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# UAV による諫早湾の水質調査

日高悠広*, 大坪俊太郎*, 小川進*, 鈴木誠二*

# Water Quality Estimate in the Isahaya Bay with UAV

by

Haruhiro Hidaka*, Shuntaro Otsubo*, Susumu Ogawa*, and Seiji Suzuki*

A Watergate in the Isahaya bay was closed because of reclamation construction which started in 1989, and water conversion became a very serious problem. Then, remote sensing research was carried out with a few centimeters of resolution and 6 bands. Pictures were taken by UAV and a digital camera on the ground with two infrared filters from May to August in 2016. The research had the following four processes. First process is acquiring photograph data. The data of RGB was acquired by UAV directly, and the ocean temperature data were acquired from Japan Coast Guard. Second, multivariable analysis was performed. Multivariable analysis was applied for water quality in the Isahaya bay and picture data, and regression lines of water quality were obtained by calculating six bands. Third, using these regression water distributions were mapped by PhotoScan (three-dimensional structure software) each water quality. As a result, UAV was available for water quality estimate. Correlations among the water quality were very high. In this research, mapping water quality in the Isahaya bay was successful for environmental management using UAV. The advantage of mapping was visualization of numerical analysis for water quality.

***Key Words:*** *Chlorophyll-a, Correlation, Multivariable analysis*

## 1. Introduction

Recently, in the Isahaya Bay, a critical problem with the worse environmental system occurred as well as rapid water conversion. After constructing the levee in the Isahaya Bay, during winter, higher amount of solar radiation than usual and nutrient flow made red tide, then the color of laver seaweed became faded (Koibuchi, 2003), and the reclamation of the Isahaya Bay made worse infections to the coastal environment and became a problem in the society. This is estimated that breaking down the periodic current made water quality worse by the construction of the levee in the Isahaya Bay.

However, preconstruction data in the Isahaya Bay was so little. Some researchers pointed out that there was the correlation between the construction of levee of the Isahaya Bay and the water quality getting worse, while others said there revealed no correlation (Tsukamoto and Yanagi, 2002, Odamaki *et al.,* 2003, Nishinokubi *et al.,* 2004, Komatsu *et al.,* 2004, Tai *et al.,* 2006). There is some correlation between fishery collapse in the Isahaya Bay and the Ariake Sea and construction of the levee. The Isahaya Bay is damaged area on fishery. Especially, in summer in the Isahaya Bay, dysoxic environment forms with density stratification in the low layer (Nakayama *et al.,* 2004). Moreover, in summer of 2008, as current due to southwest winds occurred, blue tide occurred near the levee in the Isahaya Bay because of advective flows in the dysoxic water body (Tada *et al.,* 2009). Also, in the northern sea of the Isahaya Bay, the density stratification was formed, and dysoxic water body occurred (Tada *et al.,* 2008, Tai, 2015). Especially, on dry beaches in Kama district, Konagai-cho, Isahaya, Nagasaki, cultivated Japanese littleneck died in large amount because of dysoxic environment (Fujii, 2003), and then, compressed air by the pump was injected (Hirano, 2010). In the Isahaya bay, 77% of dissolved oxygen supply for the low layer was estimated as vertical diffusion, while 23% was estimated as advective flows (Yamaguchi

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and Keizuka, 2006). Therefore, to clear the development mechanism for occurrence of dysoxic water body in the sea area, relationship between DO in the low layer, formation of the density stratification and flow characteristics was required. Moreover, applications for water quality with UAV were carried out in the Isahaya bay (Otsubo *et al.*, 2016).

As above, remote sensing on water quality estimate in the Isahaya bay was still not enough. In this paper, 6 items of water quality were examined with high spatial resolution.

## 2. Study Area

The study area is shown in Fig.1 in the right image with a red line boundary. As you see, the bay looks like sandy land, but it is seriously polluted water.


Fig. 1 Study area of the Isahaya Bay

## 3. Methods

Remote sensing data in the research was obtained by UAV (Fig. 2) in the field and from the seawater temperature by Japan Coast Guard. Next, water quality data were obtained from water sampling (Fig. 3). Table 1 shows six reflection bands, colors, and wave lengths. Bands 1 to 5 were obtained by UAV and a digital camera on the ground, and band 6 was obtained from MODIS and a thermal camera.

Fig. 2 Phantom 4

Fig. 3 Water sampling

Table1. Bands, colors, and wave lengths

| Band | color | Wave length(μm) |
|---|---|---|
| band1 | Blue | 0.45-0.52 |
| band2 | Green | 0.52-0.60 |
| band3 | Red | 0.63-0.69 |
| band4 | Near-infrared | 0.76-0.90 |
| band5 | Middle Infrared | 1.55-1.75 |
| Band6 | Thermal Infrared | 7.5-15 |

### 3.1 UAV and thermal camera

The data were made through four processes. First, RGB and Infrared data were acquired by UAV in the field directly, and the ocean temperature data were acquired from Japan Coast Guard and a thermal camera. Second, from obtaining water quality and acquiring water image data, multivariable analysis was applied to get water quality regression lines. Third, for mapping water quality distributions, water quality regression equations by multivariable analysis were substituted into PhotoScan. Finally, all the data were summarized from water quality correlations.

### 3.2 Acquiring data

(a) Photograph data

The authors performed the field study on May 7 and August 5 in 2016 in the Isahaya bay, using UAV (Phantom 4) to take photographs from the sky and a digital camera on the ground. Each photograph has GPS information: latitudes, longitudes, and altitudes. The three-dimensional images were constructed by PhotoScan. Moreover, the sea temperature data were acquired from MODIS.

(b) Water quality

On May 7, 2016, water was sampled with GPS at 10 observation points as shown in Fig. 4. Water quality index were chlorophyll-a, conductivity, turbidity, DO, water temperatures, and pH.

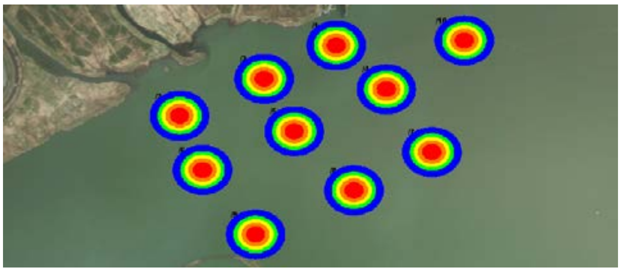


Fig. 4 observation points in the Isahaya Bay

3.3 Multivariable analysis

The multivariable analysis was applied for water quality data using bands 1, 2, 3, and 4 to get regression equations. Water quality was estimated by these equations, and then, the water quality indices are shown in Table 2. Mapping water quality indexes was made from the expressions of multivariable analysis using PhotoScan, which estimates water quality from RGB with functions.

Table.2 Multivariable analysis results of water quality index

| | |
|---|---|
| Chlorophyll-a (μg/l) | -2.53band1+3.85band2-1.35band3＋0.65band4-57.7(R=0.84) |
| Conductivity(μS/cm) | 0.01band1-0.01band2＋0.01band3-0.002band4＋0.113 (R=0.50) |
| Turbidity | －6.39band1＋8.59band2-3.06band3+1.52band4-35.3 (R=0.82) |
| DO (%) | 26.7band1-68.7band2+8.16band3+6.55band4＋3073 (R=0.662) |
| Water temperature (ºC) | 0.03band1-0.06band2＋0.01band3+0.01band4＋21.5 (R=0.71) |
| pH | -0.02band1+0.03band2-0.01band3+0.002band4＋8.35 (R=0.75) |

4. Results

4. 1 Correlation

Table 3 shows the correlations among the water quality indexes. Chlorophyll-a and water temperature negatively correlated as shown in Fig. 5. In the Isahaya Bay two types of water body exist, river flows and the sea water. The former has low temperatures and high nutrient salts that relate with sewerage, while the latter has high temperatures in summer and low nutrient salts. This mechanism suggested negative correlation between chlorophyll-a and water temperatures. Moreover, there was negatively-correlated between water temperatures and DO, which suggested that water temperatures drove to consume oxygen. Table 3 shows a lot of correlations among almost water quality indices.

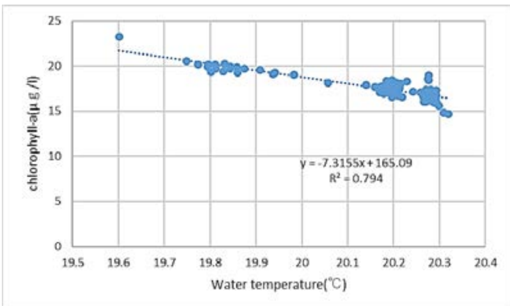



Fig.5 Correlation between water temperature and chlrophyll-a

Table 3 Water quality correlation

| | Chlorophyll-a | conductivity | EC25 | turbidity | DO(%) | DO(mg/l) | Water temperature | pH | salt |
|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll-a | 1 | 0.828 | 0.830 | 0.699 | 0.664 | 0.667 | -0.891 | -0.883 | -0.829 |
| Conductivity | 0.828 | 1 | 0.999 | 0.764 | 0.639 | 0.642 | -0.933 | -0.875 | 0.999 |
| EC25 | 0.830 | 0.999 | 1 | 0.765 | 0.640 | 0.644 | -0.935 | -0.877 | 0.999 |
| Turbidity | 0.699 | 0.764 | 0.765 | 1 | 0.640 | 0.431 | -0.684 | -0.616 | 0.769 |
| DO(%) | 0.664 | 0.639 | 0.640 | 0.428 | 1 | 0.999 | -0.764 | -0.797 | 0.639 |
| DO(mg/l) | 0.667 | 0.642 | 0.644 | 0.431 | 0.999 | 1 | -0.767 | -0.800 | 0.642 |
| Water temperature | -0.891 | -0.933 | -0.684 | -0.684 | -0.764 | -0.767 | 1 | 0.968 | -0.934 |
| pH | -0.883 | -0.875 | -0.616 | -0.616 | -0.797 | -0.800 | 0.968 | 1 | -0.875 |
| Salt | 0.829 | 0.999 | 0.767 | 0.769 | 0.639 | 0.642 | -0.934 | -0.875 | 1 |

### 4. 2 Mapping data

Water quality index distributions are summarized in Fig.6. (a) is a photo combined by UAV. (b) is a salt content distribution, and it shows the river flows into the bay. Thus, the Isahaya Bay was in a water conversion state. (c) is a chlorophyll-a distribution. There were much chlorophyll-a on the sea, while a little in the river. (d) is conductivity. Conductivity in the river was lower than the sea. Conductivity is almost proportion to salt content. (e) is a turbidity distribution. Turbidity comes from mostly soils. (f) is a pH distribution, depending on carbon dioxide, which relates chlorophyll-a.

## 5. Discussion

### 5.1 UAV and software

Phantom 4 can fly at a height of 300m if you have permission to apply. Considering an angle of view for UAV, the horizontal range is 600m. To capture bands of IR and RGB, it is important to obtain high altitudes.

PhotoShop can pile up IR and RGB images. However, because of time-consuming work, it should be desirable to automate.

Photoscan can combine 3D, but it is impossible to make Band 4 as a layer in 3D state. Photoshop can resolve this problem because of making a layer as an orthophoto. As you apply an IR filter to UAV, it is difficult to pilot the UAV, thus you must pilot it visually. Also, UAV should not be piloted on a rainy day.

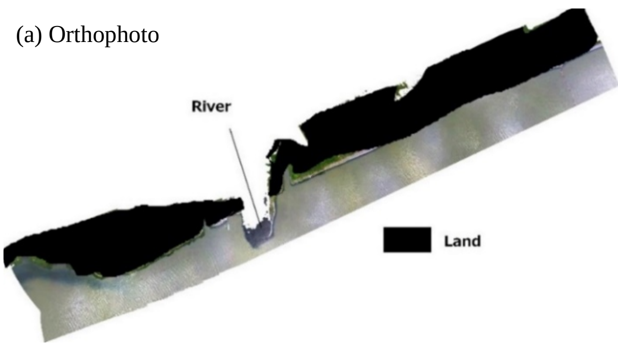
### 5.2 Water quality and multivariable analysis

As a result of adding IR to RGB, for most water quality items, the precision was degraded. However, only for water temperatures, the determination coefficients increased. Also, the values of IR and RGB vary with high resolution, thus the correlation between the values of bands and water quality can be obtained.

Except a portion of halation and retrograde, bands were measured. Bands 1, 2, 3, and 4 can be estimated in the first order approximation if bands could not be read.

There was a positive or negative correlation between Chlorophyll-a and water quality items. Chlorophyll-a can be estimated by reflectance of R and IR. As a result, it is possible to estimate the other water quality items.

(a) Orthophoto



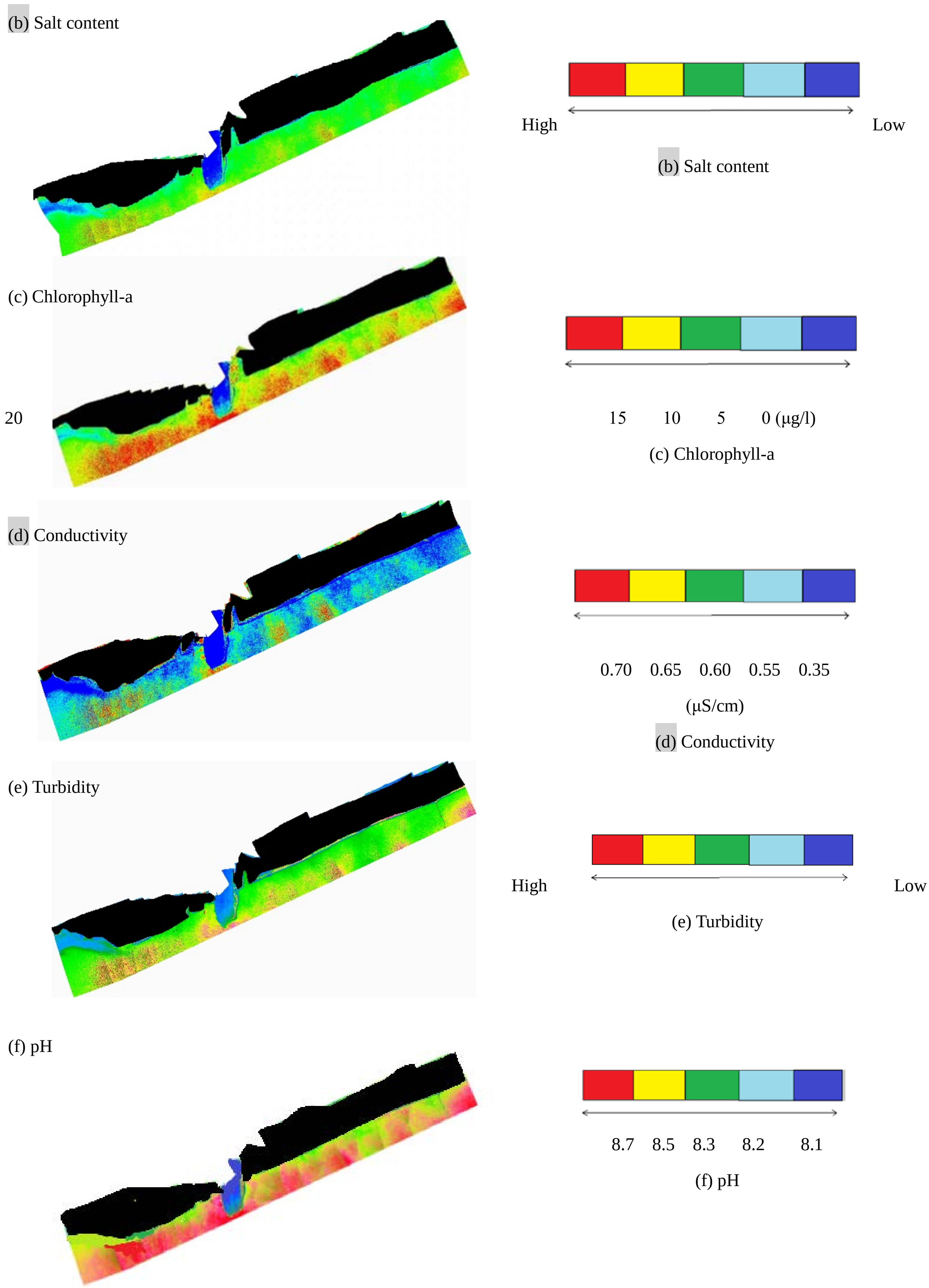



Fig. 6 Spatial distributions of water quality indices using UAV in the Isahaya Bay.
(a) Orhophoto, (b) Salt content, (c) Chlorophyll-a, (d) Conductivity, (e) Turbidity, and (f) pH

## 6. Conclusion

The water quality analysis was carried out with regression equations by multivariable analysis for UAV photographs and water sampling tests. In the Isahaya bay, the correlation among water quality indices was very high and water quality could be estimated each other. Finally, water quality distributions each index were obtained with high spatial resolution using UAV RGB and IR regression equations.

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## References

1) S. Kim, A study on mechanism of hypoxic water formation in the northern part of Isahaya Bay during summer season, Doctoral thesis of Nagasaki University, 2016

2) A. Tada, Y. Nakamura, A. Tai, S. Suzuki, T. Nakamura, Influence of fresh water's inflow upon water quality dynamics in Isahaya Bay, *Journal of JSCE,* B2 (coastal engineering), 66, 1, pp. 366-370, 2010.

3) S. Tsukamoto and T. Yanagi, Sea tide and periodic current in the Ariake Sea, *the Sea and Sky,* 79, 1, pp. 31-38, 2002.

4) M. Odamaki, Y. Ooba, and N. Shibata, Historical observation results of tide current in the Ariake Sea, *Marine Information Department Research Report,* 39, pp. 33-61, 2003.

5) E. Nishinokubi, T. Komatsu, S. Yano, and M. Saida, Influence estimate by the Isahaya reclamation project for flowage structure in the Ariake Sea, *Journal of Coastal Engineering,* 51, pp. 336-340, 2004.

6) T. Komatsu, S. Yano, M. Saida, and A. Tai, Study on change of tidal current and material transport in the Ariake Sea, *Journal of Coastal Engineering,* 53, pp. 326-330, 2006.

7) A. Tai, M. P. Hatta, S. Yano, M. Saida, and T. Komatsu, Influence of the levee for the sea tide and periodic current, *Journal of Coastal Engineering,*53, pp. 331-335, 2006.

8) T. Nakayama, S. Saeki, and K. Kimoto, Relationship of flowage, structure of bedding and DO on low layer in the Isahaya Bay in Summer, *Journal of Coastal Engineering,* 51, pp. 906-910, 2004.

9) A. Tai, T. Ohba, Y. Hayami, T. Komatsu, S. Yano, and A. Tada, Study on flow characteristics in the Isahaya Sea based on field observations, *Journal of JSCE,* B2 (coastal engineering), 71, pp.433-438, 2015.

10) K. Hirano, J. Higano, H. Nakata, A. Shinagawa, T. Fujita, M. Tokuoka, K. Kogo, An experiment for preventing mass mortality of cultured short-neck clams due to hypoxia formation during summer in Isahaya Bay, *Fishery Engineering,* 47(1) pp.53-62, 2010.

11) S. Yamaguchi and Y. Keizuka, Generation mechanism of hypoxia in Isahaya Bay, *Journal of Oceanography,* 15(1) pp. 37-51, 2006.

12) S. Kim, A. Tada, A. Tai, K. Yaoyama, and S. Suzuki, Behavior of fresh water in the northern part of Isahaya Bay during summer season in 2013, *Journal of JSCE,* B1 (Hydro-engineering), pp. 667-672, 2015.

13) S. Otsubo, S. Ogawa, H. Hidaka, and G. Yamada, Present state of UAV and applications for civil engineering, *NAOSITE,* 46, 87, 2016.

14) S. Hosaka, K. Iwashita, and T. Ohki, Relationship of chlorophyll-a and water quality index, 42, 2, 2009.