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Modeling of Water Quality Parameters in lakes using Hyperspectral Remote sensing Technique

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Abstract: The present paper is the research work carried on to model Total Suspended Solids and Total Phosphorus using Hyperspectral Remote sensing techniques in Shamirpet lake and Miralam tank. The water quality parameters are estimated through regression models demonstrating the efficient application of Hyperspectral data for monitoring and modeling the lake waters from year 2010-14. The field Spectro-radiometer reflectance values are combined with simultaneous analytical ground data which is correlated and validated with the satellite data. The optical indicators efficiently indicate lake water quality in a very cost effective manner over spatial and temporal variability. The formulation of band ratio models is based on data collected and processed from sample locations. The trained sets of pixels extracted from hyperspectral data for pure spectra are processed for preparing water quality distribution maps. When subjected to multi-variant statistical tests of significance, the models have yielded satisfactory R^2 values. The model versus in situ analysis results demonstrated 0.785% correlation and that of model versus satellite data exhibited 0.68% mean efficiency. It is seen that the parameters TSS-850/550nm and TP- 467/560nm studied have dominant absorption bands respectively. The most appropriate bands for algorithms were selected based on correlation analysis.

Keywords: Band Ratio models, Correlation Analysis, Hyperspectral Remote sensing techniques, Regression, Water quality parameters.

I. INTRODUCTION

Water, the elixir element for survival of life on earth is at stake, posing challenge to mankind for its protection and restoration. History reveals civilizations flourished near water resources and vanished due to its scarcity, evident from the ancient scriptures which say "Jalam Jeevamrutham". But during the recent decades, human interventions causing pollution of the water sources not only threaten the water quality but also the innocent other life forms in the aquatic and terrestrial environment which are adversely affected and are been pushed away from their tranquil habitats to inclement extermination. This is the major cause for the dwindling stability of the ecosystems leading to extrapolated global catastrophic scene of environmental quality concerns. Ritchie et al., [1] emphasized the lake water quality importance, its conservation and its role in environmental protection.

The inland lake environment being strategically significant in a country's economy, the hydrological, ecological concerns and water quality frame critical value in planning of water management. The quality data is essential in regulation and enforcement of legality for maintaining the standards and protect the resource from extinction. Spatio- Temporal variability would offer much reliable information for such execution and further planning for recreation and as aesthetic resource that add to economic constancy and quality of life.

The use of remote sensing technology in monitoring inland and coastal waters date back to 1980's [2]. Models prepared by correlating the laboratory data with the satellite data can be used for predicting similar scenarios successfully. This technique is proven economically feasible and quicker in getting the results for monitoring, measuring and managing the resources at large scale [3].

In recent times, the hyperspectral remote sensing technique gained more attention due to its high spectral resolution. Santini F., et al., [4] used this technique in coastal and marine water applications. Dekker [5] used empirical and semi-empirical & analytical methods based techniques for qualitative and quantitative assessment. Later empirical regression formulas from spectro radiometer data using spectral reflectance ratios as independent variables are developed by many investigators. So, location specific models utilizing the field data are now prominent in predicting the water quality parameters. Addition of in situ samples and field reference spectra would enhance the capability of hyperspectral remote sensing technique in quantizing the quality constituent more accurately.

In this study the reflectance measured by the spectroradiometer and spectra extracted from the imagery are used to formulate the regression models for the prediction of the concentrations of the Total Phosphorus and Total suspended solids.

II. STUDY AREA

The Study areas are the lakes in the Hyderabad metropolitan which are chosen on the basis of the size, relevance of the lake and satellite coverage. The below given Fig: 1 reveals the location of the lakes chosen for the study. The lakes considered for the study are covered in the HMDA boundary of the Hyderabad, capital city of state Telangana of India. The lakes are Shamirpet lake and Miralam tank.

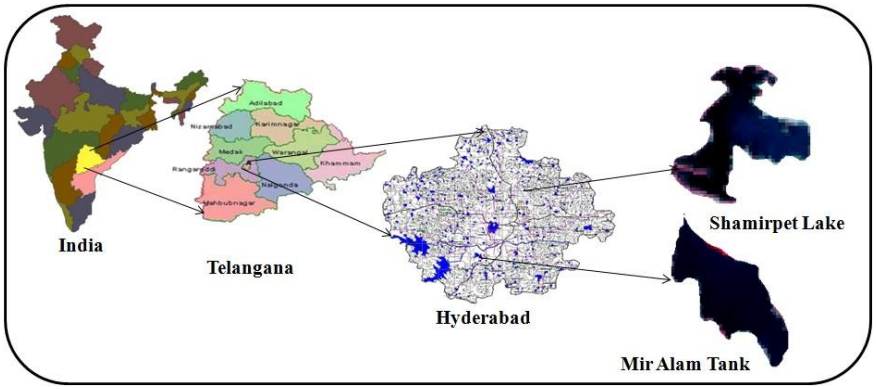

Fig: 1Location map of the Study areas

Hyderabad known as the city of lakes is suffering with scarcity of drinking water and water related problems. When pondered over the previous studies relating the present scenario of lake water quality in Hyderabad, it is evident that the irresponsible and neglected activities and attitude of the residents and the authorities were to be blamed. Over the years all these drinking water and irrigation sources are shrunk and deteriorated in their quality. The degree of disappearance and degradation is due to the drastically changed land use by the overwhelming populations and raising industries. Here elevates the necessity of regular monitoring for tracing the encroachers, disappearing recharge points and planning effective legislation with respect to these lakes.

III. METHODOLOGY

The methodology of the present study has been framed in such a way that the research objective of the study is met in a structural manner. The initial step of the research is suitable geometric and atmospheric correction model being applied on the Hyperion data, since the spectral data collected by satellite sensors are influenced by atmospheric and geometric variations. Further the spectral signatures extracted were processed in a sequential manner through MNF, PPI, n-D and finally to the end- members which emphasizes the water constituents as the pure pixels categorized accordingly.

The next step was the water sampling from the selected lakes in the study area with simultaneous collection of the field signatures with the ASD spectroradiometer. The spectral signatures from the radiometric survey were also subjected with the same procedure as of the imagery and both were compared. Mathematical models are incorporated for characterization of the spectral data from the absorption band features of different water quality parameters.

The in situ data is correlated and analyzed with spectral data collected from the spectroradiometer. Band ratio model and regression models are used to developed the algorithms and further used to estimate the water quality parameters for the lakes selected from the study area. End members were extracted from the Hyperion image is used to validate the quality of the lakes.

The study period is five years, 2010 to 2014. The samples were collected twice a year during pre and post monsoon seasons in both the lakes. In the years 2010, 2011 and 2012 April and October months and in 2013 and 2014 May and October months were the sampling periods. From each lake five sampling locations were chosen and a total of 50 water samples and 250 spectral signatures respectively were collected. The collected 100 water samples and 500 spectral data were analyzed in the laboratory.

IV. RESULTS

For the quantification of the quality parameters various spectral bands are widely used since the band ratios can reduce irradiance, atmospheric and air- water surface influences in the spectral signatures collected [6]. The details of the lakes under investigation is tabulated in Table:1 and the Topographical map with Hyperion showing the coordinated is illustrated in Fig:2.

Table:1 Details of the Lakes selected for the study

S.No.	Name of the Lakes	Location (Lat/Long) (Centre point)	Area of the Lakes	Perimeter
1	Miralam Tank	78° 26' 23" E 17° 20' 46" N	149.62 hectares / 1.5 Sqkm	9201.86m
2	Shamirpet Lake	78° 33' 47" E 17° 36' 36" N	46.8 hectares / 0.47 Sqkm	6224.93m

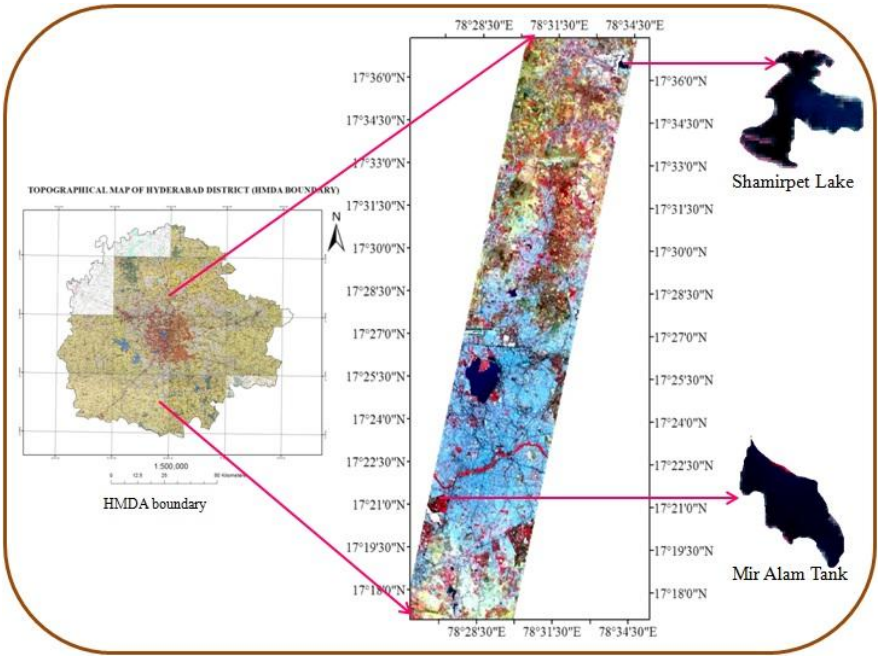

Fig:2 Location of the Hyperion covered study area

Characterizing the endmember spectra is the purpose of the present study for quantizing the water quality parameters. So, field spectral collection is inevitable. The analysis of the water samples for quality assessment, comparison and development of the mathematical model marks the essentiality of field investigations. The collected radiometric spectra are processed and the water spectra of the lakes are presented in the below Fig: 3.

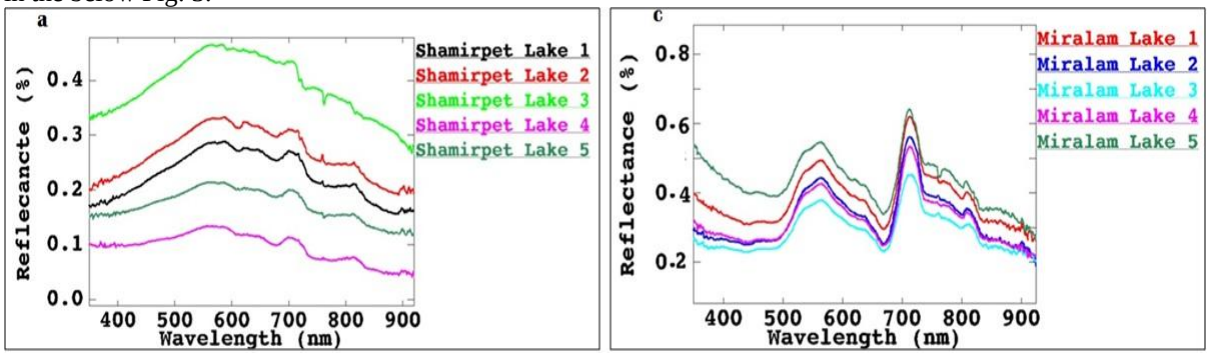

Fig: 3 Portrays the spectral signatures of different water quality parameters of the lakes under study (a- Shamirpet lake and c- Miralam tank).

The above Fig:3 illustrates that different wavelengths like R850, R550, R467 and R560 are exhibiting absorption and reflectance of the reflected spectra whose values are utilized in the model development and TSS and TP concentrations calculations.

The Mean values of the parameters total phosphorus and total suspended solids, are illustrated in the Fig: 4 of Shamirpet lake and Miralam tank during the five year study period 2010 to 2014 for both the seasons premonsoon and post monsoon.

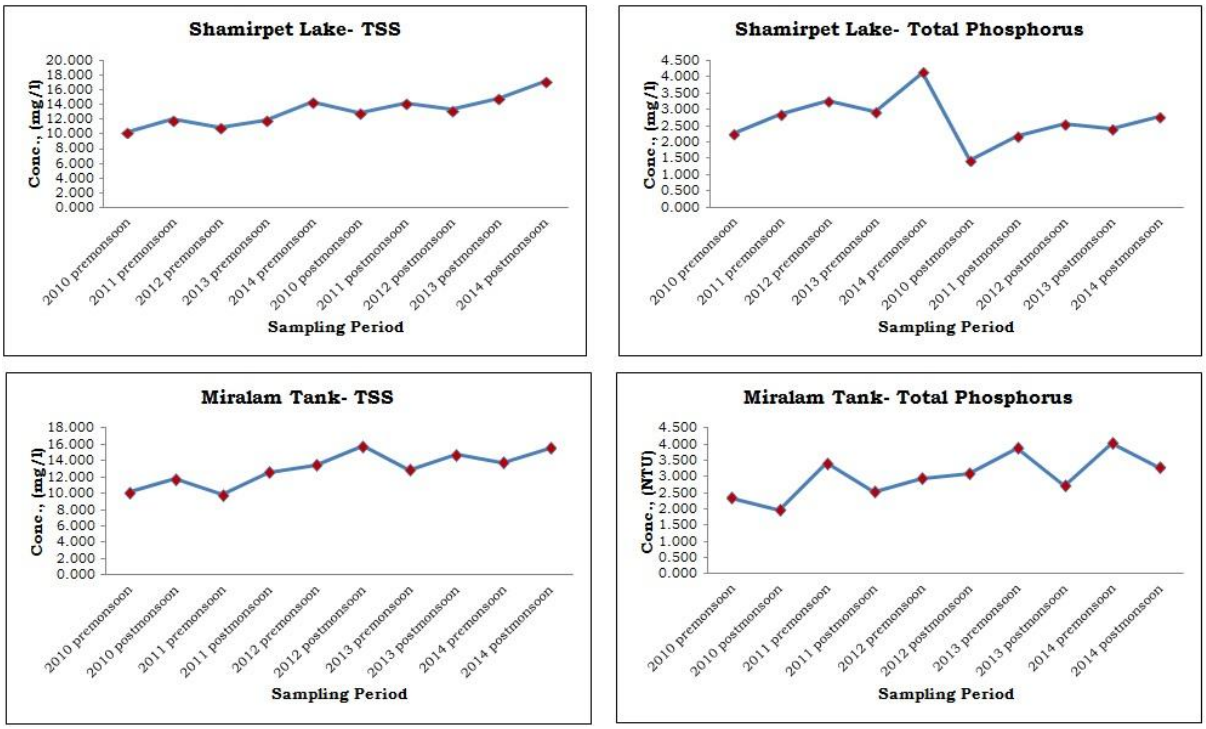

Fig: 4 Illustrate Shamirpet Lake and Miralam Tank water quality parameters mean concentration during the study period.

Band ratio technique principle exhibit band ratios of two spectral bands selected, representing the scattering or absorption features [7]. The band ratios of the reflected spectra at total suspended solids and R467/R560 total phosphates are used for the development of the mathematical model along with regression based analysis of the quality parameters. The absorption and reflectance of the water spectrum in VNIR region lead to the development of the mathematical model for the estimation of the parameter concentration.

The TSS exhibited excellent correlation with the band ratio NIR/Green and therefore the spectral reflectance at 850nm and 550nm in hyperspectral remote sensing facilitate well for the determination of the TSS concentration. 750-900nm range, the NIR domain absorbs the suspended sediments reflectance in the water and in the green domain reflectance peak is due to the TSS in the lake waters. The average R^2 of the Total suspended solids in the lakes is 0.83. The mathematical model developed with band ratio combination is as follows:

Total Suspended Solids (mg/l)= $m(R850/R550)^2 - n(R850/R550)+l$ (1)

Where, l=5; n=2.5; m=10;

The following regression graphs exhibit the correlation between the model and the laboratory analysis. The model developed for the total suspended solids in the lake waters hold good with an overall average regression value of 0.83. The regression equations of the individual lakes are present in the Fig: 5 below.

From the Fig:5 it is observed that R^2 values of Shamirpet lake is 0.8046 and Miralam Tank is 0.86. A relatively high degree of correlation was found to be in Miralam Tank with regard to the TSS concentration. Thus, the developed TSS model is suitable for the two lakes in the study area with an average R^2 value of 0.83.

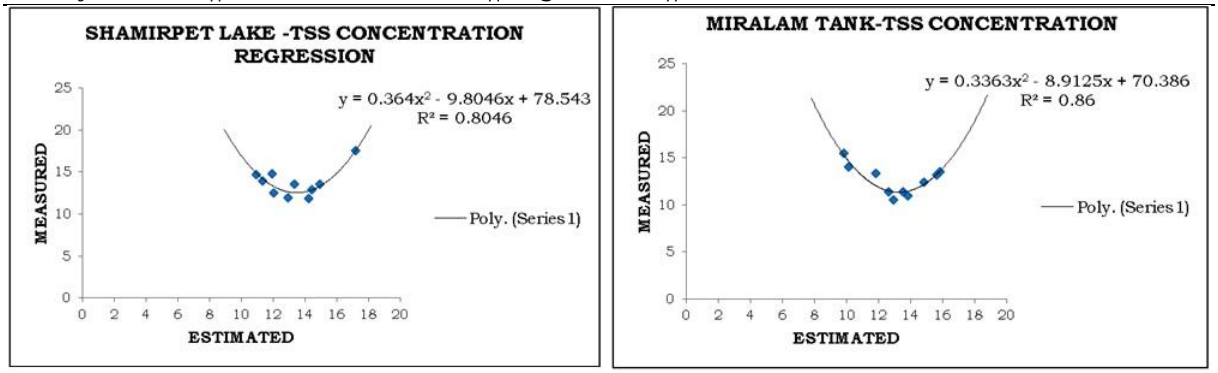

Fig: 5 Regression for Measured versus Estimated values of TSS in the Two lakes under investigation**.**

Total Phosphorus concentration has an indirect correlation with the water's optical properties (Wu et al. 2010). The model thus developed is of the ratio between R467/R560, blue and green domain reflectance's indicating the TP content. Correlation analysis with the hyperspectral band ratios gave 0.74 confidence with the following model to evaluate TP concentration.

TP (mg/l)= $m(R467/R560)^2 - n(R467/R560)+l$ (2)

The empirical coefficient values are l= 1.92, n= 0.38 and m=2.11.

The regression analysis verified that the model is valid and acceptable for the estimation of TP concentration and the model demonstrated relatively good performance with average R^2 of 0.74. The regression values are shown in the following Fig: 6, measured vs. estimated values of the TP concentration.

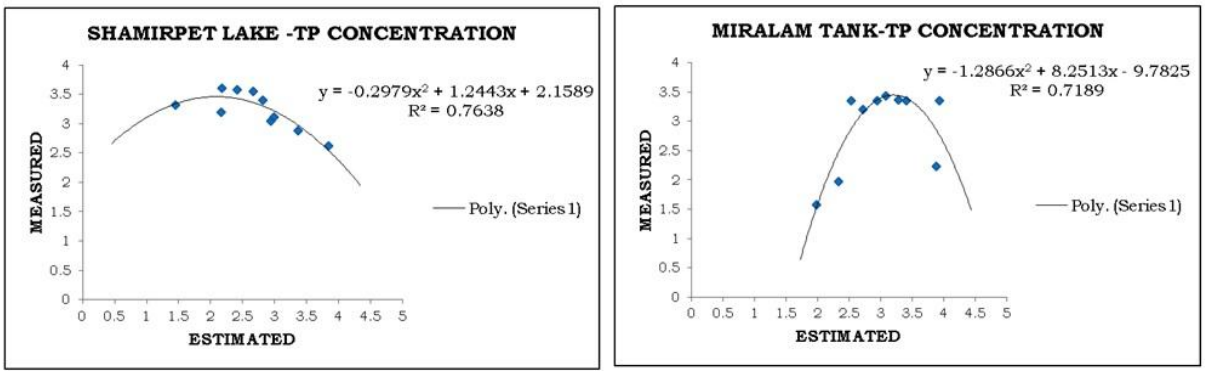

Fig: 6 Regression for Measured versus Estimated values of Total Phosphorus in the Two lakes under investigation.

From the Fig:6 it is clear that the confidence when compared with the other parameters is relatively less but the average value in itself is good for estimation and acceptance. Shamirpet exhibit the R2 value of 0.7638, and Miralam Tank display R2 value of 0.7189.

The following regression plots show the satellite based spectral result of the parameters correlating with mathematical model developed in the two lakes. Both the parameters exhibit second order polynomial regression as the best fit.

Fig:7 exhibits the correlation between the R850/R550 band ratio and the total suspended solids concentration with good R^2 value. Although the value compared with that of the in situ R^2 is less the parameter prediction has the high certainty in NIR and Green ratio. The average R^2 is 0.70 which proves to be effective.

The band ratio of R467 and R560 gave the effective estimate of the parameter total phosphorus (Fig:7) with the mean R^2 0.66. The mathematical model hold good for the estimation of two parameters under study in this research with satellite as well as the radiometer data sets. The same mathematical models of each water quality parameter is applicable for the two water bodies emphasizes the successful validation in varied environmental conditions.

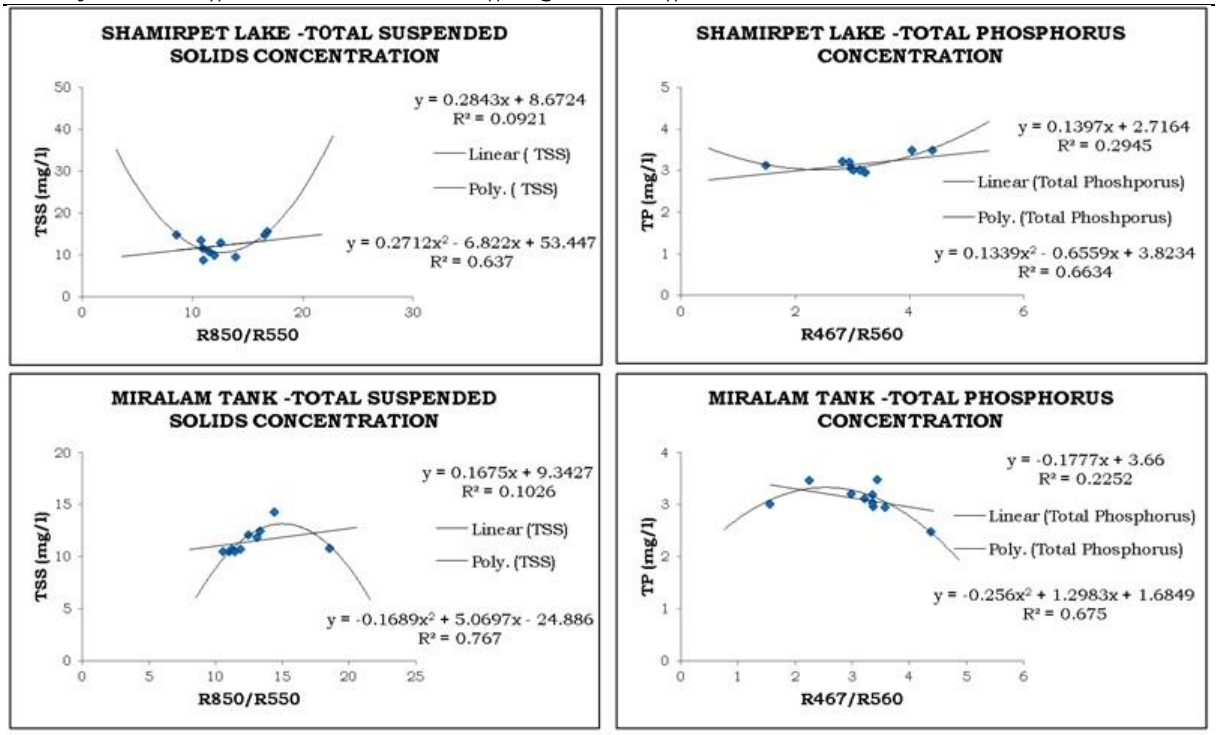

Fig: 7 Regression model for Estimating TSS and TP.

The empirical relationship between the model and satellite analysis is found to be 0.68 and model and in situ analysis is found to be 0.785. Since the regression value is holding good in both the cases proving the model derived, the hyperspectral remote sensing technique can be utilized for the estimation of the water quality parameters as a tool in monitoring mechanism of the water bodies. The model results are validated by checking with the measured values through the linear regression equations and the R^2 values were computed which strongly correlated. The correlation showed 0.75 R^2 value which is a very potential validation to prove the adequacy of the model developed.

Thus, the empirical estimation of water quality parameters in each lake carried on TSS and TP results best fit the polynomial equation for better regression analysis. Linear regression is the most common method followed in the remote sensing estimation of water quality but during processing the data it is found that Non-linear regression was most valid in this study. The highest R^2 was found to be achieved with the second order polynomial equation.

V. CONCLUSION AND RECOMMENDATIONS

The results showed that the application of hyperspectral data yield good results for the estimation of water quality parameters in lake waters and thus assist in the pollution check. The in situ results of water quality shows that the lakes are Eutrophic and proceeding to hypereutrophic state. The seasonal variations are also computed and the data provide for the reference and for mode of action. The use of the statistical regression analysis in the parameter determinations helped for the validation of the model results and attain scientific approach. Regression analysis worked well in both the parameters and the two lakes in the study area. The developed monitoring hyperspectral technique is considered effective in turbid waters.

Future research scope is to assess the water pollutants such as: volatile organic chemicals, heavy metals, and contaminants of bacterial origin where few studies have been conducted can be monitored using hyperspectral remote sensing and building spectral libraries for the parameters.

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