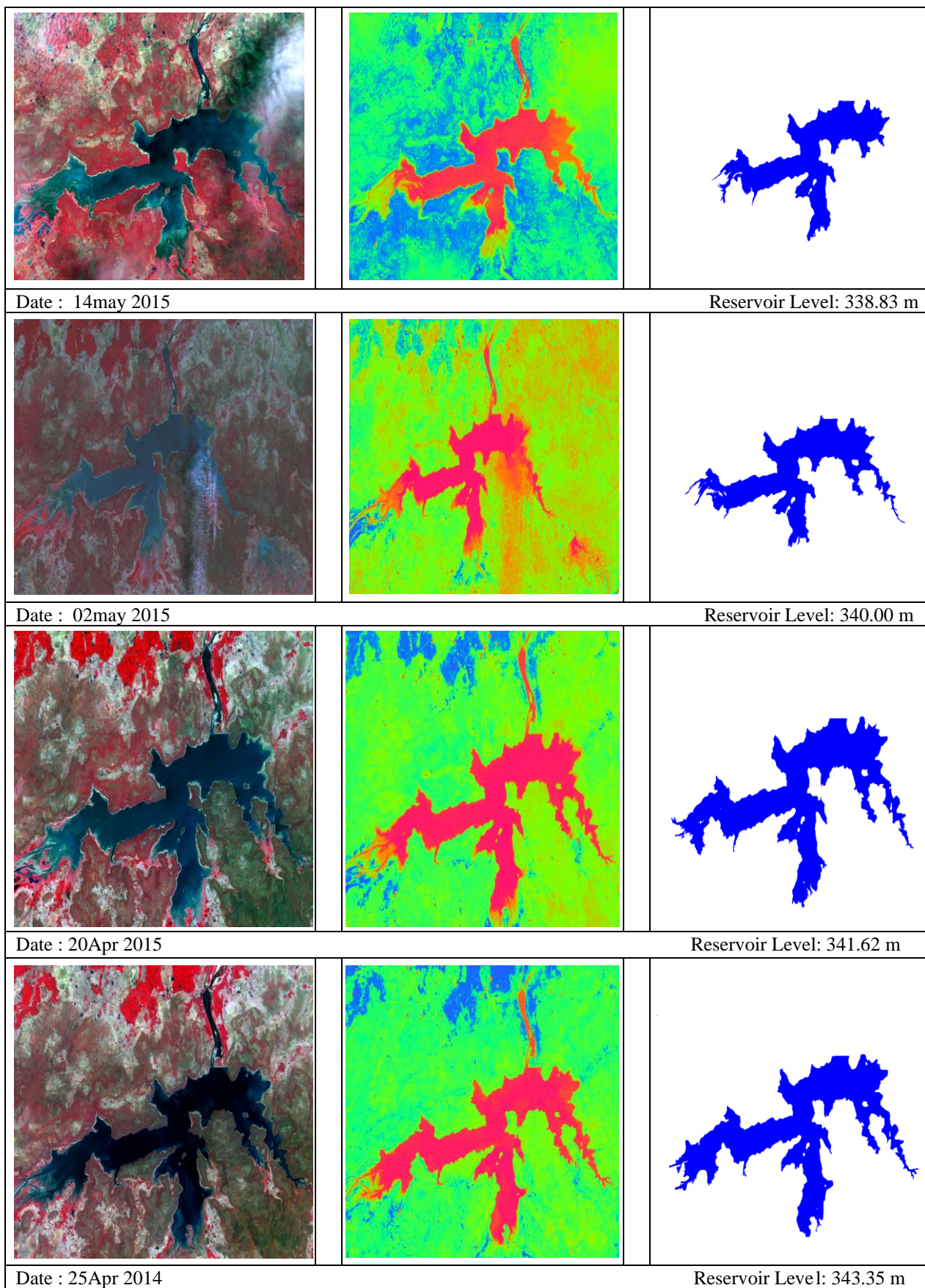


Fig 5.1 (a) FCC, NDWI and extracted water spreads of few dates for Ravishankar Sagar reservoir

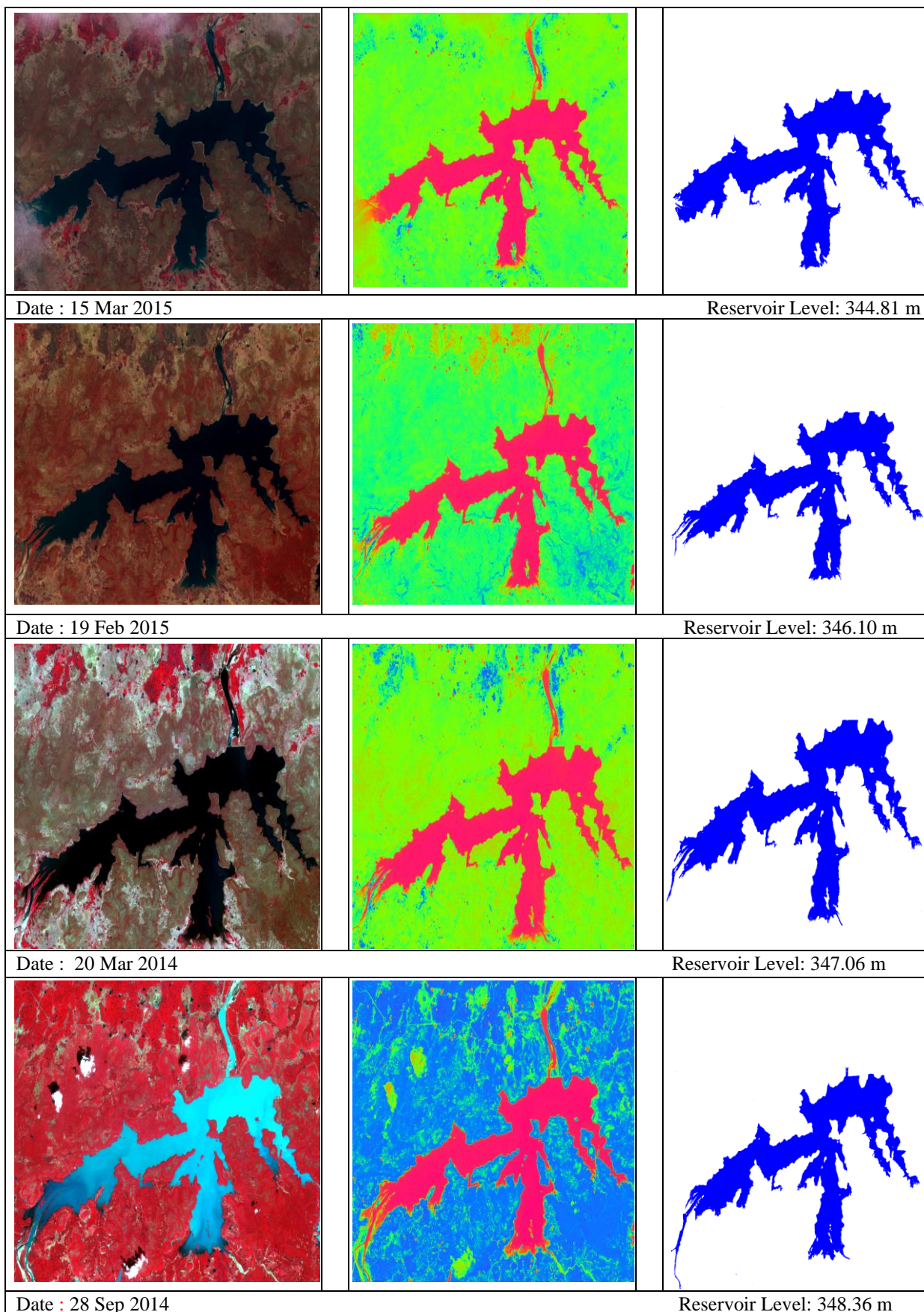


Fig 5.1 (b) FCC, NDWI and extracted water spreads of few dates for Ravishankar Sagar reservoir

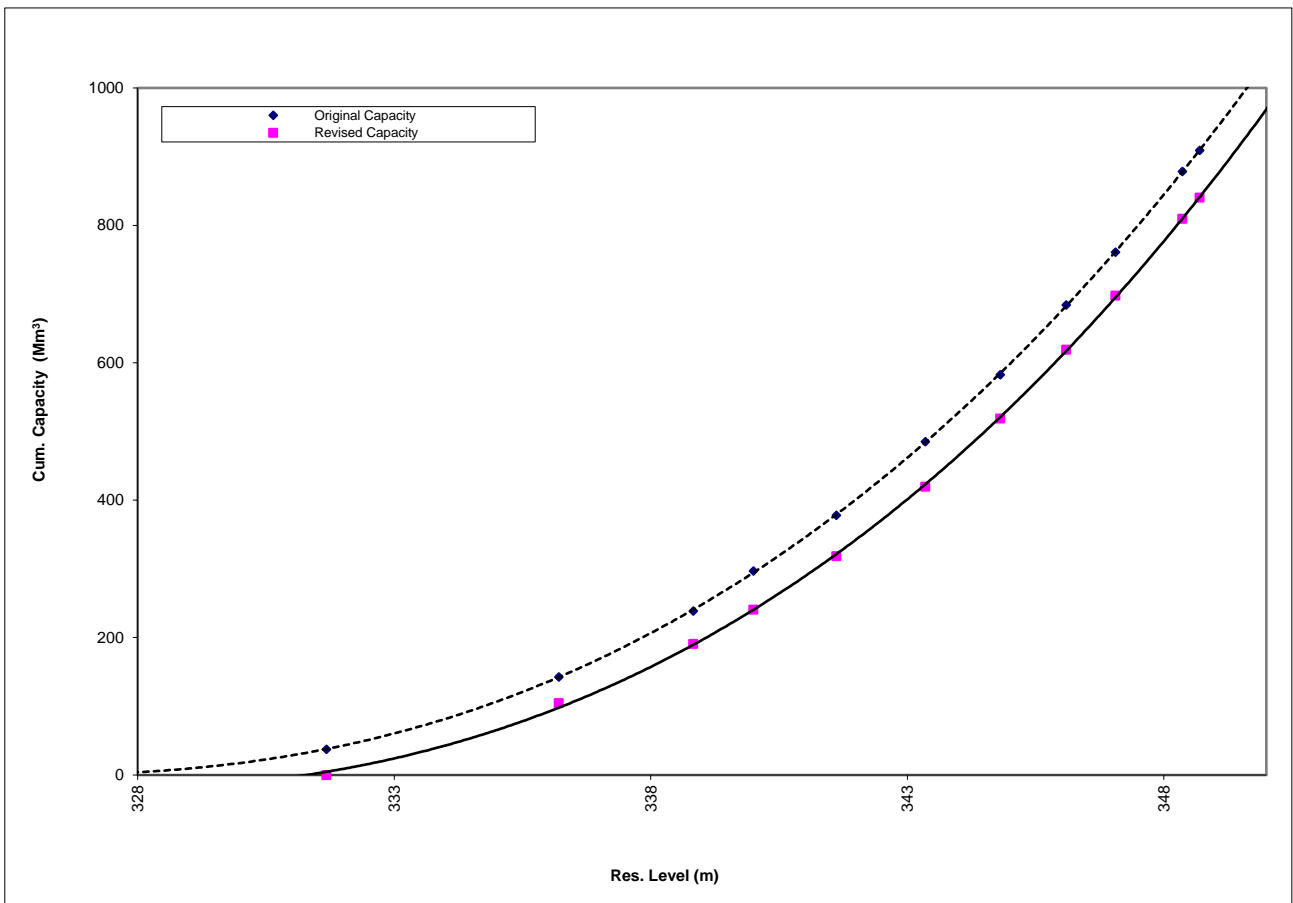


Fig. 5.1 (c) Original and revised cumulative capacity curve for Ravishankar Sagar reservoir

5.2 Tandula Reservoir

In case of Tandula reservoir, nine temporally varied scenes covering live storage zones were analyzed and revised water spreads were computed. The FCC and extracted water spreads at different levels of Tandula reservoir have been presented in Fig. 5.2 (a) & 5.2 (b). A scatter graph has been plotted between revised water spread and reservoir level; the best-fit curve was extended backward to find out revised bed level and revised water spread at F.S.L. The present bed level found out from analysis is 320.34 m in comparison of actual bed of 320.12 m given in original capacity table. The computation of revised capacities and loss in cumulative capacities of Tandula reservoir has been presented in Table 5.2 (a) and 5.2 (b) and Fig. 5.2 (c). From the analysis, it has been found that 24.75 Mm³ (8.2 %) of gross storage and 1.1 Mm³ (89%) of dead storage have been lost in 93 years (1922 to 2015) from Tandula reservoir. The rate of deposition in Tandula reservoir may be computed as 0.26 Mm³/year.

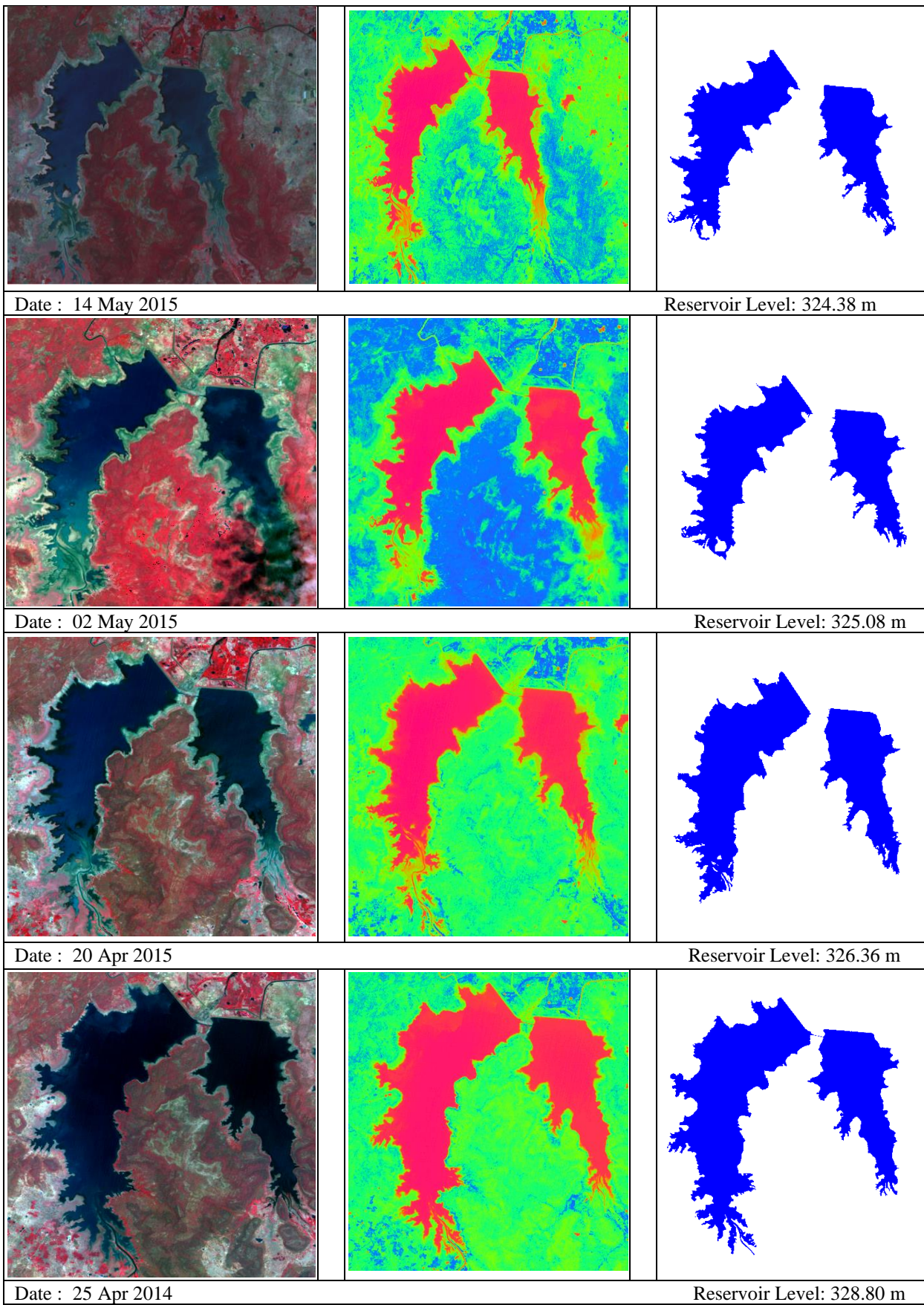


Fig 5.2 (a) FCC, NDWI and extracted water spreads of few dates for Tandula reservoir

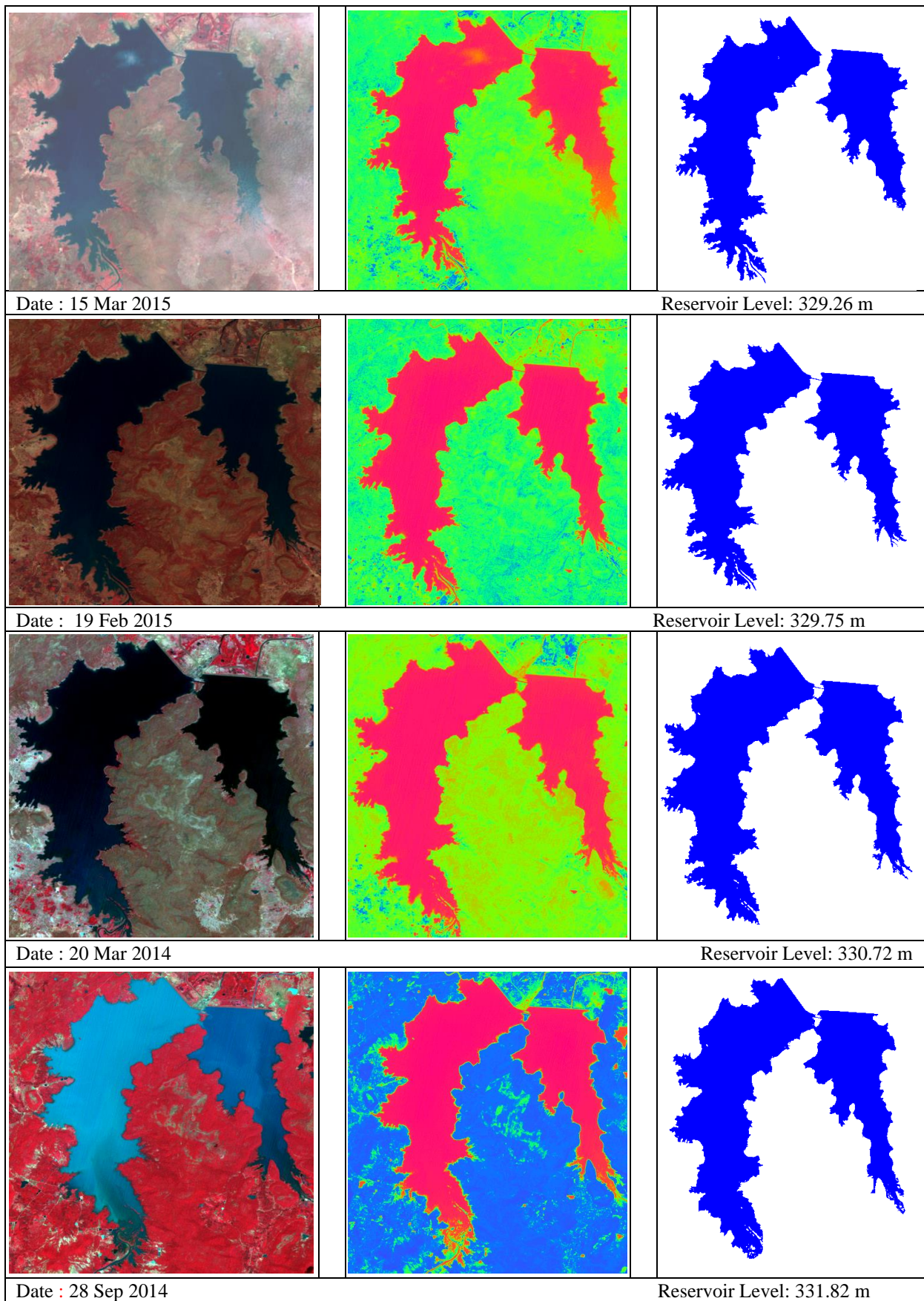


Fig 5.2 (b) FCC, NDWI and extracted water spreads of few dates for Tandula reservoir

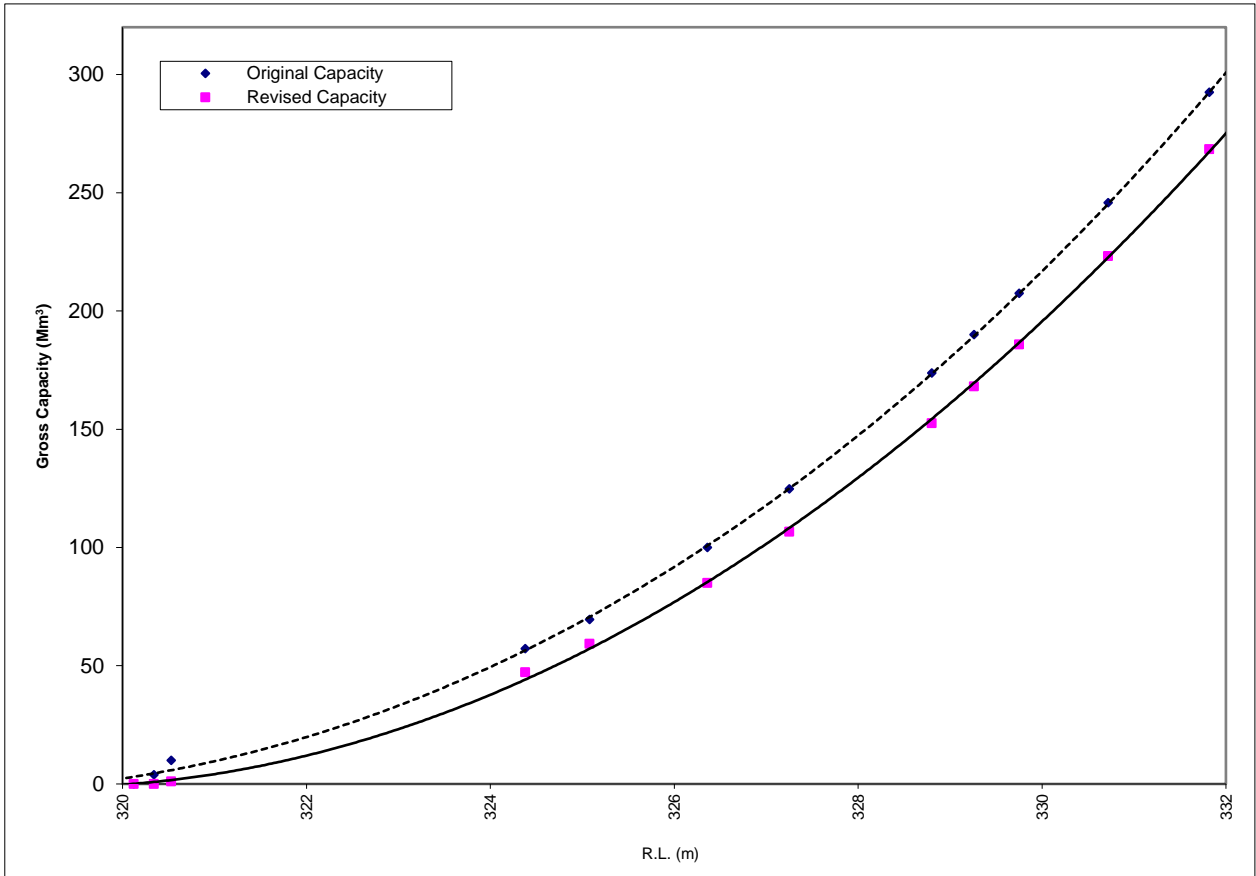


Fig. 5.2 (c) Original and revised cumulative capacity curve for Tandula reservoir

5.3 Maramsilli Reservoir

The revised capacity of Maramsilli reservoir was computed using ten different LISS III data covering whole range of live storage. The FCC and extracted water spreads at different levels of Maramsilli reservoir have been presented in Fig. 5.3 (a) & 5.3 (b). From the analysis of scatter graph plotted between levels and revised water spreads fitted with a smooth curve, it has been found that present river bed at dam site of Maramsilli reservoir can be considered as 360.14 m in place of original bed of 359.50 m. The computation of revised cumulative capacities and loss in gross storages of Maramsilli reservoir has been presented in Table 5.3 (a) and 5.3 (b). The graphical representation of original and revised capacity curve of Maramsilli reservoir is depicted in Fig. 5.3 (c). From the analysis, it has been found that 29.75 Mm^3 (18.3%) of gross storage and 1.22 Mm^3 (90.6%) of dead storage have been lost in 92 years (1922 to 2015) from Maramsilli reservoir. The rate of deposition in Maramsilli reservoir may be computed as $0.32 \text{ Mm}^3/\text{year}$. The loss of storages in Maramsilli reservoir is more towards dead storage zone than live storage zone may be due to steep slope towards reservoir. The soil conservation measures should be taken in Maramsilli reservoir to limit siltation in live storage zone.

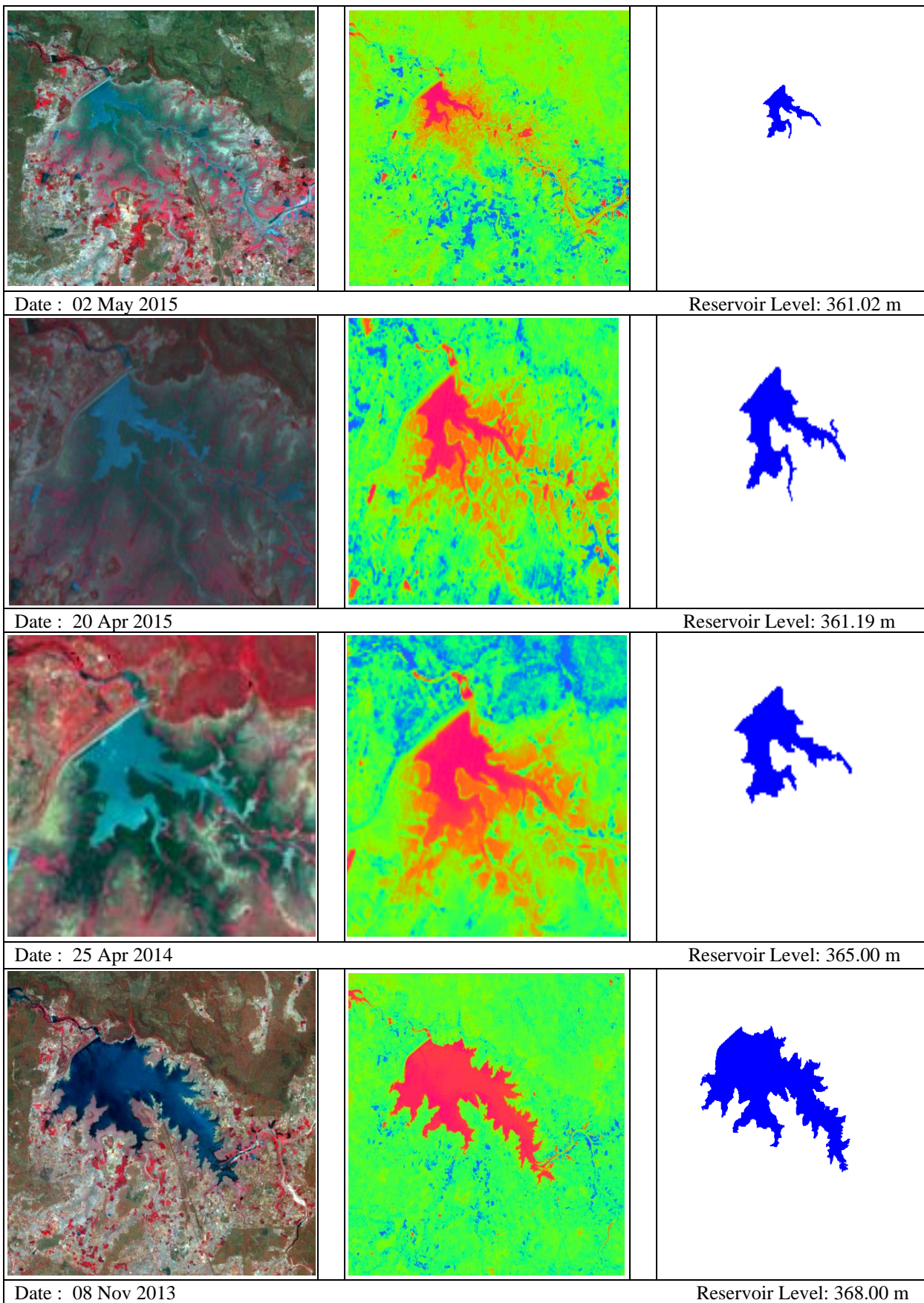


Fig 5.3 (a) FCC, NDWI and extracted water spreads of few dates for Maramsilli reservoir

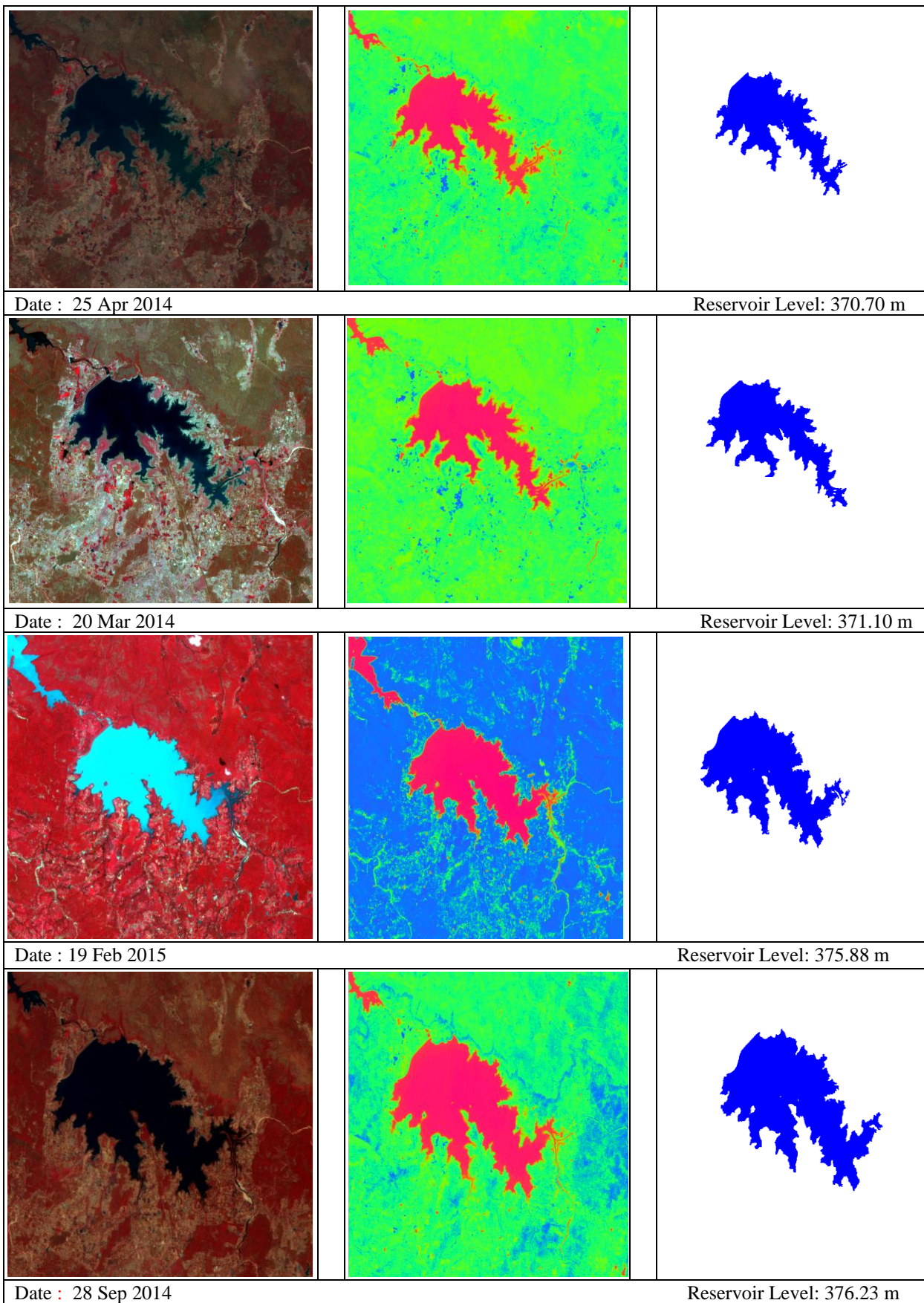


Fig 5.3 (b) FCC, NDWI and extracted water spreads of few dates for Maramsilli reservoir

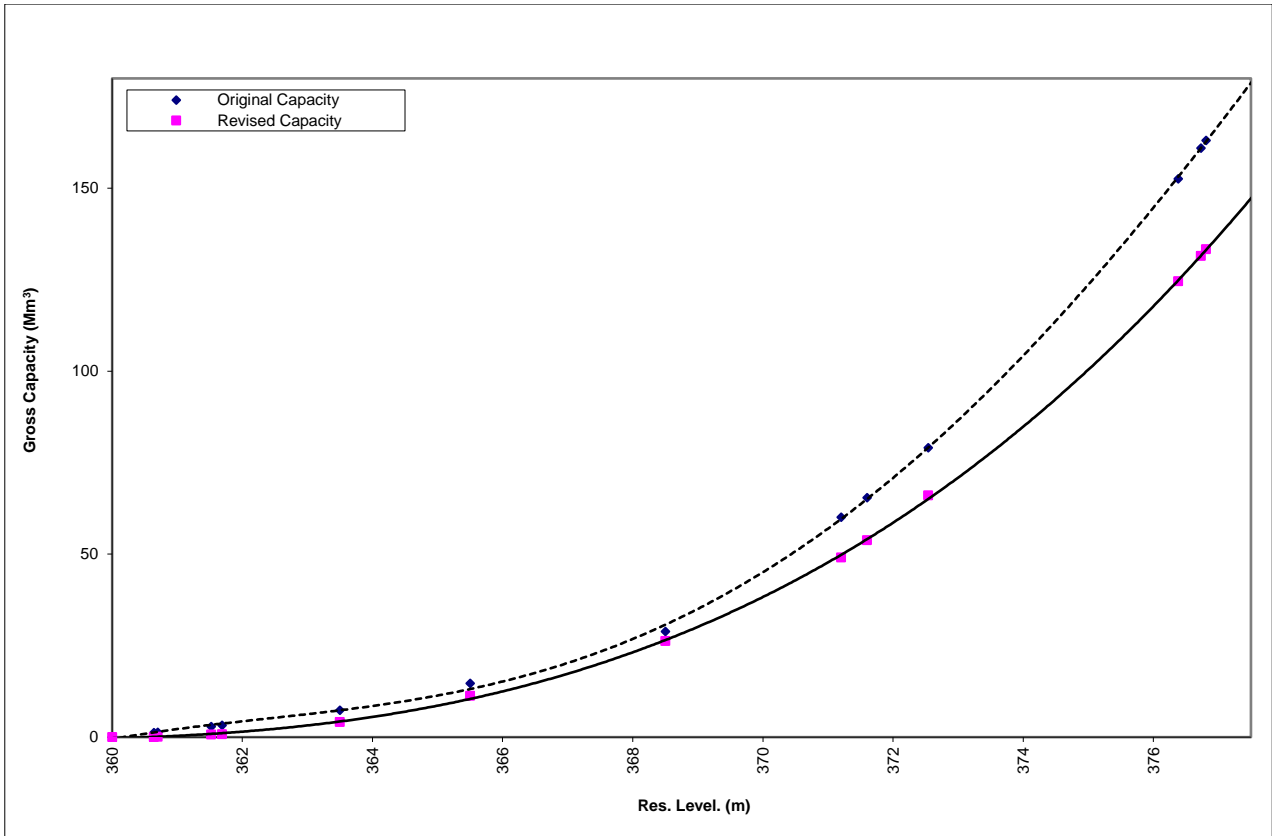


Fig. 5.3 (c) Original and revised cumulative capacity curve for Maramsilli reservoir

5.4 Dudhawa Reservoir

For estimation of revised capacity of Dudhawa reservoir, eight different scenes of remote sensing LISS III sensors were imported and digitally processed in GIS software. The FCC and extracted water spreads at different levels of Dudhawa reservoir have been presented in Fig. 5.4 (a) & 5.4 (b). The graphical representation of revised water spreads at different reservoir levels revealed the present river bed as 406.01 against original bed of 404.22 m. The same graph has been used to determine revised water spread at F.S.L. of Dudhawa reservoir. The computation of revised cumulative capacities and loss in gross storages has been presented in Table 5.4 (a) and 5.4 (b). The graphical representation of original and revised capacity curve of Dudhawa reservoir has been presented in Fig. 5.4 (c). The Dudhawa reservoir has started its operation in 1964 and this assessment has been carried out in the year 2015. During this period 19.33 Mm³ (6.8%) of gross storage and 1.68 Mm³ (38.6%) of dead storage have been lost due to sediment deposition. The constant rate of siltation in Dudhawa reservoir may be about 0.37 Mm³/year.

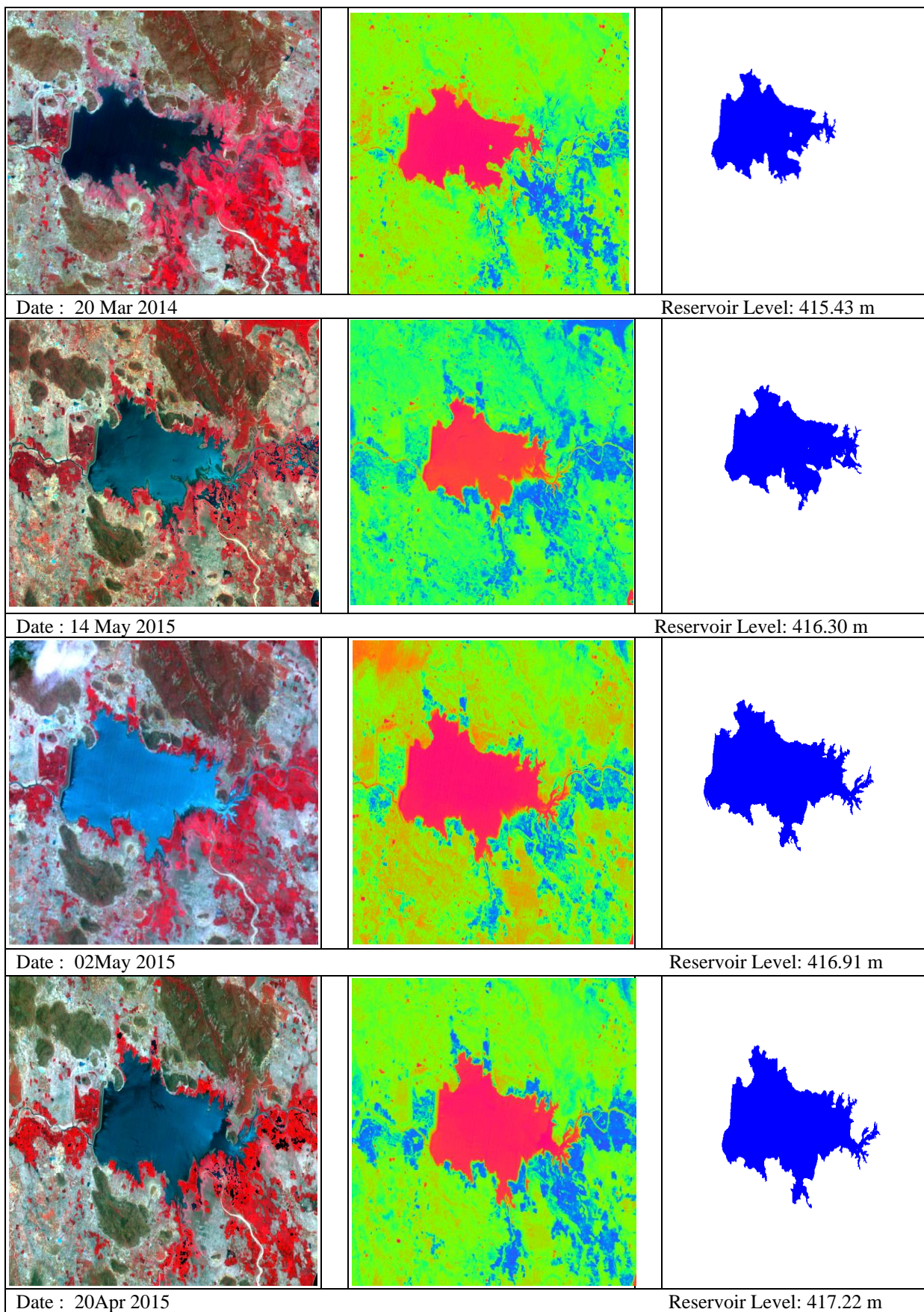


Fig 5.4 (a) FCC, NDWI and extracted water spreads of few dates for Dudhawa reservoir

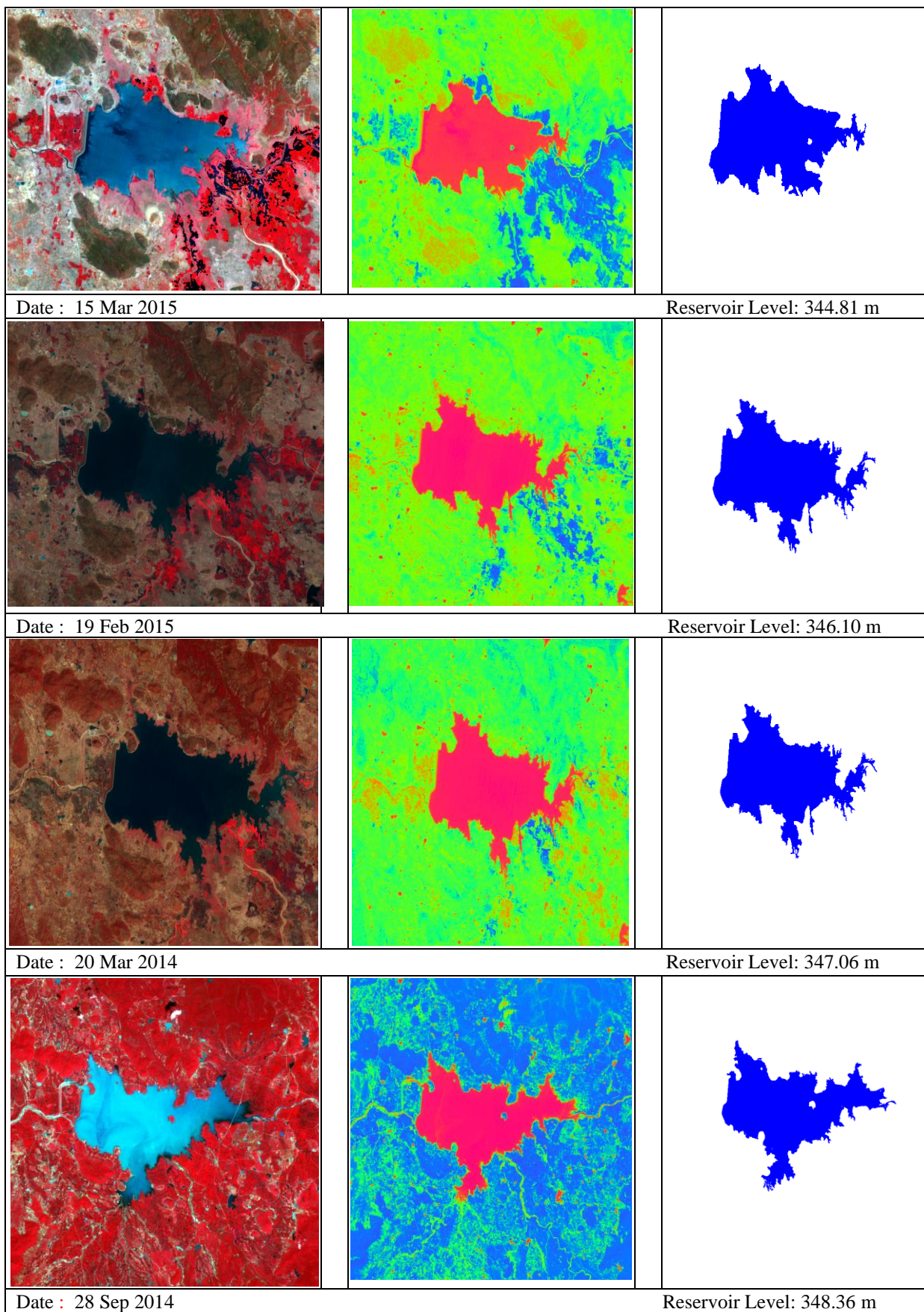


Fig 5.4 (b) FCC, NDWI and extracted water spreads of few dates for Dudhawa reservoir

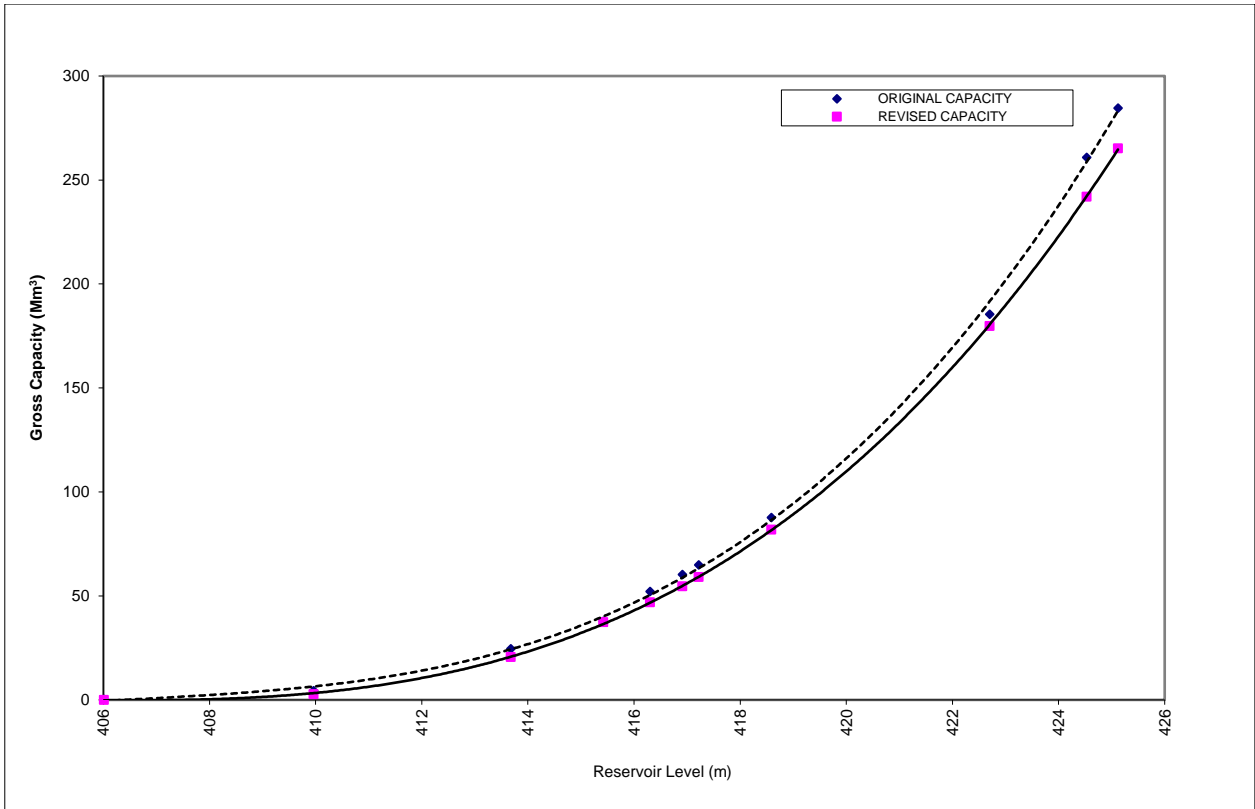


Fig. 5.4 (c) Original and revised cumulative capacity curve for Dudhawa reservoir

5.5 Gondli Reservoir

The revised capacity of Gondli reservoir was computed using nine different scenes covering whole range of live storage. The FCC and extracted water spreads at different levels of Gondli reservoir have been presented in Fig. 5.5 (a) & 5.5 (b). As revised water spreads below DSL and on FSL were not available, a scatter graph has been plotted as done for other reservoir between reservoir levels and revised water spreads. A best-fit curve has been plotted and extended below DSL and up to FSL to compute revised water spreads on these levels. From the analysis, it has been found that present river bed at dam site of Gondli reservoir can be considered as 333.23 m in place of original bed of 332.31 m. It shows that the storage between these two levels has completely lost due to deposit of sediment material brought by the river. The computation of revised cumulative capacities and loss in gross storages has been presented in Table 5.5 (a) and 5.3 (b). The graphical representation of original and revised capacity curve for Gondli reservoir has been presented in Fig. 5.5 (c). From the analysis, it has been found that 7.21 Mm³ (7.26%) of gross storage and 4.80 Mm³ (96.2%) of dead storage have been lost in 60 years (1956 to 2015) from Gondli reservoir. The rate of deposition in Gondli reservoir may be computed as 0.12 Mm³/year if constant rate is considered.

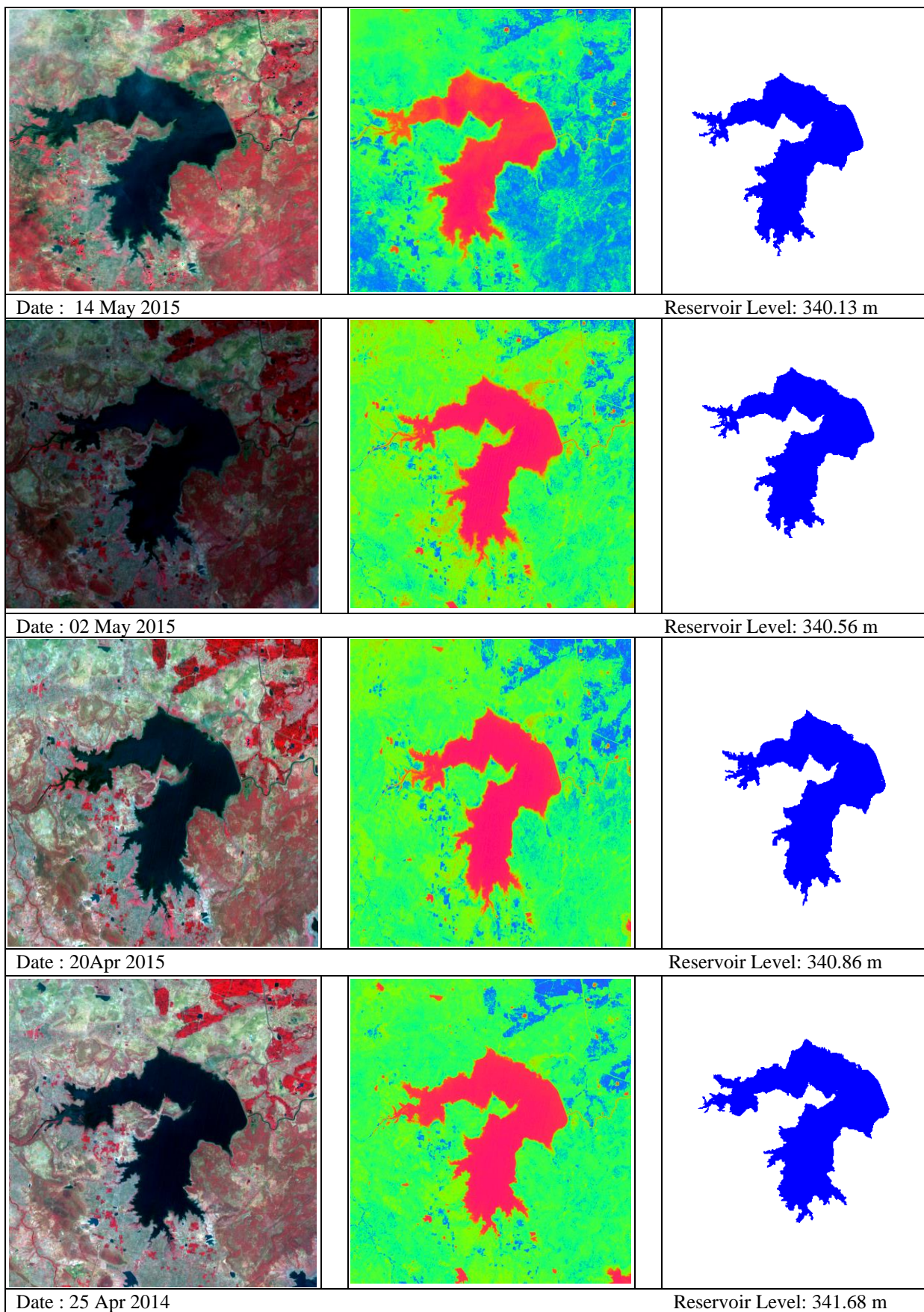


Fig 5.5 (a) FCC, NDWI and extracted water spreads of few dates for Gondli reservoir

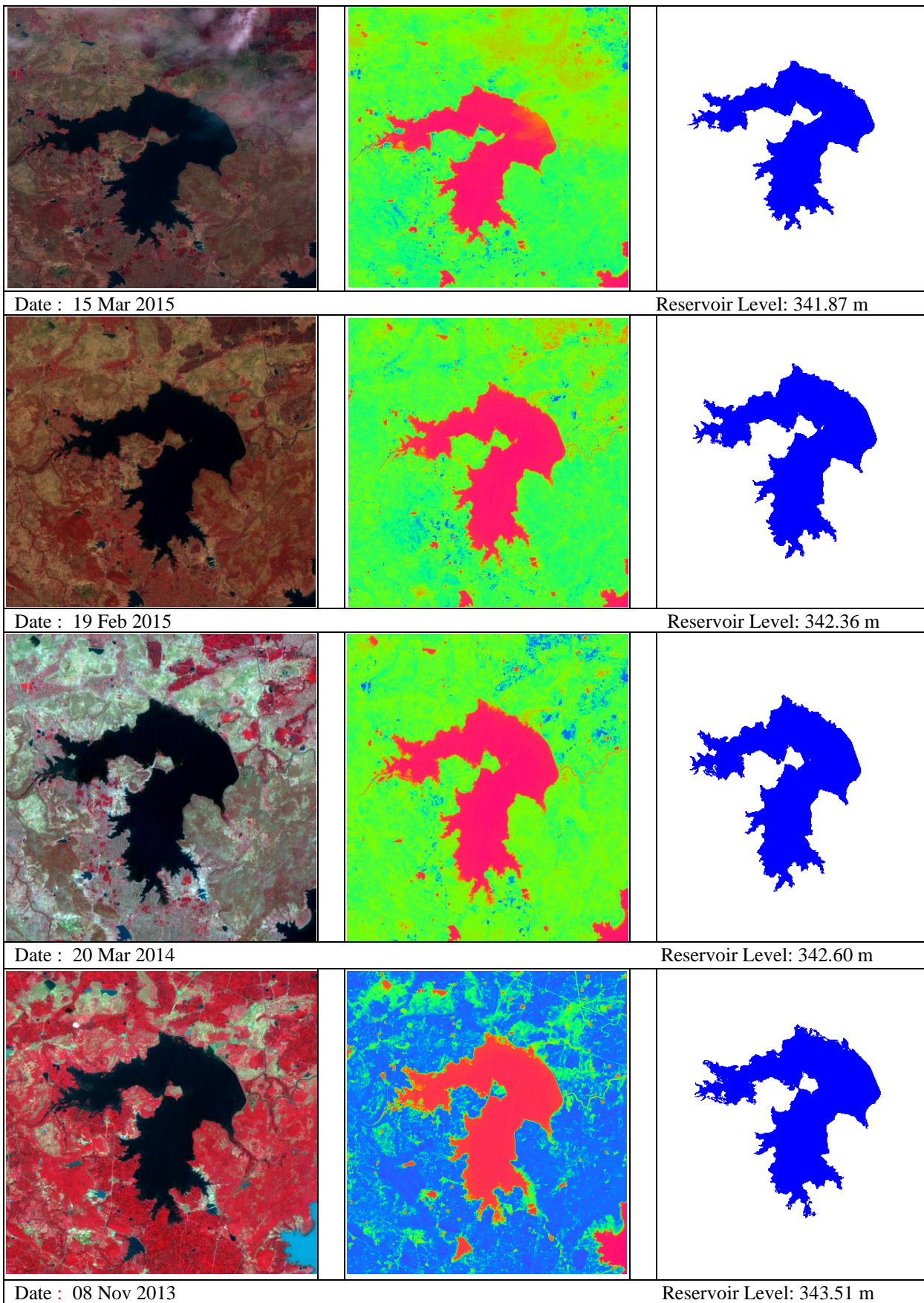


Fig 5.5 (b) FCC, NDWI and extracted water spreads of few dates for Gondli reservoir

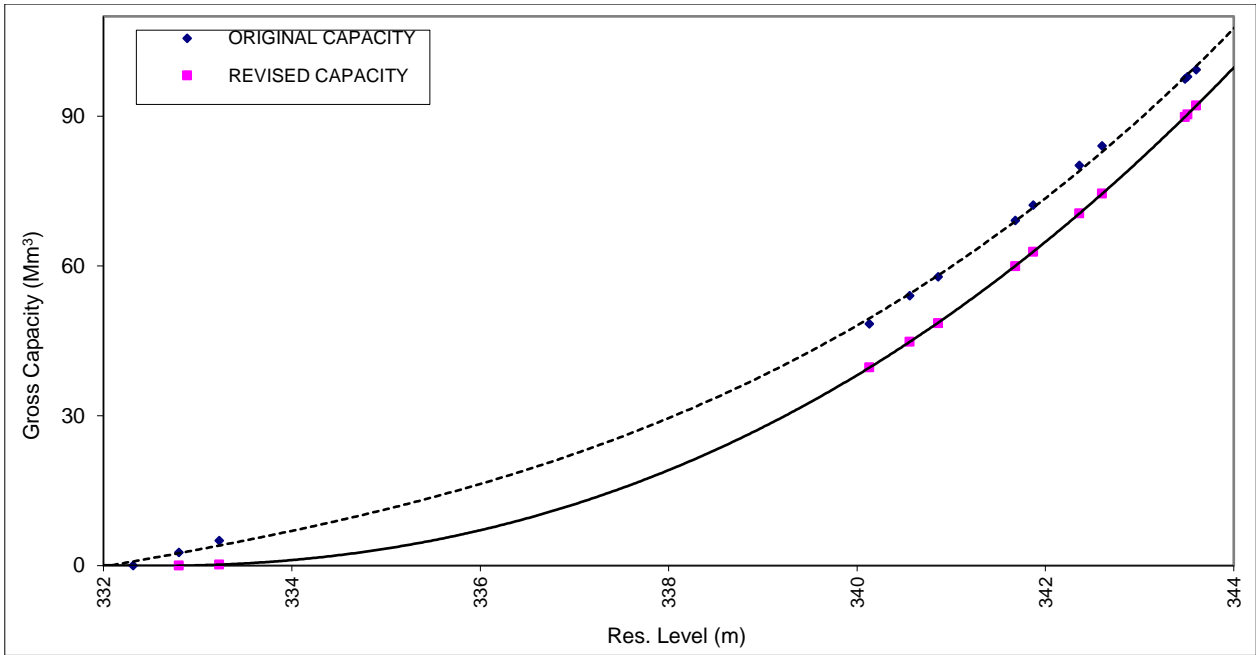


Fig. 5.5 (c) Original and revised cumulative capacity curve for Gondli reservoir

The rates of sediment in reservoirs considered in the present study were compared with empirical equations given by Khosla and Jogelkar for Indian reservoirs. The glimpses of results obtained from the study of reservoir sedimentation of selected reservoirs are presented in Table 5.6. From the analysis, it has been observed that the rate of sediment in reservoirs in upper Mahanadi basin may vary between 0.032 and 0.076 Mm³/100 km²/yr. The curves of reservoir sediment rates from Khosla and Jogelkar curves were plotted along with the results of present study and shown in Fig. 5.6. From the analysis, it has been observed that the rates of sediment in the reservoirs of Chhattisgarh follow Khosla's curve more closely and following equation may be used for determination of rate of sedimentation presently, which will be modified when some more reservoirs were analyzed in the next year work.

$$V_s = \frac{0.103}{A^{0.09}} \quad (5.1)$$

5.6 Sediment Profiling

For determination of sediment profile of a reservoir by conventional and optimized method, a program in FORTRAN has been developed where original and revised elevation-area-capacity table and total sediment deposit were used as input to the program. The conventional and LH-OAT based optimized C , m and n were determined and subsequently used in determination of revised bed level and total sediment deposited which provided revised capacities at different levels of

reservoir. These analyses have been carried out for Ravishankar Sagar and Tandula reservoirs in Chhattisgarh.

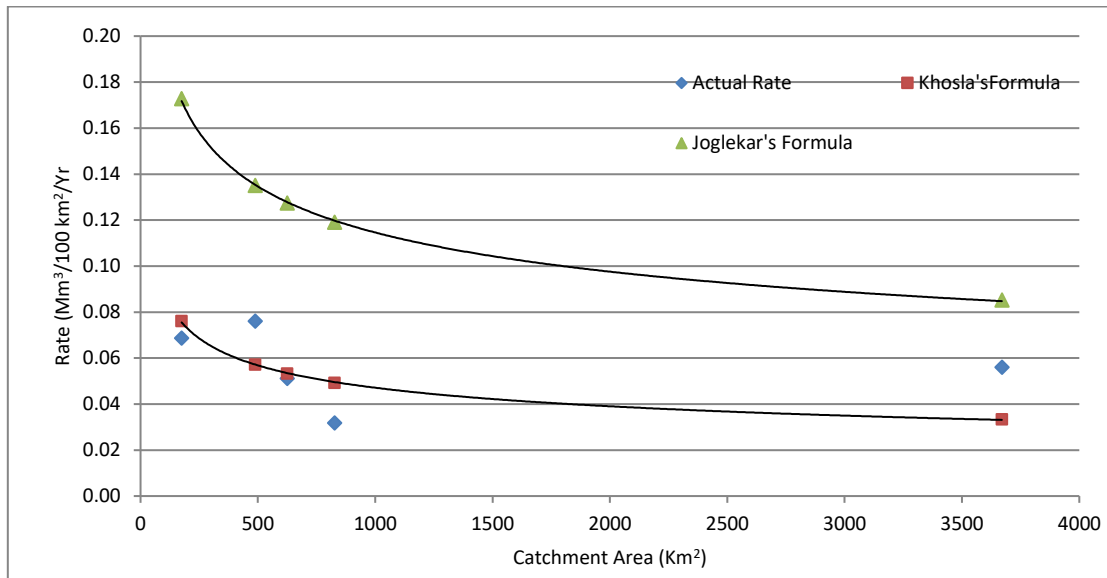


Fig. 5.6 Relation of sediment deposit with catchment characteristics

5.6.1 Sediment profile for Ravishankar Sagar reservoir

The developed program was run to determine revised capacities at different levels of Ravishankar Sagar reservoir for deposition of 69.11 Mm³ of sediment. Conventionally, the parameters C , m and n of empirical area reduction method were found out as 2.324, 0.5 and 0.4 indicated that this reservoir is Type II reservoir which means foothill reservoir. The revised bed obtained for this sediment deposit was 332.08 m. The program when run with LH-OAT optimization, the values of C , m and n were found out as 6.4, 3.6 and 2.6. The revised bed found out as 331.78 m which is close to the revised river bed (331.68 m) obtained from remote sensing analysis proved that the approach of back ward extension of revised water spread curve can be used to find out revised river bed. The revised cumulative capacity curve obtained from remote sensing analysis, conventional and optimized empirical area reduction method has been depicted in Fig. 5.7 clearly indicated close match proved use of back ward extension of revised water spread curve in dead storage zone to determine revised river bed level in remote sensing method.

5.6.2 Sediment Profile for Tandula reservoir

The sediment profiles using conventional and optimized LH-OAT technique were obtained for Tandula reservoir with sediment deposit of 24.75 Mm³. The conventional method gives values of coefficient C , m and n as 15.882, 1.1 and 2.3 respectively which confirmed this reservoir is flood

plain type. The optimized C , m and n were found out as 2.2, 0.2 and 0.3 respectively. The revised bed obtained from remote sensing, conventional and optimized techniques were 320.34m, 320.31 m and 320.33 m respectively and graphical representation in Fig. 5.8 showed a close resemblance in optimization and remote sensing technique.

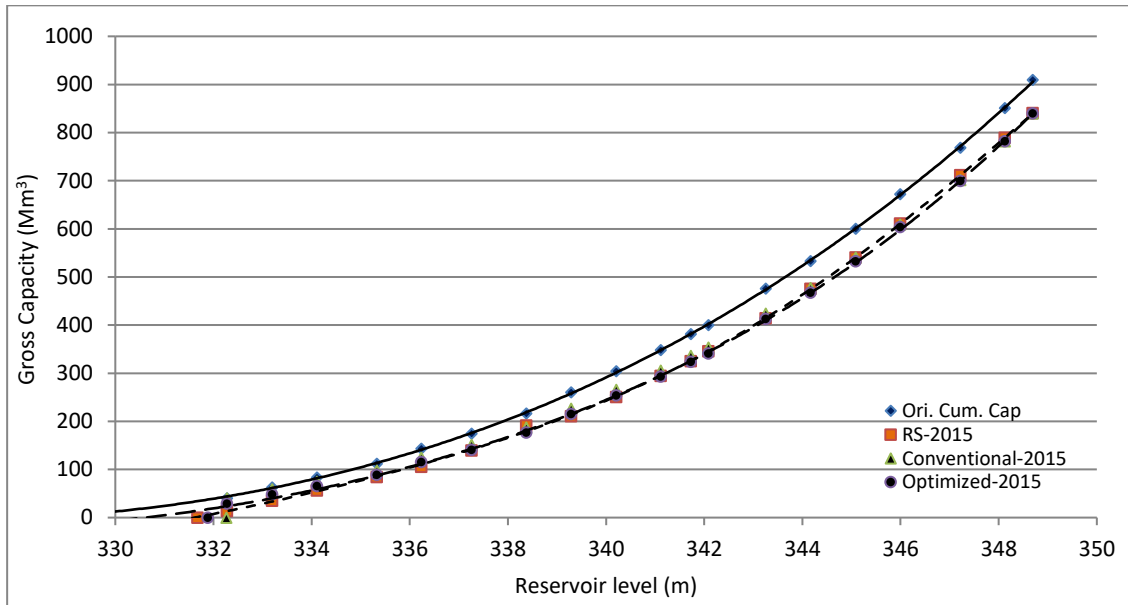


Fig. 5.7 Original and revised capacity curves from RS, Conventional and optimized techniques for Ravishankar Sagar reservoir

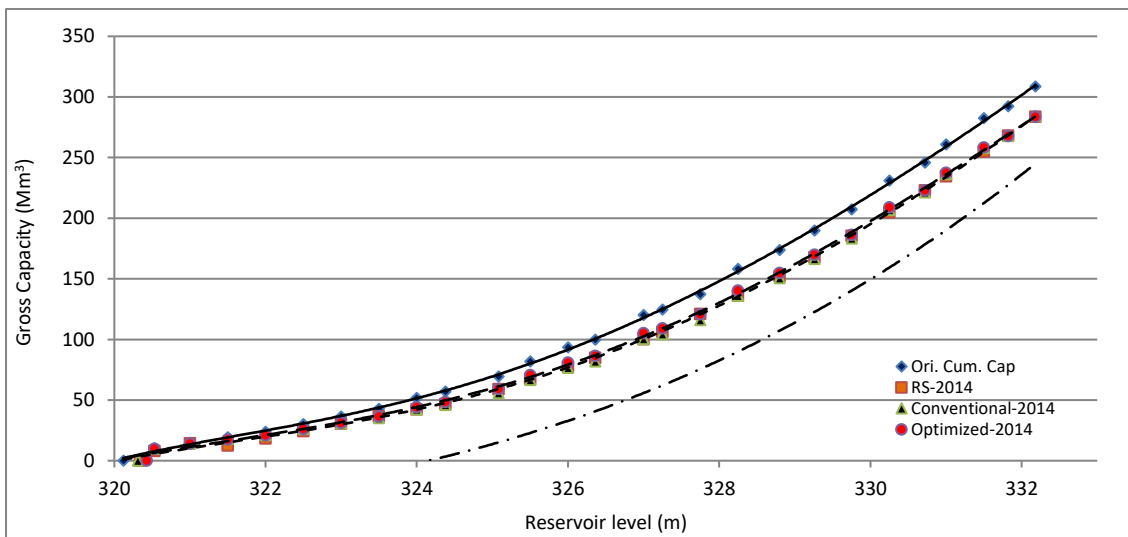


Fig. 5.8 Original and revised capacity curves from RS, Conventional and optimized techniques for Tandula reservoir

CHAPTER- 6: CONCLUSIONS

The systematic and scientific analysis of catchment and command areas may be helpful in planning to reduce distribution losses, equitable distribution of water and increase in crop yields which lead to overall livelihood in the region. In the part I of reservoir sedimentation study, the reservoir sedimentation from five reservoirs in Mahanadi basin of Chhattisgarh state have been determined by estimation of revised capacity using digital image analysis of remote sensing data. The revised capacities at different levels were estimated for Ravishankar Sagar, Tandula, Maramsilli, Dudhawa and Gondli reservoirs. The multi-temporal LISS 3 data were used in the analysis to cover whole live storage range in approximately equal intervals. The revised water spreads obtained from digital image processing were used to compute revised storage and cumulative capacities at different levels.

The analysis suggested that the 30.91 Mm³ from 766.32 Mm³ of live storage of Ravishankar Sagar reservoir has been lost due to deposition of sediment in 37 years (1979 to 2015). The rate sediment in this reservoir may be about 5.60 ha-m/100 km²/year.

The Tandula reservoir, one of the oldest reservoirs in Chhattisgarh has lost 8.91 Mm³ storage from 10.01 Mm³ dead storage and 15.84 Mm³ from original 298.65 Mm³ of live storage in 93 years (1922 to 2015). The rate of sediment in Tandula reservoir may be about 3.18 ha-m/100 km²/yr.

The revised capacity assessment of Maramsilli reservoir concluded that 1.22 Mm³ of dead storage and 28.53 Mm³ of live storage have lost in 92 years (1923 to 2015). The rate of sediment in Maramsilli reservoir may be about 5.12 ha-m/100 km²/yr.

Dudhawa reservoir started its operation in the year 1964 and up to 2015 nearly 1.68 Mm³ of dead storage and 17.65 Mm³ of live storage have been lost in 52 years. The rate of sediment in Dudhawa reservoir may be about 7.60 ha-m/100 km²/yr.

Gondli reservoir is fifty years old and during this period (1956 to 2015) nearly 7.21 Mm³ gross storage from 99.31 Mm³ original storage has been lost. The rate of sediment in Tandula reservoir may be about 6.87 ha-m/100 km²/yr.

The loss of capacity in reservoir from these reservoirs may vary from 0.12 Mm³/year in Gondli reservoir to 1.87 Mm³/year in Ravishankar Sagar reservoir. The sediment profile of Ravishankar Sagar and Tandula reservoirs were determined using empirical area reduction method where parameters C , m and n were computed conventional and LH-OAT based optimization

techniques. The river bed obtained from optimization technique was found close to method of backward extension of best fitted curve of revised water spreads obtained from remote sensing approach. This implies the use of best fit curve of revised water spreads for determination of revised bed level.

CHAPTER- 7: REFERENCES

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TABLES

Table 3.1 The original elevation-area-capacity Table of Ravishankar Sagar reservoir

S.N.	Elevation (m)	Area (km ²)	Capacity (M. m ³)
1.	332.28	19.340	40.44
2.	333.20	21.540	62.93
3.	334.11	24.200	83.54
4.	335.33	28.080	112.29
5.	336.24	32.000	143.61
6.	337.26	35.110	174.90
7.	338.38	40.550	216.73
8.	339.29	45.160	260.49
9.	340.21	49.370	304.24
10.	341.12	53.090	348.00
11.	341.73	56.250	381.53
12.	342.09	57.790	400.48
13.	343.26	63.900	476.26
14.	344.17	68.110	533.10
15.	345.09	73.655	600.29
16.	346.00	79.281	672.33
17.	347.22	86.606	768.50
18.	348.13	91.875	851.09
19.	348.74	95.412	909.54

Table 3.2 The original elevation-area-capacity Table of Tandula reservoir

S.N.	Elevation (m)	Area (km ²)	Capacity (M. m ³)
1.	320.12	0	0
2.	320.43	3	9.982
3.	321.04	4.64	15.322
4.	322.26	7.73	27.192
5.	323.17	10.17	38.771
6.	324.09	12.61	53.532
7.	325	15.06	69.885
8.	326.22	19.33	98.915
9.	327.14	22.55	124.199
10.	328.05	25.91	151.239
11.	329.27	30.38	193.646
12.	330.18	34	228.362
13.	331.1	38.57	264.836
14.	332.01	43.14	305.403
15.	332.83	46.87	348.039
16.	333.13	50.5	368.116

Table 3.3 The original elevation-area-capacity Table of Maramsilli reservoir

S.N.	Elevation (m)	Area (km ²)	Capacity (M. m ³)
1.	359.5	0	0
2.	360.2	0.55	1.35
3.	361.02	1.27	2.93
4.	361.19	1.54	3.25
5.	362	1.85	4.88
6.	363	2.90	7.38
7.	364	4.22	11.09
8.	365	5.75	14.74
9.	366	7.71	20.28
10.	367	10.01	26.34
11.	368	12.86	28.87
12.	369	16.23	42.71
13.	370	20.07	52.79
14.	371.1	25.35	65.46
15.	373	36.63	96.37
16.	374	43.56	114.60
17.	375	51.27	134.89
18.	375.88	58.81	152.54
19.	376.23	62.10	160.98
20.	376.31	62.88	163.06

Table 3.4 The original elevation-capacity Table of Dudhawa reservoir

S.N.	Elevation (m)	Capacity (M. m ³)
1.	404.16	0.00
2.	406.91	0.51
3.	407.52	0.71
4.	408.43	0.85
5.	409.04	2.12
6.	410.26	5.66
7.	411.18	9.51
8.	412.09	14.16
9.	413.00	20.39
10.	414.22	30.02
11.	415.14	38.51
12.	416.05	50.12
13.	417.27	68.53
14.	418.19	82.97
15.	419.10	97.13
16.	420.01	115.82
17.	421.23	143.00
18.	422.15	167.92
19.	423.06	203.88
20.	424.28	254.85
21.	425.12	288.61
22.	426.11	339.94
23.	426.23	352.40

Table 3.5 Original elevation-area-capacity table of Gondli reservoir

S.N.	Elevation (m)	Area (km ²)	Capacity (Mm ³)
1.	332.23	0	0
2.	333	0.33	4.19
3.	333.5	0.54	5.74
4.	334	0.80	9.84
5.	335	1.44	16.12
6.	335.5	1.76	19.28
7.	336	2.08	22.42
8.	336.5	2.40	25.57
9.	337	2.84	28.72
10.	337.5	3.48	31.87
11.	338	4.11	35.01
12.	338.5	4.75	38.16
13.	339	5.39	41.31
14.	339.5	6.03	44.46
15.	340	6.81	47.6
16.	340.56	7.91	54.04
17.	341	9.02	59.78
18.	341.68	10.72	69.1
19.	341.87	11.27	72.18
20.	342.36	12.68	80.13
21.	342.6	13.38	84.03
22.	343	14.80	90.13
23.	343.48	17.68	97.46
24.	343.51	17.91	97.92
25.	343.6	18.57	99.31

Table 3.6 (a) Remote sensing data used for Ravishankar Sagar reservoir

S.N.	Date of pass	Elevation (m)	Path/Row	Satellite	Sensor
1	14-May-2015	338.83	102/58	IRS-P6	LISS-III
2	02-May-2015	340.00	102/58	IRS-ID	LISS-III
3	20-Apr-2015	341.62	102/58	IRS-P6	LISS-III
4	25-Apr-2014	343.35	102/58	IRS-ID	LISS-III
5	15-Mar-2015	344.81	102/58	IRS-P6	LISS-III
6	19-Feb-2015	346.10	102/58	IRS-ID	LISS-III
7	20-Mar-2014	347.06	102/58	IRS-ID	LISS-III
8	28-Sep-2014	348.36	102/58	IRS-ID	LISS-III

Table 3.6 (b) Remote sensing data used for Tandula reservoir

S.N.	Date of pass	Elevation (m)	Path/Row	Satellite	Sensor
1	14-May-2015	324.38	102/58	IRS-P6	LISS-III
2	02-May-2015	325.08	102/58	IRS-1D	LISS-III
3	20-Apr-2015	326.36	102/58	IRS-P6	LISS-III
4	12-Jun-2014	327.25	102/58	IRS-1D	LISS-III
5	25-Apr-2014	328.80	102/58	IRS-1D	LISS-III
6	15-Mar-2015	329.26	102/58	IRS-P6	LISS-III
7	19-Feb-2015	329.75	102/58	IRS-1D	LISS-III
8	20-Mar-2014	330.72	102/58	IRS-1D	LISS-III
9	28-Sep-2014	331.82	102/58	IRS-1D	LISS-III

Table 3.6 (c) Remote sensing data used for Maramsilli reservoir

S.N.	Date of pass	Elevation (m)	Path/Row	Satellite	Sensor
1	02-May-2015	361.02	102/58	IRS-ID	LISS-III
2	20-Apr-2015	361.19	102/58	IRS-P6	LISS-III
3	20-Mar-2015	363.00	102/58	IRS-ID	LISS-III
4	25-Apr-2014	365.00	102/58	IRS-ID	LISS-III
5	08-Nov-2013	368.00	102/58	IRS-ID	LISS-III
6	25-Apr-2014	370.70	102/58	IRS-ID	LISS-III
7	20-Mar-2014	371.10	102/58	IRS-ID	LISS-III
8	15-Mar-2015	372.04	102/58	IRS-P6	LISS-III
9	19-Feb-2015	375.88	102/58	IRS-ID	LISS-III
10	28-Sep-2014	376.23	102/58	IRS-ID	LISS-III

Table 3.6 (d) Remote sensing data used for Dudhawa reservoir

S.N.	Date of pass	Elevation (m)	Path/Row	Satellite	Sensor
1	12-Jun-2014	413.68	102/58	IRS-ID	LISS-III
2	20-Mar-2014	415.42	102/58	IRS-ID	LISS-III
3	14-May-2015	416.30	102/58	IRS-P6	LISS-III
4	02-May-2015	416.91	102/58	IRS-ID	LISS-III
5	20-Apr-2015	417.22	102/58	IRS-P6	LISS-III
6	15-Mar-2015	418.59	102/58	IRS-P6	LISS-III
7	08-Nov-2013	422.70	102/58	IRS-ID	LISS-III
8	28-Sep-2014	424.53	102/58	IRS-ID	LISS-III

Table 3.6 (e) Remote sensing data used for Gondli reservoir

S.N.	Date of pass	Elevation (m)	Path/Row	Satellite	Sensor
1	14-May-2015	340.13	102/58	IRS-P6	LISS-III
2	02-May-2015	340.56	102/58	IRS-1D	LISS-III
3	20-Apr-2015	340.86	102/58	IRS-P6	LISS-III
4	25-Apr-2014	341.68	102/58	IRS-1D	LISS-III
5	15-Mar-2015	341.87	102/58	IRS-1D	LISS-III
6	19-Feb-2015	342.36	102/58	IRS-1D	LISS-III
7	20-Mar-2014	342.60	102/58	IRS-1D	LISS-III
8	28-Sep-2014	343.48	102/58	IRS-1D	LISS-III
9	08-Nov-2013	343.51	102/58	IRS-1D	LISS-III

Table 4.1 Classification of reservoir and constant C , m and n (Borland and Miller, 1960)

Reciprocal of slope (m)	Reservoir type	Standard Classification	C	m	n
1.0 to 1.5	Gorge	IV	3.1470	1.5	0.2
1.5 to 2.5	Foothill	III	2.3240	0.5	0.4
2.5 to 3.5	Flood Plain	II	15.882	1.1	2.3
3.5 to 4.5	Lake	I	4.2324	0.1	2.5

Table 5.1 (a) Computation of revised capacities in Ravishankar Sagar reservoir

Date of pass	Reservoir elevation (meter)	Revised area (hectare)	Revised volume (Mm ³)	Original cum. capacity (Mm ³)	Original volume (Mm ³)	Loss in volume (Mm ³)	% Loss in volume
River Bed	323.50	0.00		0.000			
					37.783	37.783	100.00
Revised Bed	331.68	0.00		37.783			
			104.804		105.217	0.413	0.39
DSL *	336.21	2473.74		143.000			
			86.323		95.740	9.417	9.84
14-May-2015	338.83	4190.8		238.740			
			49.519		58.200	8.681	14.92
02-May-2015	340.00	4274.2		296.940			
			77.822		81.360	3.538	4.35
20-Apr-2015	341.62	5353.7		378.300			
			101.046		107.120	6.074	5.67
25-Apr-2014	343.35	6341.8		485.420			
			99.608		97.140	-2.468	-2.54
15-Mar-2015	344.81	7314.7		582.560			
			99.978		101.780	1.802	1.77
19-Feb-2015	346.10	8194.1		684.340			
			78.821		76.870	-1.951	-2.54
20-Mar-2014	347.06	8227.0		761.210			
			111.740		117.210	5.470	4.67
28-Sep-2014	348.36	8969.1		878.420			
			30.550		30.900	0.350	1.13
FSL *	348.70	9001.7		909.320			

Table 5.1 (b) Original and Revised capacities and loss in storages of Ravishankar Sagar reservoir

Date of Pass	Reservoir Elevation (meter)	Original Capacity (Mm ³)		Revised Capacity (Mm ³)		Loss in capacity (Mm ³)	% Loss in Cumulative Capacity
		Volume	Cum. capacity	Volume	Cum. capacity		
River bed	323.50		0.000		0.000		
Revised Bed*	331.68	37.783	37.783	0.000	0.000	37.783	100.00
DSL	336.21	105.217	143.000	104.804	104.804	38.196	26.71
14-May-2015	338.83	95.740	238.740	86.323	191.127	47.613	19.94
02-May-2015	340.00	58.200	296.940	49.519	240.646	56.294	18.96
20-Apr-2015	341.62	81.360	378.300	77.822	318.468	59.832	15.82
25-Apr-2014	343.35	107.120	485.420	101.046	419.514	65.906	13.58
15-Mar-2015	344.81	97.140	582.560	99.608	519.123	63.437	10.89
19-Feb-2015	346.10	101.780	684.340	99.978	619.101	65.239	9.53
20-Mar-2014	347.06	76.870	761.210	78.821	697.922	63.288	8.31
28-Sep-2014	348.36	117.210	878.420	111.740	809.662	68.758	7.83
FSL *	348.70	30.900	909.320	30.550	840.212	69.108	7.60

Table 5.2 (a) Computation of revised capacities in Tandula reservoir

Date of pass	Reservoir elevation (meter)	Revised area (hectare)	Revised volume (Mm ³)	Original cum. capacity (Mm ³)	Original volume (Mm ³)	Loss in volume (Mm ³)	% Loss in volume
River Bed	320.12	0.00		0.000			
					3.848	3.848	100.00
Revised Bed	320.34	0.00		3.848			
			1.097		6.163	5.066	82.21
DSL *	320.53	802.4		10.011			
			46.131		47.146	1.015	2.15
14-May-2015	324.38	1643.8		57.157			
			12.038		12.413	0.375	3.02
02-May-2015	325.08	1796.8		69.57			
			25.770		30.372	4.602	15.15
20-Apr-2015	326.36	2237.8		99.942			
			21.593		24.805	3.212	12.95
12-Jun-2014	327.25	2619.5		124.747			
			45.861		49.079	3.218	6.56
25-Apr-2014	328.8	3311.5		173.826			
			15.616		16.180	0.564	3.48
15-Mar-2015	329.26	3478.9		190.006			
			17.696		17.417	-0.279	-1.60
19-Feb-2015	329.75	3745.5		207.423			
			37.394		38.391	0.997	2.60
20-Mar-2014	330.72	3965.6		245.814			
			45.155		46.646	1.491	3.20
28-Sep-2014	331.82	4246.1		292.460			
			15.559		16.203	0.644	3.97
FSL	332.18	4398.2		308.663			

Table 5.2 (b) Original and Revised capacities and loss in storages of Tandula reservoir

Date of Pass	Reservoir Elevation (meter)	Original Capacity (Mm ³)		Revised Capacity (Mm ³)		Loss in Cum. Capacity	% Loss in Cumulative Capacity
		Volume	Cum. capacity	Volume	Cum. capacity		
River bed	320.12		0.000		0.00		
Revised bed*	320.34	3.848	3.85	0.00	0.00	3.85	100.00
DSL	320.53	6.163	10.01	1.09	1.10	8.91	89.05
14-May-2015	324.38	53.309	57.16	46.13	47.23	9.93	17.37
02-May-2015	325.08	12.413	69.57	12.04	59.27	10.30	14.81
20-Apr-2015	326.36	30.372	99.94	25.77	85.04	14.91	14.91
12-Jun-2014	327.25	24.805	124.75	21.59	106.63	18.12	14.52
25-Apr-2014	328.80	49.079	173.83	45.86	152.49	21.34	12.27
15-Mar-2015	329.26	16.180	190.01	15.62	168.11	21.90	11.53
19-Feb-2015	329.75	17.417	207.42	17.70	185.80	21.62	10.42
20-Mar-2014	330.72	38.391	245.81	37.39	223.20	22.62	9.20
28-Sep-2014	331.82	46.646	292.46	45.16	268.35	24.11	8.24
FSL	332.18	16.203	308.66	15.56	283.91	24.75	8.02

Table 5.3 (a) Computation of revised capacities in Maramsilli reservoir

Date of pass	Reservoir elevation (meter)	Revised area (hectare)	Revised volume (Mm ³)	Original cum. capacity (Mm ³)	Original volume (Mm ³)	Loss in volume (Mm ³)	% Loss in volume
River Bed	359.50	0.00		0.00			
					1.221	1.22	100.00
Revised Bed	360.14	0.00		1.22			
			0.13		0.127	0.00	0.03
DSL *	360.20	54.45		1.35			
			0.55		1.579	1.03	65.18
02-May-2015	361.02	80.5		2.93			
			0.14		0.327	0.19	56.80
20-Apr-2015	361.19	85.9		3.26			
			3.29		4.119	0.83	20.05
20-Apr-2015	363.00	299.5		7.37			
			7.16		7.362	0.201	2.73
25-Apr-2014	365.00	420.0		14.74			
			14.94		14.138	-0.79	-5.64
08-Nov-2013	368.00	580.0		28.87			
			22.87		31.257	8.38	26.82
25-Apr-2014	370.70	1146.1		60.13			
			4.74		5.330	0.59	11.01
20-Mar-2014	371.10	1226.1		65.46			
			12.23		13.622	1.39	10.21
15-Mar-2015	372.04	1377.8		79.08			
			58.47		73.453	14.99	20.40
19-Feb-2015	375.88	1672.0		152.54			
			6.97		8.446	1.48	17.53
28-Sep-2014	376.23	2326.0		160.98			
			1.83		2.082	0.256	12.30
FSL	376.31	2239.5		163.06			

Table 5.3 (b) Original and Revised capacities and loss in storages of Maramsilli reservoir

Date of Pass	Reservoir Elevation (meter)	Original Capacity (M cu. m)		Revised Capacity (M cu. m)		Loss in Cum. Capacity (M cu.m)	% Loss in Cumulative Capacity
		Volume	Cumulative Capacity	Volume	Cumulative Capacity		
River bed	359.50		0.00		0.00		
Revised Bed*	360.14	1.22	1.22	0.00	0.00	1.22	100.00
DSL	360.20	0.13	1.35	0.13	0.13	1.22	90.58
02-May-2015	361.02	1.71	2.93	0.55	0.68	2.25	76.87
20-Apr-2015	361.19	0.33	3.26	0.14	0.82	2.44	74.85
20-Apr-2015	363.00	4.12	7.37	3.29	4.11	3.26	44.24
25-Apr-2014	365.00	7.36	14.74	7.16	11.27	3.46	23.50
08-Nov-2013	368.00	14.14	28.87	14.94	26.21	2.67	9.23
25-Apr-2014	370.70	31.26	60.13	22.87	49.08	11.05	18.38
20-Mar-2014	371.10	5.33	65.46	4.74	53.82	11.64	17.78
15-Mar-2015	372.04	13.62	79.08	12.23	66.06	13.03	16.47
19-Feb-2015	375.88	73.45	152.54	58.47	124.52	28.02	18.37
28-Sep-2014	376.23	8.45	160.98	6.97	131.49	29.50	18.32
FSL	376.31	2.08	163.06	1.83	133.31	29.75	18.25

Table 5.4 (a) Computation of revised capacities in Dudhawa reservoir

Date of pass	Reservoir elevation (meter)	Revised area (hectare)	Revised volume (Mm ³)	Original cum. capacity (Mm ³)	Original volume (Mm ³)	Loss in volume (Mm ³)	% Loss in volume
River Bed	404.22	0.00		0.00			
					0.31	0.31	100.00
Revised Bed	406.01	0.00		0.31			
			2.67		4.03	1.37	33.88
DSL *	409.96	139.4		4.35			
			17.93		20.26	2.33	11.51
12-Jun-2014	413.68	943.7		24.61			
			16.82		13.245	-3.56	-26.94
20-Mar-2014	415.42	989.2		37.85			
			9.44		14.28	4.84	33.91
14-May-2015	416.3	1157.5		52.13			
			7.68		8.15	0.47	5.73
02-May-2015	416.91	1364.2		60.28			
			4.48		4.63	0.14	3.08
20-Apr-2015	417.22	1529.5		64.91			
			22.80		22.82	0.03	0.13
15-Mar-2015	418.59	1801.9		87.73			
			97.94		97.75	-0.19	-0.19
08-Nov-2013	422.70	3015.9		185.48			
			62.24		75.41	13.17	17.47
28-Sep-2014	424.53	3801.4		260.89			
			23.17		23.60	0.43	1.81
FSL	425.12	4054.7		284.49			

Table 5.4 (b) Original and Revised capacities and loss in storages of Dudhawa reservoir

Date of Pass	Reservoir Elevation (meter)	Original Capacity (Mm ³)		Revised Capacity (Mm ³)		Loss in Cum. Capacity (Mm ³)	% Loss in Cumulative Capacity
		Volume	Cumulative Capacity	Volume	Cumulative Capacity		
River bed	404.22		0.000		0.000		-
Revised Bed*	406.01	0.312	0.312	0.000	0.000	0.312	100.00
DSL	409.96	4.034	4.346	2.668	2.668	1.679	38.63
12-Jun-2014	413.68	24.295	24.607	17.928	20.596	4.012	16.30
20-Mar-2014	415.42	13.246	37.854	16.815	37.411	0.443	1.17
14-May-2015	416.30	14.278	52.132	9.436	46.846	5.285	10.14
02-May-2015	416.91	8.150	60.281	7.7	54.529	5.752	9.54
20-Apr-2015	417.22	4.625	64.907	4.5	59.012	5.895	9.08
15-Mar-2015	418.59	22.823	87.730	22.8	81.807	5.924	6.75
08-Nov-2013	422.70	97.752	185.482	97.9	179.749	5.733	3.09
28-Sep-2014	424.53	75.411	260.893	62.2	241.989	18.904	7.25
FSL	425.12	23.598	284.491	23.2	265.161	19.330	6.79

Table 5.5 (a) Computation of revised capacities in Gondli reservoir

Date of pass	Reservoir elevation (meter)	Revised area (hectare)	Revised volume (Mm ³)	Original cum. capacity (Mm ³)	Original volume (Mm ³)	Loss in volume (Mm ³)	% Loss in volume
River Bed	332.31	0.00		0.000			
					2.644	2.644	100.00
Revised Bed	332.80	0.00		2.644			
			0.190		2.344	2.154	91.88
DSL *	333.23	132.8302		4.988			
			39.502		43.434	3.933	9.05
14-May-2015	340.13	1187.5		48.422			
			5.143		5.621	0.478	8.51
02-May-2015	340.56	1204.4		54.043			
			3.720		3.820	0.100	2.61
20-Apr-2015	340.86	1276.0		57.863			
			11.373		11.237	-0.14	-1.21
25-Apr-2014	341.68	1500.9		69.099			
			2.887		3.084	0.197	6.38
15-Mar-2015	341.87	1538.3		72.183			
			7.745		7.953	0.209	2.63
19-Feb-2015	342.36	1623.1		80.137			
			3.958		3.895	-0.06	-1.61
20-Mar-2014	342.60	1675.6		84.032			
			15.282		13.425	-1.86	-13.83
28-Sep-2014	343.48	1798.3		97.457			
			0.549		0.464	-0.09	-18.45
08-Nov-2013	343.51	1864.6		97.921			
			1.757		1.391	-0.37	-26.30
FSL *	343.60	2042.2		99.313			

Table 5.5 (b) Original and Revised capacities and loss in storages of Gondli reservoir

Date of Pass	Reservoir Elevation (meter)	Original Capacity (Mm ³)		Revised Capacity (Mm ³)		Loss in Cum. Capacity (Mm ³)	% Loss in Cumulative Capacity
		Volume	Cumulative Capacity	Volume	Cumulative Capacity		
River bed	332.31		0.00		0.00		
Revised Bed*	332.80	2.64	2.64	0.00	0.00	2.64	100.00
DSL	333.23	2.34	4.99	0.19	0.19	4.80	96.18
14-May-2015	340.13	45.78	48.42	39.50	39.69	8.73	18.03
02-May-2015	340.56	5.62	54.04	5.14	44.84	9.21	17.04
20-Apr-2015	340.86	3.82	57.86	3.72	48.56	9.31	16.09
25-Apr-2014	341.68	11.24	69.10	11.37	59.93	9.17	13.27
15-Mar-2015	341.87	3.08	72.18	2.89	62.82	9.37	12.98
19-Feb-2015	342.36	7.95	80.14	7.75	70.56	9.58	11.95
20-Mar-2014	342.60	3.90	84.03	3.96	74.52	9.51	11.32
28-Sep-2014	343.48	13.43	97.46	15.28	89.80	7.66	7.86
08-Nov-2013	343.51	0.46	97.92	0.55	90.35	7.57	7.73
FSL *	343.60	1.39	99.31	1.76	92.11	7.21	7.26

Table 5.6 Glimpses of sediment study results from different reservoirs in Chhattisgarh

Particulars	Reservoir				
	Ravishankar Sagar	Tandula	Maramsilli	Dudhawa	Gondli
Intercepted Catchment Area (km ²)	3335.16	827	625	489	175
Year of Impoundment	1979	1922	1923	1964	1956
Year of Survey	2015	2015	2015	2015	2015
Dead Storage Level (meter)	336.21	320.53	360.2	409.96	333.23
Full Supply Level (meter)					
Original Bed Level (meter)	323.5	320.23	359.5	404.22	332.31
Revised Bed 2015 (meter)	331.68	320.34	360.14	406.01	332.8
Original Cumulative Capacity	909.32	308.66	163.06	284.49	99.31
Revised Cumulative Capacity 2015	840.21	283.63	133.11	265.16	91.11
Loss in Gross storage (Mm ³)	69.11	24.75	29.75	19.33	7.21
Rate of Sediment (Mm ³ /yr)	1.87	0.26	0.32	0.37	0.12
Rate (ha-m/100 km ² /yr)	5.60	3.18	5.12	7.60	6.87
Rate (Mm ³ /100 km ² /yr)	0.056	0.032	0.051	0.076	0.069
Rate from Khosla Formula (Mm ³ /100 km ² /yr)	0.033	0.049	0.053	0.057	0.076
Rate from Joglekar Formula (Mm ³ /100 km ² /yr)	0.085	0.119	0.127	0.135	0.173

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