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WATER QUALITY STUDIES IN URBAN LAKES

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ABSTRACT

Water is the second most significant requirement for life to exist after air. Accordingly, water quality has been depicted broadly in the logical writing. The most well-known meaning of water quality is "it is the physical, chemical, and biological parameter of water". This work undertaken as a water quality studies in urban lakes project to investigate the use of remote sensing in water quality studies. The lakes of study were chosen based on analyzing weightage ranking method. Among them polluted lakes were considered for the study. The main objective of the study is to Estimation of water quality parameters using satellite image and lab analysis. The water quality parameters are Turbidity (TU), Total suspended solids (TSS), pH, and Dissolved oxygen (DO). These parameters can indicate water quality of lakes and shows the distribution of pollutants.

The project period at RRSC-South was from May – September 2022. The first part of this study involve the Prioritization of Bengaluru urban lakes for study of water quality, The selection of lakes was done by applying weightage ranking method. Also water samples were collected during field visit, lab analysis also done for collected samples with standard method. Then in second part of the study is selection of best band indexing from sentinel 2A MSI satellite image. In this part different band indexing were applied with lab analysis of each quality parameters to get best fit linear regression model, after getting suitable regression model water quality parameter estimated. Then RMSE, BIAS, MAPD are calculated and mapping done for each estimated Water quality parameters.

So in this study by using Sentinel 2A MSI satellite image, Turbidity and Total suspended solid gives less than 60% accuracy, for pH and Dissolved oxygen gives more than 80% accuracy. As per this study sentinel 2A MSI satellite image is the suitable for the estimation of pH and Dissolved oxygen.

Keywords: Water Quality, Band Index, Statistical Models, Regression Analysis, Reflectance, Sentinel-2 MSI.

Chapter-1

Introduction

1.1 Background of study

Water is the second most significant requirement for life to exist after air. Accordingly, water quality has been depicted broadly in the logical writing. The most well-known meaning of water quality is "it is the physical, chemical, and biological parameter of water". Water quality is a proportion of the state of water comparative with the prerequisites of at least one biotic animal type as well as to any human need or reason

The role that urban lakes play in cities big and small goes beyond adding aesthetic value and a healthy dose of flora to the otherwise sparse urban landscape. From increasing biodiversity to aiding with flood control to providing a space for recreation and community businesses to thrive, increasing of ground water, lakes can be a vital and beautiful part of the urban fabric.

Lakes are significant part of urban environment. However generally little in size, lakes perform huge ecological, social and financial capabilities, going from being a source of drinking water, recharging groundwater, going about as wipes to control flooding, supporting biodiversity and giving livelihoods.

The impact of urbanization has negatively affected the lakes of Bangalore and in urban regions can possibly contaminate water in numerous ways. Runoff from roads, carries oil, elastic, weighty metals, and different toxins from automobiles. Also the approach of industrialization and the rising populace, the scope of necessities for the water has expanded along with more prominent requests for higher water quality. In lined up with the water use for the range of human exercises (drinking and individual cleanliness, fisheries, horticulture, industry, transport and diversion), since old time's water has been viewed as the most appropriate medium to clean, scatter, transport and arrange squanders.

Extending dispose of wastes in the water bodies suggests a remarkable potential for the regular damage and stresses the need to screen, secure and administer water resources and quality.

Traditional water quality observing normally includes expensive and time consuming in-situ boat reviews in which in-situ estimations or water tests are gathered and gotten back to research facility for testing of water quality markers for example Turbidity (mark of green growth) and Total suspended solids, pH and so forth. This strategy permits exact estimations inside water body yet just at discrete places, they can't give the continuous spatial outline that is fundamental for the worldwide evaluation and observing of water quality

The test of water-quality management related with the guideline of practical improvement has been of worry to numerous analysts and chiefs somewhat recently. Different models have been produced for supporting missions of water-quality management

Innovations are turning out to be increasingly more significant for water-quality management, because of the quick advancement of computational critical thinking apparatuses and the improvement of logical methodologies for data support.

The main advantage of satellite remote sensing for inland water quality checking is the development of concise perspectives without the need of expensive in-situ examining. Brief, multi-sensor satellite information items and symbolism have become progressively significant apparatuses for the evaluation of water quality in inland (lakes) and approaches shore seaside waters. Remote sensing of lakes utilizing satellite pictures can possibly deliver a really brief device for the checking of water quality factors like pH, Total suspended solids (TSS), Dissolved Oxygen (DO), turbidity (TU) particulate natural carbon and hued broke up natural matter.

Statistical procedures have been utilized to examine the relationship between spectral wavebands or waveband mixes and the ideal water quality parameter. Prescient conditions for water quality boundaries have been created after these relationships not entirely settled.

This work portrays how remote Sensing has been utilized to screen water nature of Lakes in Bengaluru, utilizing sentinel MSI satellite symbolism estimations. In land water normally has a more modest surface region and more confounded ghastly elements, particularly water system lakes, which are in many cases affected by human utilize like horticulture exercises or by other wastage. Thus, inland or Lake Water quality checking presents higher necessities for both worldly and spatial goal of satellite sensor information, consequently right now involved satellite sensors frequently have restricted common sense appropriateness in surveying moderately more modest inland water bodies. Since there are a set number of wavebands for Sentinel and other multispectral sensors, tracking down wavebands to work on the presentation of water quality assessment.

Bengaluru lakes are getting more polluted due impact of urbanization, industrialization and the rising population. So need of water quality assessment in urban lakes is more important, this work shows the use of remote sensing in urban water quality assessment.

1.2 Objectives

- Prioritization of Lakes
- Estimation of water quality parameters using satellite image and lab analysis

Chapter-2

Literature review

There is a vast literature available that deals with different aspects of the Sentinel 2A image remote sensing for water Quality. The literature can be classified broadly into various aspects, dealing with processing, analysis, integration, application and other studies.

This section gave a compact hypothetical survey and foundation of the ideas that were connected with the centre focal point of this review. This started with a survey on the overall data, grouping in Bengaluru. From there on, the review focused on the various physio-chemical parameters and what these parameters meant for the water quality wellbeing as well as how they had been extracted both traditionally and through remote sensing methods.

2.1 Need of urban lakes water quality assessment

- **Rachna Bhateria** et.al, (2015) [1], Ever increasing population, urbanization and modernization are posing problems of sewage disposal and contamination of surface waters like lakes. Natural water gets contaminated due to weathering of rocks, leaching of soils and mining processing, etc. Various types of problems in lake which cause nutrient enrichment in lake have been reviewed. Land use change and longer growing seasons could increase the use of fertilizers with subsequent leaching to watercourses, rivers and lakes, increasing the risk of eutrophication and loss of biodiversity. Water quality can be assessed by various parameters such as BOD, temperature, electrical conductivity, nitrate, phosphorus, potassium, dissolved oxygen, etc.

2.2 Remote sensing selection

- **Rim Katlane** et.al., (2020)[2], in this study explain about applying calculations or experimental connections between water constituent and reflectance utilizing sea variety sensors like SeaWiFS, MERIS, and MODIS. The semi-logical, exact bio-optical models, band proportion or chlorophyll measurement calculations have been grown chiefly as per the focus scope of in situ Chl-a and turbidity and furthermore as far as the particular frequencies accessible in the multi or hyperspectral sensors (MODIS, SeaWiFS, EO1, MERIS, SENTINEL, and so forth) The high spatial goal and the phenomenal Chl-a phantom quality groups of the Sentinel 2A (S2A) information give clear and exact data on the optical properties of water. Different turbidity planning calculations have been produced for various districts utilizing multi or hyperspectral satellite information.
- **F. Torre** et.al.,(2021) [3], This exploration was done for Field estimations of pH, temperature, turbidity, electrical conductivity and disintegrated oxygen were performed at 22 destinations Through a direct relapse investigation between field-estimated factors and the reflectance upsides of the Sentinel 2 picture, models to address the spatial fluctuation of the different water quality boundaries were gotten. All generated models have a determination coefficient (R^2). The models are characterized by having correspondence in the electromagnetic spectrum with the areas belonging to the Different wavelength. These models, obtained from Sentinel 2 images in combination with GIS tools, allowed a complete analysis that contributes to the spatial–temporal monitoring of the studied aquatic ecosystems.
- **Matthew Ellero** (2018) [4], Sentinel-2 and Landsat 8 showed good Result in the assessment of physio-chemical parameters these sensors will play a proceeded with significant part to play in the estimation of WQ parameter. This study gives strong evidence for success. The assessment algorithms for parameters for example, SDD, pH, TDS, EC and chl-a were at times poorly modelled but their respective RMSE indicated that their absolute values could still be accurately retrieved. in this the calculations tried and modified by this study will help with the assessment of parameters from the one region as well as in comparable other also. The proceeded with utilization of water quality assessment calculations in recovering these parameters will reduce costs; time spent in the field and considers assessment in hard to arrive at regions. This might prompt the more effective checking of WQ parameter.
- **Giulia Sent** el.at., (2021) [5], This review assesses the capability of water quality checking involving Sentinel-2 perceptions for the period through a calculation inter comparison exercise and time series examination of various water quality parameters (CDOM), chlorophyll-a (Chl-a), suspended particulate matter (SPM), and turbidity). That's results propose Sentinel-2 is helpful for observing these parameters in a highly dynamic system

- **Chunlei Fan** et.al, (2013) [6], in this paper they explain about how Hyperspectral remote sensing offers a successful methodology for incessant, brief water quality estimations over a huge spatial extent. The main goal of this study was to foster calculations for hyperspectral remote sensing of water quality in view of in situ spectral measurement of water reflectance. In this study, water reflectance spectra R (λ) were acquired by spectroradiometers and concentrations of chlorophyll a and total suspended solids (TSS), as well as absorption of colored dissolved organic matter (CDOM) were measured. Empirical models that based on spectral features of water reflectance generally showed good correlations with water quality parameters. The retrieval model that using spectral bands at Red/NIR showed a high correlation with chlorophyll a concentration the ratio of green to blue spectral bands is the best predictor for TSS and CDOM absorption is best correlated with spectral features at blue and NIR regions. These empirical models were further applied to the ASIA Eagle hyperspectral aerial imagery to demonstrate the feasibility of hyperspectral remote sensing of water quality in the optical complex estuarine waters.

2.3 Methodology selection

- **Zuomin Wang** et.al., (2017) [7], The goal of this study is to lay out a quantitative model for assessing the Chl-a and the TSS focuses in water system lakes utilizing field hyperspectral estimations and actual examination. Field tests were led in six lakes and spectral readings for Chl-a and TSS were gotten from six field perceptions in 2014. For measurable methodologies, we utilized two spectral files, the ratio spectral index (RSI) and the normalized difference spectral index (NDSI), and an incomplete least squares (PLS) relapse. The prescient capacities were analyzed utilizing the coefficient of determination (R2), the root mean square error.
- **Kaire Toming** et.al.,(2016) [8], In paper they explain about different band indexing of sentinel 2A MSI satellite image to estimation of water quality by applying correlation method to get best fit model for each parameter, The height of the 705 nm peak was used for estimating Chl-a. The suitability of the commonly used green to red band ratio was tested for estimating the CDOM, DOC and water color. Different band indexing done for each parameter.
- **J.E. Escoto** et.al.,(2021) [9], This utilizations estimations of essential water quality (WQ)parameters Sentinel-2 pictures are used to appraise biological oxygen demand (BOD), Chloride, Color, Dissolved Oxygen (DO), Fecal Coliform, Nitrate, pH, Phosphate, Temperature, and Total suspended solids (TSS). Feature generation involved computation of various band reflectance from the satellite picture. Thorough include choice through utilization of a Pearson Correlation threshold was applied to restrict number of independent variables. The box-cox changes of water quality boundaries (with the exception of Temperature) were utilized as reliant factors and the chose highlights are utilized as reliant factors for the common least squares relapse model. The root mean square error (RMSE) values for the models which are registered. Tests for multi collinearity, autocorrelation, and homoscedasticity show disuse in models made.
- **Gabriel B** et.al, (2002) [10], this work explains about Connections between optical water quality parameters and one or two broad wavebands were. An attempt was made to use portions of the electromagnetic range, which limit the impacts of atmospheric anomalies, thusly normalizing the spectrally additive substance

constants in all wavebands. Since this supposition that was not met for turbidity, a first derivative approach was utilized. The derivative reflectance is another option and hypothetically more vigorous connection between the water quality boundary and nearby wavebands.

- **Chapter-3**

Study Area

3.1 Geographical information

Bengaluru is the capital of the Indian state of Karnataka. It has a populace of north of ten million, making it a megacity and the third-most crowded city and fifth-most crowded metropolitan agglomeration in India. Bengaluru lies in the southeast of the South Indian Territory of Karnataka. It is in the core of the Mysore Plateau (a district of the bigger Precambrian Deccan Plateau) at a typical height of 920 m (3,020 ft.). It is situated at 12.97°N 77.56°E and covers an area of 1741 km^2 (673 mi^2). Most of the city of Bengaluru lies in the Bengaluru Urban locale of Karnataka and the encompassing country regions are a piece of the Bangalore Rural locale. The area involving the Bangalore Urban and Rural locale is known as the Bengaluru (district).

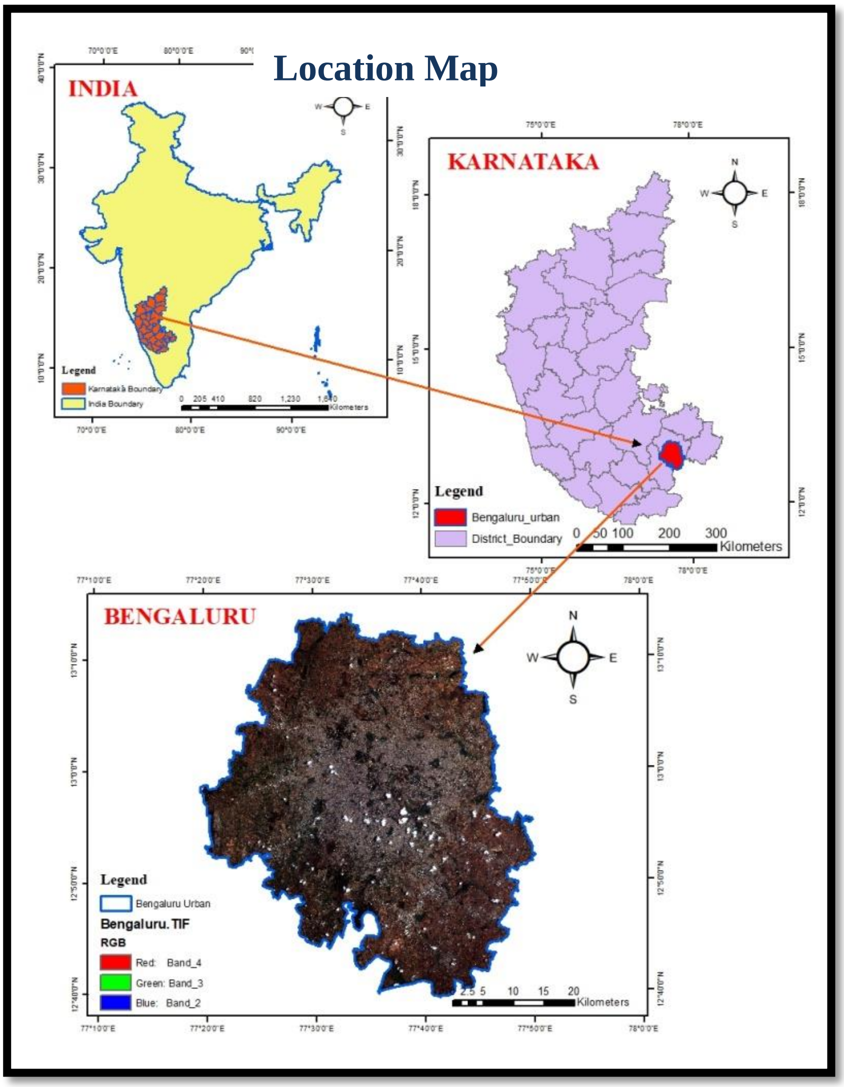

Figure 1: Location map

3.2 Topographical information

Bengaluru has two extraordinary Topography landscapes North Bengaluru taluk and the South Bengaluru taluk. The North Bengaluru taluk is a moderately more level and lies between a normal of 839 to 962 meters above ocean level. The center of the taluk has a conspicuous edge running NNE-SSW. The most elevated point in the city, Doddabettahalli, (962m) is on this edge. There are delicate inclines and valleys on one or the other side of this edge. The low-lying region is set apart by a progression of water tanks changing in size from a little lake to those of significant degree; yet at the same all genuinely shallow.

Topography of Bangalore is undulating with a focal edge running NNE-SSW. No significant streams go through the city; however the Arkavathi and [Dakshin Pinakini River] run into each other at the Nandi Hills, 60 km (37 mi.) toward the north. Stream Vrishabhavathi, a minor feeder of the Arkavathi, emerges inside the city at Basavanagudi and courses through the city. The streams Arkavathi and Vrishabhavathi together convey a lot of Bangalore's sewage.

The South Bengaluru taluk has a lopsided scene with mixing slopes and valleys. The southern and western parts of the city comprise of geography of rock and gneissic masses. The eastern piece is a plane, with intriguing minor undulations.

3.3 Drainage system

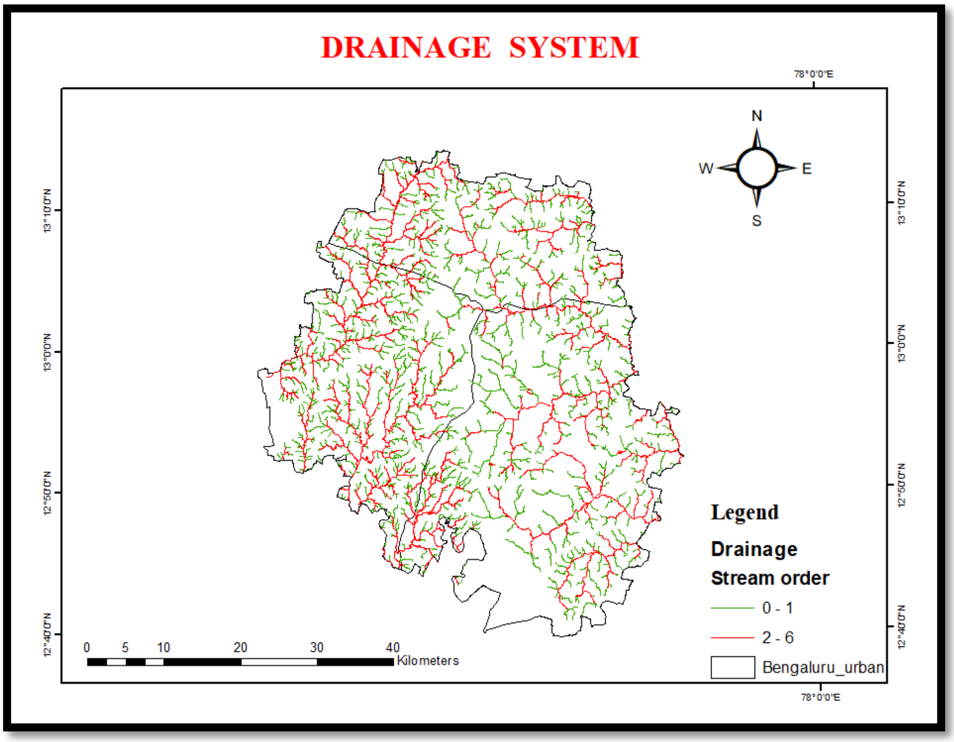

Figure 2 : Drainage system in Bengaluru

3.4 Valley system in Bengaluru

Bengaluru, prominently called as "The City of Lakes" is situated in the semi-arid peninsular plateau in the south-eastern part of Karnataka. Bengaluru and its encompassing locales are not upheld by enduring waterway framework, but rather have three significant Valley frameworks to be specific Vrishabhavathi Valley, Hebbal Valley and Kormangala-Challaghatta Valley and not many minor Valleys. These three significant Valleys assume a significant part in Bengaluru's hydrological processes. Vrishabhavathi (V-Valley), Koramangala-Challaghatta (KC), run generally in a north to south direction and divide the greater part of the metropolitan area which lies to the south of the ridge and Hebbal valley forms the drainage zone to the north of the ridge and runs in a north-easterly direction.

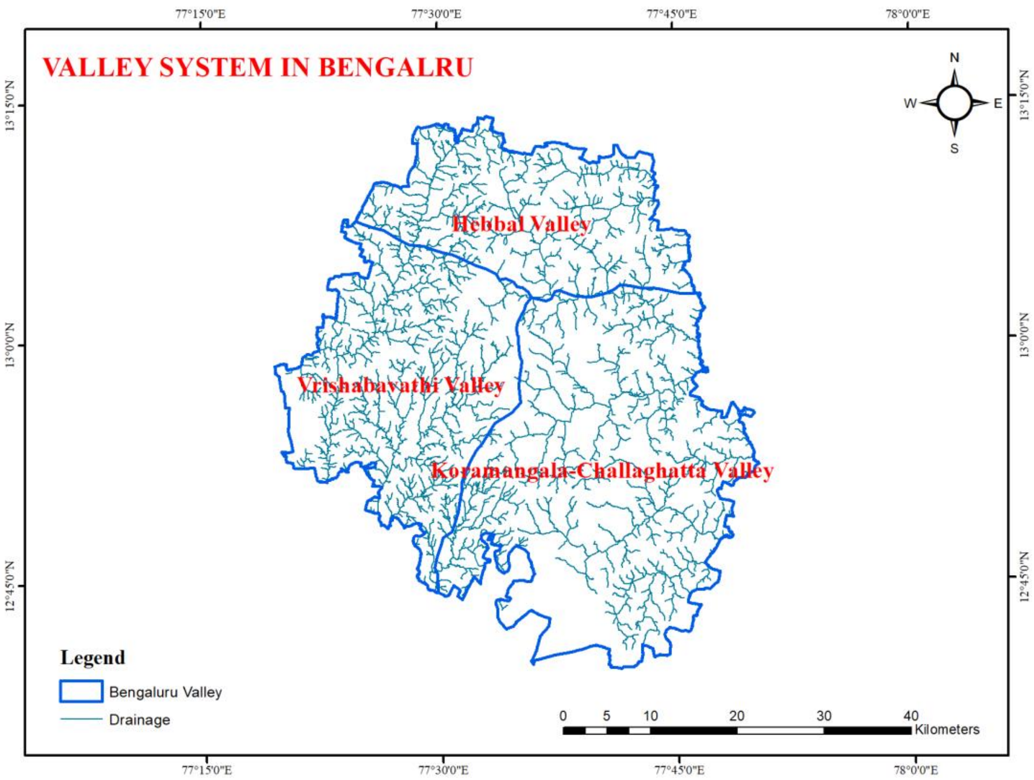

Figure 3: Valley system in Bengaluru

Table 1: Major Valleys in Bengaluru

Major Valley(s)	Area (ha)
Vrishbavathi	3800
Koramangala&Challagatta	7100
Hebbal	3222

3.5 Study area map

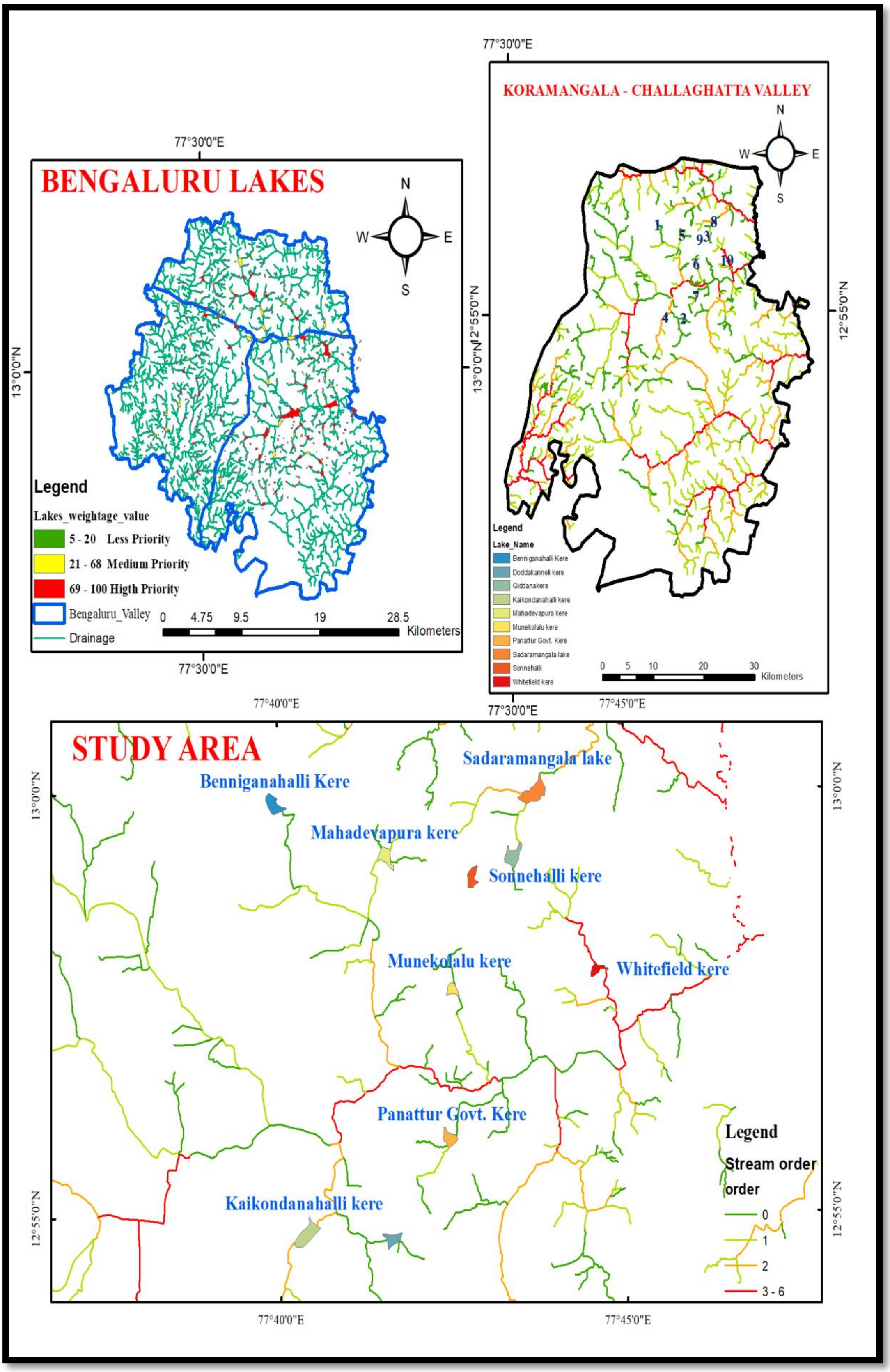

Figure 4: Study area lakes map

3.6 Photography taken during samples collection

Fig 5(a): Benniganahalli Outlet

Fig 5(b): Benniganahalli Outlet

Fig 5(c): Mahadevapura Inlet

Fig 5(d): Mahadevapura Inlet flow

Fig 5(e): Mahadevapura Peripheral

Figure 5: Photography taken during samples collection

In Bengaluru 291 lakes are existing(Ref: R.Hebbar, 2019)[11] Historically lakes in the Bengaluru region were managed by a plethora of government agencies such as the Forest Department, Minor Irrigation Department, Horticulture Department, Public Works Department (PWD), Bruhat Bengaluru Mahanagara Palike (BBMP), Bangalore Development Authority (BDA), Tourism Department, City Municipal Councils and Panchayath; each organisation claiming its own jurisdiction of ownership and maintenance rights resulting in a deficient, inconsistent and uncoordinated approach

Table 2: Study area lakes names

Table 2: shows the lakes name, area of lakes and weightage value of each lake

SL No	Lakes Names	Area(ha)	Weightage Value
1	Sonnenahalli kere	8.70	88
2	Whitefield kere	5.93	85
3	Kaikondrahalli lake	18.11	83
4	Panattur Govt. Kere	9.08	83
5	Mahadevapura kere	10.11	71
6	Munekolalu lake	5.79	71
7	Sadaramangala lake	19.99	61
8	Benniganahalli Lake	12.18	20

Prioritization of lakes done by weightage values using spatial analysis, complete analysis explained in methodology.

Table 3: Priority of lakes

Priority	Low	Medium	High
Weightage	5-20	21-68	68-100

Based on the weightage value priority to lakes given, low priority means less polluted, medium priority means polluted but not much, high priority means lakes are highly polluted so immediate action as to be take.

3.7 Lab analysis

Water samples were collected during field visit in pre-monsoon season, date of 18-04-2022. After collecting water samples from 8 lakes, water quality testing was carried out in laboratory with standard method.

Figure 5.1: Lab setup

Chapter-4

Material used and Methodology

This chapter and its subsections provide information on the methods employed in this study in order to achieve the stipulated objectives. This includes details on how the in situ collection of physio-chemical parameters is conducted and details of the instruments involved with this. All workings with remote sensing including the acquisition of remote sensing imagery and the estimation of physio-chemical parameters from the remotely sensed images are also discussed. Finally, an overview of the methods used for accuracy assessment is given. All results that are generated following this methodology for this study are presented in the results chapter. The overall methodological process followed over the course of the study is simplified.

4.1 Data source used

In this project work different remote sensing data were used to Estimate of water quality parameters. Data used in this work are listed below:

Table 4 : List of data used

SL NO	Data used	Date of acquisition	Data Source	Resolution	Purpose
1	Sentinel 2A MSI Satellite image	18-4-2022	USGS earth explorer	10-60 m	• Band indexing • Regression analysis • Estimation of water quality parameter
2	Lab analysed data	18-4-2022	Laboratory	-	• Comparison with estimated values

4.1.1 Satellite Imagery

Monitoring water quality parameters and their ecological effects in transitional waters is usually performed through in-situ sampling programs. These are expensive and time-consuming, and often do not represent the total area of interest. Remote sensing techniques offer enormous advantages by providing cost-effective systematic observations of a large water system. Most of the study evaluates the potential of water quality monitoring using Sentinel-2 observations through an algorithm inter comparison exercise and time series analysis of different water quality parameters. Results suggest that Sentinel-2 is useful for monitoring some parameters in a highly dynamic system

4.1.2 Satellite Description

SENTINEL-2A and SENTINEL-2B have both been launched with the European launcher VEGA. The satellite lifespan is 7.25 years, which includes a 3 month in-orbit commissioning phase and revisiting time 2 to 5 days. Batteries and propellants have been provided to accommodate 12 years of operations, including end of life de-orbiting manoeuvres.

Two identical SENTINEL-2 satellites operate simultaneously, phased at 180° to each other, in a sun-synchronous orbit at a mean altitude of 786 km. The position of each SENTINEL-2 satellite in its orbit is measured by a dual-frequency Global Navigation Satellite System (GNSS) receiver. Orbital accuracy is maintained by a dedicated propulsion system.

The SENTINEL-2 satellite system was developed by an industrial consortium led by Astrium GmbH (Germany). Astrium SAS (France) is responsible for the Multispectral Instrument (MSI).

4.1.3 Data Products

Table 5: Sentinel-2 products available for users are listed in the product types.

Name	High-Level Description	Production and Distribution	Data Volume
Level-1C	Top-Of-Atmosphere reflectance in cartographic geometry	Systematic generation and online distribution	~600MB (each 100km x 100km$_2$)
Level-2A	Bottom-Of-Atmosphere reflectance in cartographic geometry	Systematic and on-user side (using Sentinel-2 Toolbox)	~800MB (each 100km x 100km$_2$)

For this study, among these two products sentinel 2A MSI satellite image used for estimation of water quality of lakes

4.1.4 Spectral bands for the Sentinel-2A sensors

The Sentinel 2A satellites have a Multi-Spectral Instrument (MSI) with 13 spectral bands that range from the visible range to the shortwave infrared (SWIR). Groups come in factor goals from 10 to 60 meter and their wavelength is resolved based on specific purposes.13 Spectral bands are listed below

Table 6: Sentinel 2A MSI all bands with wavelength and resolution

Sentinel-2 bands	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
Band 1 – Coastal aerosol	442.7	21	60
Band 2 – Blue	492.4	66	10
Band 3 – Green	559.8	36	10
Band 4 – Red	664.6	31	10
Band 5 – Vegetation red edge	704.1	15	20
Band 6 – Vegetation red edge	740.5	15	20
Band 7 – Vegetation red edge	782.8	20	20
Band 8 – NIR	832.8	106	10

Band 8A – Narrow NIR	864.7	21	20
Band 9 – Water vapour	945.1	20	60
Band 10 – SWIR – Cirrus	1373.5	31	60
Band 11 – SWIR	1613.7	91	20
Band 12 – SWIR	2202.4	175	20

4.1.5 In-situ data

17 ground based Water samples were collected during field visit and all samples are sent for laboratory analysis, study of water quality parameters by remote sensing done with these lab results.

4.2 Software Used

In this section explain about software used, different software used to process the remote sensing data and some statistical analysis, software used in this work is listed below in table 7:

Table 7: software used

SL. NO	Software used	Version	Purpose
1	ArcGIS	10.5 version	Band indexing(Raster calculator) Water quality parameter mapping
2	JASP	0.16.3.0 version	All statistical analysis done including RMSE, derivative analysis, correlation, etc.

4.2.1 ArcGIS 10.5

ArcGIS is a general purpose GIS license software system developed by ESRI, The company is headquartered in Redlands, Californi. It is an extensive and integrated software platform technology for building operational GIS. It is a geographical information system (GIS) software that allows handling and analyzing geographic information by visualizing geographical statistics through layer building maps.

In this project, ArcGIS 10.5 was used for band indexing and mapping by using the exported output.

4.2.2 JASP software

JASP is a free and open-source program software for statistical analysis supported by the University of Amsterdam. It is designed to be easy to use, and familiar to users of SPSS. It offers standard analysis procedures in both their classical and Bayesian form. and it is one of the statistical analysis software.

In this project, JASP 0.16.3.0 version was used for regression and other statistical analysis.

4.3 Methodology

This includes details on how the lakes are selected and in-situ collection of physio-chemical water parameters is conducted, All workings with remote sensing including the acquisition of remote sensing imagery and the estimation of physio-chemical parameters from the remotely sensed images, And all the results that are generated from using these methodology's for the study.

4.3.1 Lakes Prioritization

In Bengaluru there are 291+ lakes are there. In that water quality study done by weightage values using spatial analysis based on various parameters.

Table 8: Distribution of weightage value for each parameter of lake

SL NO	Parameter	Maximum weightage	Sub Parameter	Priority weightage
1	Status	30	Polluted	30
			Muddy	20
			Green/Sewage	15
			Clean/clear	5
2	Area (ha)	20	More than 5	20
			More than 3	15
			More than 1	10
			Less than 1	5
3	Type	20	Seasonal	20
			Perennial	10
4	Depth (m)	10	More than 1m	10
			Less than 1m	5
5	Custodian	10	BBMP	10
			BDA	8
			ZP	7
			KFD	6
			MI/LDA	5
6	Inlets	10	More than 3	10
			Less than 3	5

4.3.2 Sentinel 2A MSI processing in ArcGIS

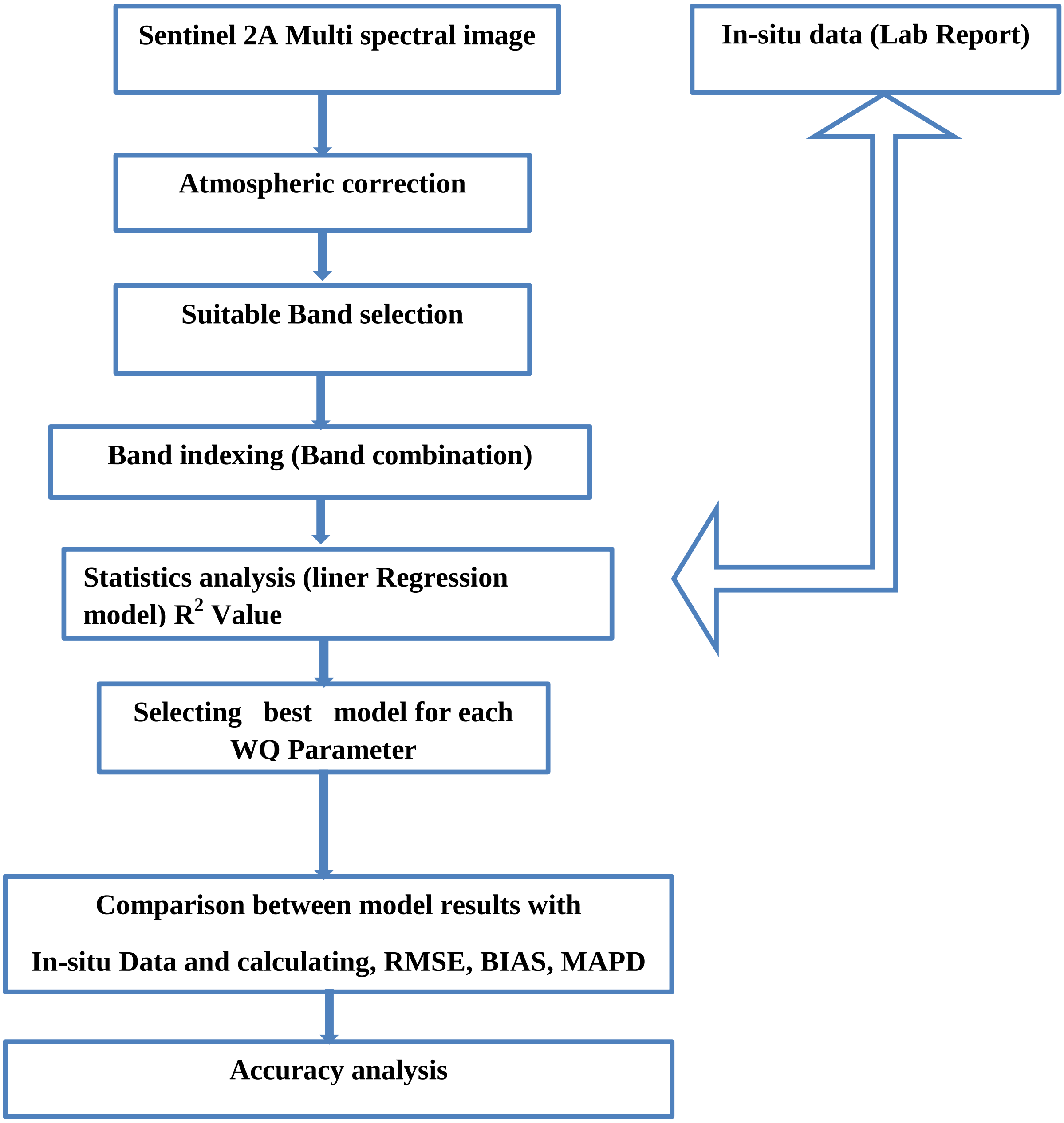

Figure 6: Flow chart for water quality estimation

Sentinel 2A MSI image were obtain from USGS earth explorer date of 18-April-2022 above Flow chart provides information on the methods employed in this study. Flow chart includes details on how the Sentinel image used and suitable band selection for developing linear regression model with in-situ data for estimation of water quality parameters from the Sentinel 2A MSI satellite image. Finally, an overview of the methods used for accuracy analysis.

4.4 Statistics analysis

Different statistical analyses were applied in this project work to estimate water quality parameters, those are explained below:

4.4.1 Band Indexing

An index is basically a ratio of values in different bands to measure how high or low a reflectance of a particular feature and selection of Suitable band ratio for estimation of water quality parameter. Different band ratio are listed below

Table 9: Different band indexing for different parameter

SL NO	WQ Parameter	Band index	Band index wavelength(nm)	Bands Name
1	Turbidity	B3/B4 B5/B3 B5/B4 B3/B1 B5/B2	560/665 665/560 705/665 560/443 705/490	Green/Red VRE/Green VRE/Red Green/Coastal aerosol VRE/Blue
2	Total suspended solids	B4/B8a B4/B3 B2/B4 B8a/B3	665/865 665/560 490/665 865/560	Red/VGE Red/Green Blue/Red VRE/Green
3	pH	B1/B3 B1/B6 B6/B3 B6/B8 B8a	443/560 443/740 740/560 740/842 865	Coastal aerosol/Green Coastal aerosol/VRE VRE/Green VRE/NIR Vegetation Red Edge
4	Dissolved oxygen	B3/B4 B8/B9 B3/B5 B8/B10 B9/B11	560/665 842/945 560/705 842/1375 945/1610	Green/Red NIR/SWIR Green/VRE NIR/SWIR Water Vapour/SWIR

4.4.2 Model development

Development of remote sensing techniques for monitoring water quality began in the early 1970s. These early techniques measured spectral and thermal differences in emitted energy from water surfaces. Generally, empirical relationships between spectral properties and water quality parameters were established, Developed an empirical approach to estimate water quality. The general forms of these empirical equations are Y=AX+B where Y is the remote sensing measurement (i.e., radiance, reflectance, energy) and X is the water quality parameter of interest (i.e., suspended sediment, DO, pH). A and B are empirically derived factors. In empirical approaches statistical relationships are determined between measured spectral/thermal properties and measured water quality parameters. Often information about the spectral/optical characteristic of the water quality parameter is used to aid in the selection of best wavelength(s) or best model in this empirical approach. The empirical characteristics of these relationships limit their applications to the condition for which the data were collected. Such empirical models should only be used to estimate water quality parameters for water bodies with similar conditions

Groups of calculations were applied for water quality parameters retrieval from sensing data that is experimental calculations, theoretic calculations, and their combinations. Because of the complexity of the theory and the trouble of estimation, many individuals were all the while utilizing experimental calculations. The linear, logarithmic, quadratic, cubic power, growth, and exponential models between the in-situ measurement of every single band DN values and combination of all band DN values were calibrated respectively, with the least-squares technique to find the best fitting model for parameter estimation. Finally, the determination coefficients (R^2) and estimated standard errors (SE) and Root mean square error (RMSE) of all the calibrated models are compared to determine the best-fitting model.

Linear Regression models were developed by correlating measured Water quality parameter and corresponding pixel DN/ index value (Ref: Jerry C, 2003) [12]

4.4.3 Root mean Square error

The Root-mean-square error (RMSE) is a frequently used measure of the differences of between values predicted by a model and the values observed. The RMSE addresses the square base of the second sample moment of the differences between predicted values and observed values or the quadratic mean of these differences. When the calculations are performed over the data sample that was used for estimation and are called error (or prediction errors) when computed out-of-sample. The RMSE totals the aggregate the magnitudes of the errors in predictions for various data points into a single measure of predictive power. RMSE is a measure of accuracy, to compare forecasting errors of different models for a particular dataset.

RMSD is always non-negative, and a value of 0 would indicate a perfect fit to the data. In general, a lower RMSD is better than a higher one. However, comparisons across different types of data would be invalid because the measure is dependent on the scale of the numbers used.

The intention behind performing the regression analyses is to imagine the regression possibilities between the actual and the remotely sensed assessed water quality parameters. In this way, the actual parameters will be plotted against the assessed parameters and root mean square error (RMSE) values are utilized to acquire the best fit. RMSE is obtained as follows: (Ref: Giulia Sent, 2021) [5]

$$\text{RMSE} = \sqrt{\frac{\sum_{i=0}^{n}(E_i - A_i)^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1) \text{ (Ref: Giulia Sent, 2021)[5]}$$

Where

E_i = is the Estimated value A_i = is the in-situ values n = Number of samples

4.4.4 BIAS (bias error)

Bias calculation is used to get difference between the true parameters of a Water quality and the statistics used to estimate those parameters.

$$\text{BIAS} = \frac{1}{n}\sum_{i=1}^{n}(E_i - A_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2) \text{ (Ref: Giulia Sent, 2021)[5]}$$

Where

E_i = is the Estimated value A_i = is the in-situ values n = Number of samples

4.4.5 Mean absolute percentage difference (MAPD)

MAPD is the mean absolute percentage difference is a relative error measure that uses relative errors to enable you to compare forecast value between actual values.

$$\mathrm{MAPD} = \frac{1}{n}\sum_{i=1}^{n} \frac{E_i - A_i}{A_i} \times 100 \ldots\ldots\ldots\ldots(3)$$ (Ref: Giulia Sent, 2021)[5]

Where

E_i = is the Estimated value A_i = is the in-situ values n = Number of samples

Chapter-5

Result and discussion

This chapter and its subsections serve as a collection for all the results produced throughout this project work. This starts with Lake Prioritization and the inclusion of all variables descriptive statistical results that are extracted from remote sensing and lab testing. The results of the remote sensing estimation algorithms for each physico-chemical parameter are also given, with this mapping also done for each parameter

5.1 Lakes Prioritization

Taking considering of status (condition), area, type (sessional/perennial), Depth, Custodian, Inlets (total number of inlets) of the lakes, Prioritization of lakes done by giving a weightage value to the each parameter. Based on the weightage value selection of lakes for study done, selected lakes for study shown below:

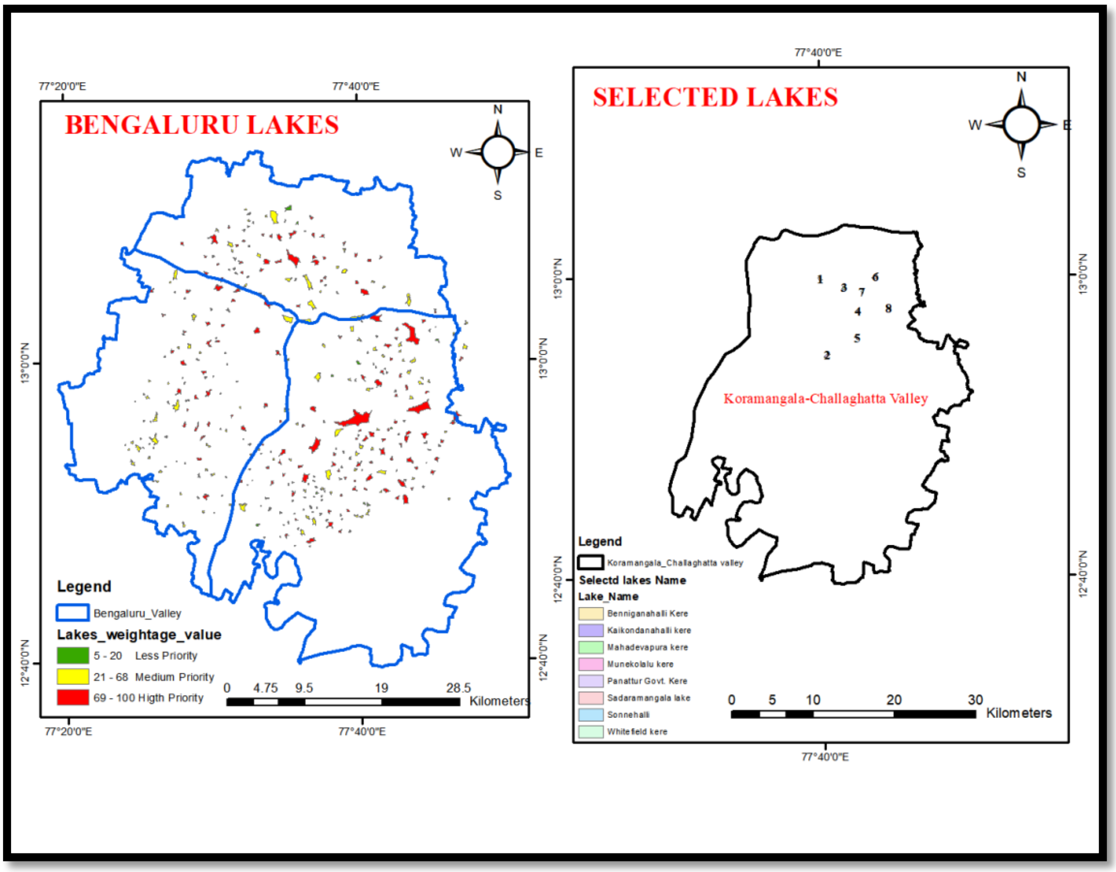

Figure 7: Lakes Prioritization lakes map

Table 10: lakes with weightage value

SL.NO	Selected lakes name	Weightage value
1	Sonnenahalli kere	88(H)
2	Whitefield kere	85(H)
3	Kaikondrahalli lake	83(H)
4	Panattur Govt. Kere	83(H)
5	Mahadevapura kere	71(H)
6	Munekolalu lake	71(H)
7	Sadaramangala lake	61(M)
8	Benniganahalli Lake	20(L)

These lakes are comes under Kormangala-Challaghatta Valley

5.1.1 Lab analysis

From the selected water samples were collected during pre-monsoon season and sent it for laboratory test to know actual water quality of collected samples

Table 11: Actual water quality lab analysis of collected samples

Sample Code	Lake Name	pH	Dissolved Oxygen (mg/l)	Turbidity (NTU)	Total Suspended Solids(mg/l)
668P	Benniganahalli Lake	8.71	8.5	15.98	75
734O	Mahadevapura kere	9.79	7.6	35.76	147
734P2	Mahadevapura kere	9.57	8	35.76	118
734P3	Mahadevapura kere	9.79	7.9	32.55	132
734I2	Mahadevapura kere	9.56	7.8	36.24	129
601P	Munekolalu lake	9.19	5.1	55.99	106
601I	Munekolalu lake	8.8	5.5	47.56	104
565O	Kaikondrahalli lake	9.03	5.6	77.42	349
565I1	Kaikondrahalli lake	8.94	3.9	108.1	297
565P2	Kaikondrahalli lake	9.78	5.8	76.35	344
612P2	Panattur Govt. Kere	8.96	5.5	8.3	133
764P2	Sonnenahalli kere	9.78	7.4	25.78	386
788I1	Whitefield kere	9.21	5.3	292.1	147
788C	Whitefield kere	7.93	4.8	315.3	49
758P2	Sadaramangala lake	9.38	4.8	13.53	39
758I2	Sadaramangala lake	10.84	5.8	9.67	55
758I3	Sadaramangala lake	10.69	5.2	12.22	154

Water samples were collected during field visit in pre-monsoon season. After collecting samples Lab analysis done in standard method in laboratory to get actual value of water samples. Graphically results shown below:

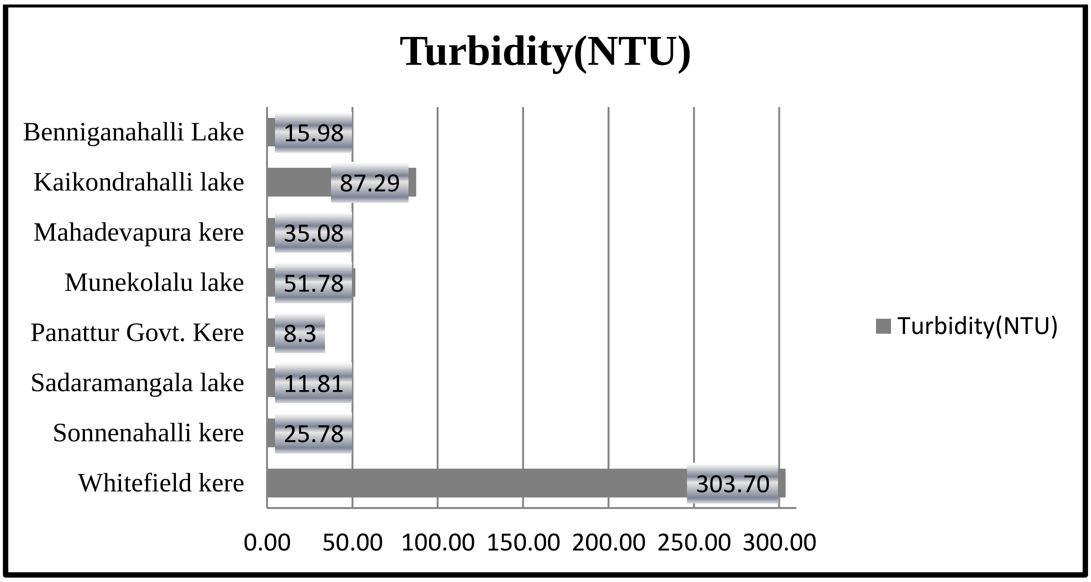

Figure 8: lab analysis of Turbidity

As per the laboratory analysis of water samples, Whitefield Lake having higher turbidity level of 303.70 NTU compare to other lakes and panattur govt lake having less turbidity of 8.3 NTU. Remain lakes are having turbidity level of less than 100 NTU.

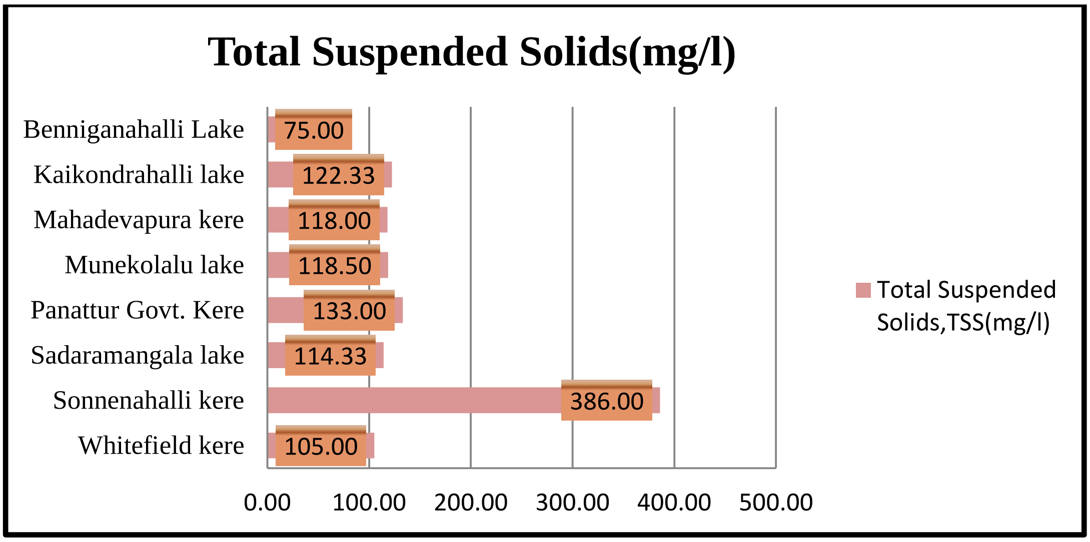

Figure 9: lab analysis of Total suspended solids

As per the laboratory analysis of water samples, Sonnenahalli Lake having higher Total suspended solids level of 386 mg/l compare to other lakes and Benniganahalli lake having less Total suspended solids of 75 mg/l. Remain lakes are having Total suspended solids level between 75 to 386 mg/l.

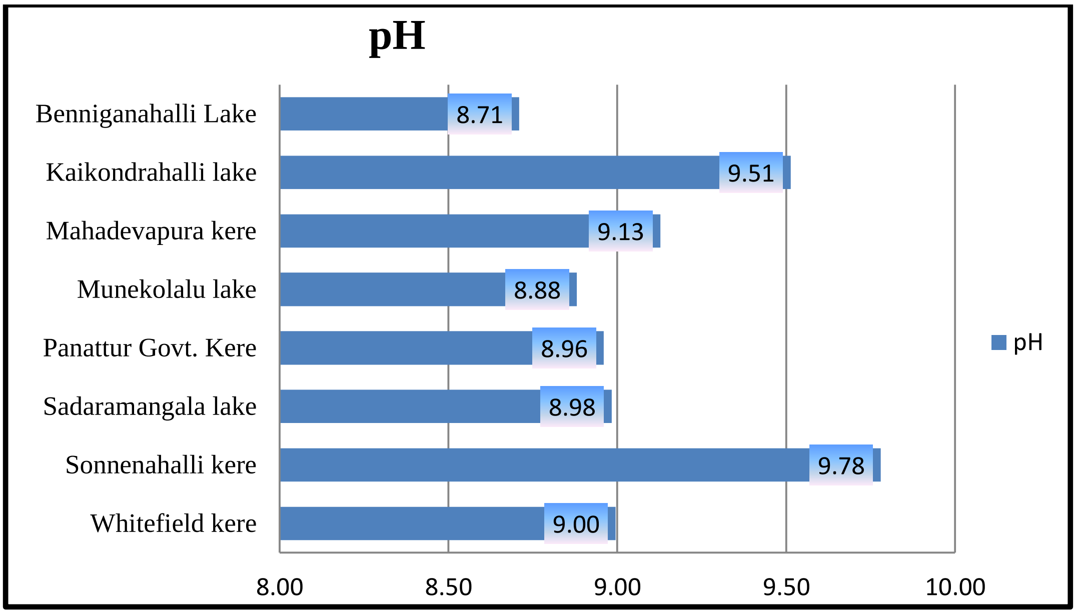

Figure 10: lab analysis of pH

As per the laboratory analysis of water samples, Sonnenahalli Lake having higher pH level of 9.78 compare to other lakes and Benniganahalli lake having less pH of 8.71. Remain lakes are having pH level between 8.71 to 9.78.

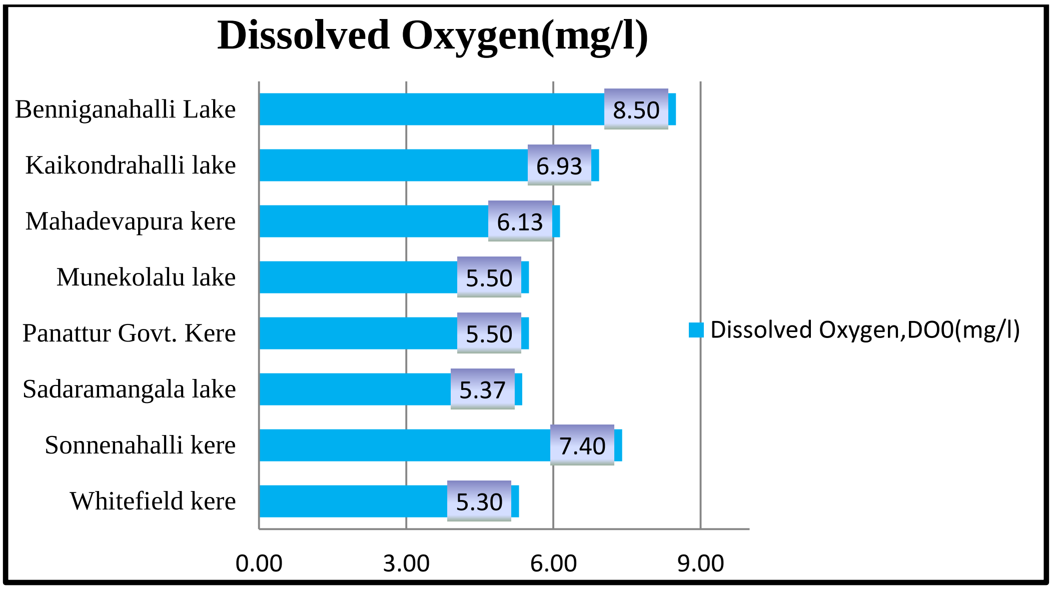

Figure 11: lab analysis of Dissolved oxygen

As per the laboratory analysis of water samples, Benniganahalli Lake having higher Dissolved oxygen of 8.5 mg/l compares to other lakes and Whitefild Lake having less Dissolved oxygen of 5.3 mg/l. Remain lakes are having Dissolved oxygen level between 5.3 to 8.5 mg/l.

5.2 Results of Sentinel 2A MSI

5.2.1 Reflectance of sample in sentinel 2A Multi spectral image

The shape and nature of the water reflectance curves depends upon the physio-chemical quality parameter of the water. The important physio-chemical quality parameter that influence the reflectance curve are turbidity, total suspended solid, dissolved oxygen, pH, TDS, Chl-a etc. results in the absorption of incident radiation and is seen on reflectance curves as troughs.

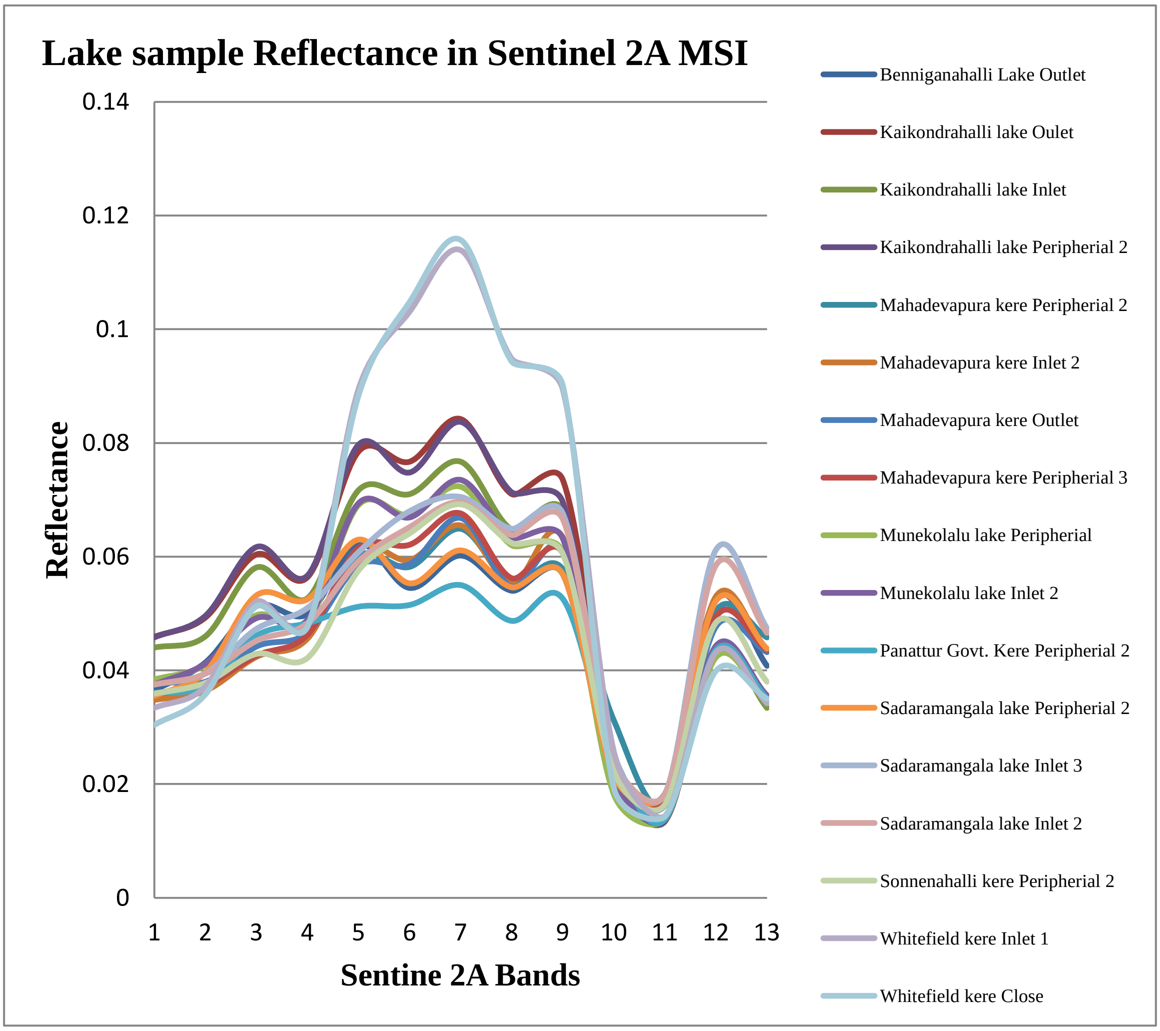

Figure 12: Lake Water sample Reflectance in Sentinel 2A MSI

Fig 12: shows reflectance spectra of water samples of lakes at different Point (inlet, outlet, peripheral) in each Sentinel Bands. Based on water quality of lakes reflectance curve also changes if pollution is more in Lake Reflectance of curve also increase,

5.2.2 Development of the Regression Model for Estimation of Water Quality parameter

The fig: 12 show the spectral reflectance curve for the water samples of lakes at different points (inlet, outlet, peripheral). The linear regression modelling was applied to estimate each water quality parameter. The 17 water samples were used for the development of linear regression model. Five different Band indexing (band ratio) were applied with the actual water quality parameter obtain from lab report. In that best fit models for different parameter shown in table 12.

Table 12: Regression models for each water quality parameter

SL.No	Parameter	Bands Index	Wavelength index	Bands Name Index	Model	R^2
1	Turbidity(NTU)	B5/B2	R705/R490	VRE/Blue	y = 294.65x - 423.75	0.91
2	Total suspended solids(mg/l)	B2/B4	R490/R665	Blue/Red	y = 1810.3x - 1306.8	0.6267
3	pH	B8A	R865	VRE	y = 46.091x + 6.3924	0.4813
4	Dissolved oxygen(mg/l)	B9/B11	R945/R1610	Water vapour/SWIR	y = 8.3732x + 2.3716	0.60

5.3 Turbidity value

To estimate turbidity from sentinel 2A MSI image Different band indexing were developed to get best fit liner regression model. In that Best fit model shown below:

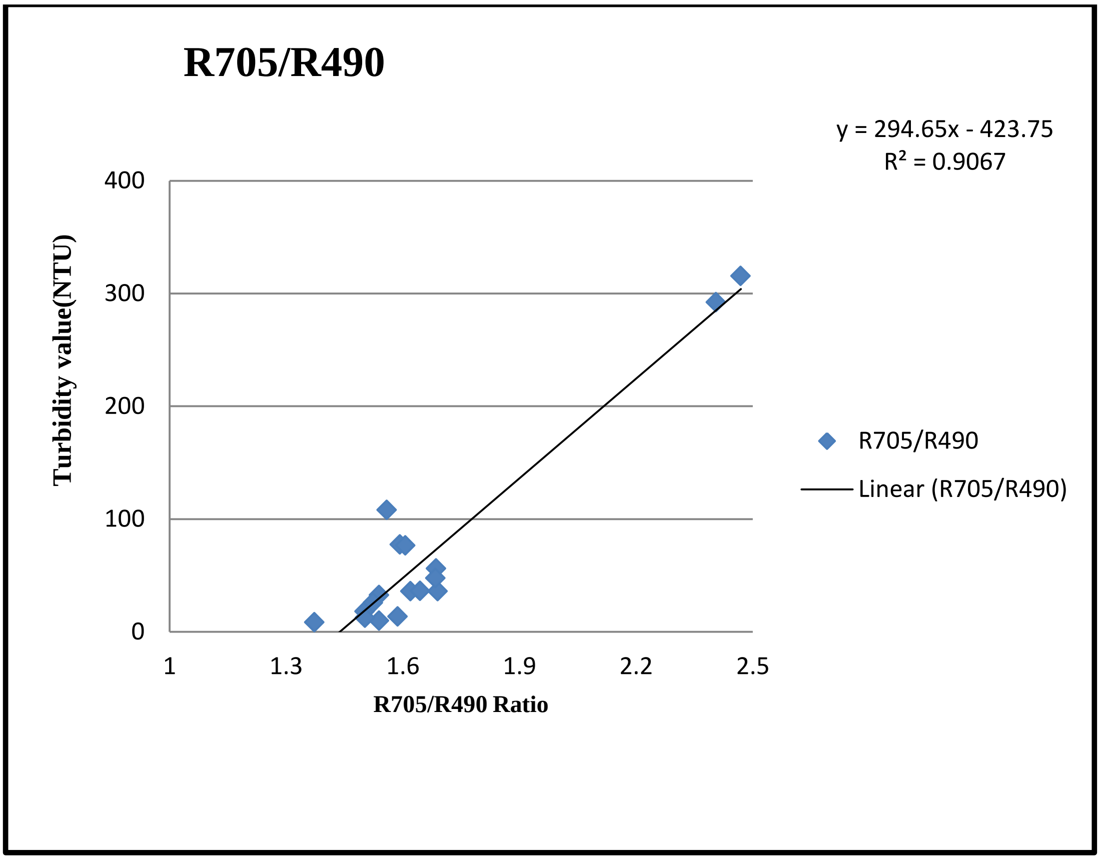

Figure 13: Liner regression model of actual turbidity value with R705/R490 (Vegetation red edge /Blue) band ratio.

For calculating Turbidity value from Satellite image developed by combination of different bands index. After conducting many excises, in that, Vegetation Red Edge and Blue band index gives good regression model, i.e. R^2=0.91. And also RMSE, BIAS, MAPD models are calculated and the result are shows in table 13.

Table 12: Turbidity model value

Sample Code	Turbidity(NTU)	R705/R490	Model	Error	Square Error	RMSE (NTU)	BIAS	MAPD (%)
668O	17.98	1.502	18.937	0.957	0.916	14.63	0.056285	45.28
565O	77.42	1.652	63.098	-14.322	205.122			
565I1	108.1	1.709	79.717	-28.383	805.582			
565P2	76.35	1.651	62.624	-13.726	188.390			
734O	35.76	1.620	53.567	17.807	317.096			
734P2	35.76	1.610	50.507	14.747	217.477			
734P3	32.55	1.539	29.856	-2.694	7.258			
734I2	36.24	1.614	51.929	15.689	246.133			
601P	55.99	1.685	72.843	16.853	284.026			
601I	47.56	1.604	49.006	1.446	2.091			
612P2	8.3	1.504	19.323	11.023	121.507			
758P2	13.53	1.587	43.831	30.301	918.133			
758I2	9.67	1.502	18.935	9.265	85.833			
758I3	12.22	1.453	4.240	-7.980	63.673			
764P2	25.78	1.524	25.241	-0.539	0.291			
788I1	292.1	2.406	285.153	-6.947	48.265			
788C	315.3	2.469	303.822	-11.478	131.755			

Turbidity is the one of the parameter for the assessment of quality of water. In that, the accuracy assessment is based on the values of RMSE, BIAS and MAPD. In this there are 17 sample points are collected from the 8 Lakes. By calculating the value of RMSE is 14.63 NTU, BIAS is 0.056285 and MAPD is 45.28%.

5.3.1 Turbidity map from sentinel 2A MSI satellite image

After getting best model from linear regression, Turbidity map were prepared for selected lakes of Bengaluru

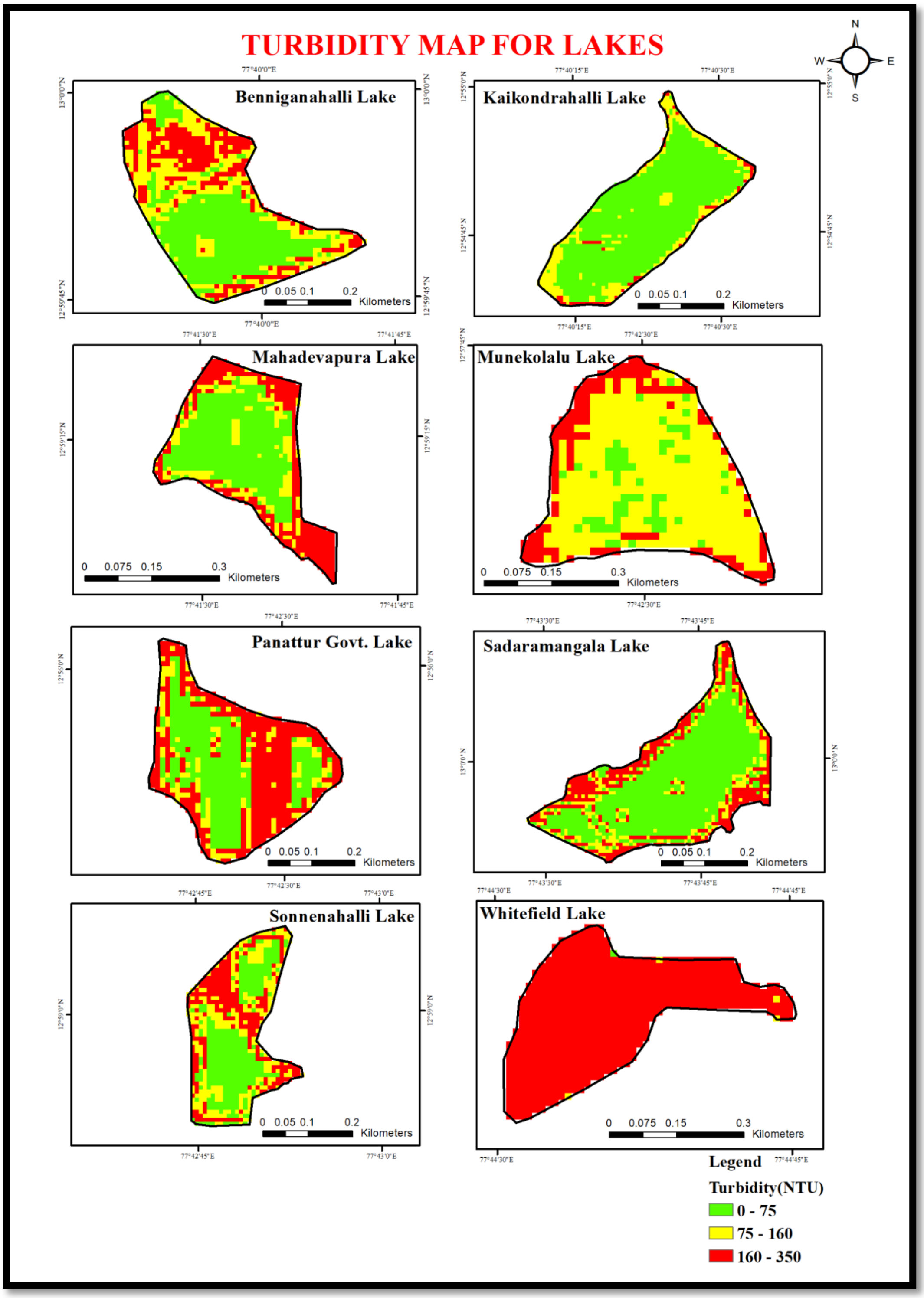

Figure 6: Turbidity maps for different lakes

5.4 Total suspended solids values

To estimate Total suspended solids from sentinel 2A MSI image Different band indexing were done to get best fit liner regression model. In that Best fit model shown below:

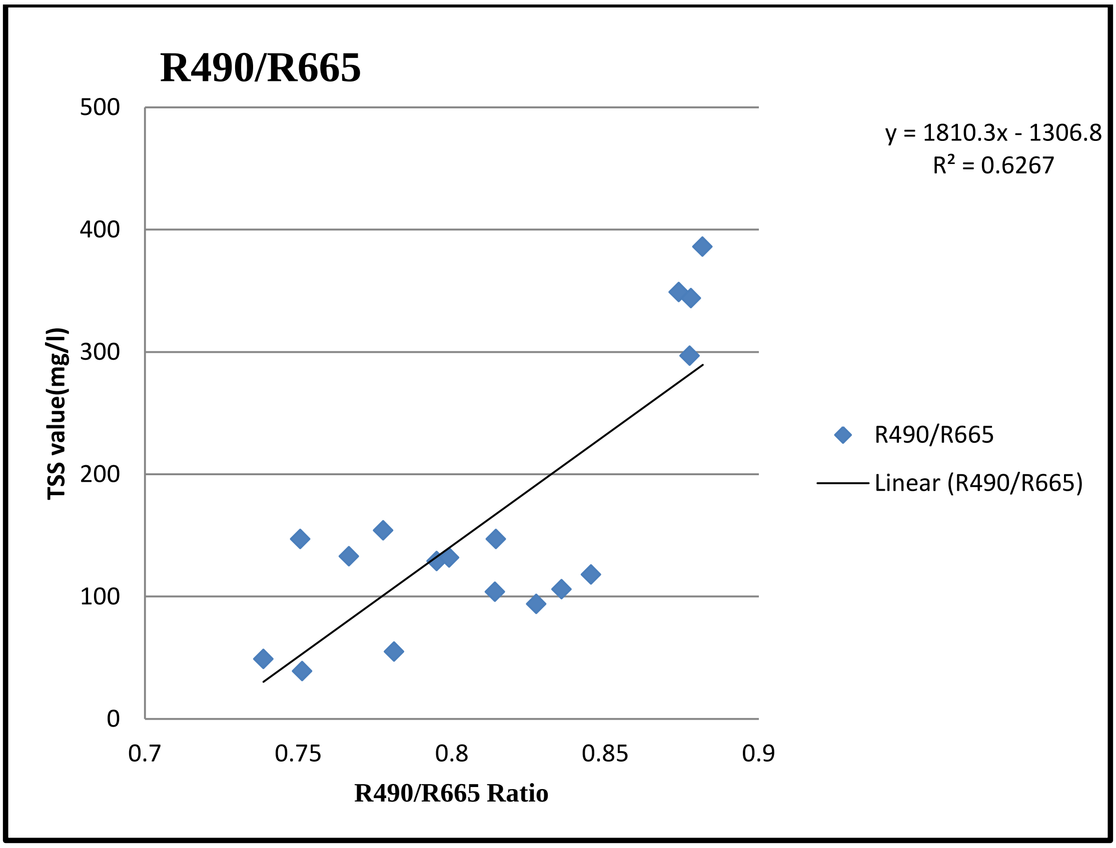

Figure 7: Liner regression model of actual Total suspended solids value with R490/R665 (Blue/Red) band ratio.

For calculating Total suspended solids value from Satellite image developed by combination of different bands index. After conducting many excises, in that, Blue and Red band index gives good regression model, i.e. R^2=0.62. And also RMSE, BIAS, MAPD models are calculated and the result are shows in table 14.

Table 13: Total suspended solids model value

Sample Code	TSS	R490/R665	Model	Error	Square Error	RMSE (NTU)	BIAS	MAPD (%)
668O	94	0.828	191.281	97.281	9463.628	64.963	5.722	44.032
565O	349	0.874	275.339	-73.661	5425.967			
565I1	297	0.878	281.843	-15.157	229.727			
565P2	344	0.878	282.672	-61.328	3761.079			
734P2	118	0.845	223.611	105.611	11153.752			
734I2	129	0.795	132.675	3.675	13.502			
734O	147	0.814	167.507	20.507	420.517			
734P3	132	0.799	140.041	8.041	64.652			
601P	106	0.836	206.321	100.321	10064.334			
601I	104	0.814	167.023	63.023	3971.919			
612P2	133	0.766	80.779	-52.221	2727.069			
758P2	39	0.751	53.289	14.289	204.183			

758I3	154	0.778	101.143	-52.857	2793.892			
758I2	55	0.781	107.564	52.564	2762.959			
764P2	386	0.882	289.408	-96.592	9329.920			
788I1	147	0.751	52.078	-94.922	9010.156			
788C	49	0.739	30.385	-18.615	346.506			

Total suspended solid is the one of the parameter for the assessment of quality of water. In that, the accuracy assessment is based on the values of RMSE, BIAS and MAPD. In this there are 17 sample points are collected from the 8 Lakes. By calculating the value of RMSE is 64.963 mg/l, BIAS is 5.72 and MAPD is 44.032%.

5.4.1 Total suspended solids map of sentinel 2A MSI satellite image

After getting best model from linear regression Total suspended solid map were prepared for selected lakes of Bengaluru

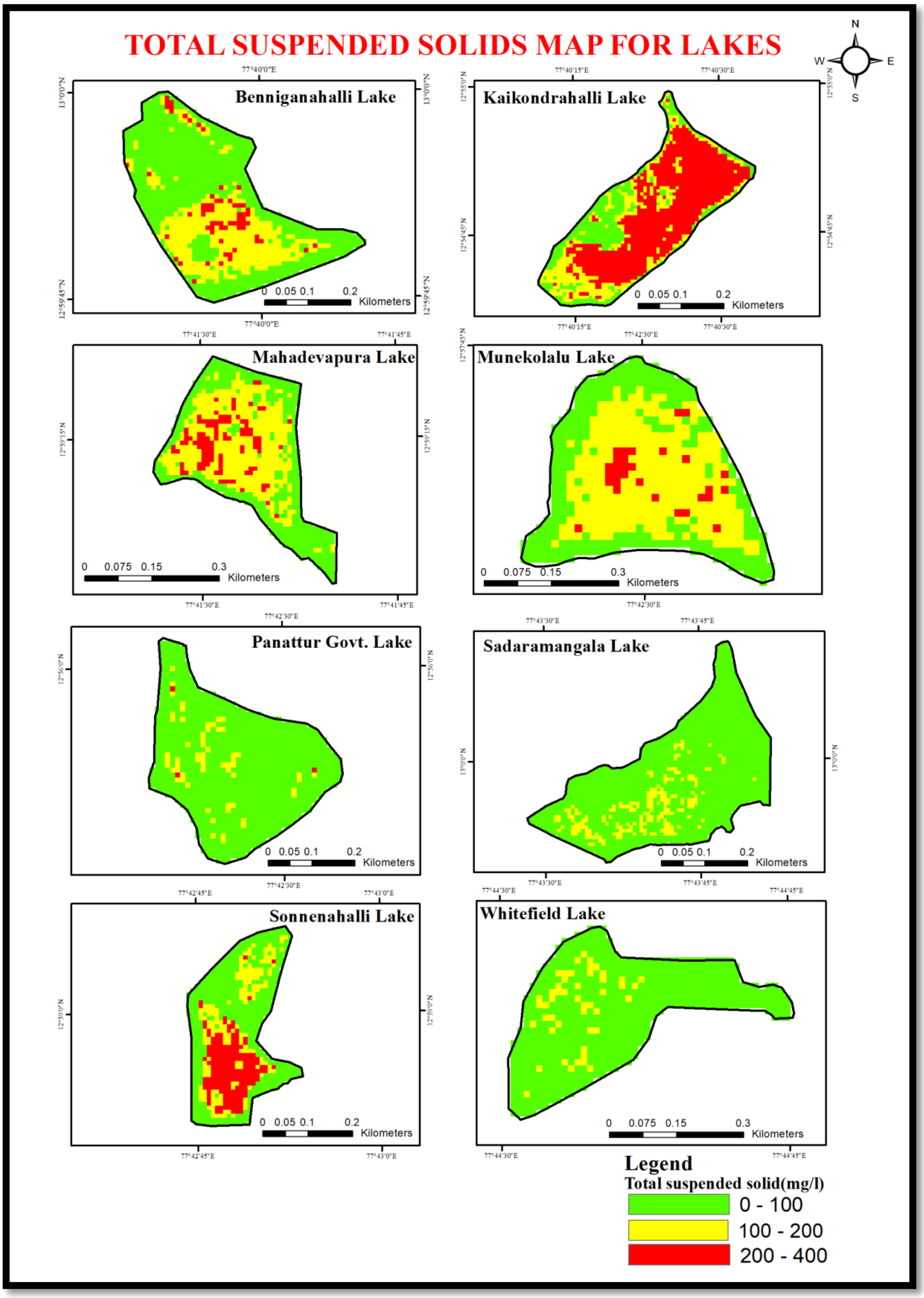

Figure 8: Total suspended solids maps for different lakes

5.5 pH values

To estimate pH from sentinel 2A MSI image Different band indexing were done to get best fit liner regression model. In that Best fit model shown below:

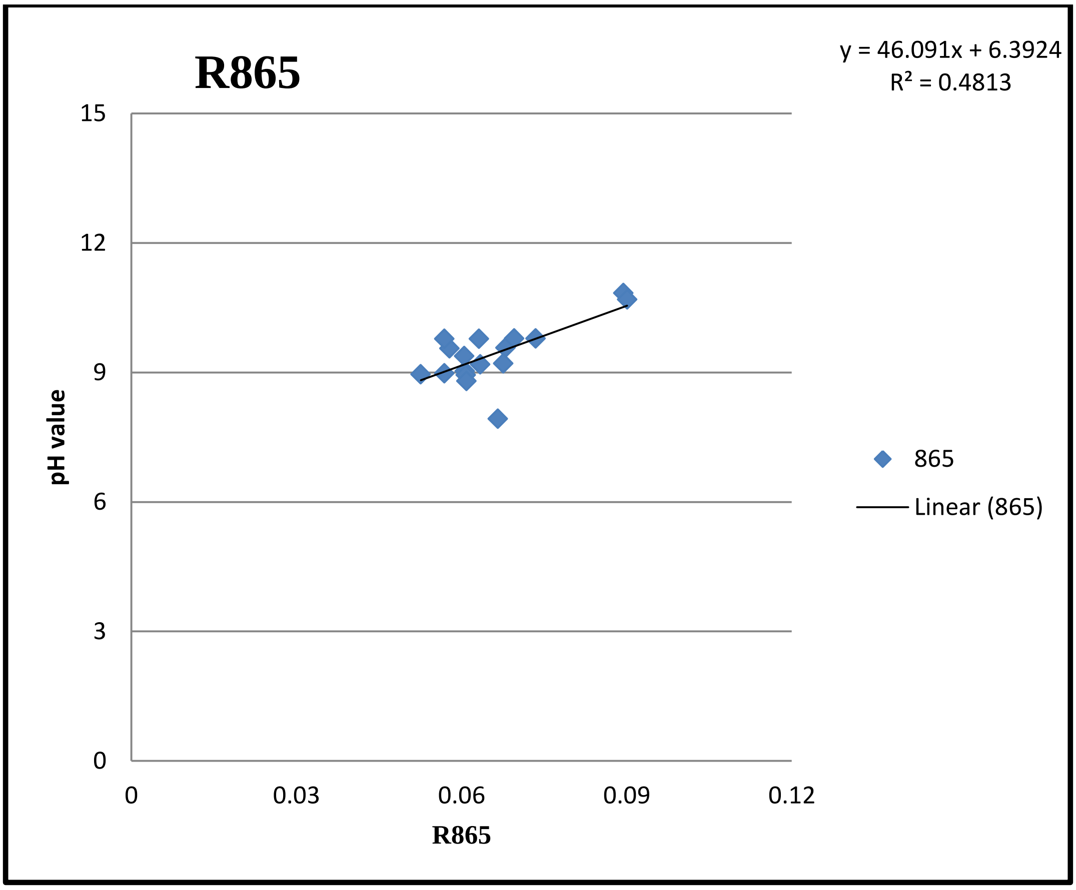

Figure 17: Liner regression model of actual pH value with R865 (Vegetation red edge) single band.

For calculating pH value from Satellite image developed by combination of different bands index. After conducting many excises, in that, single bands Vegetation Red Edge gives good regression model, i.e. R^2=0.48. And also RMSE, BIAS, MAPD models are calculated and the result are shows in table 15.

Table 15: pH model value

<table>
<tr><th>Sample Code</th><th>pH</th><th>R865</th><th>Model</th><th>Error</th><th>Square Error</th><th>RMSE</th><th>BIAS</th><th>MAPD (%)</th></tr>
<tr><td>668O</td><td>8.98</td><td>0.057</td><td>9.015</td><td>0.035</td><td>0.001</td><td rowspan="10">0.485</td><td rowspan="10">0.002</td><td rowspan="10">3.84</td></tr>
<tr><td>565O</td><td>9.03</td><td>0.061</td><td>9.186</td><td>0.156</td><td>0.024</td></tr>
<tr><td>565I1</td><td>8.94</td><td>0.061</td><td>9.195</td><td>0.255</td><td>0.065</td></tr>
<tr><td>565P2</td><td>9.78</td><td>0.063</td><td>9.305</td><td>-0.475</td><td>0.225</td></tr>
<tr><td>734O</td><td>9.79</td><td>0.073</td><td>9.780</td><td>-0.010</td><td>0.000</td></tr>
<tr><td>734P2</td><td>9.57</td><td>0.068</td><td>9.527</td><td>-0.043</td><td>0.002</td></tr>
<tr><td>734P3</td><td>9.79</td><td>0.070</td><td>9.600</td><td>-0.190</td><td>0.036</td></tr>
<tr><td>734I2</td><td>9.56</td><td>0.058</td><td>9.056</td><td>-0.504</td><td>0.254</td></tr>
<tr><td>601P</td><td>9.19</td><td>0.063</td><td>9.315</td><td>0.125</td><td>0.016</td></tr>
<tr><td>601I</td><td>8.8</td><td>0.061</td><td>9.199</td><td>0.399</td><td>0.159</td></tr>
</table>

612P2	8.96	0.053	8.817	-0.143	0.021			
758P2	9.38	0.060	9.181	-0.199	0.040			
758I2	10.84	0.089	10.513	-0.327	0.107			
758I3	10.69	0.090	10.545	-0.145	0.021			
764P2	9.78	0.057	9.015	-0.765	0.585			
788I1	9.21	0.068	9.508	0.298	0.089			
788C	7.93	0.067	9.462	1.532	2.347			

pH is the one of the parameter for the assessment of quality of water. In that, the accuracy assessment is based on the values of RMSE, BIAS and MAPD. In this there are 17 sample points are collected from the 8 Lakes. By calculating the value of RMSE is 0.48, BIAS is 0.056285 and MAPD is 3.84%.

5.5.1 pH map of sentinel 2A MSI satellite image

After getting best model from linear regression pH map were prepared for selected lakes of Bengaluru

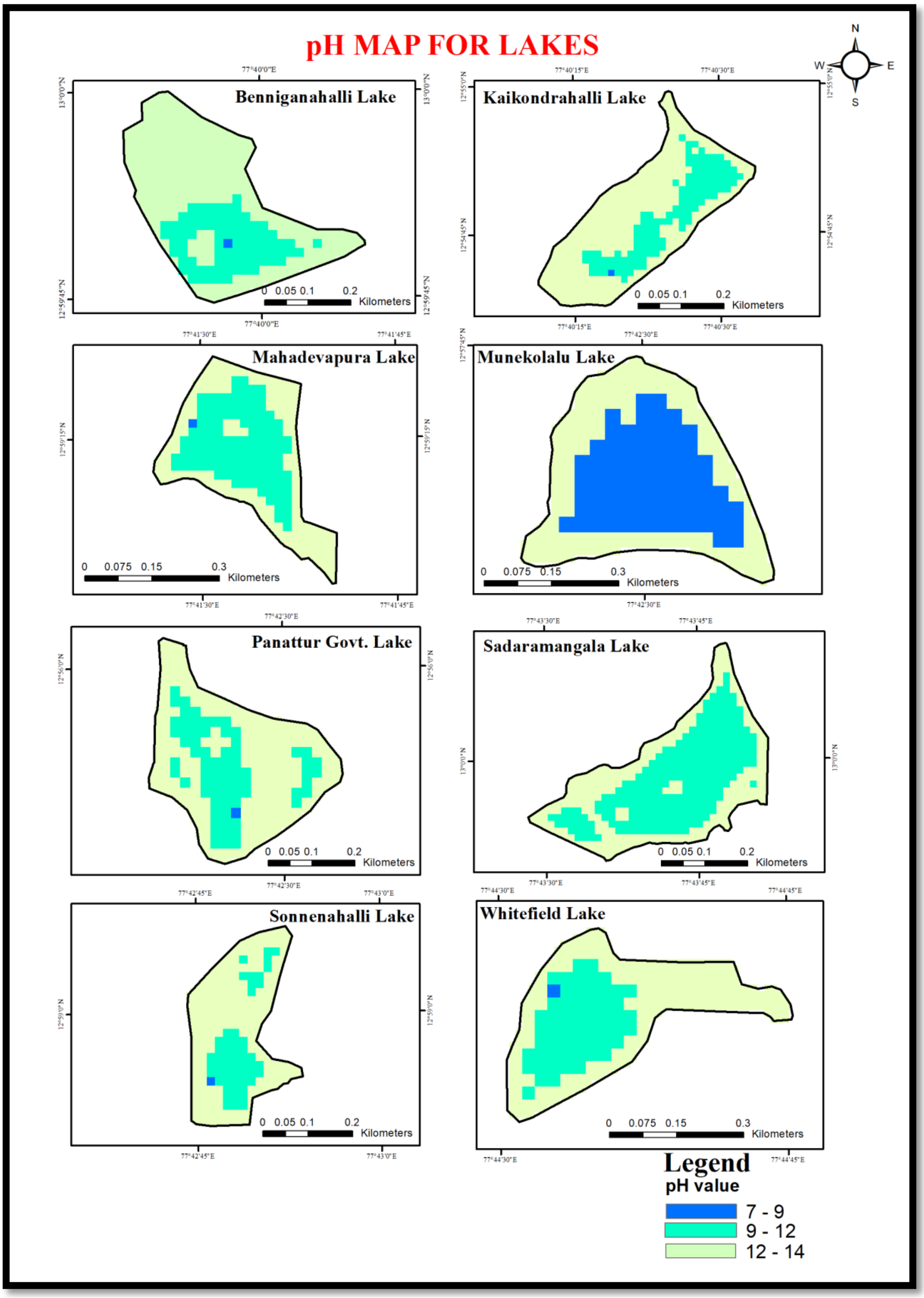

Figure 18: pH maps for different lakes

5.6 Dissolved oxygen values

After getting best model from linear regression, Dissolved oxygen map were prepared for selected lakes of Bengaluru. In that Best fit model shown below:

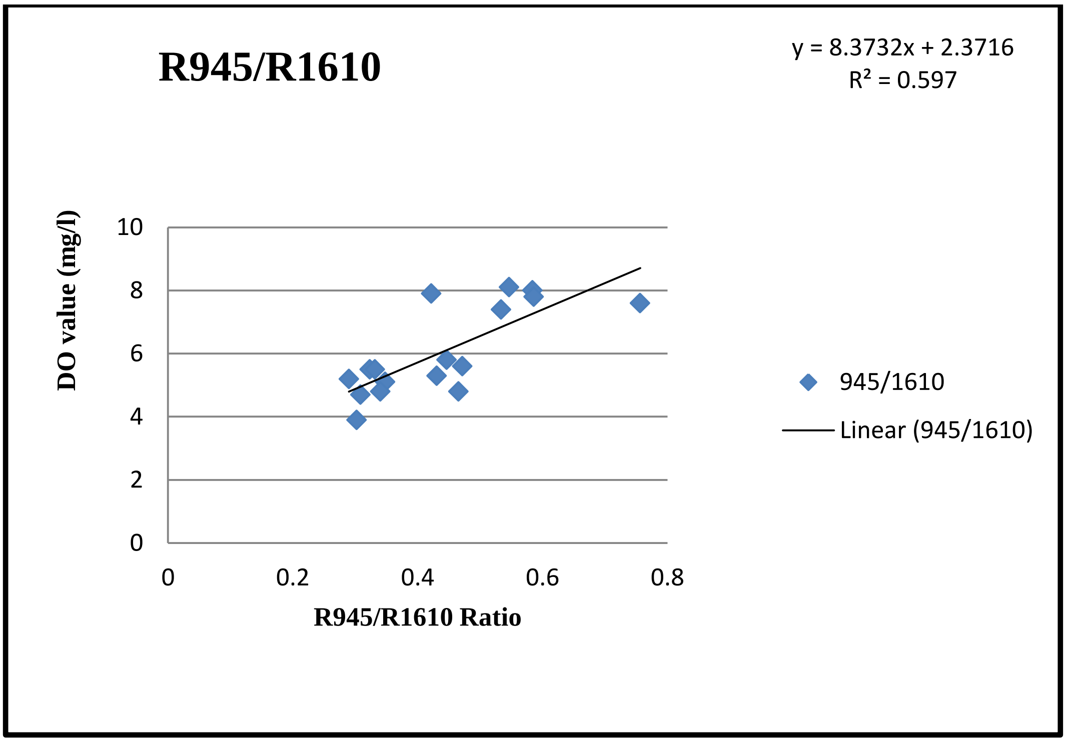

Figure 19: Liner regression model of actual Dissolved oxygen value with R560/R705 (Green/Vegetation red edge) band ratio.

For calculating Dissolved oxygen value from Satellite image developed by combination of different bands index. After conducting many excises, in that, Water Vapour and SWIR band (B2) index gives good regression model, i.e. R^2=0.55. And also RMSE, BIAS, MAPD models are calculated and the result are shows in table 16.

Table 16: Dissolved oxygen model value

Sample Code	**Dissolved Oxygen,DO$_0$(mg/l)**	**R945/R1610**	**Model**	**Error**	**Square Error**	**RMSE (mg/l)**	**BIAS**	**MAPD (%)**
668O	8.1	0.546645	6.948	-1.15123	1.32534			
565O	5.6	0.471373	6.318	0.718496	0.516237			
565I1	3.9	0.30243	4.903	1.003909	1.007833			
565P2	5.8	0.446365	6.109	0.309105	0.095546			
734O	7.6	0.756432	8.705	1.105358	1.221816			
734P2	8	0.583734	7.259	-0.74068	0.548603			

734P3	7.9	0.421846	5.903	-1.9962	3.984825	0.862	0.068	12.020
734I2	7.8	0.586026	7.278	-0.52149	0.27195			
601P	5.1	0.347939	5.284	0.184964	0.034212			
601I	5.5	0.323418	5.079	-0.42035	0.176696			
612P2	5.5	0.331591	5.148	-0.35192	0.123847			
758P2	4.8	0.340425	5.222	0.42205	0.178127			
758I1	4.7	0.308597	4.955	0.255545	0.065303			
758I3	5.2	0.289819	4.798	-0.40168	0.161351			
764P2	7.4	0.533885	6.841	-0.55807	0.311444			
788I1	5.3	0.43043	5.975	0.675674	0.456536			
788C	4.8	0.465208	6.266	1.466883	2.151744			

Dissolved Oxygen is the one of the parameter for the assessment of quality of water. In that, the accuracy assessment is based on the values of RMSE, BIAS and MAPD. In this there are 17 sample points are collected from the 8 Lakes. By calculating the value of RMSE is 0.862 mg/l, BIAS is 0.068 and MAPD is 12.020%.

5.6.1 Dissolved oxygen map of sentinel 2A MSI satellite Image

After getting best model from linear regression pH map were prepared for selected lakes of Bengaluru

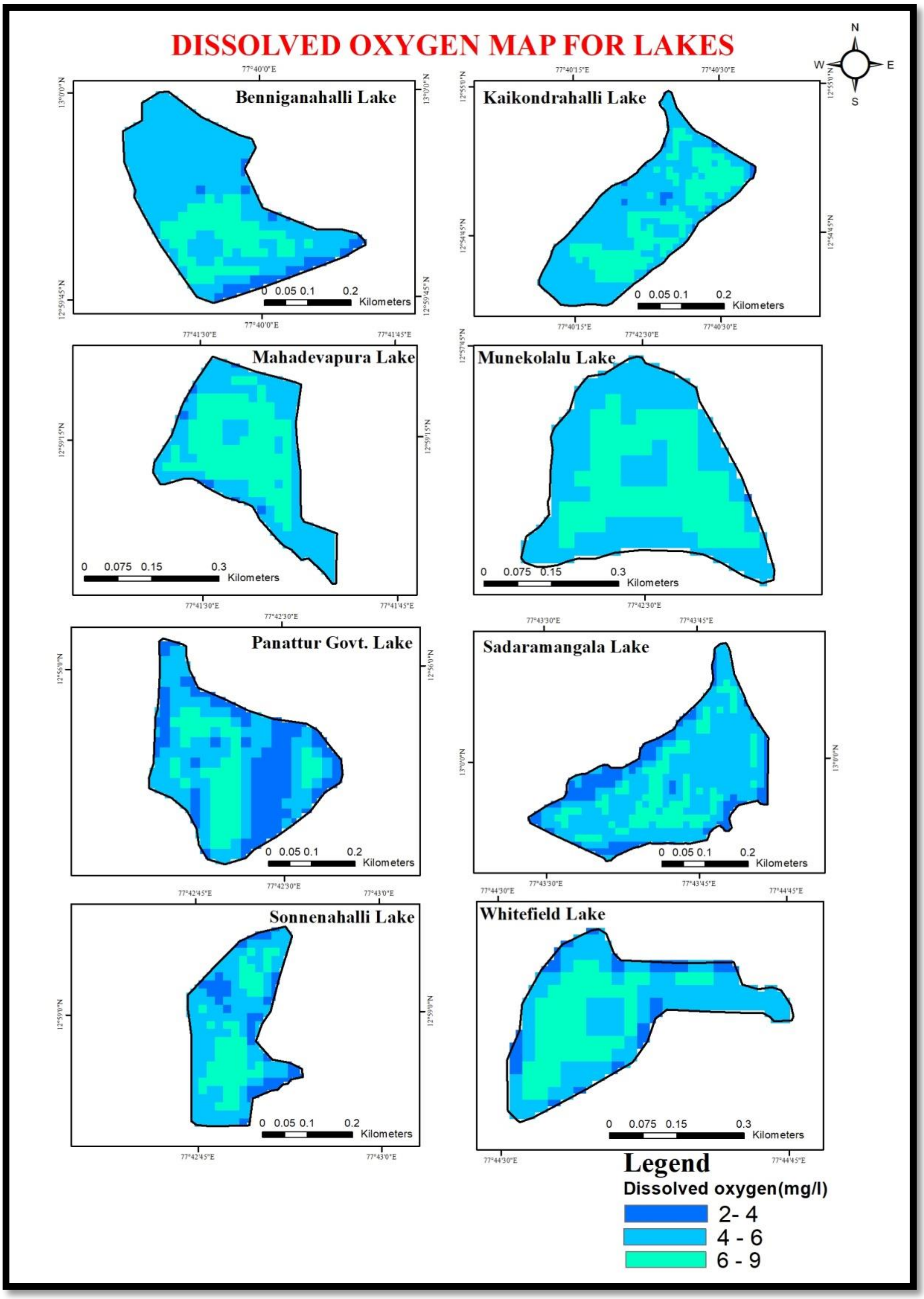

Figure 20: Dissolved oxygen maps for different lakes

Chapter 6
Conclusion

This project work undertaken to Estimate of water quality of Bangalore City lakes by using satellite image and lab analysis. The selected water quality parameters are Turbidity (TU), Total suspended solids (TSS), pH, and Dissolved oxygen (DO). This parameter can indicate water quality of lakes and shows the distribution of pollutants.

In that, by using sentinel 2A Satellite Image bands,

The Turbidity parameter: Vegetation Red Edge (R705) and Blue (R490) bands are gives best regression index models. The values becomes R^2= 0.91, RMSE = 14.63 NTU, MAPD = 45.28%.

The *Total suspended solids parameter:* Blue (R490) and Red (R665) bands giving best regression index model of R^2= 0.63, RMSE = 65 mg/l, MAPD = 44.03%.

The pH parameter: vegetation red edge (R865) single bands giving best regression model of R^2= 0.48, RMSE = 0.48, MAPD = 3.84.

The Dissolved oxygen Parameter: water vapor (R945) and SWIR (R1610) bands index giving best regression model of R^2= 0.59, RMSE = 0.86 mg/l, MAPD = 12.02%

According to Giulia sent, 2021[5] research paper, lesser RMSE and MAPD gives higher accuracy, higher RMSE and MADP gives lower accuracy, so that, The Turbidity and Total suspended solids gives less accuracy. pH and Dissolved oxygen gives higher accuracy.

So in this study by using Sentinel 2A MSI satellite image, Turbidity and Total suspended solid gives less than 60% accuracy, for pH and Dissolved oxygen gives more than 80% accuracy. As per this study sentinel 2A MSI satellite image is the suitable for the estimation of pH and Dissolved oxygen.

The KSPCB report said, “Water quality with Class A is fit for drinking without conventional treatment and Class B is fit for outdoor bathing. While under the Class D categorisation water from the lakes could be used for propagation of wildlife and fisheries, Class E is fit for irrigation.”

In Bengaluru lakes, no lake falls into the category of Class A, B, and C, some of them confirm Class D, and some lakes fall under Class E.

Considering these parameters, not a single lake in Bengaluru is fit to be a drinking water source and the entry of untreated sewage and industrial effluents into them remain the major reasons behind the contamination of these water bodies.

Acknowledgment

In this research, the data and software are used in this project was provided by *RRSC-South, Dept of Space, ISRO Bengaluru - 560 037*

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