

## Application of Unmanned Aerial Vehicle Imagery for Algal Bloom Monitoring in River Basin

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### Abstract

*The purpose of this study is to enhance control capability of river water quality and environment by developing algal bloom monitoring technology using Unmanned Aerial Vehicle. The study acquired remote sensing data using UAV on the midstream area of Nakdong River, one of four major rivers in South Korea. The study also conducted water quality analysis and spectral reflectance measuring in the field to identify emergence aspect of phytoplankton in waters of the river and to induce algal bloom detection index equation through wavelength mixing of sensors. The result showed that the result values of algal bloom detection obtained from wavelength band mixing had strong positive correlation with algae standing crops. Besides, the results of analyzing spatial distribution of algal bloom of the overall investigated water area showed that the area of 0.22 km<sup>2</sup> ~ 0.26 km<sup>2</sup> had severity equivalent to the level of warning (5,000 ~ 1,000,000 cells/mL) in 2015 criteria for issuing algae warnings. It is expected that when this remote water quality and pollution monitoring technology is applied in the field, it would be able to improve capabilities to deal with the river water quality and pollution at the early stage.*

**Keywords:** Algal Bloom, Unmanned Aerial Vehicle, Monitoring, Water Quality Exam, Spectral Reflectance

### 1. Introduction

Algal bloom refers to the phenomenon in lakes or river with slow flow velocity where the color of water changes into green due to rapid increase of algae such as Cyanobacteria, Chlorophyceae and Bacillariophyceae, which is caused by eutrophication [1]. Algal bloom has continuously been occurring from the past to the present, but with the rise of water temperature and pollution in the water environment, the frequency and severity is increasing even more [2-6]. Such massive reproduction of algae causes negative effects on use of water resources, including unpleasant taste and smell, impure water, and death of fish due to lack of oxygen in the water [7]. In Korea, water pollution caused by algal bloom has currently been bringing serious anxiety of people over safety of water supply sources and it is now being recognized as a national issue [8-10]. In the

Korean Peninsula, four main rivers of Han River, Geum River, Nakdong River and Youngsan River are flowing across the country, and particularly in the case of Han River and Nakdong River, major big cities have been developed along the rivers which have been major sources of water supply for agricultural, industrial and drinking uses [11]. However, with worsening of eutrophication, continuous heat and drought, algal bloom in the water has increased, and it raised continuous water quality issues [12]. Therefore, in order to address the anxiety of people over use of drinking water and to supply stable water resources by securing clean water sources, it is urgently needed to develop technologies preventing water pollution caused by algal bloom. Furthermore, it is important to enhance capabilities to deal with emergence and distribution of algal bloom preemptively through regular forecasting and effective monitoring activities.

Currently, monitoring of algal bloom in Korea is conducted through local sampling in field investigations and aerial forecasting using manned vehicles. First, the sampling investigation is effective in identifying severity and conditions of algal bloom. However it costs a lot of time and research personnel, and it is not possible to identify spatial distribution such as the volume of emergence and expansion due to the characteristics of local investments [13]. Next, in the case of aerial forecasting using the manned vehicle, it is effective in identifying spatial distribution of algal bloom as it can monitor the whole range of the river within a short time. However, it costs enormous amount to operate the system regularly. When massive algal bloom occurs, aerial forecasting can provide information about the spatial expansion in the wide range, but when it comes to small and medium range of algal bloom around a river, interpretation can be difficult. Therefore, in order to enhance the capability to deal with emergence of algal bloom preemptively, it is required to develop a new kind of forecasting and monitoring system which can overcome limitations of the existing methods. This study attempts to develop algal bloom monitoring technology using unmanned aerial vehicle (UAV) which can implement effective interpretation of spatial distribution at a relatively lower cost compared to aerial forecasting and can overcome visual and spatial limitations of sampling investigation in order to improve controlling capability of river water quality and environment.

## 2. Study Site

Nakdong River locates at the southern east part of the Korean Peninsula and is the second largest river in Korea with length of 521.5 km and size of 23,717 km<sup>2</sup> (Figure 1a) [14]. Total quantity of Nakdong River is 385 tons per year, and 9.5 billion tons (24.7%) of water for use (industrial, agricultural, living and drinking purposes) are supplied to big cities converged with major industries and population such as Busan and Daegu Metropolitan Cities [15]. In the midstream and downstream where these big cities locate, water pollution is frequently occurring due to increased inflow of sewage and aggravation of eutrophication [12]. The present study targeted the midstream area of Nakdong River, in which all the administrative districts of Daegu Metropolitan City are located with high dependency of water resource uses and with frequent occurrence of algae related water pollution (Figure 1b). Among the midstream areas of Nakdong River, the selected site for the study is Dodong-ri, Guji-Myeon, Dalseong-gun, Daegu (Figure 1c), which was covered by Korean media several times due to the frequent occurrence and severity of algal bloom[19].

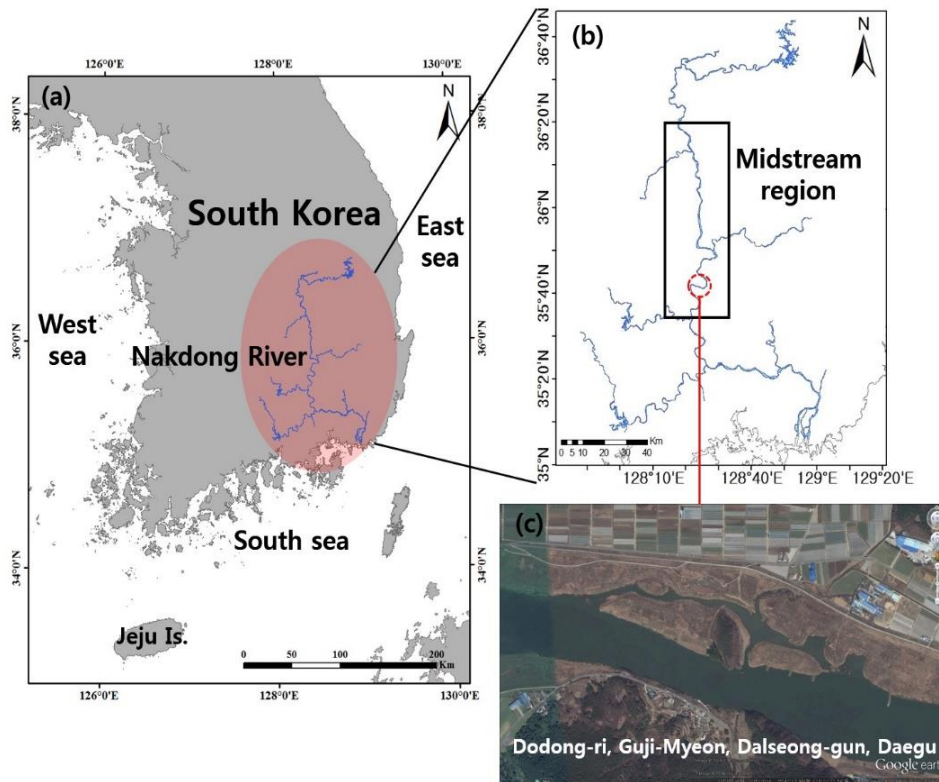


Figure 1. Location of the Nakdong River and Survey Area

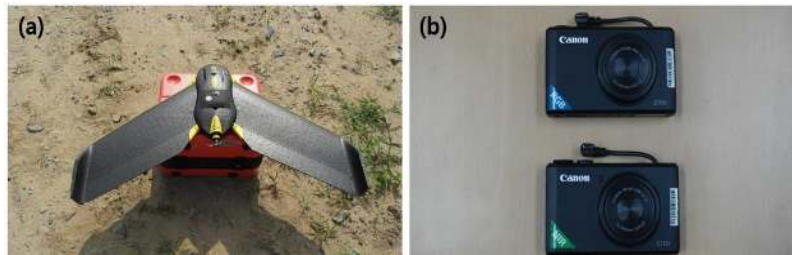
### 3. Methodology

#### 3.1. UAV Imagery

The existing remote sensing method using a satellite or manned vehicle is effective to observe a wide space in a short period. But, the limitation is that it costs a very high price for the operation and that it is difficult to use regularly [17].

Recently, the remote sensing method using unmanned aerial vehicle (UAV) is applied in various areas as an innovative multi-purpose tool to obtain data including geo-spatial information [13, 18-19]. Remote sensing method using UAV can implement operations regularly whenever necessary at a lower cost compared to manned vehicles or satellites to obtain spatio-temporal data in high resolution [20-23]. Besides, with its excellent mobility, it can be applied in places with difficult accessibility for human or in dangerous environments [24-26]. In this aspect, this UAV can be a new solution to supplement disadvantages of conventional remote sensing and field investigation methods.

**UAV and Sensors Description.** The unmanned aerial vehicle (UAV) used in this study is Sensefly Ltd's eBee (Figure 2a) which can make a long flight (single flight: 12 km<sup>2</sup> at 974m altitude) and can obtain high resolution images (ground sampling distance: down to 1.5 cm per pixel) [27].



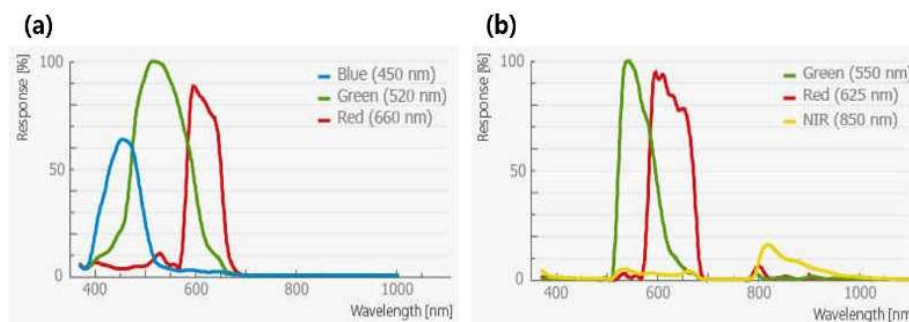
**Figure 2. The Unmanned Aerial Vehicle and Sensor Used in this Study**

eBee is a fixed wing UAV, with function of automatic flight using flight control software, GPS of the vehicle and IMU as well as the function of manual operation. The specification of eBee can be found in Table 1.

**Table 1. Technical Specifications of the UAV Used in the Present Study [27]**

<b>Weight</b>	Approx. 0.69 kg
<b>wingspan</b>	96 cm
<b>Maximum flight time</b>	50 min
<b>Maximum coverage(single flight)</b>	12 km <sup>2</sup>
<b>Nominal cruise speed</b>	40-90 km/h
<b>Ground sampling distance</b>	Down to 1.5 cm per pixel

Next, for the sensors to install in UAV for obtaining image materials, Canon Powershot S110 RGB and NIR were selected. Technical features of S110 RGB and NIR sensors are: Resolution – 12 million pixels, Size – 7.44 × 5.58 mm, Weight – 0.7 kg, Pixel pitch – 1.86  $\mu\text{m}$ , Image format – JPEG and RAW (Figure 2b). S110 RGB sensor basically has the function of digital camera and provides standard band data of Red, Green and Blue to enable visible spectrum analysis of images. S110 NIR sensor consists of NIR (850 nm) band used to calculate NDVI (normalized difference vegetation index) for assessing biomass and plant health, apart from Green and Red band. The specific wavelength band of S110 RGB and NIR sensors are shown in Figure 3.

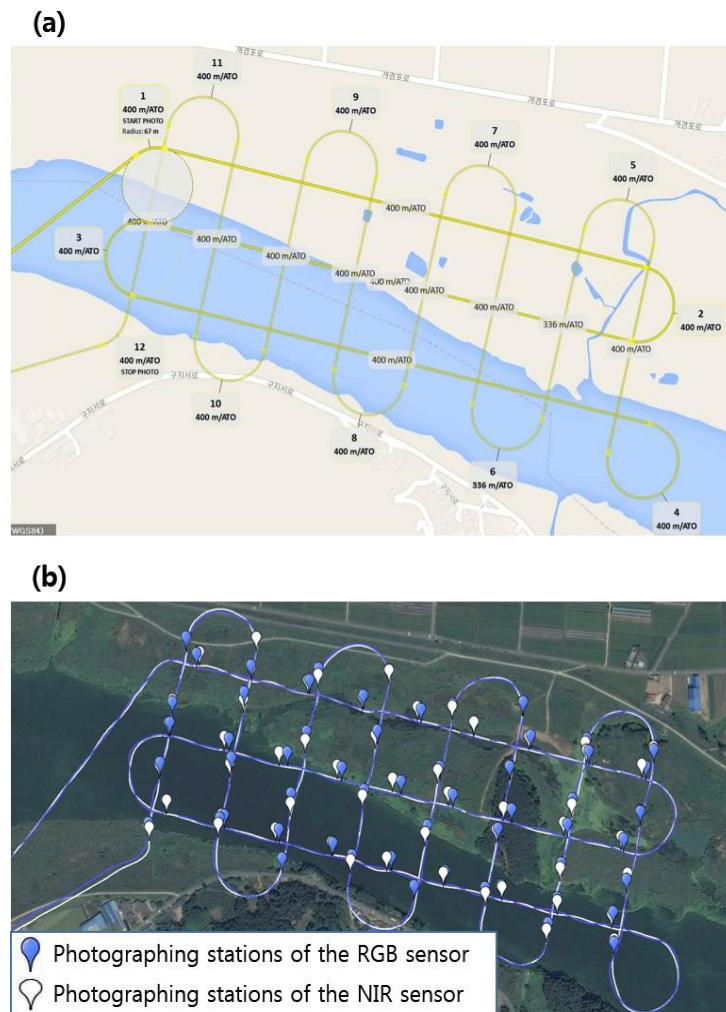


**Figure 3. Spectral Performance of the Camera Sensors Mounted on the UAV: (a) RGB and (b) NIR sensors**

**UAV Image Acquisition and Processing.** Adequate flight planning for UAV is a very important part to acquire high quality data to meet the purpose of using the vehicle [23]. In this study to monitor algal bloom in the river, mission parameters for the photographic flight of UAV were established as follows: flight height – 400 m (ground resolution: 14 cm/pixel), single flight time – within 20 minutes, Flight strip – rectangular route (11 line) (Figure 4a). To generate orthomosaic images of the photographed area, the camera was

set as follows: pixel size – 1.86  $\mu\text{m}$ , focal length – 4.4 mm, lateral overlap – 75%, longitudinal – 70%.

The actual monitoring of Nakdong River water area of Dodong-ri, Guji-Myeon, Dalseong-gun, Daegu (Figure 1c) was conducted two times on July 29<sup>th</sup> and August 18<sup>th</sup> 2015 when high severity of algal bloom continued since the first observation on June 10<sup>th</sup> 2015 by the media [28]. As eBee is made of EPP foam material and has a light weight of 0.69 kg, it is not possible to mount 2 sensors at the same time for a long flight. For this reason, the researcher mounted S110 RGB and NIR separately for each time of monitoring to acquire image data. In order to conduct monitoring of the river's reservoir area including the surrounding areas in a single flight, 57 photographing stations were required, and individual images with 4,000 (width)  $\times$  3,000 (height) pixels were acquired (Figure 4b).

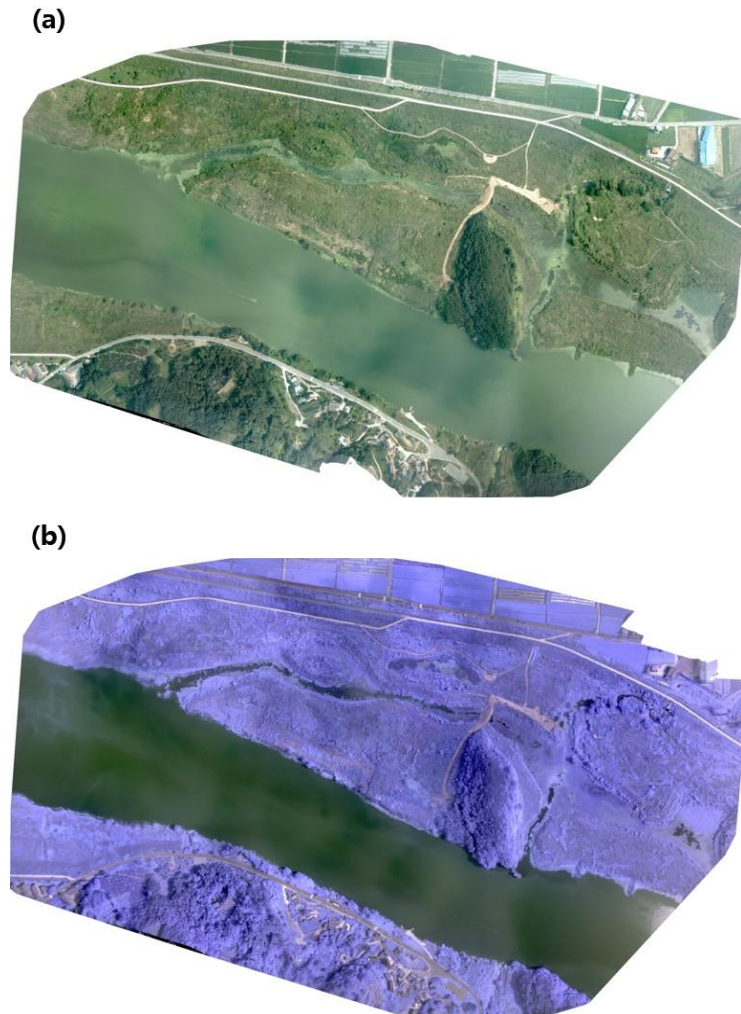


**Figure 4. Flight Plan for Aerial Photography and Photographing Stations:**  
**(A) UAV Imaging Was Started At Position 1 and Ended At Position 12 and**  
**(B) Photographing Stations of Sensors**

Individual images acquired through S110 RGB and NIR were implemented processes of geotagging and georeferencing through flight logs (latitude, longitude, altitude, accuracy horz (m), accuracy vert (m), etc.), which were recorded automatically by GPS and IMU sensors. Besides, in order to identify spatial distribution of algal bloom within the photographed reservoir area of the river, the researcher produced an orthomosaic



image by matching georeferenced images (Figure 5). The information of orthomosaic images photographed on July 29<sup>th</sup> and August 18<sup>th</sup> 2015 are shown in Table 2.



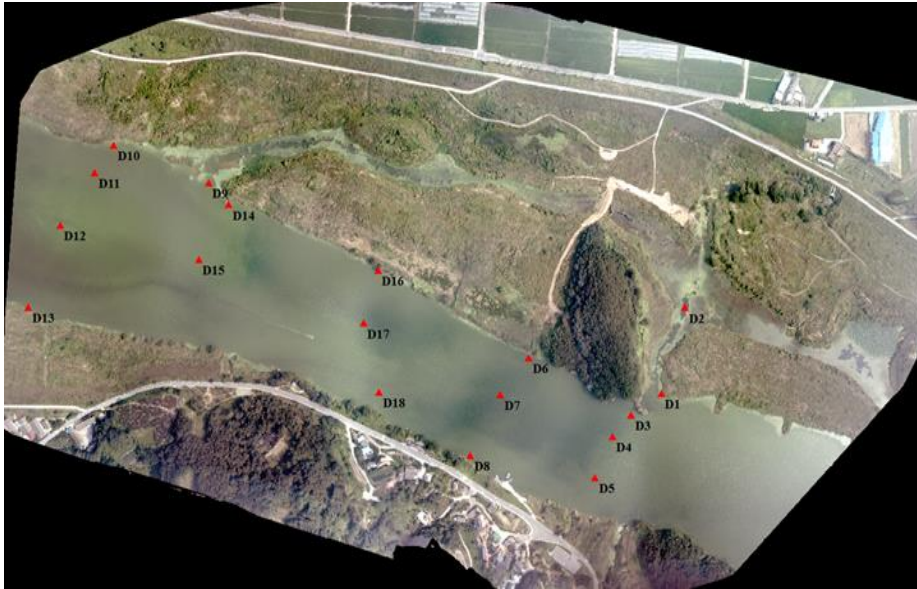
**Figure 5. (a) RGB and (b) NIR Ortho Image Production through Image Preprocessing**

**Table 2. Results of Ortho Images Generation**

	<b>2015.07.29</b>	<b>2015.08.18</b>
<b>Average ground sampling distance(GSD)</b>	12.98 cm/ 5.11 in	12.9 cm/ 5.08 in
<b>Area covered</b>	0.6291 km <sup>2</sup> / 62.9085 ha	0.5847 km <sup>2</sup> / 58.4716 ha
<b>Image coordinate system</b>	WGS 84	WGS 84
<b>Output coordinate system</b>	WGS 84/UTM 52N	WGS 84/UTM 52N

### 3.2. Water Quality Exam

To identify emergence aspects of phytoplankton in the reservoir area of the river photographed by UAV and to examine the results of image detection by integrating the sensors' wavelength band mixing, the researcher conducted field investigation and quantity analysis of 18 sites on July 29<sup>th</sup> 2015 (Figure 6).



**Figure 6. The distribution of Sampling Sites for Water Quality Analysis in Unmanned Aerial Photograph Shooting Range**

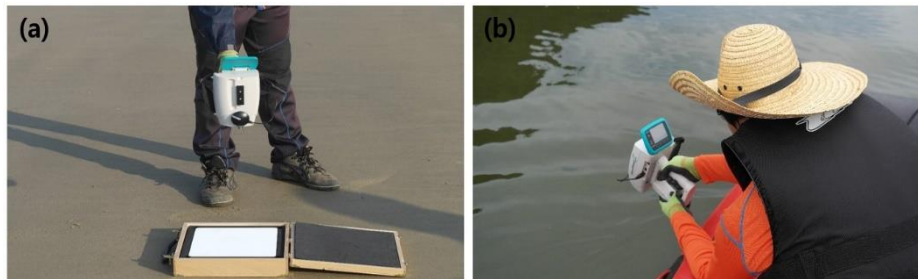
For collection of water, the researcher made judgments about visually polluted sites and relatively unpolluted sites and filled in 1,000 mL bottles at each site while moving the sites by boat. At the same time, by using GPS, the researcher acquired location information of each site. The samples of collected water bottles were fixed with Lugol's solution at the site, and in order to prevent photo-oxidation, aluminum foils were wrapped around the bottle to shut off from the lights (Figure 7). Then, after precipitating the water in centrifuge tube for 48 hours, the researcher removed the supernatant and concentrated the water to 10 mL liquid. Sedgwick-Rafter Counting Chamber was used to yield the coefficient and it was indicated in the converted figures of emergence per unit volume (cells/mL). For species identification, the researcher used high magnification optical microscope (Motic BA210) to conduct analysis up to species level. In the case when the identification up to species level was difficult, the identification was conducted up to the upper level classification.



**Figure 7. Field Water Sampling and Obtaining Coordinate Information at Each Points**

### 3.3. Field Measurement of Spectral Reflectance

The researcher conducted field spectral reflectance on reservoir area of the river using spectroradiometer to investigate algal bloom within the images generated from wavelength band mixing of UAV sensors. For measuring field spectral reflectance, the spectroradiometer was used with functions of wavelength range of 325 nm - 1075 nm, an accuracy of  $\pm 1$  nm and a resolution of  $< 3$  nm at 700 nm (FieldSpec<sup>®</sup> HandHeld2, ASD inc., USA). The researcher measured basic reflectivity using Spectralon panel (10×10-inch) with 99% reflectivity, and each reflectivity of totally 30 sites including 18 sites of water collection were measured (Figure 8). In order to minimize any noise from wind and so on at the point of measurement, the researcher measured 5 times at each site and used the mean value of the measured values.



**Figure 8. Field Spectral Reflectance Measurement Using Spectroradiometer: (A) Reference Reflectance Measurement Using Spectralon Panel and (B) Water (Fresh and Algal Bloom) Reflectance Measurement**

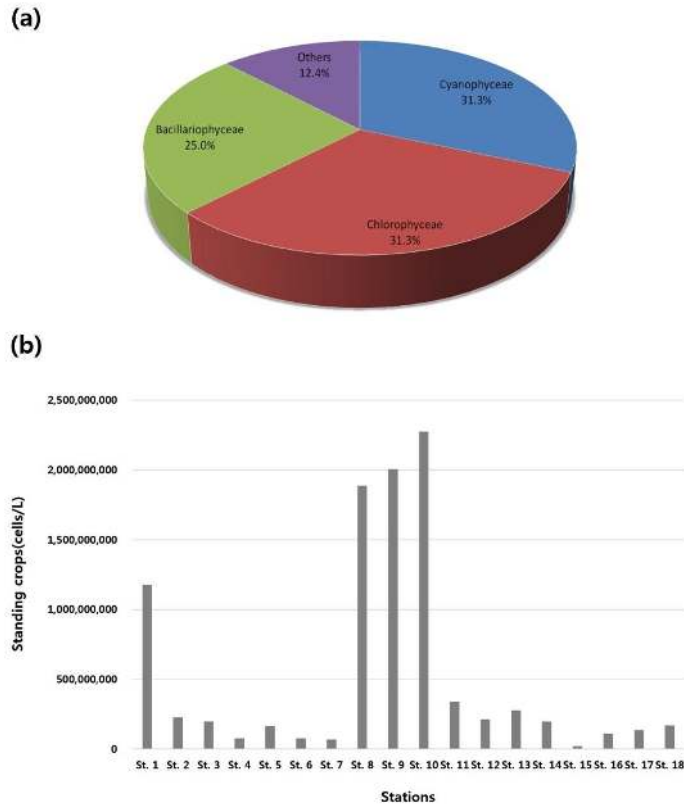
## 4. Results

### 4.1. The Emergence Aspects of Phytoplankton

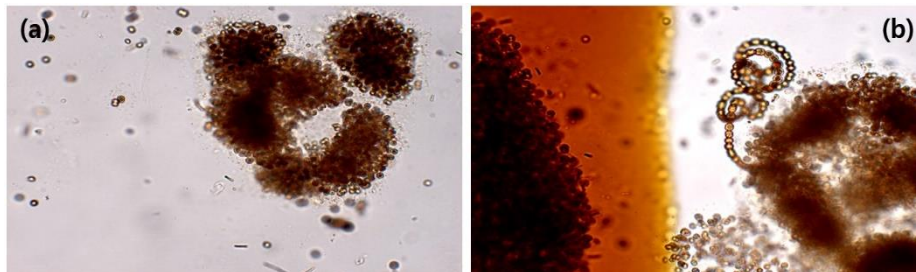
The species composition of phytoplankton emerged in the investigated water showed to be 16 species of 5 classification group. Among them, Cyanophyceae and Chlorophyceae accounted for the biggest proportion with 5 species (31.3%) each, and followed by Bacillariophyceae, Euglenophyceae, and Dinophyceae, each of which with 1 species (Figure 9a). The result of analyzing the quantity of phytoplankton showed that the total standing crop was 9,639,001 cells/mL. Among this, Cyanophyceae accounted for 99.9% (9,637,026 cells/mL) and the standing crops of other species were very low. When the standing crops of each collected site were compared, Site 10 showed the highest standing crop with 23,230 ~ 2,273,800 cells/mL (mean value - 535,500 cells/mL) and Site 15 showed the lowest one (Figure 9b).

Cyanophyceae, which showed the highest standing crop, contains blue-green protein and cause algal bloom making the color of water dark green. Some of Cyanophyceae emit smelling material and small amount of toxin, which cause harm to the health. Ministry of Environment has designated and is managing 4 species of Cyanophyceae including *Microcystis* sp., *Anabaena* sp., *Oscillatoria* sp., and *Aphanizomenon* as harmful cyanobacteria [29]. In the investigated area, among the 4 species of harmful cyanobacteria, *Microcystis* sp.(Figure 10a) and *Anabaena* sp.(Figure 10b) appeared as dominant species with 8,502,525 cells/mL (88.2%) and 1,076,967 cells/mL (11.2%) respectively. The cell quantities of harmful cyanobacteria at each collected site are shown in Table 3.





**Figure 9. The Results of Water Quality Exam: (a) The Emergence Aspects of Phytoplankton and (B) Standing Crop of Phytoplankton at Each Sampling Sites**



**Figure 10. The Shape of Harmful Cyanobacteria Detected In the Study Area: (A) *Microcystis* sp. and (B) *Anabaena* sp.**

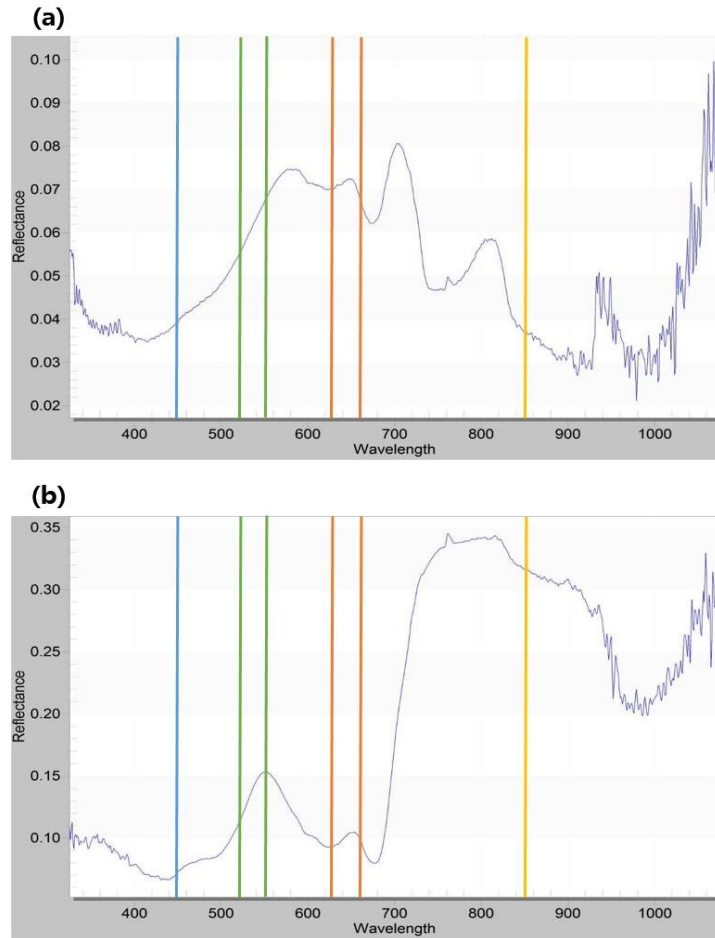
**Table 3. The Number of Harmful Cyanobacteria Cells Detected in Each Sampling Sites**

		Harmful cyanobacteria			Total
		<i>Microcystis sp.</i>	<i>Anabaena crassa</i>	<i>Anabaena sp.</i>	
<b>Sampling sites</b>	St. 1	1,178,361	0	0	1,178,361
	St. 2	227,174	33	0	227,207
	St. 3	197,376	0	0	197,376
	St. 4	73,728	577	4,363	78,668
	St. 5	160,358	0	7,920	168,278
	St. 6	70,464	0	7,080	77,544
	St. 7	66,864	0	0	66,864
	St. 8	1,879,680	0	8,400	1,888,080
	St. 9	1,605,120	0	401,280	2,006,400
	St. 10	1,818,960	0	454,740	2,273,700
	St. 11	222,720	0	74,239	296,959
	St. 12	212,486	0	0	212,486
	St. 13	222,984	0	55,746	278,730
	St. 14	159,408	0	39852	199,260
	St. 15	20,582	0	2,572	23,154
	St. 16	94,147	0	15,691	109,838
	St. 17	126,547	0	1,204	127,751
	St. 18	165,564	0	3,878	169,442
<b>Total</b>		8,502,523	610	1,076,965	9,580,098

#### 4.2. Image Detection Results Using Algal Bloom Index

The reflectivity of natural light reflected from the water surface changes depending on the condition of the surface. The investigated water areas can be broadly divided into conditions of relatively clear water and algal bloom emerged water, and there were differences in the reflectance depending on the condition of water surface in each site. As the quantity and quality of materials contained in the water surface can be different, the color or reflection of the water surface, *i.e* the signal strength of dispersed light is not same. Therefore, when it is measured by spectroradiometer, the resulting value can be different each time. This study attempted to develop algal bloom detection index equation by applying the method of algal bloom detection of water surface using artificial satellite [30]. Figure 11

shows the graph of reflectance data measured in the conditions of relatively clear water surface and algal bloom emerged water surface.



**Figure 11. The Results of Field Spectral Reflectance Measurement Using Spectroradiometer: (A) Fresh Water and (B) Algal Bloom**

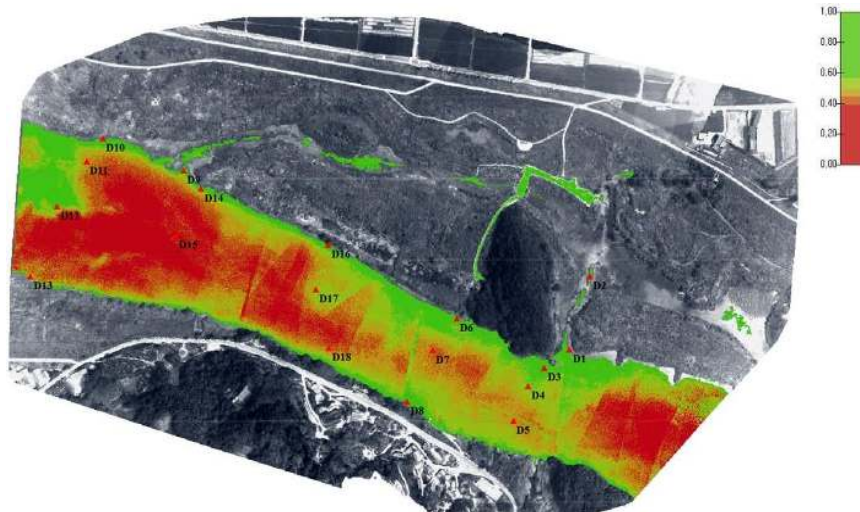
When we examine the features of reflectance, the water surface in clear condition shows reflectance of 0.03 to maximum 0.1 in the range from Blue band to NIR band, and the reflectance by channels does not show significant difference (Figure 11a). However, in the case of algal bloom water, within the visible light, it showed the low peak in Red band and showed the reflectance not lower than 0.3 in NIR band (Figure 11b). Therefore, this study considered wavelength band of sensors mounted on UAV and drew Equation (1) by using the ratio of 660nm showing the low peak reflectance and 850nm showing the high peak.

$$AI = \frac{R_{850nm} - R_{660nm}}{R_{850nm} + R_{660nm}} \quad (1)$$

However, as the absolute value of the reflectance is not high, there's some limitation in the distinction between the conditions of clear water and algal bloom. Thus, by making the difference of the index values bigger, the study attempted to make this distinction more precisely and induced Detection Index (Equation (2)) by calculating Red band (625 nm) with bigger difference between the reflectance of clear water and algal bloom.

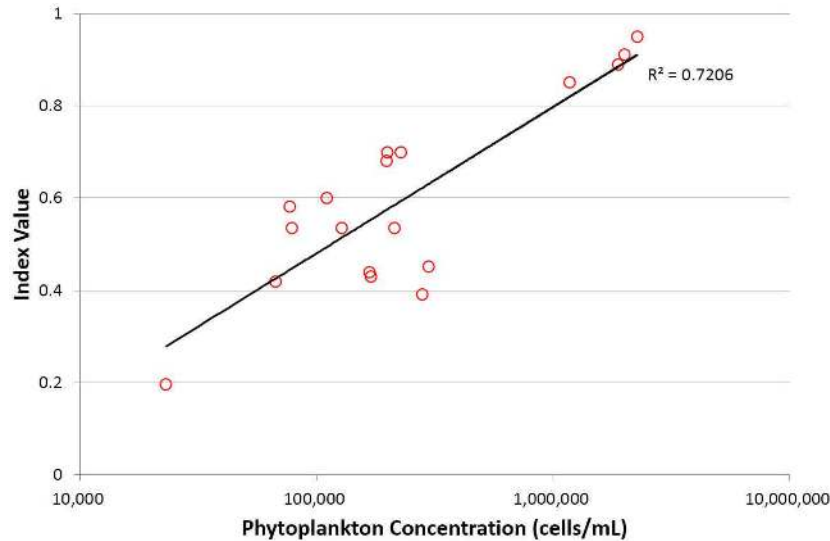
$$AI = \frac{R_{850nm} - R_{660nm}}{R_{850nm} + R_{660nm}} + \frac{R_{850nm} - R_{625nm}}{R_{850nm} + R_{625nm}} \quad (2)$$

The results obtained by applying the induced Algal Bloom Detection Index are shown in Figure 12. The applied date was July 29<sup>th</sup> 2015 when unmanned aerial photographing, water collecting in the field and measuring of spectral reflectance were conducted at the same time. Except for the water surface, the land areas are inactivated, and the values of detected results are indicated in the form of index from 0 to 1 with no unit. The result of comparing Algal Bloom Detection Index and standing crops at each water collected site mentioned in 4.1 showed that the quantity of algae was smallest in D-15 with 23,230 cells/mL. The index value was 0.195 and indicated by red pixel. On the other hand, in D-10 with the largest quantity of algal emergence with 2,273,800 cells/mL, the index value was 0.95 and indicated by green pixel. Based on this, the researcher compared correlation of the Index and algal stranding crops at 18 sites, and the result showed that the coefficient of determination ( $R^2$ ) was 0.7206 having positive correlation (Figure 13). Therefore, it can be considered that the severity of algal bloom emergence is higher at green than red.



**Figure 12. Detection Results through the Application of the Calculated Algal Bloom Index**





**Figure 13. Correlation Analysis Result between Phytoplankton Concentration and Algal Bloom Index Value**

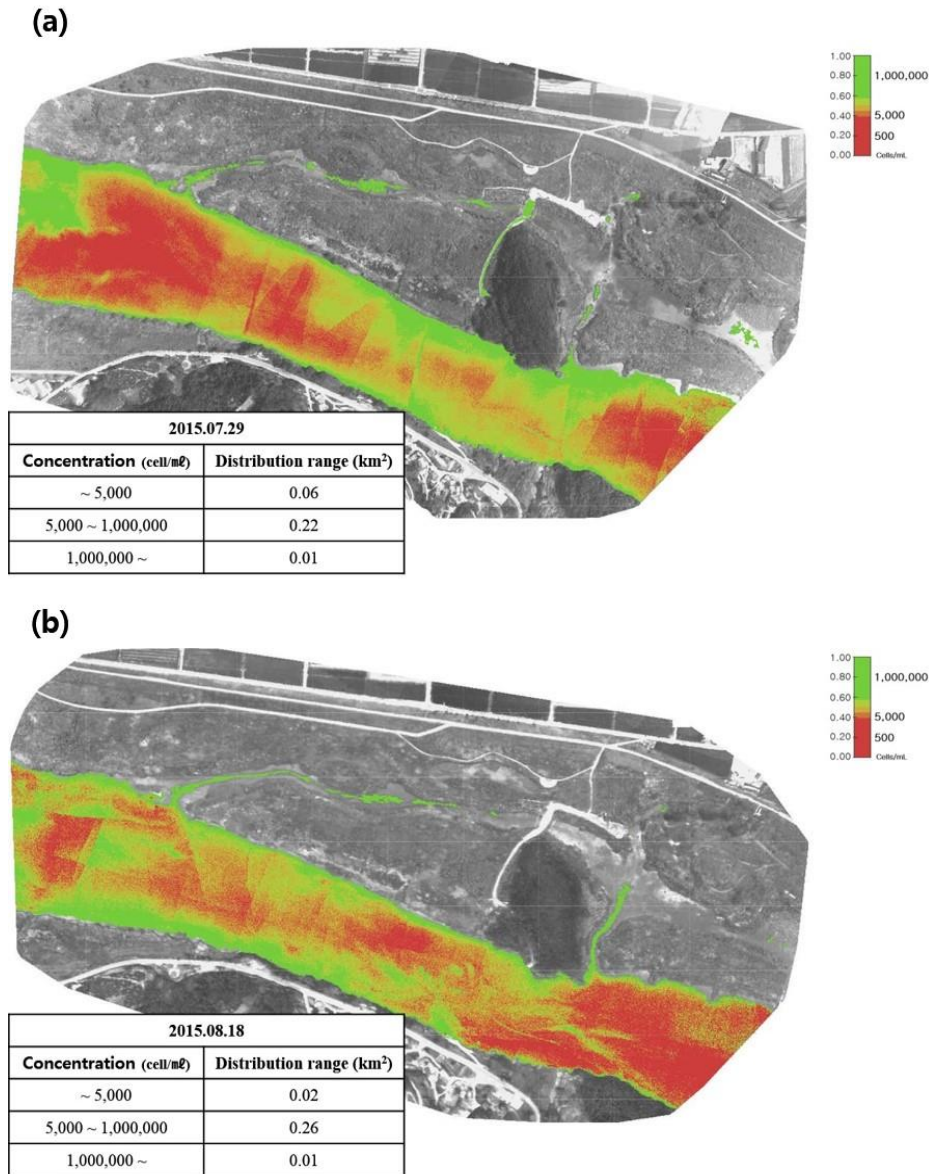
#### 4.3. Estimating Spatial Distribution of Algal Bloom

In Korea, algae warnings have been implemented since 1988 to secure safety of water supply source. Algae warnings are issued into Watch, Warning and Algal Bloom by classifying the degree of algal bloom emergence [29]. For the Algae Warnings Index, concentration of chlorophyll-a and quantity of harmful cyanobacteria cells are used. The criteria for issuing algae warnings in 2015, the year this study conducted, are shown in Table 4.

**Table 2. Criteria and Indicators of Algae Bloom Warning System**

	Chlorophyll-a(mg/m <sup>3</sup> )	Cyanobacteria(cells/mL)
Watch	15	500
Warning	25	5,000
Algal Bloom	100	1,000,000

The study identified spatial distribution of algal bloom in the investigated area by applying the detection index to the above criteria for issuing algae warnings. In the case of July 29<sup>th</sup> 2015, the following data showed: Watch (not higher than 5,000 cells/mL) - 0.06 km<sup>2</sup>, Warning (5,000 ~ 1,000,000 cells/mL) - 0.22 km<sup>2</sup>, Algal Bloom (not lower than 1,000,000 cells/mL) - 0.01 km<sup>2</sup>. The severity of emergence was the highest at both banks of the river (Figure 14a). On August 18<sup>th</sup> 2015, the area with concentration of algae equivalent to watch level was 0.02 km<sup>2</sup>. This indicates that 0.04 km<sup>2</sup> decreased compared to that of July 29<sup>th</sup> 2015, however, the area with concentration of algae equivalent to Warning level increased to 0.26 km<sup>2</sup> and the severity of algal bloom was more aggravated. Besides, the severity of emergence was highest in the left side water area within the image corresponding to the downstream of the river (Figure 14b).



**Figure 14. Spatial Distribution of Algal Bloom in the Survey Area Photographed by UAV: (a) 29 July 2015 and (b) 18 August 2015**

## 5. Discussion and Conclusion

This study attempted to enhance controlling capability of river water quality and environment by developing algal bloom monitoring technology using UAV which can conduct effective interpretation of spatial distribution at a lower cost. For this purpose, the study obtained remote sensing data using UAV focusing on midstream areas of Nakdong River, with high dependency for water resource use and with frequent emergence of algae related water pollution. Besides, the study conducted spectral reflectance measuring of the sites and analysis of water quality to verify results and to induce algal bloom detection index equation through wavelength band mixing of sensors. The results showed that the algal bloom detection values obtained from wavelength band mixing of Red and NIR had highly positive correlation with algae standing crops at 18 sites. Besides, the result of analyzing spatial distribution of algal bloom on the overall investigated water area

showed that the severity in the area from 0.22 km<sup>2</sup> to 0.26 km<sup>2</sup> was at the level of Warning (5,000 ~ 1,000,000 cells/mL) in the criteria for issuing algae warnings. This finding may suggest that the algal bloom monitoring technology using UAV presented in this study can be sufficiently utilized for controlling river water quality and environment. However, the study has limitations for verifying the accuracy because it did not consider monitoring of the river before algal bloom emergence and the results are obtained from only two occasions of monitoring. Therefore, in future, to apply the algal bloom remote monitoring technology using UAV in the actual field, it would be necessary to increase the reliability through additional water quality analysis on various water surface conditions depending on the degree of pollution along with continuous research on spectral features.

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