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Mapping Turbidity Levels in the Lake's Water using Satellite Remote Sensing Technique

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Abstract: Haleji lake, Thatta, Sindh, has been affected by water pollution in the past decades. This study focuses on mapping water pollution at Haleji lake using turbidity as the pollution indicator. In this study, an algorithm was developed by correlating satellite reflectance data and in-situ turbidity measurements using regression analysis. The determination coefficient R^2 of the developed algorithm showed a value of 0.83 that is evidence of a good correlation between field-based and mapped turbidity. Moreover, a temporal analysis was carried out using the same algorithm for the years 1999 and 2011. Results of temporal analysis confirmed that the turbidity levels in Haleji lake have increased from below 5 NTU to around 15 – 30 NTU. This is a clear sign of lake pollution in the interim of the past twelve years.

Keywords: Water quality modeling, multiple regression analysis, turbidity, satellite remote sensing.

Introduction

Haleji lake in addition to an area for native inhabitants has heterogeneity and diversification for different plants and animals in winter and is also a zone and habitat for transient migratory birds. Substantially, it is a waterfall hold and persistent clear freshwater lively lake with connected bogs and swamps and percolated brine lagoons. Not only that, Haleji lake water sustains a statistic of vulnerable species and is one of the vital nurturing, raising, and spawning domains in Sindh for waterfall. The administration of Sindh has endowed shelter to conserve and secure nature along with the surrounding habitat of the said zone and consequently in 1972, Haleji was proclaimed as a wildlife sanctuary. Furthermore, in 1976, the region is declared as a Ramsar wetland locale (Ali et al., 2011).

In connection with apparent decaying of biotic affair and the infiltration of defiled contaminated water from lake's non-point and point sources, water has exalted turbidity ranks, granting a surge to the most eutrophic predicament.

To safeguard this eminent wildlife sanctum which is providing shelter to so many species, routine pollution surveillance is unavoidable since the condition of water quality is considered as a crucial component to assist existence at the wetland. On location testing and biochemical inspection call for immense fiscal sources and is labor profound. However, remote sensing proficiencies yield a preferred cost-efficient option to oversee water defilement by reckoning polluted and contaminated specifications (Brezonik et al., 2005; Hellweger et al., 2004).

Turbidity in a water body influence the radiation mechanism beneath the water surface. It triggers scattering and absorption of sunlight that alter the transmission of light in lower depths. It plays opposite role to the clarity of water bodies. Turbidity levels in a water body depend on the presence of fluvial suspended particles, hence, it works as a measure for determining concentrations of suspended matter (Wass et al., 1997). An instrument called nephelometer is used to measure turbidity in water resources and report the levels in nephelometric units (NTUs). High levels of humus acid, produced due to decay of vegetation, peats and bogs in water body, or suspended solids in the water body lead to high level of turbidity therefore it is one of the indicators of pollution in a water body if it exists in higher levels as compared to safe limits (Mark and Stapp, 2003).

Environmental satellites provide efficient and cost-effective means for water quality mapping. Diversified tasks have been occasionally executed and conducted to portray water trait specifications with the help of aircraft and spacecraft-based sensors (Brezonik et al., 2005; Olmanson et al. 2008; Nas et al., 2010).

Satellite mounted sensors could provide beneficial information with respect to space (spatial) and time (temporal) deviations of water properties. Such scientific data conceivably exercised for establishing ameliorated procedures concerning quality of water (Nas et al., 2010; Jensen, 2000). In several wavebands of VNIR, to delineate quality parameters in a water body at satellite reflectance, in-situ information is additionally linked regression analysis to make statistical algorithms for assessment of contamination parameters (Kloiber et al., 2002).

The purpose of this research was to adopt regression analysis to formulate an algorithm to define turbidity levels at Haleji lake.

Materials and Methods

Figure 1 shows the outline for this investigation. Haleji lake is the sole wetland in Sindh with immense biodiversity which has extreme water contamination, making this an unavoidable research section for the researchers and hence opted for this study.

In the initial step, the desired information referring to the turbidity was assembled concurrently to every overpass of satellite. In the next phase, feature reflectance (predictor) was used to produce a regression model, computed from the satellite imagery and turbidity esteems (estimate), and finished on field overview. The algorithm developed in this research work was used to map turbidity levels of the lake's water in the years 1999 and 2011.

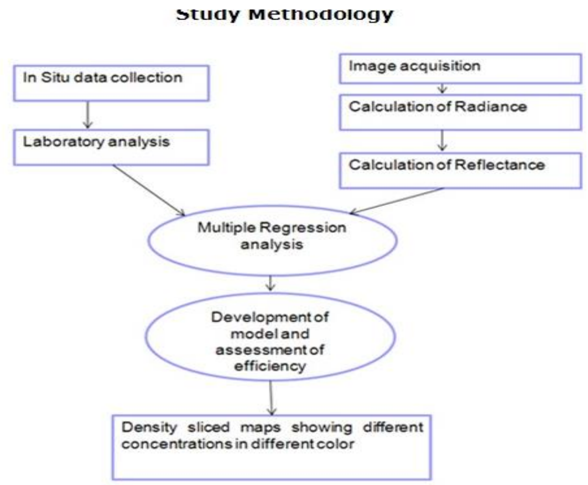

Fig. 1 Study design

Study Area

Haleji lake is situated at 24º 47' 00" N and 67º 45' 01" E in the north of Thatta city at a distance of 80 km (Fig. 2). The area comprises of a stony desert having limestone and sandstone bedrock (IUCN, 1994). Haleji lake roughly shows a square shape structure over a satellite image with area coverage of 174 hectares. It was utilized as a water supply with a specific profundity of 3 - 8 meters at the time of development but as time passed, sedimentation has caused to decrease its profundity to 1.8 - 4.5 meters. Haleji lake is a constructed wetland having rich biodiversity. Numerous species of flora and fauna are relying over this small wetland.

Fig. 2 Location of Haleji.

Water Sampling

Throughout the survey on 2nd May 2011, Polyethylene bottles, firstly bathed with chromic acid followed by cleansing with distilled water, were used to collect 40 samples (from Haleji lake), using random sampling technique from pre-designated sampling sites (Fig. 3). The average depth of Haleji lake is greater than 4m hence the samples were collected at a depth of 0.1m as described in CCME, 2011. The state of the art Magellian Triton 400 GPS which has an accuracy of up to 3-5m was operated to organize the position of various sampling spots. Then, after transferring data from the GPS, the next step was to create a shape file in ArcGIS 10.1 software. Onsite testing of turbidity was computed with portable EUTEC-TN 100 turbidity meter that can gauge from 0 to 1000 NTU.

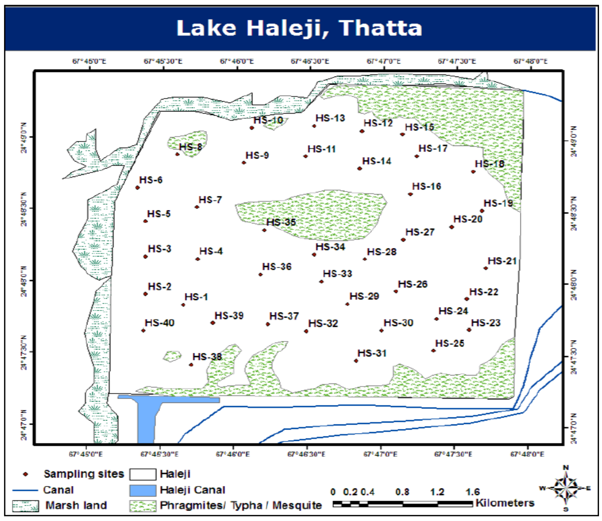

Fig. 3 location of sampling sites at Haleji Lake.

Data Sets Used

Landsat TM images acquired on 2nd May, 2011and 31st Dec, 1999 were used in this study (Table 1).

Table 1. Image specification of Landsat TM data

S. No.	Date	No. of Bands	Scene No.
1	02-05-2011	seven	L5_152043_04320110502
2	31-12-1999	seven	L5_152043_04319991211

Preprocessing of Satellite Data

Visible bands of Landsat-TM satellite (TM1, TM2, and TM3) were used in the study for estimation of turbidity levels in Haleji lake. The data were available in digital numbers (DN) which show empirical values of radiances per pixel (Blackbridge AG, 2015). DN numbers on Landsat TM image ranged from 0 to 255 depending on the radiance flux received on the satellite sensor. The radiance values of visible bands were converted to reflectance (R_1, R_2, and R_3) using the information available in the metadata file received with satellite data (Chander and Markham, 2003).

Development of Algorithm

To develop the algorithm, lake's water samples were taken from designated sample sites coinciding with the 3x3 pixel window of Landsat TM satellite image from where average values of surface reflectance were recorded. Afterwards, the surface water's reflectance in Blue (R_1), Green (R_2) and Red (R_3) wavelengths were tested in different combinations as independent variables to perform multiple regressions keeping field estimates of turbidity data as dependent variables (Table 2) (Reddy, 1997). The selection of only visible bands was on the basis of spectral reflectance curve of water showing maximum reflectance in visible bands and no reflectance in infrared bands (Reflectance, 2016). The developed algorithms were evaluated for the appropriate fit of the regression model on the basis of Pearson correlation coefficient R^2.

Results and Discussion

Regression Model

During the research, the succeeding regression equations (Table 2) were catered by using the three bands' (R_1, R_2, & R_3) multiple regression reflectance data. If the R^2 value is greater than 0.7, the regression is considered. The third algorithm has the maximum R^2 value based on four algorithms assayed, rationalizing the preference to delineate turbidity from the third algorithm for Haleji lake.

Table 2. Multiple regression equations of turbidity along with determination coefficient (R^2).

Algorithm No.	Regression equation	R^2	Adjusted R^2	RMSE
1	$-99.4 - 136 \times R_1 + 1048 \times R_2$	0.82	0.76	3.9726
2	$-42.6 - 317 \times R_1 + 977 \times R_3$	0.77	0.74	4.4595
3	$-116 + 1030 \times R_2 + 31 \times R_3$	0.83	0.77	4.0083
4	$-94.8 - 152 \times R_1 + 947 \times R_2 + 101 \times R_3$	0.82	0.77	4.1054

The turbidity levels determined from field survey is shown in Table 3. The determined levels of turbidity from remote sensing satellite are shown in Fig. 4. As a practice of many scientists to use three or four bands, these images represent and highlight turbidity of water body that hinder light penetration in a water body (Tyler et al., 2006; Zhou et al., 2006; Duan et al., 2007). This being said, the conclusion firmly authenticates Wang et al. (2006) findings in which they conclude that green and red bands of Landsat TM satellite significantly predict water quality parameters. According to Wang et al. (2006) contaminated water outcomes are in a high reflectance, estimated by band 2, which demonstrate a positive examination with the turbidity levels in the water body. Despite what might be expected, band 3 demonstrated a negative connection with the poor water quality which portrayed a low reflectance (Wang et al., 2006).

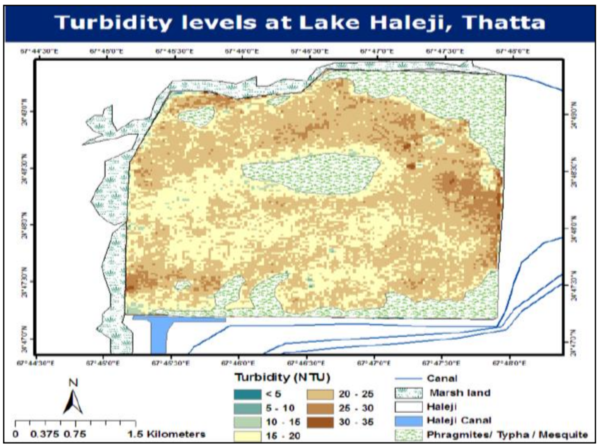

Fig. 4 Density sliced map of Haleji lake showing turbidity levels in NTU.

Table 3. Turbidity levels in Haleji Lake.

S. No.	Turbidity levels (NTU)	Value
1	Average	14.52
2	Min	1.69
3	Max	28.1

Temporal Analysis

The formulated algorithm was applied for a time-based analysis of turbidity levels in the Haleji lake (Fig. 5). The results disclosed that the turbidity levels expanded throughout the last twelve years (1999-2011). It is found that turbidity levels in Haleji lake are well beyond the limits of potable water, i.e. 5NTU as proposed in NSDWQ (2008). This makes lake Haleji's water unhealthy for human intake.

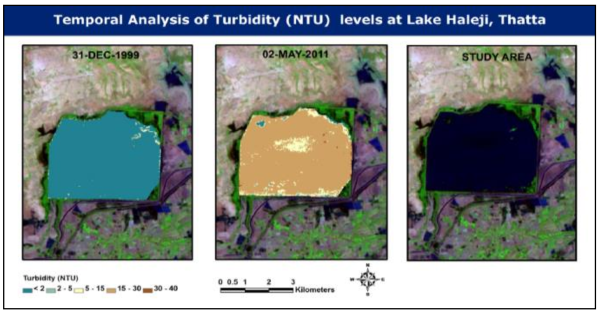

Fig. 5 Temporal map of Haleji lake showing turbidity levels.

Conclusion

Considering time and cost restrictions, comprehensive sampling is practically limited. However, remote sensing offers an adequate and effective means of providing much required environmental data. A small volume of sample collected from the study area could promptly be exercised to create predictive anticipated algorithms utilizing the reflectance information data. Finally, it is concluded that the at-surface reflectance of second (R_2) and third (R_3) bands of Landsat TM sensor precisely anticipate the levels of turbidity in Haleji lake on remote detecting based information. Assisting investigation of other water quality attributes can be accomplished to anticipate and indicate the physical quality parameters of the lake's water.

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