ENVIRONMENTAL MONITORING USING PHILIPPINES' DIWATA-2: A CASE STUDY IN LAGUNA DE BAY

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ABSTRACT: The Philippines extensive coastline, fertile land and high species diversity makes the country abundant in natural resources. Protection of the environment and sustainable use of resources is of paramount importance, especially with the continuous increase in population and exposure of the country to natural hazards. This has been one of the primary motivations for the development of the Philippines' microsatellites, Diwata-1 and Diwata-2, with missions focusing on environmental monitoring and disaster assessment. This paper highlights the improvements made in the second satellite mission which makes it more effective for spatiotemporal change analysis. Launched in 29 October 2018, Diwata-2 is deployed at 621 km sun-synchronous orbit with 8°inclination, allowing 11-day revisit period and 3 to 5 years expected mission lifetime. This, together with wider image swaths and improved signal-to-noise ratio of its imaging cameras, make Diwata-2 capable for more in-depth studies of water quality in high-value coastal and inland waters. This is demonstrated through the retrievals of turbidity in Laguna de Bay, which at ~900 km^2 area, is considered as the largest lake in the country. Using Diwata-2 Spaceborne Multispectral Imager (SMI) with Liquid Crystal Tunable Filter (LCTF), series of images of the lake were captured within the period of March to June 2019. The highest turbidity values were observed in April, which coincides with the peak months of dry season. The turbidity of the lake then gradually drops at the end of the dry season. Large spatial variability is also observed across the lake's major bays. This detailed information is valuable to fish pen and cage operators, lake managers, local and national government, and other stakeholders in ensuring the sustainable use of the lake. Through the improved capabilities of Diwata-2, images can be captured and analyzed to track the spatiotemporal changes of different geophysical variables that are relevant for the management of the country's natural resources and environment.

1. INTRODUCTION

The Philippines boasts rich natural resources with fertile and arable lands, which are home to a diverse flora and fauna. It is a country with many different kinds of water forms which has extensive coastlines and is rich in mineral resources. More than half of the country's land area is classified as forests (Integrated Environmental Management for Sustainable Development, 2019). It is a valuable resource in the country's regulation of water flows and carbon cycles, as well as in providing habitats to a variety of animal and plant life. The country's land and soil resources are devoted for agricultural use which is commensurate to food production. Its aquatic and fishery resources comprised the cultivated and non-cultivated fish stocks and other aquatic species in the ocean, inland and coastal waters (Integrated Environmental Management for Sustainable Development, 2019).

The Philippines is one of the most hazard prone countries in the world by virtue of its geographical circumstances. For a country with rich natural resources and a pathway of natural hazards; close monitoring, assessment and protection is very important. In 2015, the Philippines embarked on space science and technology development program in collaboration with Japanese universities: Tohoku and Hokkaido University with the main mission of monitoring the country's land and coastal environments as well as obtain information about the extent of damages caused by disasters using on demand satellite acquisition. The program paved the way on the launching of the two microsatellites: Diwata-1 and Diwata-2.

Diwata-1 was launched on April 27, 2016 from the International Space Station (ISS) and orbits at an altitude of 420 km. Diwata-2 on the other hand was launched on October 31, 2018 at an altitude of 621 km via H-IIA rocket from Tanegashima, Japan. The higher altitude of Diwata-2 entails larger swath and its sun-synchronous orbit enables the satellite to have 11-day revisit at 8° inclination making it ideal for improved spatiotemporal analysis of areas in the Philippines. This capability makes it possible to detect changes in land use and more in-depth studies of water quality in high-value coastal and inland waters. Similar to Diwata-1, onboard in Diwata-2 are the high precision telescope (HPT), spaceborne multispectral imager (SMI) with liquid crystal tunable filter (LCTF), wide field camera (WFC) and the middle field camera (MFC) with the addition of Enhanced Resolution Camera (ERC). Diwata-2's HPT has 4 CCDs of red, green, blue and near-infrared band which has a spatial resolution of 5 m. SMI contains two LCTFs at the visible and near infrared band with wavelengths of 400-750 nm and 730-1050 nm respectively and a spatial resolution of 123 m. WFC is a fish-eye lens panchromatic camera with a spatial resolution of 7 km. MFC is an engineering payload with spatial resolution of 185 m. Lastly, ERC is a panchromatic payload used to pan sharpen the SMI images to 54 m.

This study aims to present the spatiotemporal analysis of Laguna de Bay's turbidity from March - June 2019 derived from Diwata-2 images. Laguna de Bay is the largest lake in the Philippines covering an area of 900 km^2. The vicinity of the lake spans over Metro Manila and provinces of Rizal and Laguna which makes it the focal point of national and regional development efforts for agriculture, fisheries and energy sectors (Santos-Borja and Nepomuceno, 2003). The lake also has a dynamic salt-water interaction with Manila Bay and Pasig River making it ideal for fish and aquaculture farming. However, the lake is regarded as a waste heap due to pollution contributed by industrial and anthropological activities as well as massive fishing farms in the area. This results in regular occurrences of massive fish kills (Cuvin-Aralar, 2001) which warrants better understanding on the mechanisms of the lake environment through water quality research. This study presented Diwata-2 images showing spatiotemporal variation in turbidity in Laguna Lake. Its relationship with seasonality and biological and industrial factors within the lake's vicinity is also discussed.

2. METHODOLOGY

2.1 Pre-processing of SMI images

Diwata-2 SMI images taken at 550 nm and 670 nm channels were geolocated and converted to the at-sensor radiance and top-of-atmosphere reflectance using equations 1 and 2, respectively,

$$L(\lambda) = (m \cdot DN) + A \tag{1}$$

$$\rho(\lambda) = \frac{\pi \cdot d_0^2 \cdot L(\lambda)}{F_0 \cdot cos\theta} \tag{2}$$

where $L(\lambda)$ is the at-sensor radiance at a particular band, m and A is the gain and bias, respectively, derived from preflight radiometric calibration, $\rho(\lambda)$ is the TOA reflectance, d_o is the sun-earth distance in astronomical units, F_o is the band-averaged extraterrestrial solar irradiance, and θ is the solar zenith angle.

2.2 Atmospheric Correction of Images

The TOA reflectance can be expressed as shown in equation 3,

$$\rho(\lambda) = \rho_R(\lambda) + \rho_A(\lambda) + t \cdot \rho_w(\lambda) \tag{3}$$

where $\rho_R(\lambda)$ contribution of Rayleigh scattering, $\rho_A(\lambda)$ is the aerosol scattering, $\rho_w(\lambda)$ is the water-leaving reflectance, and t is the diffuse atmospheric transmittance (Vanhellemont and Ruddick, 2015) To retrieve the water-leaving reflectance or most commonly used as the remote-sensing reflectance, the atmospheric correction process described by Ruddick and Vanhellemont (2015) was implemented. Using the ratio of the 778 and 865 nm band shown in equation 4, the aerosol contribution in the visible bands were estimated on an area of clear water pixels near the study area.

$$\rho_A(\lambda) = [\rho(\lambda) - \rho_R(\lambda)] \cdot \{\left(\frac{[\rho(778) - \rho_R(778)]}{[\rho(865) - \rho_R(865)]}\right) exp\ exp\ \left[\frac{865 - \lambda}{865 - 778}\right]\} \tag{4}$$

A homogeneous aerosol distribution across the image is assumed and applied on the whole image. The Rayleigh scattering and diffuse atmospheric transmittance was computed analytically using the single scattering approximation with the satellite and sensor viewing angles as inputs and hence the water-leaving reflectance is finally derived. Note that an initial calibration factors of 0.95 and 1.04 were used for the 550 and 670 nm band, respectively.

2.3 Turbidity Retrieval

During the dry season of 2017, in situ measurements through water sampling on 40 sites around the lake were collected. Water surface measurements such as spectral radiances were collected using ASD spectrometer. Conductivity, pH, temperature, total dissolved solids, dissolved oxygen, turbidity and salinity were measured using Horiba Multiparameter. From these measurements, a turbidity model based on the spectral ratio of 670 and 550 nm bands was derived, as shown in Figure 1. This turbidity model is applied to convert the spectral values obtained from Diwata-2 images to turbidity values at Nephelometric Turbidity Units (NTU).

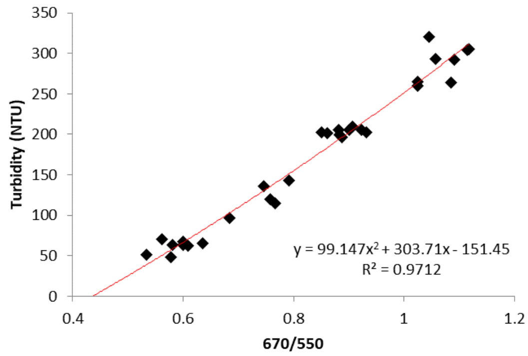

Figure 1. Correlation Plot of the 670/550 Band Ratio and Turbidity Measured In Laguna De Bay

3. RESULTS AND DISCUSSION

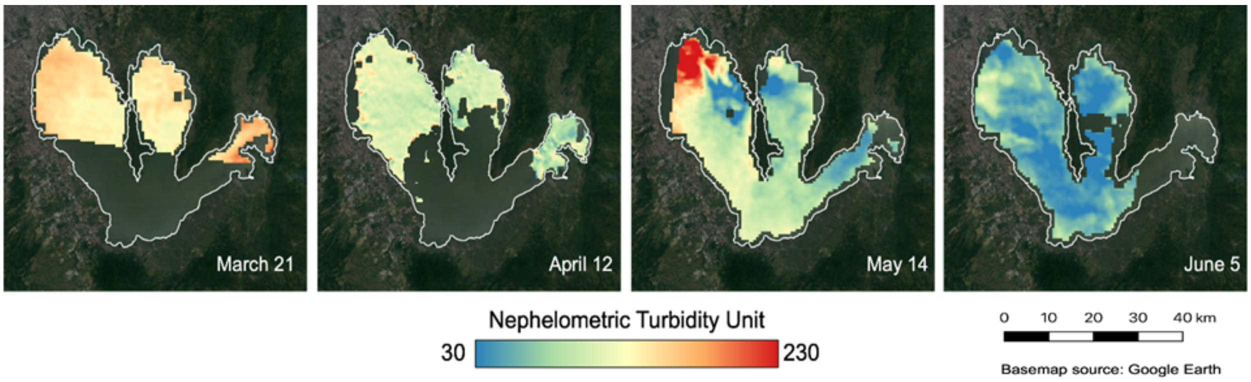

Figure 2. Turbidity Maps Of Laguna De Bay from March To June 2019

A series of images of Laguna de Bay taken by Diwata-2 on March 21, April 12, May 14 and June 5, 2019 shows spatiotemporal variability of the lake's water quality (Figure 2). This period coincides with the dry season where rainfall around the region is minimum for the year. Spatial analysis shows generally elevated turbidity values on the northern portion of West Bay, whereas, temporal trend reveals a decreasing lake turbidity towards the end of dry season. The portions of the lake without turbidity values correspond to either cloud-covered areas or regions beyond the field-of-view of SMI. The turbidity level of the lake can be influenced by several factors such as effluence from surrounding urban and sub-urban community flowing through different channels, and fish-induced and wind-induced resuspension of bottom sediments (Scheffer and Zambrano, 2003; Eleveld, 2012; Philippine Population Density, 2019). The relatively high turbidity observed on the northwest part of Laguna de Bay may be attributed to the lake's hydrodynamics. During the dry season, with prevailing winds coming from southeasterly direction, the lake circulation pattern is dominated by counter-clockwise gyre creating surface-layer current converging at the northwest part of the West Bay (Cunanan and Salvacion, 2016 and Herrera et al., 2015). This current consequently transports sediments along the same direction leading to elevated turbidity that is exacerbated by the presence of numerous fish pens and urban effluence from the Metro Manila flowing through the Pasig and Taguig river. The west bay of the lake is known for its high-density fish pens. Movements from bottom-feeders within these pens may result to the resuspension of bottom sediments and thereby increasing the turbidity level within the vicinity. Moreover, located just above the west bay is Metro Manila, the country's most populated administrative region. Urban waste and byproducts from this area flowing through the Taguig and Pasig river may have a significant contribution on the lake's increased turbidity.

However, effluence from different inlet channels and fish-induced resuspension are mainly localized phenomena which may not explain the elevated turbidity across the lake on March 21. It is surmised that the lake-wide increase in turbidity may be a direct result of wind-induced resuspension of bottom sediments. This is evident on Figure 3, wherein the highest wind speed was also observed on the same date (OGIMET, GSOD, 2019). Since no in situ measurements were collected within the lake's vicinity, wind data from two synoptic stations located on northwest (Science Garden) and northeast (Tanay) portion of Laguna de Bay were used. Among these two stations, the average turbidity correlates more with the wind speed recorded on the Science Garden. During the peak of dry season (February to March), strong northeast monsoon wind prevails. By the end of the dry season, monsoon break occurs resulting to the absence of strong winds as observed in this study. Given this relationship between wind speed and turbidity, the seasonal variation of other quality parameters such as chlorophyll-a, total suspended sediments, dissolved oxygen, and nutrients (chloride, nitrogen and phosphorus) may also be inferred. Ultimately, better understanding on the dynamics between water quality and environmental parameters can then result to more efficient and sustainable utilization of the lake's resources.

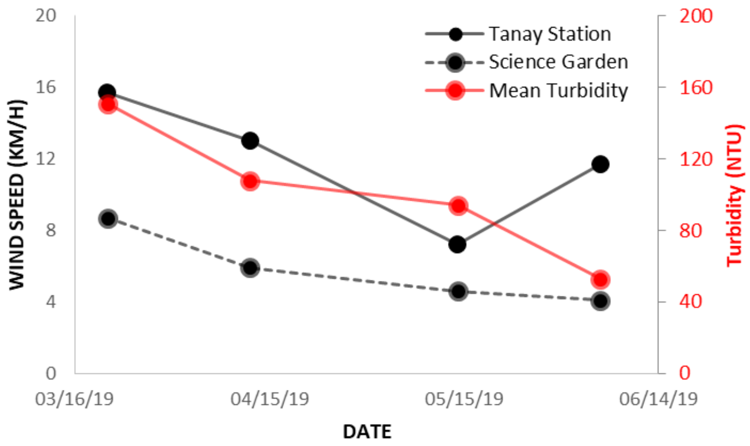

Figure 3. Temporal Variation of Wind Speed And Turbidity

4. SUMMARY & RECOMMENDATIONS

With an increased spatial coverage and revisit period, the capability of the SMI onboard Diwata-2 for spatiotemporal monitoring of lake turbidity was demonstrated. A decreasing trend in turbidity from March to June 2019, which peaked at March 21 was observed. Correlation analysis of wind speed and turbidity suggests that the high turbidity level across the lake on March 21 is driven by the wind-induced resuspension of bottom sediments. Future studies are then suggested to determine different scenarios that will result to wind-induced resuspension. Moreover, in situ measurements of other water quality parameters aside from turbidity is highly recommended. The next phase for Diwata-2 include ground calibration and validation to ensure its reliability for water quality monitoring applications. Furthermore, algorithm development is currently done to maximize the capability of Diwata-2 not only for aquatic but also for terrestrial applications.

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