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Dynamic state of river-mouth bar in Yuragawa River and application of drone photography image to obtain its topographical data

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1. Introduction

Topographic changes of the river-mouth bar in the Yuragawa River of Japan (Fig.1) are continuously activated by sediment transport due to river flows and sea waves. The bar has formed on the right bank only since 2004 (Fig.2) and its size has gradually decreased as a long-term tendency. In resent years, the expansion of the bar has been identified at the upstream of the bar. In order to clarify the characteristics of the topographical changes of the bar and their causes, we have measured the bar topography by using an RTK-GNSS receiver. However, this method may have disadvantage for swift actions upon a disaster investigation. In this study, temporal variations in geometrical properties (e.g. area) of the river-mouth bar were analyzed based on the hydrological and topographical data in the Yuragawa River estuary. As for the measurement of the bar topography, we proposed the method of calculating coordinate values of stations on the shoreline by a coordinate transformation using aerial photography images. The estimated results of the shorelines of the river-mouth bar and coastal zones were compared with the measurement results by the RTK-GNSS survey. The estimation results of their areas based on the estimated shorelines were also compared with those by using the measurement results of the shorelines, and then effectiveness of the proposed method was discussed.

Figure 1. Location and basin of the Yuragawa River.

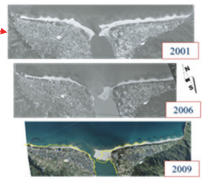


Figure 2. Changes in river-mouth topography.

2. Field measurements on river mouth topography

The area of the river-mouth bar kept on fluctuating until July 2018, whereas the fluctuation is not so large after that. As concerns of the short-term tendency, the area increased in the winter seasons of 2016, 2017 and 2018, and it decreased in their summer and rainy season. Increase of the area may be activated by an increase of longshore sediment transport rate due to high wave heights in the winter seasons and decrease of that was caused by the flooding in rainy and summer season. A possible reason why the area hardly increases in the winter seasons of 2019 and 2020 is that the drift sand from the offshore may be accumulated on the seabed eroded by the flood flow on July and September 2018. The expansion of the river-mouth bar has been identified at the upstream of the present bar in resent years. The red symbols in Figure 3(a) show the area of the river-mouth bar including the upstream bar, which might have been formed since the winter season of 2017-2018. This may be because the drift sand from the offshore has more easily entered to the estuary.

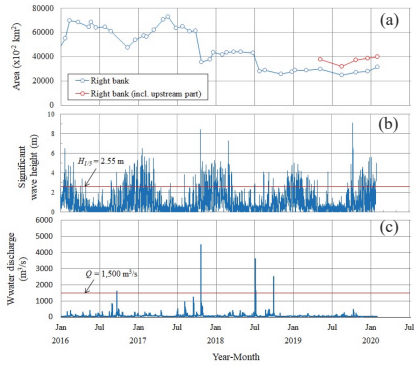


Figure 3. Temporal variations in (a) river-mouth bar area, (b) significant wave height and (c) water discharge.

3. Topographical data by using drone photography images

Figure 4. Phantom 4 (DJI).

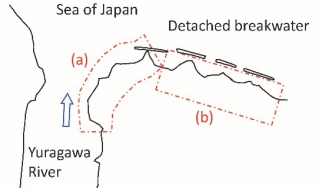


Figure 5. Target zones for topographical data.
(a) Yuragawa river-mouth zone,
(b) Kanzaki coastal zone.

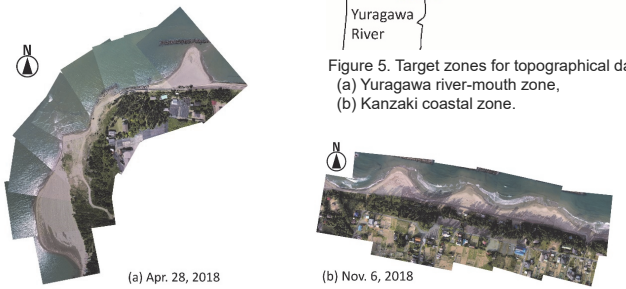


Figure 6. Examples of combined images of Yuragawa and Kanzaki zones.

3.1 Coordinate transformation method and estimation of shorelines

The coordinate values of the stations on the shoreline in the combined image are transformed into the plane rectangular coordinate system as following procedure:

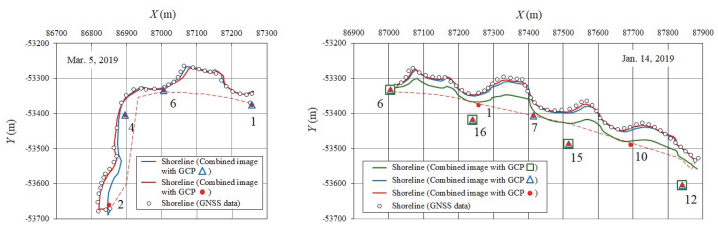
(1) Some GCPs are chosen in the combined images.

(2) The affine coefficients are calculated so that the coordinate values of GCPs in the combined image match their coordinate values in the plane rectangular coordinate system.

(3) The coordinate value (U, V) in the combined image is transformed into the coordinate value (X, Y) in the plane rectangular coordinate system by using the following relation:

$$\begin{cases} X = aU + bV + c \\ Y = dU + eV + f \end{cases} \quad (1) \qquad \begin{pmatrix} a \\ b \\ c \end{pmatrix} = A^{-1}\begin{pmatrix} \Sigma xu \\ \Sigma xv \\ \Sigma x \end{pmatrix}, \quad \begin{pmatrix} d \\ e \\ f \end{pmatrix} = A^{-1}\begin{pmatrix} \Sigma yu \\ \Sigma yv \\ \Sigma y \end{pmatrix}, \quad A = \begin{pmatrix} \Sigma u^2 & \Sigma uv & \Sigma u \\ \Sigma uv & \Sigma v^2 & \Sigma v \\ \Sigma u & \Sigma v & \Sigma 1 \end{pmatrix} \quad (2)$$

where a - f = affine coefficients, u, v = lateral and longitudinal coordinate values of GCP in the combined image, respectively, x, y = those in the plane rectangular coordinate system.

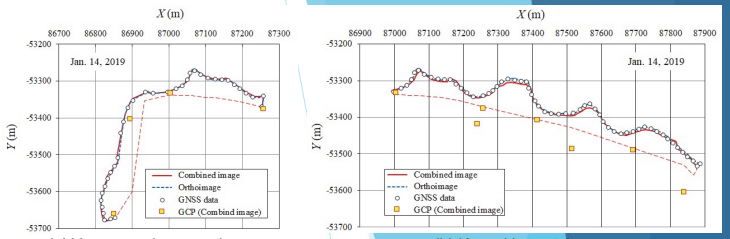


(a) Yuragawa river-mouth zone (b) Kanzaki coastal zone

Figure 8. Effects of GCP on accuracy of estimation results of shoreline

(a) When the GCP were Nos.1, 4 and 6, the shoreline around No.2 shifted in the East direction from the shoreline of the RTK-GNSS survey. This is improved by addition of No.2.
(b) The shoreline colored in green was estimated by using GCPs of Nos.6, 12, 15 and 16, it was away from the shoreline measured by the RTK-GNSS survey. The blue line was estimated by addition of GCP No.7, which is located away from the linear position of the other GCPs. The addition of Nos.1 and 10 caused the further improvement of the estimation as shown by the red line.

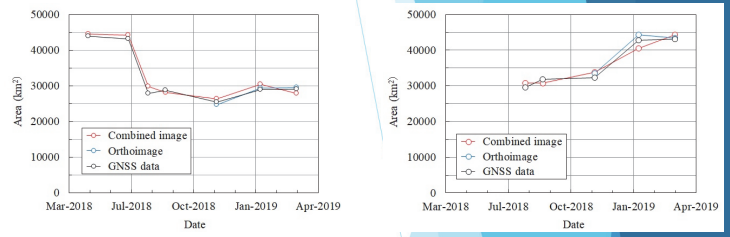
3.2 Estimation of shoreline and area of Yuragawa river-mouth and Kanzaki coastal zones



(a) Yuragawa river-mouth zone (b) Kanzaki coastal zone

Figure 8. Examples of estimation and measurement results of shoreline and their comparison.

The estimation results can roughly follow the shorelines measured by the RTK-GNSS surveys in the both zones. The relatively low accuracy in Kanzaki coastal zone (b) might be caused by not only the distortion of the image but also the unbalanced arrangement of GCPs.



(a) Yuragawa river-mouth zone (b) Kanzaki coastal zone

Figure 9. Estimation results of areas in their temporal variations.

The ratio of the estimated area A_C to the measured one by the RTK-GNSS survey A_G is 0.96 - 1.07 for Yuragawa zone. As for the Kanzaki zone, the value of A_C/A_G is 0.95 - 1.05. These results indicate that since the estimation of areas by means of the combined images and the affine coordinate transformation give a few percent error, the small-scale variations in areas may not always be grasped. However, a relatively large-scale variations in areas due to a flood and high wave events can be grasped.

4. Conclusions

1. The area of the river-mouth bar of the Yuragawa River kept on fluctuating (increase in winter season and decrease in rainy and summer season) until 2018, whereas the fluctuation is not so large after that. Most of the river-mouth bar has been flushed out by some floods in recent years, whereas the expansion of the bar has been identified. This may be because the drift sand from the offshore has more easily entered to the estuary.
2. We proposed the method of calculating coordinate values of stations on lands by a coordinate transformation using aerial photography images and grand control points (GCPs). The shorelines of the Yuragawa river-mouth zone and the Kanzaki coastal zone could be estimate by the method. However. the reproducibility of the estimation results depends on not only the distortion of the image and the personal attributes but also the unbalanced arrangement of GCP. Therefore, the GCP needs to be arranged dispersively. In particular, since the coastal zone widely extends in one direction, the GCP in the onshore or offshore direction are also required.
3. The estimation results of areas of the Yuragawa and Kanzaki zones method keep an error within a few percent. Although the small-scale variations of the areas may not be grasped, a relatively large-scale variations due to a large flood could be grasped.