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Estimating total dissolved solids and total suspended solids in Mosul dam lake in situ and using remote sensing technique

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ABSTRACT

This study was conducted to demonstrate the ability of using remote sensing technique to estimate the concentrations of total suspended solids and total dissolved solids in Mosul dam lake, Iraq. In situ measurement were done to detect the mentioned parameters during the period July 2018-April 2019, also within this period satellite images were obtained (Landsat 8), where satellite images were georefrencing, those images were transported to their original form(digital numbers "DNs", after that they were atmospherically corrected to minimize atmosphere effects. Equations to estimate TSS and TDS were made depending on linear regression correlation between reflectance values and in situ data. Results showed that TSS concentrations correlate to band 1 (highest R2) in Summer (July) and band 5 in Spring (April) are strongly significant correlated to TSS concentration while band 6 in Autumn (September) significant to TSS values, while TDS correlated to band 5 has highly significant correlation (Highest R2 =0.41) in summer (August) while bands: 7,6 and 3 have significant correlation in Autumn (September), Summer (July) and (Spring) April, respectively.

Keywords: Mosul dam lake, Limnology, Iraq , Remote sensing, Mosul

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1. Introduction

Remote sensing plays an increasingly important role in providing complementary data needed to confront key water challenges [1].

Remote sensing technique can detect pollution in water and facilitate the observing of it effect on aquatic life also spectral analysis can tell the different between salty and fresh water as well as its ability to monitor flood and hurricanes [2].Also enables the monitoring of many parameters of surface water quality to assess the repercussions of river basin management policies, land use practices, and non-point-source pollution as well as the likelihood of algal blooms and other threats to the quality of water supply systems and monitoring fragile ecosystems, in particular wetlands and peat lands providing a solution of a global coherent approach for monitoring Change in the extent of water-related ecosystems over time [3].

The application of remote sensing can be amplified to monitoring surface waters since the back diffusing characteristics of water depend on the sorts and concentrations of substances within the water [4].

The main spectral bands of interest for remote sensing in water bodies are visible (VIS), infrared (IR), and microwave (MW) [5].

Particular approaches for water quality inspecting incorporate testing to esTablish standard conditions at lakes and supplies, observing for priority pollutants, surveying compliance with water quality directions, developing a daTabase for examination and sharing, exploring water management problems, planning alterations, making strides strategies, back for reservoir direction, partaking in plan and designing of aquatic ecosystems and reclamation ventures, and keeping up environmental awareness for watershed administration and natural stewardship [6]. Numerous components contribute to the choice of fitting symbolism and analytical strategies particular to the objectives of person ventures. Selecting appropriate sensors, bands, and strategies is to a great extent subordinate on the measure of the study region, desired mapping unit/scale/resolution, water quality objectives and parameters of intrigued, cost of imagery and investigation, project timelines, and level of skill [7].

2. Materials and methods

2.1 Study area

Mosul dam lake extends vertically on Tigris river in area between longitude (40°86'),(40°55') and latitude (32°00'), (27°50') with 45 km long and vary from 2-14 km width, it surface area 380 km in 330 m above sea level, there are ten valleys pour into the lake [8]. As shown in Fig.1. The climate of the study area characterized by hot and dry summers and cold winters with rare snow [9]. Annual mean temperature is 19.5◦ C and rainfall is 383 mm [10].

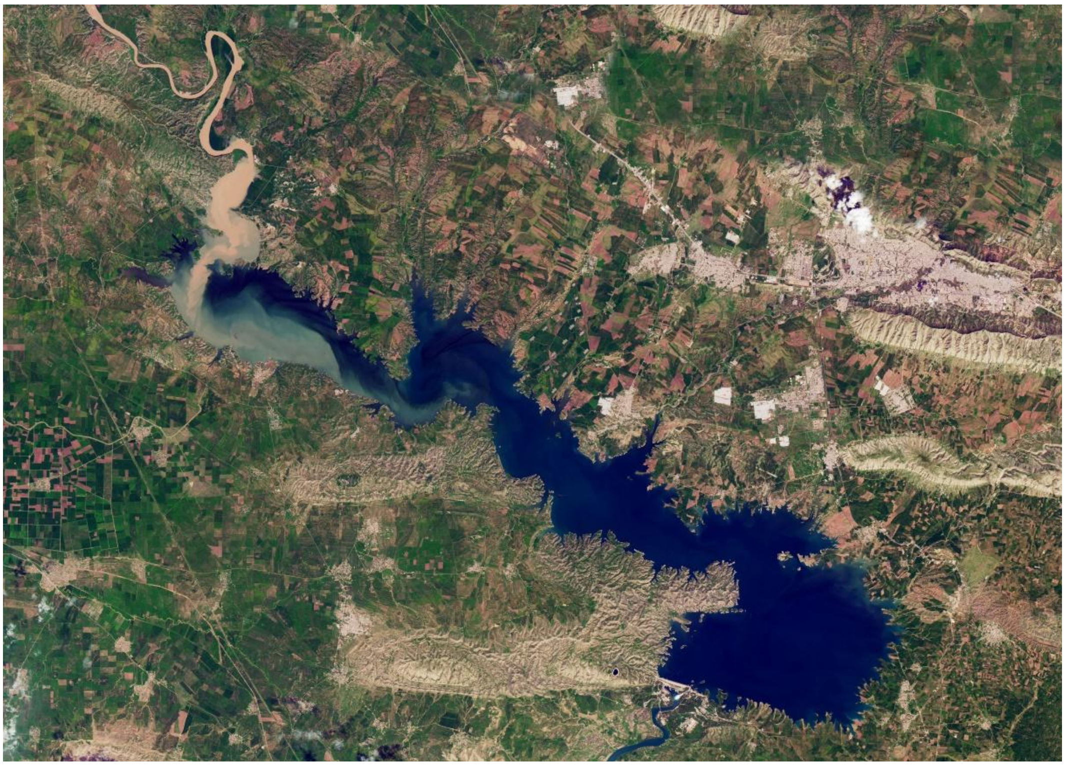

Figure 1. Mosul Dam Lake

2.2 *In situ* measurement

Twenty two stations within Mosul Dam Lake were chosen due to their coverage to the whole lake as shown in Table 1 and Fig.1.

Samples were taken from July2018 to April 2019 where July and August represent summer, September and October exemplify autumn, December and January state winter and March and April represent spring. Bottles of 1liter size made from glass were washed with distilled water , marked, and used to collect samples by inundation of bottle in the water (10-20 cm) below surface then it were kept in icebox and transported to the lab in university of Mosul/ college of science/ Biology department for making measurement [11]. Samples were collected in triple replicates from the study area and were measured three times in order to have the right result, some of tests were done by using instruments while the others done by using chemical processes.

Table 1. Stations and coordinates of Mosul dam lake

Stations	Longitude	Latitude
S1	42.823795	36.637655
S2	42.858127	36.634625
S3	42.892545	36.630079
S4	42.9334	36.626497
S5	42.94267	36.653219
S6	42.900098	36.670294
S7	42.884992	36.692596
S8	42.888082	36.714892
S9	42.843793	36.707736
S10	42.802594	36.720396
S11	42.785085	36.741583
S12	42.753843	36.7259
S13	42.737707	36.752862
S14	42.720369	36.764139
S15	42.705607	36.784077
S16	42.687238	36.807308
S17	42.659343	36.801673
S18	42.649816	36.783527
S18	42.624067	36.788064
S19	42.594884	36.799749
S20	42.564071	36.822187
S21	42.514032	36.838881
S22	42.823795	36.637655

Total dissolved solids were measured in field using portable multimeter device Juan/ China, while total suspended solids were estimated based on the method described by [11].

2.3 Remote sensing measurements

First all samples were collected during the passage of the satellite over the lake, the time of passage were determine the official website of landsat8. Remote sensing data which is used in this study was as Tagged Image File Format (TIFF). Mentioned files where scanned by Landsat satellite (Landsat-8 OLI images;path:168 and row:37) which has many bands that were used to capture the satellite images as shown in Table 2, which were downloaded from the website of United States Geological Survey (USGS) (www.glovis.usgs.com).

ArcGIS 10.6 is software for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

Mentioned software used Georeferencing "process of assigning real-world coordinates to each pixel of the TIFF" where many ground control points (GCPs) were recorded by a GPS device around the lake then they were calibrated with the satellite images to obtain the ultimate accuracy.

Table 2. Landsat-8 OLI Bands

Band	Wavelength range (micrometers)	Spatial Resolution (meters)	Spectral Width (nm)
Band 1 - Coastal aerosol	0.430 – 0.450	30	2.0
Band 2 - Blue	0.450 – 0.510	30	6.0
Band 3 - Green	0.530 -0.590	30	6.0
Band 4 - Red	0.640 - 0.670	30	0.03
Band 5 - Near Infrared (NIR)	0.850 - 0.880	30	3.0
Band 6 - SWIR 1	1.570 – 1.650	30	8.0
Band 7 - SWIR 2	2.110 – 2.290	30	18
Band 8 - Panchromatic	0.500 - 0.680	15	18
Band 9 - Cirrus	1.360 – 1.380	30	2.0

After satellite images georefrencing, those images were transported to their original form (digital numbers"DNs", after that they were atmospherically corrected to minimize atmosphere effects.
ENVI 5.5 satellite image processing software were used to convert digital numbers (DNs) into a reflectance values.
Reflectance was computed using Equation (1).

$$P\lambda = \pi L\lambda d2 / ESUN\lambda \sin\theta$$

Where
$L\lambda$ = radiance in units of W/(m2.sr.µm)
d = Earth-sun distance, in astronomical units
$ESUN\lambda$ = Solar irradiance in units of W/(m2•µm)
θ = Sun elevation in degrees

2.4 Statistical analysis

All obtained result were subjected to various statically analysis such as analysis of variance(ANOVA) and least significant difference test(L.S.D) as well as correlation matrix analysis.
Further the test of the difference between two means of dependent samples were used at (α= 0.05)(significant level). All mentioned variance methods of static were done by SPSS version 25 programs and excel function.

Also correlation between OLI band reflectance data and total suspended solid and total dissolved solid during three seasons: summer, autumn and spring.

3. Results

3.1 *In situ* measurement

3.1.1 Total dissolved solids

The results of water T.D.S. have shown that the mean value was ranged from minimum value of 116.0 ± 9.25 mg/l recorded in site 14 in winter season to maximum value of 162.7 ± 4.68 mg/l again in the same site but in autumn season as shown in Fig. 2 and Fig 3.

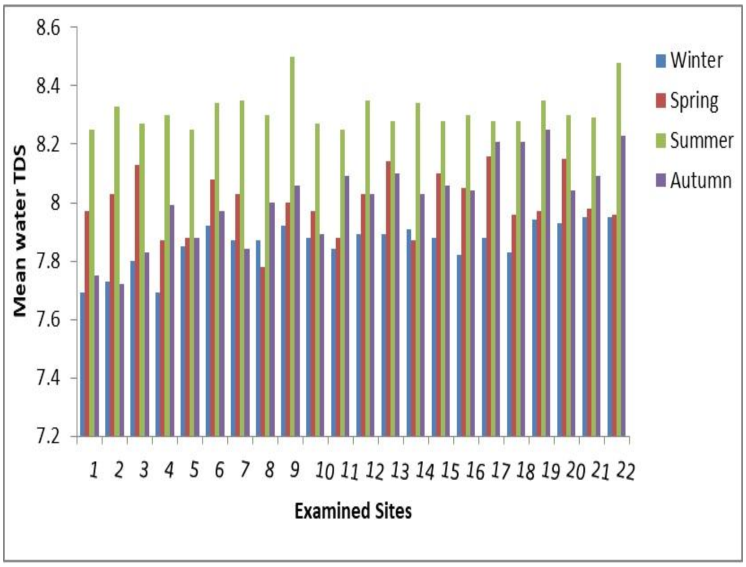

Figure 2. Mean water T.D.S. (mg/l) recorded in 22 sites of Al-Mosul Dam Lake during four seasons

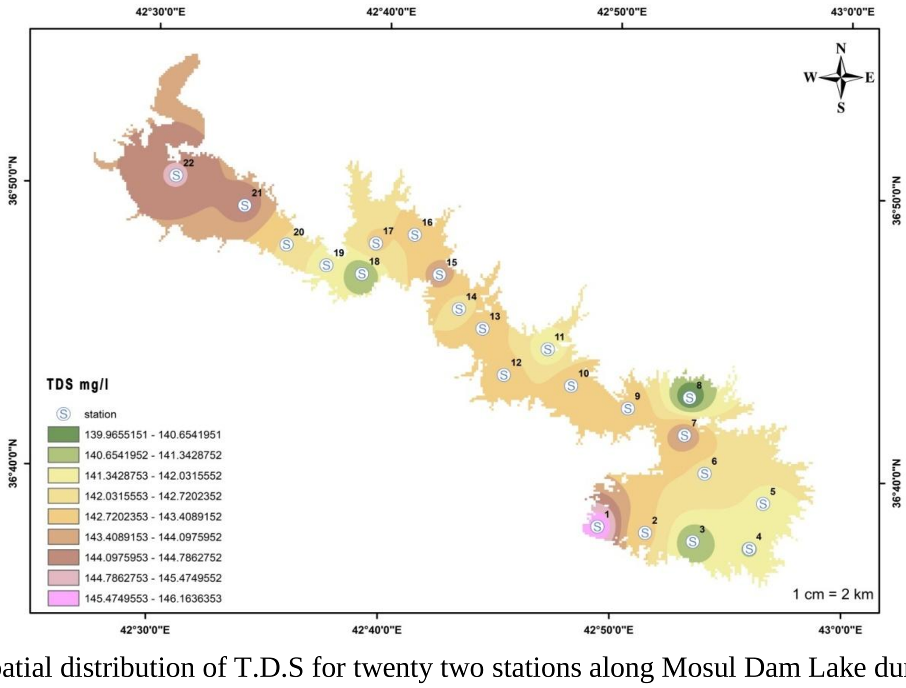

Figure 3. The spatial distribution of T.D.S for twenty two stations along Mosul Dam Lake during 2018-2019

3.1.2 Total suspended solid

The current work has shown that highest T.S.S. mean value (121.83 ± 95.5 mg/l) was recorded in site 22 at autumn season, while the lowest mean value was 6.995 ± 3.30 mg/l measured in site 8 during summer season Fig. 4 and Fig 5.

However, apparent significant differences ($P \leq 0.001$) were detected by the analysis of variance test and the least significant value ($P \leq 0.05$) for both seasons and sites has clearly confirmed these differences where it was 5.226 mg/l and 3.416 mg/l for seasons and sites, respectively.

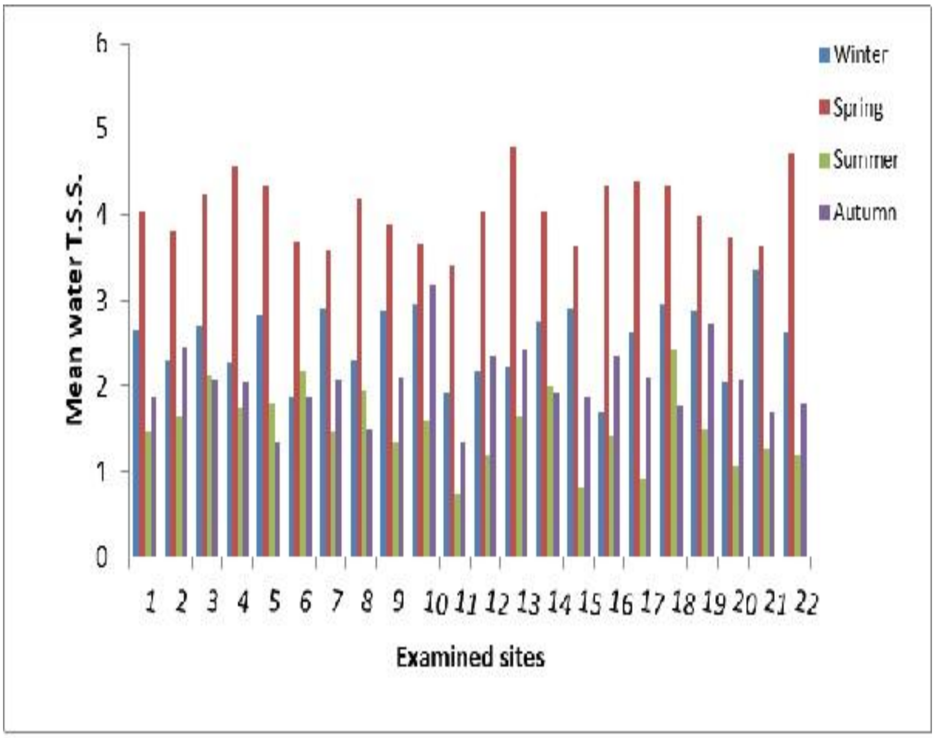

Figure 4. Mean water T.S.S. (mg/l) recorded in 22 sites of Al-Mosul Dam Lake during four Seasons

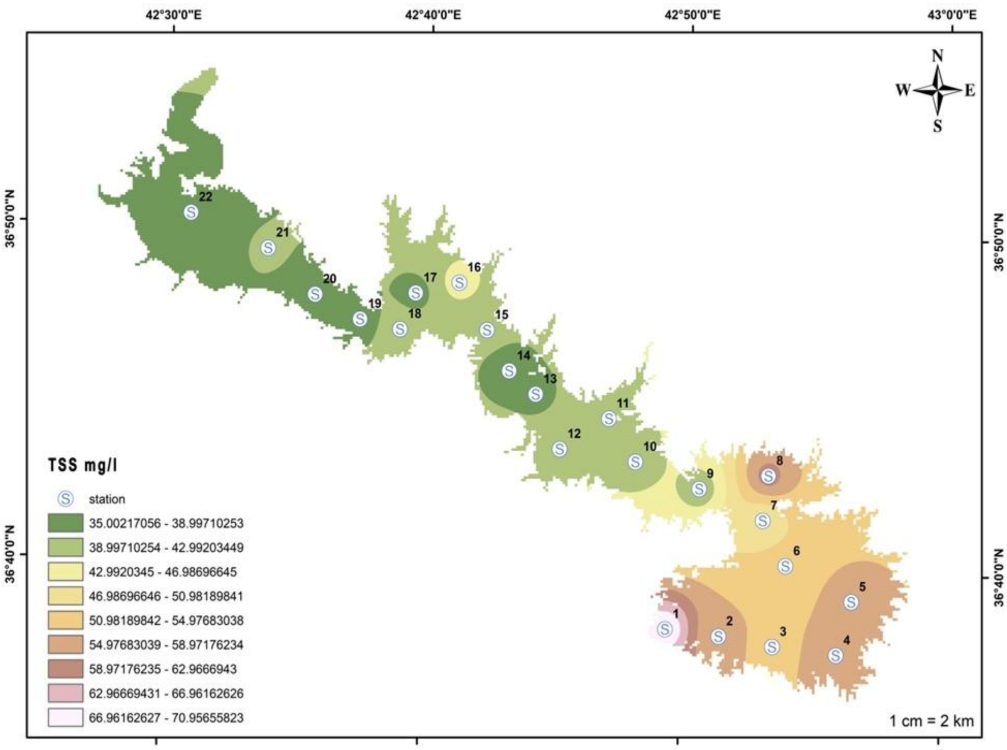

Figure 5. The spatial distribution of TSS for twenty two stations along Mosul dam lake during 2018-2019

3.2 Remote sensing results

In fact, remote sensing data is converting of spectral reflectance value to digital number (DN) known as a pixel. Each spectral wavelength represents as a single layer in remote sensing data called “Band” or “Channel”. The more bands or channels present, the more spectral properties in remote sensing data [14].
In its liquid state, water has relatively low reflectance, with clear water having the greatest reflectance in the blue portion of the visible part of the spectrum. Water has high absorption and virtually no reflectance in near infrared wavelengths range and beyond. Turbid water has a higher reflectance in the visible region than clear water. This is also true for waters containing high chlorophyll-concentrations.
Table 3 shows the reflectance obtained during the period of study for the 7 bands that were used to determine the concentration of some parameters.
The following Table 4 shows the average and the standard deviation of the seven bands for reflectance of Mosul Dam Lake.

Table 3. Reflectance values of Mosul dam lake for the period of study

Bands / Stations	Band1 0.43-0.45 (μm)	Band2 0.45-0.52 (μm)	Band3 0.53-0.59 (μm)	Band4 0.64-0.67 (μm)	Band5 0.76-0.90 (μm)	Band6 1.57-0.90 (μm)	Band7 2.11-2.29 (μm)
1.	0.071	0.077	0.136	0.116	0.058	0.045	0.039
2.	0.079	0.073	0.115	0.135	0.078	0.077	0.05
3.	0.067	0.071	0.129	0.139	0.08	0.033	0.066
4.	0.066	0.073	0.11	0.111	0.082	0.073	0.051
5.	0.073	0.08	0.124	0.103	0.086	0.033	0.056
6.	0.073	0.07	0.123	0.136	0.07	0.048	0.061
7.	0.069	0.078	0.123	0.124	0.061	0.042	0.07
8.	0.08	0.08	0.111	0.131	0.073	0.078	0.049
9.	0.075	0.073	0.113	0.116	0.105	0.068	0.043
10.	0.081	0.08	0.13	0.125	0.059	0.072	0.038
11.	0.067	0.079	0.118	0.115	0.083	0.049	0.063
12.	0.07	0.07	0.132	0.135	0.079	0.047	0.065
13.	0.078	0.08	0.127	0.122	0.104	0.077	0.041
14.	0.078	0.081	0.127	0.116	0.107	0.075	0.048
15.	0.068	0.085	0.132	0.127	0.093	0.058	0.073
16.	0.077	0.083	0.119	0.125	0.07	0.035	0.055
17.	0.072	0.081	0.135	0.13	0.056	0.046	0.062
18.	0.074	0.081	0.123	0.134	0.093	0.037	0.037
19.	0.067	0.077	0.133	0.107	0.101	0.048	0.036
20.	0.083	0.078	0.132	0.122	0.093	0.035	0.071
21.	0.077	0.074	0.12	0.106	0.094	0.034	0.053
22.	0.07	0.076	0.112	0.136	0.068	0.057	0.041

Table 4. Averages and standard deviation of the seven bands for reflectance of Mosul dam lake

Statistic value	Band1	Band2	Band3	Band4	Band5	Band6	Band7
Average	0.0734	0.07727	0.12381	0.12322	0.081	0.0534	0.0530
S.D	0.0051	0.00425	0.00818	0.0107	0.0159	0.0164	0.0119

3.2.1 Total dissoved solids

Obtained results of this study revealed that band 5 has highly significant correlation (Highest R^2 =0.41) in summer (August) while bands: 7,6 and 3 have significant correlation in Autumn (September), Summer (July) and (Spring) April respectively, as shown in Table 5.

By applying the equations in Table 5 for each month to predict the total dissolved solids concentrations depending on Bands reflectance from the water a comparison were made with the in situ measurement as shown in Table 6. Also the difference values between the field measurement(*in situ*) values and the concentrations which were obtained by applying remote sensing technique, a different were appear between the two methods as shown in Table 7.

Table 5. Regression equation and determination coefficients – R^2 of TDS on Reflexive with difference band and month

Rank	Band	Month	Linear equations	R^2	Sig.
1	5	August	TDS = 171.139 -88.528Band5	0.41	**
2	7	September	TDS = 155.151 -47.655Band7	0.19	*
3	6	July	TDS = 131.92 +132.313Band6	0.18	*
4	3	April	TDS = 100.04 -251.248Band3	0.17	*
5	5	July	TDS = 148.87 -112.246Band5	0.13	NS

* (P<0.05), ** (P<0.01), NS: Non-Significant

Table 6. Comparison between TDS concentration(mg/l) *in situ* and remote sensing results

	Summer				**Autumn**				**Spring**	
stations	**July**		**August**		**September**		**October**		**April**	
	In situ	RS	*In situ*	RS	*In situ*	RS	*In situ*	RS	*In situ*	RS
1.	145	137.87	164.66	166.00	151.333	153.29	155.33	153.29	130	135.87
2.	146	142.10	164	164.23	153.333	157.53	154	157.53	131	128.92
3.	141.66	136.28	162	164.05	151.333	158.29	156.33	158.29	128.33	132.44
4.	146	141.57	165.66	163.87	153	157.58	156	157.58	128	127.67
5.	141.66	136.28	164.66	163.52	153.666	157.81	155	157.81	128.33	131.18
6.	140.66	138.27	164.33	164.94	153	158.05	157	158.05	129.33	130.93
7.	141	137.47	165	165.73	151.333	158.48	155.66	158.48	128	130.93
8.	145.33	142.24	167	164.67	152	157.48	156	157.48	128.66	127.92
9.	141	140.91	160	161.84	151.333	157.20	158.33	157.20	131	128.42
10.	145.33	141.44	168	165.91	154.333	156.96	161.33	156.96	126.66	132.69
11.	136	138.40	163.33	163.79	152.666	158.15	162	158.15	132.33	129.68
12.	134.33	138.13	164.33	164.14	152	158.24	161	158.24	128.33	133.19
13.	134.66	142.10	162.33	161.93	154	157.10	159.66	157.10	131.66	131.94
14.	140	141.84	165	161.66	155	157.43	162.66	157.43	127.33	131.94
15.	136.33	139.59	162	162.90	150.666	158.63	155.66	158.63	128.33	133.19
16.	133.66	136.55	165.33	164.94	150.666	157.77	159	157.77	132	129.93
17.	133	138.00	165.66	166.18	154	158.10	165	158.10	131.66	133.95

18.	133.66	136.81	161.66	162.90	154.666	156.91	158.33	156.91	134	130.93
19.	128	138.27	162.33	162.19	153	156.86	161.33	156.86	127	133.44
20.	136.66	136.55	158.66	162.90	151.666	158.53	162	158.53	125	133.19
21.	136.33	136.41	164.66	162.81	152.666	157.67	161	157.67	130	130.18
22.	140.33	139.46	165.66	165.11	152	157.10	159.66	157.10	127.33	128.17

RS= results obtained by remote sensing

Table 7. The absolute difference values between in situ measurement and remote sensing values for TDS(mg/l)

	Summer		**Autumn**		**Spring**
stations	**July Difference value**	**August Difference value**	**September Difference value**	**October Difference value**	**April Difference value**
1.	7.13	0.34	1.957	2.04	5.87
2.	3.9	0.23	4.197	3.53	2.08
3.	5.38	2.05	6.957	1.96	4.11
4.	4.43	1.79	4.58	1.58	0.33
5.	5.38	1.14	4.144	2.81	2.85
6.	2.39	0.61	5.05	1.05	1.6
7.	3.53	0.73	7.147	2.82	2.93
8.	3.09	2.33	5.48	1.48	0.74
9.	0.09	1.84	5.867	1.13	2.58
10.	3.89	2.09	2.627	4.37	6.03
11.	2.4	0.46	5.484	3.85	2.65
12.	3.8	0.19	6.24	2.76	4.86
13.	7.44	0.4	3.1	2.56	0.28
14.	1.84	3.34	2.43	5.23	4.61
15.	3.26	0.9	7.964	2.97	4.86
16.	2.89	0.39	7.104	1.23	2.07
17.	5	0.52	4.1	6.9	2.29
18.	3.15	1.24	2.244	1.42	3.07
19.	10.27	0.14	3.86	4.47	6.44
20.	0.11	4.24	6.864	3.47	8.19
21.	0.08	1.85	5.004	3.33	0.18
22.	0.87	0.55	5.1	2.56	0.84

3.2.2 Total suspended solids

This study indicate that band 1 (highest R^2) in Summer (July) and band 5 in Spring (April) are strongly significant correlated to TSS concentration while band 6 in Autumn (September) significant to TSS values as shown in Table 8.

Table 8. Regression equation and determination coefficients – R^2 of TSS on Reflexive with difference band and month

Rank	**Band**	**Month**	**Linear equations**	$\mathbf{R^2}$	**Sig.**
1	1	July	TSS = 83.730 -867.20Band1	0.31	**
2	5	April	TSS = 18.584 +135.178Band5	0.24	**
3	6	September	TSS = 33.932 -231.638Band6	0.20	*
4	6	August	TSS = 11.994 +63.026Band6	0.12	NS
5	7	August	TSS = 19.567 -80.613Band7	0.11	NS

* (P<0.05), ** (P<0.01), NS: Non-Significant

By using equation (has the highest R2) of predicting TSS depending on reflectance from the water a comparison were made with the in situ measurement as shown in Table 9.

As shown below in Table 10, there were different values between in situ and values obtained by remote sensing technique.

Table 9. Comparison between TSS concentration (mg/l) in situ and remote sensing results

stations	**Summer**				**Autumn**				**Spring**	
	July		**August**		**September**		**October**		**April**	
	In situ	RS	*In situ*	RS	*In situ*	RS	*In situ*	RS	*In situ*	RS
1.	22.166	27.158	17.503	14.830	11.854	23.508	29.475	23.508	25.196	26.424
2.	21.15	20.221	18.653	16.847	17.1226	16.095	26.551	16.095	23.933	29.127
3.	23.606	30.627	10.783	14.073	21.359	26.287	26.951	26.287	30.326	29.398
4.	22.466	31.494	15.995	16.594	18.9843	17.022	24.835	17.022	32.453	29.668
5.	21.453	25.424	8.0633	14.073	23.4433	26.287	31.020	26.287	25.92	30.209
6.	20.03	25.424	16.536	15.019	18.9143	22.813	34.383	22.813	24.723	28.046
7.	11.293	28.893	13.583	14.641	20.0023	24.203	28.31	24.203	34.843	26.829
8.	10.263	19.354	11.971	16.910	25.7153	15.864	22.143	15.864	29.13	28.451
9.	13.836	23.69	15.663	16.279	16.3676	18.180	23.510	18.180	30.626	32.777
10.	7.259	18.486	17.66	16.531	12.314	17.254	30.877	17.254	30.38	26.559
11.	36.443	30.627	16.3	15.082	13.2326	22.581	30.995	22.581	27.906	29.803
12.	32.483	28.026	9.876	14.956	23.0636	23.045	31.677	23.045	31.433	29.263
13.	12.823	21.088	14.263	16.847	16.429	16.095	28.020	16.095	28.246	32.642
14.	30.833	21.088	19.463	16.720	13.883	16.559	28.867	16.559	26.373	33.048
15.	22.986	29.760	17.47	15.649	15.6086	20.496	28.779	20.496	32.37	31.155
16.	12.11	21.955	17.253	14.199	19.3963	25.824	33.447	25.824	29.306	28.046
17.	19.436	26.291	14.237	14.893	29.6323	23.276	28.826	23.276	25.686	26.153
18.	27.51	24.557	16.986	14.325	41.5333	25.361	21.068	25.361	25.36	31.155
19.	29.71	30.627	16.336	15.019	35.309	22.813	33.596	22.813	28.136	32.236
20.	9.7933	16.752	16.69	14.199	31.303	25.824	31.487	25.824	34.843	31.155
21.	20.416	21.955	13.386	14.136	31.359	26.056	20.775	26.056	30.723	31.290
22.	13.46	28.026	17.646	15.586	30.9846	20.728	38.531	20.728	24.83	27.776

RS= results obtained by remote sensing

Table 10. The absolute difference values between in situ measurement and remote sensing values for TSS (mg/l)

stations	Summer July Difference value	August Difference value	Autumn September Difference value	October Difference value	Spring April Difference value
1.	4.992	2.673	11.654	2.673	1.228
2.	0.929	1.806	1.0276	1.806	5.194
3.	7.021	3.29	4.928	3.29	0.928
4.	9.028	0.599	1.9623	0.599	2.785
5.	3.971	6.0097	2.8437	6.0097	4.289
6.	5.394	1.517	3.8987	1.517	3.323
7.	17.6	1.058	4.2007	1.058	8.014
8.	9.091	4.939	9.8513	4.939	0.679
9.	9.854	0.616	1.8124	0.616	2.151
10.	11.227	1.129	4.94	1.129	3.821
11.	5.816	1.218	9.3484	1.218	1.897
12.	4.457	5.08	0.0186	5.08	2.17
13.	8.265	2.584	0.334	2.584	4.396
14.	9.745	2.743	2.676	2.743	6.675
15.	6.774	1.821	4.8874	1.821	1.215
16.	9.845	3.054	6.4277	3.054	1.26
17.	6.855	0.656	6.3563	0.656	0.467
18.	2.953	2.661	16.1723	2.661	5.795
19.	0.917	1.317	12.496	1.317	4.1
20.	6.9587	2.491	5.479	2.491	3.688
21.	1.539	0.75	5.303	0.75	0.567
22.	14.566	2.06	10.2566	2.06	2.946

4. Discuttion

4.1 In situ measurement

4.1.1 Total dissolved solids

Variation of T.D.S values came from rainfall and erosion as well as run off to the lake which can increase T.D.S concentrations [12].

4.1.2 Total suspended solids

This study found clear increase in T.S.S values in winter season and spring decrease in summer season may be due to increase in water level, soil erosion and rainfall, as well as, other matters such as algae and organic matter [13].

4.2 Remote sensing

4.2.1 Total dissolved solids

Dissolved matter absorbs light in both ultraviolet and visible range and affects the volume reflectance spectrum but almost exclusively at the shorter wavelengths. What's more dissolved matter absorbs visible light, especially below 500nm, and its absorbance increases exponentially with decreasing wavelength [15]. This study results with [16] on Al-Habanyia lake and [17] on Al-Gharraf river, were both mention that total dissolved solids correlate with band 5.

4.2.2 Total suspended solids

Utilization of Landsat 8 OLI to monitor the sedimentation of lakes is via the estimation of TSS in water. If the number of TSS is high, the accumulation of sediment at the base of the reservoir is also high. Besides this, the recording of Landsat 8 OLI is approximately 185 km x 185 km, it will be identified the areas with high potential occurs silting, or the area that become the potential location of entrance of sedimentary material in the lake [18].The spatial distribution of TSS from each band is generally almost similar, but the estimated value of TSS is different. It is due to the difference spectral reflectance properties of each band on water. The water reflectance values can illustrate the condition and quality of the water [19].

5. Conclusions

Using of remote sensing technique shows good indicators of the ability of measuring T.D.S and T.S.S remotely, while the field measurement shows that T.D.S values were within accepted ranges. On other hand, T.S.S values were slightly above the ranges.

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