SIMULATION OF CHLOROPHYLL-A ESTIMATION BY WORLDVIEW-2 IN THE URBAN RIVERS OF THE DOMINICAN REPUBLIC USING FIELD SPECTRAL DATA

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Abstract: The objective of this study is to simulate chlorophyll-a (Chl) estimation in the urban rivers of Dominican Republic (DR) by "Worldview-2" (WV-2) satellite which is able to provide high spatial/spectral resolutions. In addition to this, WV-2 has 8 observation bands and among them the Red Edge band (705-745 nm) is attracting attention since it can be used as a new estimation method for high Chl content with high SS (suspended sediment) concentration water bodies. The spectral reflectance and in situ Chl data set were collected from Haina and Ozama-Isabela rivers using a small boat on March 9-10 and June 8-9, 2011. The estimation algorithm of Chl using WV-2 data was developed from the data set. Results revealed that in Chl estimations, the reflectance ratio of WV-2 Band 5 (Red band: 630-690 nm) and Band 6 (Red Edge band: 704-745 nm) under eutrophic conditions were effective. Finally, WV-2 data could be considered as a good monitoring tool for the mouth of the rivers which flow into the Caribbean Sea.

INTRODUCTION

Aquatic pollution has become a global concern, but even so, most developing nations are still producing huge amount of pollution loads and the trends are expected to increase (Shahidul and Tanaka, 2004). However, there is a paucity of regional marine and coastal baseline environmental data in developing nations such as most Caribbean countries. This has been attributed not only to economic reasons, but also to the lack of local staff and institutions to conduct the necessary research and monitoring (Rawlins et al, 1998).

Santo Domingo, the capital of the Dominican Republic which was chosen as the study area for this research, has also grown up to be one of the Caribbean Sea's leading cities exceeding a population of 2 million. There is concern about the adverse effects on the Caribbean Sea, its tourist spots and the public health caused by the pollution from the rivers flowing through the city. However, periodic measurement of the water quality of the main rivers and coastal areas of the country are scarcely performed. Therefore, there is deficient information to carry out environmental management. It is very difficult to implement a regional (wide area) water quality monitoring plan since specialized personnel, great amount of monetary resources and effort are necessary. Therefore, it is more practical to employ environmental management techniques not by obtaining detailed water quality data from a great number of sampling points but by capturing the environment macroscopically.

Satellite remote sensing is a powerful and leading technology to capture the water quality of the macro-environment. However, there is no exclusive sensor to observe the water quality for inland water. Therefore, conventionally, high spatial resolution land observation sensors such as LANDSAT, and SPOT (spatial resolution -

several meters; quantization - 8 bit; repeat cycle - two weeks or less; spectral resolution - about 100 nm) for water quality mapping of inland water have been substituted. It is said that quantization of 10 bits or more and spectral resolution of 20 nm or more are generally required for satellite sensors for measuring water quality. As a satellite sensor which fulfills such a demand, WorldView-2 (WV-2) was launched in October 2009. Quantization and swath width of WV-2 are 11 bits and 16.4 km at nadir. The WV-2 sensor provides a high resolution (1.8 meters GSD (ground sample distance) at nadir) eight multispectral bands; four standard colors (red, green, blue, and near-infrared 1) and four new bands (coastal, yellow, red edge, and near-infrared 2). Especially the Red Edge band (705-745 nm) becomes the key band for high-concentration chlorophyll estimation.

The objective of this research from the above backgrounds is to simulate chlorophyll (Chl) estimation by WV-2 using the spectral reflectance/Chl data set acquired in this study site in order to monitor the water quality of the rivers using WV-2 in the future.

METHODS AND EQUATION

Study site

In this study, survey of Haina and Ozama-Isabela rivers (HN and OZ-IS) which run through the city of Santo Domingo was performed. Their location and overview can be seen in Figure 1. Length, watershed, and slope of these rivers are respectively 86 km, 621 m^2, and 0.23 % for HN; 148 km, 2706 m^2, 0.28 % for OZ; and 59 km, 376 m^2, 1.12 % for IS (De La Fuente, 1976). In the basin of these rivers, severe social problems, such as lead contamination caused by a battery factory in HN (Kaul, 1999), and the appearance and proliferation of slums in HN and OZ-IS (Taylor, 2009), have occurred. Furthermore, industrial and domestic wastes are discharged directly, virtually untreated, into the coastal water as reported by Villasol et al. (1998). Because of exposure to marine currents, the wastes can be quickly redistributed along the coast, with a growing deterioration of coastal waters and loss of their natural landscape.

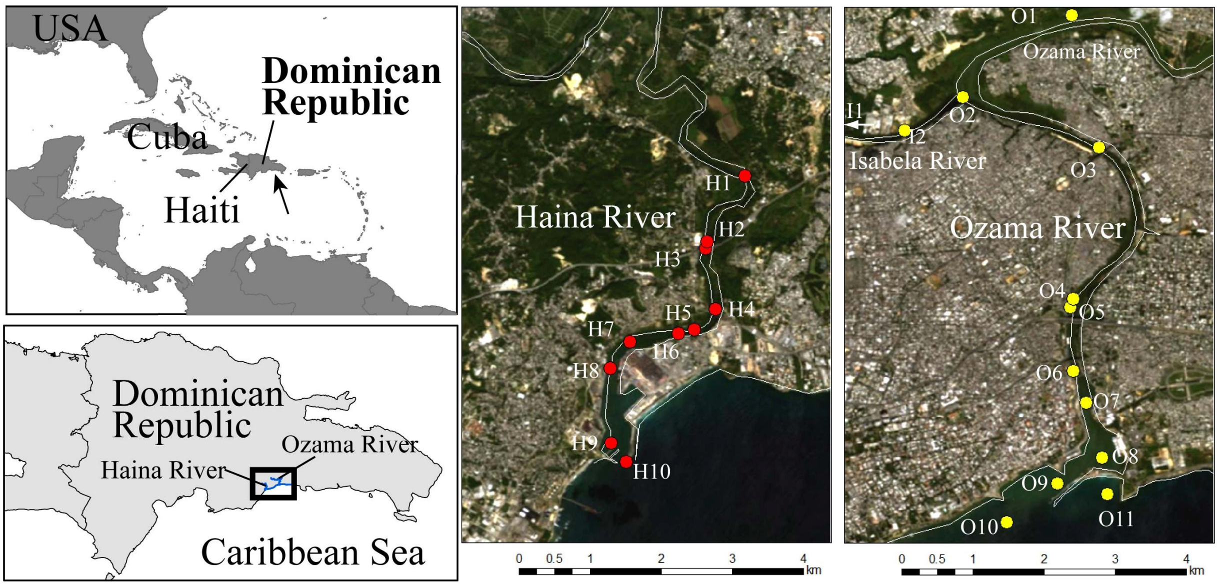


Figure 1: Location and sampling site in Haina River and Ozama-Isabela River in Dominican Republic

Field data

Sampling points taken during field surveys in HN and OS-IZ are shown in Figure 1. Field surveys were performed on March 9-10, 2011 and June 8-9, 2011. Spectral reflectance and water quality data were obtained through sampling from a small boat from 23 points (HN: 10 points, OZ-IS: 13 points). Due to waves caused by the movement of the boat or operational errors, the surface reflection data of some points had to be removed from the analysis. The final data set obtained is shown in Table 1. Spectral reflectance was measured by a portable spectrometer (MS-720, Eiko Co., Ltd., Japan) with a spectral resolution of 1 nm in the range of 350 to 1050 nm. Reflectance was computed as the ratio of the upward spectral reflectance taken just above the water surface (20 cm above the water surface) to the spectral reflectance of the white standard board (Labsphere INC, USA) measured just before that was made to reflect. Water samples were taken in 1 L containers, refrigerated and transported to the laboratory for analysis. Chlorophyll was measured according to standard methods (APHA et al., 1998). Suspended solids were quantified by the difference in weight of the filter paper before and after filtration (Miño et al., 2011).

Chl estimation model

For the optimal Chl estimation, fundamental two-band model (Gitelson et al., 2007) was tried on this research. First, the correlation analysis of two-band model and Chl was conducted at a 1-nm step using the acquired spectral reflectance / Chl data set. Next, correlation analysis using two-band model by the total combination of eight bands of WorldView-2 (WV-2), as shown in Table 1, and Chl was conducted similarly.

$$Chl = a + b \times [R(\lambda_1) / R(\lambda_2)] \quad (1)$$

where R is the water reflectance, λ_1 and λ_2 are wavelengths at each band, a and b are constants, respectively. WorldView-2 has eight bands in 400 - 1040 nm as shown in Table 2.

Table 1: Chl and SS data obtained in study area

Date	Stations	Chl(μg/l)	SS(mg/l)	Date	Stations	Chl(μg/l)	SS(mg/l)
9-10 Mar. 2011	I1	24.5	28.1	8-9 Jun 2011	O1	12.9	105.3
	O1	114.1	23.9		O2	6.5	137.1
	O2	33.3	17.9		O3	11.1	122
	O3	82	13.4		O6	8.7	141.6
	O4	165	20.8		O7	2.8	127.1
	O5	167.7	138.5		H1	1.7	20.3
	O6	170.2	11		H2	1.2	12.7
	O8	77.1	41.5		H3	1.4	19.1
	O9	49.4	59.8		H4	0.9	16.7
	H1	21.6	52.9		H5	0.3	24.1
	H2	38.7	57		H6	0.5	25.4
	H5	41.1	61.2				
	H6	45.2	49.1				
	H7	43.6	50.8				
	H8	16.7	51.2				
Min		16.7	11			0.3	12.7
Max		170.2	138.5			12.9	141.6
Ave.		72.7	45.1			4.4	68.3
N		15	15			11	11

Table 2: Spectral bands of WorldView-2

Band No.	Band name	Wavelength (nm)	Center wavelength (nm)*
1	Coastal Blue (CB)	400-450	427
2	Blue (B)	450-510	478
3	Green (G)	510-580	546
4	Yellow (Y)	585-625	608
5	Red (RD)	630-690	659
6	Red Edge (RE)	705-745	724
7	NIR1 (N1)	770-895	831
8	NIR2 (N2)	860-1040	908

*DigitalGlobe (2010)

RESULTS AND DISCUSSION

Figure 2 shows the reflectance spectra in HN and OZ-IS rivers. The spectra of Figure 2 were quite similar in magnitude to the typical reflectance spectra collected in eutrophic waters (Figure 2 (a)) (Getelson et al., 2007; Thiemann and Kaufmann, 2002) or high turbid water (Figure 2 (b)) (Han, 1997).

Figure 3 shows a contour map of the coefficient of determination (r^2) between the two-band model, Chl, and SS with the two wavelengths on the x and y axes using field spectral data. The map provides an overview of the statistical significance of the two-band model for all combinations of two wavelengths as well as the extent of the effective regions for assessment of each target variable. There is a narrow peak (reddish) such as the combination around 670 vs 700 nm region in Figure 3 (a). The peak exists in a different position from the result of SS as shown in Figure 3(b). Thus, we found optimal spectral bands for Chl estimation using the two-band model:

$$\mathrm{Chl} = 1264.7 - 1241.6 \times [R(685)/R(697)] \quad (2)$$

The Chl estimation accuracy by this model was 15.3 µg/l. Such model uses 685 nm (RD) and near 697 nm (RE) which is well known for high concentration Chl estimation. Table 3 shows a comparison of bands, coefficient of determination (r^2), root mean square error (RMSE), sampling number (N), and Chl range of the relationship between RD-RE two-band model and Chl from the conventional research. The reason for the effectivity of RD-RE two-band model in the estimation of high concentration Chl is explained by Zimba and Gitelson (2006) in detail. It is thought from the comparison that the result of this research is also appropriate. However, it is expected that Chl estimation accuracy is a little inferior since RE band (705~745 nm) of WV-2 is longer than optimal RE band (697 nm) shown by equation (2).

Next, the two-band model of only WV-2 band and the coefficient of determination (r^2) of Chl are indicated in Table 4 (Chl) and Table 5 (SS). The combination of the best as for correlation was "608 nm (Y) and 659 nm (RD)", and "659 nm (RD) and 724 nm (RE)". Those RMSE were 38.3 µg/l and 38.6 µg/l, respectively. Although both had the same r^2 and RMSE, the RD-RE two-band model compared with the Y-RD model was considered to be suitable for high-concentration (10 µg/l or more) Chl estimation as shown in Figure 5. In order to reduce the low-concentration error of RD-RE two-band model, the Chl estimation technique by WV-2 new band which combined 685 nm, 659 nm, and 724 nm used by Figure 5 were considered. In Japanese eutrophic lakes such as Lake Shinji, authors have already proposed the following original Chl estimation model (Matsunaga et al, 1996) based on the field spectral reflectance:

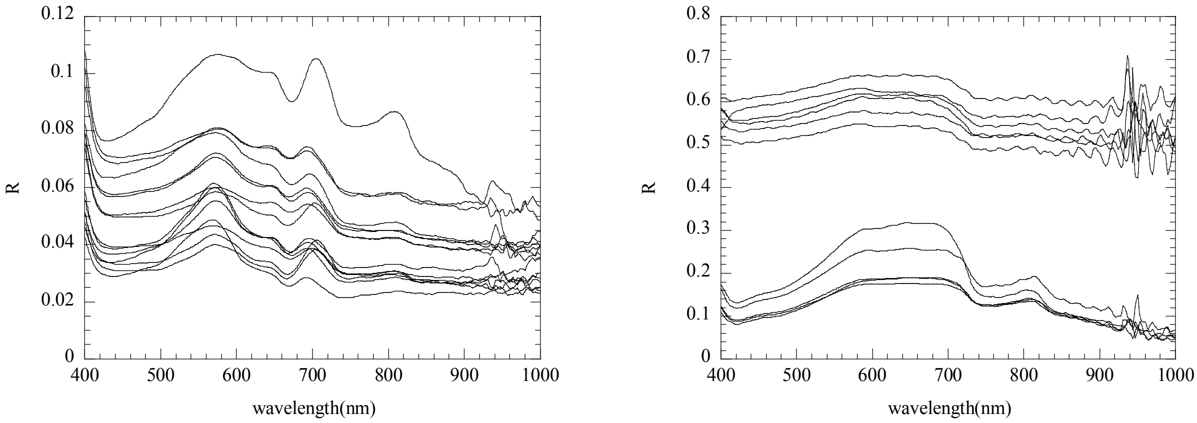
$$\mathrm{Chl} \propto [R(653)+R(688)]\times 0.5 - R(670) \quad (3)$$
$$\mathrm{Chl} \propto [R(653)+R(688)]\times 0.5 / R(670) \quad (4)$$

This equation was similar with RD-RE two-band model, uses strong absorption of Chl.a near 670 nm, and has been an index which shows the depth of the Chl absorption near 670 nm. Such models were applied and the following Chl estimation models were expected in this research.

$$\mathrm{Chl} \propto [R(608)+R(724)]\times 0.5 - R(659) \quad (5)$$
$$\mathrm{Chl} \propto [R(608)+R(724)]\times 0.5 / R(659) \quad (6)$$

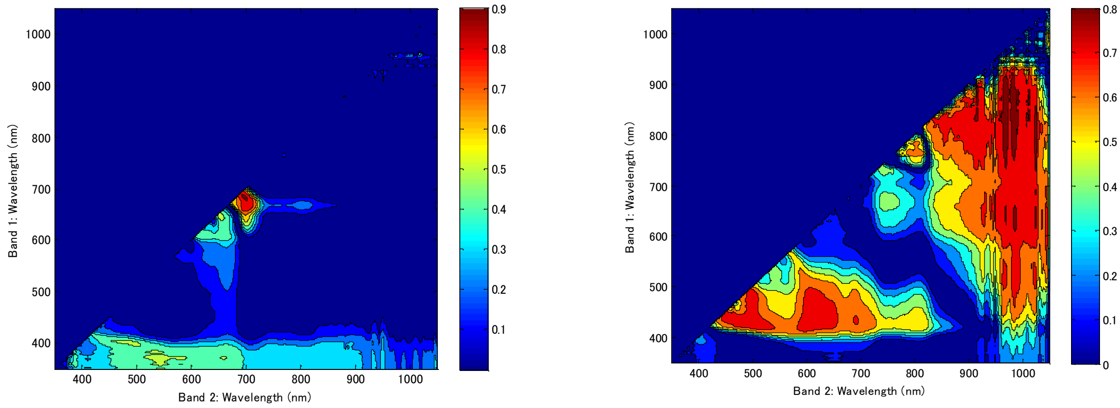
Figure 6 shows the relationship between the proposed model using equations (5) and (6) and Chl. The following good correlation was acquired from this new model using the equation (6):

$$\mathrm{Chl} = -491.6 - 540.88[(R(608)+R(724))\times 0.5 / R(659)] \quad (7)$$



(a) 9-10 Mar. 2011 **(b)** 8-9 Jun. 2011

Figure 2: Reflectance spectra in Haina and Ozama-Isabela rivers



(a) Two-band model and Chl (1nm step) (b) Two-band model and SS (1nm step)

Figure 3: A contour map of coefficient of determination (r^2) between two-band model, Chl, and SS using field spectral data

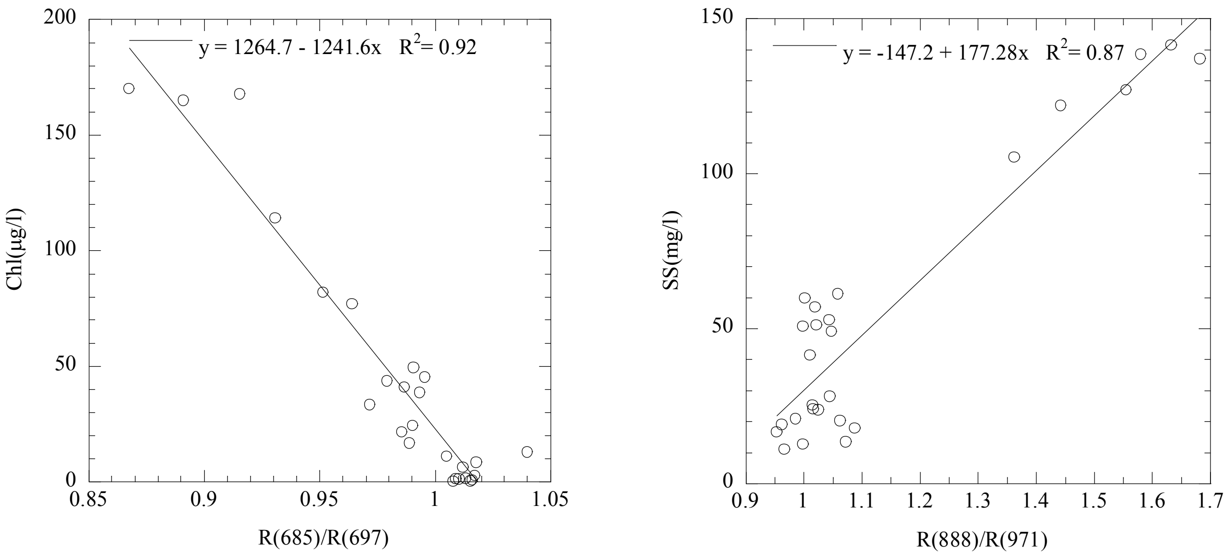


Figure 4: Optimal two-band model plotted versus analytically measured Chl, and SS using field spectral data

Table 3: Comparison of bands, coefficient of determination (r^2), RMSE, sampling number (N), and Chl range of the relationship between RD-RE two-band model and Chl

RD band (nm)	RE band (nm)	r^2	RMSE (µg/l)	N	Chl range (µg/l)	Reference
675	700	0.98	-	18	9-119	Oki and Yasuoka (1996)
678	705	0.89	9.8	27	0-100	Thiemann and Kaufmann (2002)
670	700	0.66	7.5	54	6-60	Duan et al.(2007)
650	740	0.71	369.0	-	107-3000	Zimba and Gitenlson (2006)
670	720	0.79	8.4	44	9-77	Gitelson et al.(2007)
685	**697**	**0.92**	**15.6**	**26**	**0-170**	**This study**

Table 4: Coefficient of determination (r^2) between two-band model at WV-2 bands and Chl using field spectral data

WV-2 band	427nm	478nm	546nm	608nm	659nm	724nm	831nm
478nm	0.14						
546nm	0.02	0.00					
608nm	0.06	0.04	0.11				
659nm	0.17	0.17	0.26	**0.47**			
724nm	0.04	0.01	0.01	0.02	**0.46**		
831nm	0.11	0.06	0.04	0.00	0.11	0.02	
908nm	0.12	0.02	0.01	0.00	0.07	0.00	0.02

Table 5: Coefficient of determination (r^2) between two-band model at WV-2 bands and SS using field spectral data

WV-2 band	427nm	478nm	546nm	608nm	659nm	724nm	831nm
478nm	**0.76**						
546nm	0.68	0.56					
608nm	0.76	0.73	0.34				
659nm	0.69	0.65	0.26	0.14			
724nm	0.62	0.50	0.06	0.04	0.24		
831nm	0.45	0.21	0.03	0.30	0.45	0.39	
908nm	0.01	0.13	0.40	0.62	0.67	0.64	**0.78**

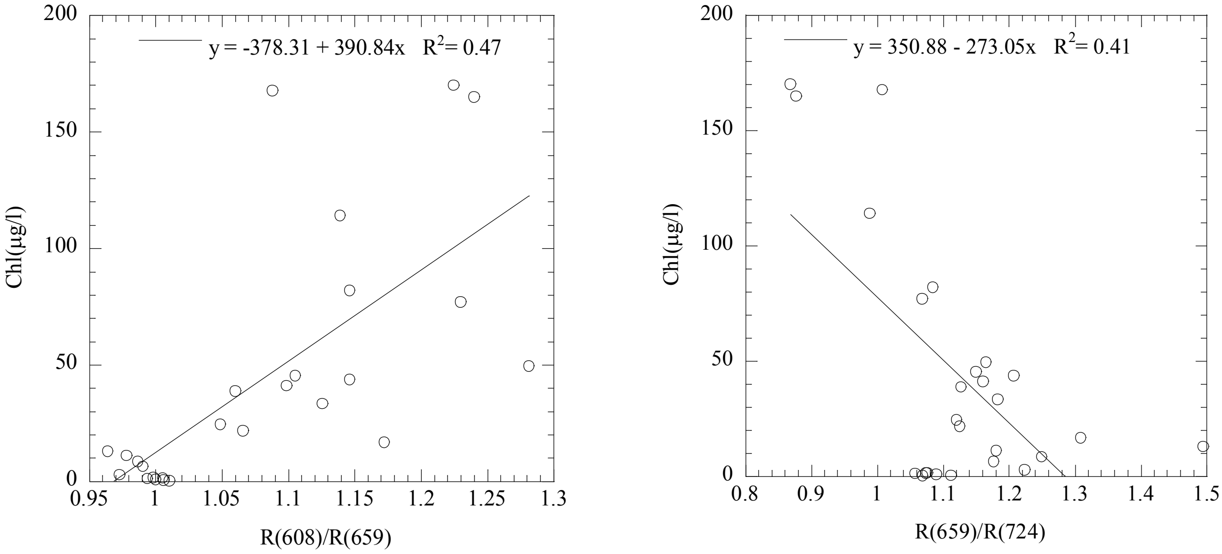


Figure 5: Optimal two-band model of simulated WV-2 versus measured Chl, using field spectral data

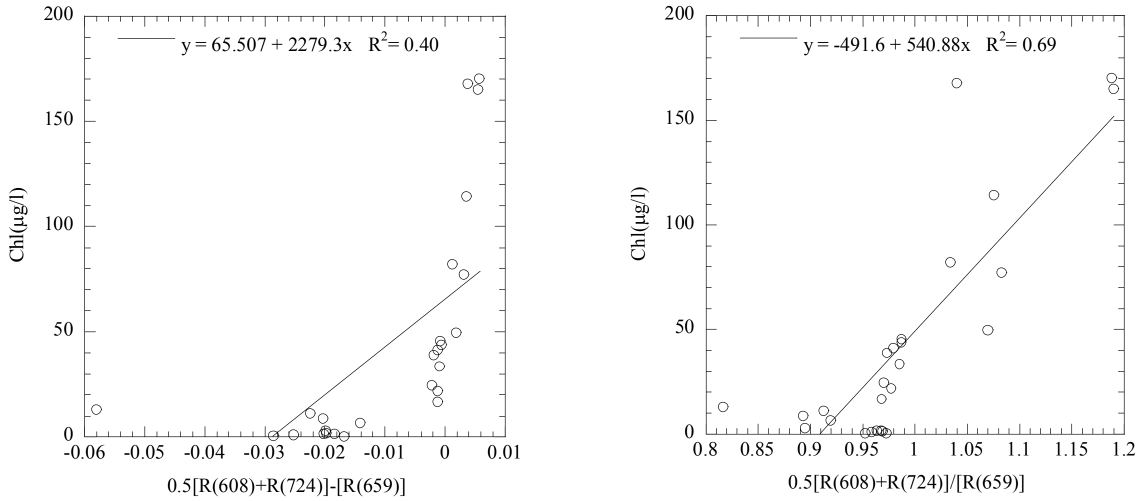


Figure 6: Relationship between the proposed model using equations (5) and (6) and Chl

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REFERENCES:

APHA, WWA, WEF, 1998. Standard methods for the examination of water and wastewater, pp.5–13.

De La Fuente, S., 1976. Geografía Dominicana. Dominican Republic: Editora Colegial Quisqueyana, Santo Domingo. pp.235-236.

DigitalGlobe, 2010. Radiometric use of WorldView-2 imagery. Technical Note (2010-11-01), pp.1-16.

Duan, H., Zhang, Y., Zhang, B., Song, K. and Wang, Z., 2007. Assessment of chlorophyll-a concentration and trophic state for Lake Chagan using Landsat TM and field spectral data. Environmental monitoring and assessment, 129, pp.295-308.

Miño E. R. A., Sakuno, Y., Nakai, S., Mutsuda, H., Okuda, T., Nishijima, W., Castro, R., Garcia, A., Peña, R., Rodriguez, M., and Depratt, C. G., 2011. Pollution Loading to the Caribbean Sea from rivers in the capital city of The Dominican Republic. Proceedings of Coastal Engineering, JSCE, 2, pp.41-45.

Gitelson, A. A., Schalles, J. F. and Hladik, C. M., 2007. Remote chlorophyll-a retrieval in turbid, productive estuaries: Chesapeake Bay case study. Remote Sensing of Environment, 109, pp.464-472.

Han, L., 1997. Spectral reflectance with varying suspended sediment concentrations in clear and algae-laden waters. Photogrammetric engineering and remote sensing, 63, pp.701-705.

Kaul, B. and Mukerjee, H., 1999. Elevated blood lead and erythrocyte protoporphyrin levels of children near a battery-recycling plant in Haina, Dominican Republic. International journal of occupational and environmental health, 5, p.307.

Matsunaga, T., Sakuno, Y., Takayasu, K., Nakamura, M., and Hidenobu, K., 1995. Water surface spectral chracteristics and water quality in Lake Shinji. Proceedings of the 20th Japanese conference on Remote Sensing, pp.67-68. (in Japanse with English abstract)

Oki, K. and Yasuoka, Y., 1996. Estimation of chlorophyll-a concentration in rich chlorophyll water area from near-infrared and red spectral signature, Journal of Remote Sensing Society of Japan, 16(4), pp.1-9. (in Japanse with English abstract)

Zimba, P. V. and Gitelson, A., 2006. Remote estimation of chlorophyll concentration in hyper-eutrophic aquatic systems: Model tuning and accuracy optimization, Aquaculture, 256(1), pp. 272-286.

Rawlins, B., A. Ferguson, P. Chilton, R. Arthurton, J. Rees and Baldock, J., 1998: Review of agricultural pollution in the Caribbean with particular emphasis on small island developing states, Marine pollution bulletin, 36(9), pp. 658-668.

Shahidul Islam, M. and Tanaka, M., 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. Marine Pollution Bulletin, 48, pp. 624-649.

Taylor, E. B., 2009. From el campo to el barrio: Memory and social imaginaries in Santo Domingo. Identities: Global Studies in Culture and Power 16, pp.157-178.

Thiemann, S. and Kaufmann, H., 2002. Lake water quality monitoring using hyperspectral airborne data--a semiempirical multisensor and multitemporal approach for the Mecklenburg Lake District, Germany. Remote Sensing of Environment, 81, pp.228-237.

Villasol, A., Alepuz, M. and Beltrán, J., 1998. Integrated management of bays and coastal zones in the wider Caribbean region: Facts and needs. Proceeding of ITMEMS 1998, pp.192-205.