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UAV photogrammetry for monitoring changes in river topography and vegetation

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Abstract

This study aims to evaluate the accuracy of digital surface model (DSM) of river-channel morphology, which is derived from the imagery acquired with a low-cost digital camera on board an unmanned multi-copter. UAV photogrammetry at flight altitude of 100 m has been carried out before and after a man-made flood in the Jyoge River in Hiroshima Prefecture, Japan along with ground survey using RTK-GPS and Total Station. The UAV photogrammetry has demonstrated that the DSM reproduces the ground elevation very well with the maximum error of 4 cm over a floodway where the vegetation height and density are low and that the DSM reasonably captures the thick vegetation cover over sandbars. It is also confirmed that the difference in DSM before and after the flood is due to the plant toppling over sandbars.

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Keywords: UAV, photogrammetry, digital mapping, river topography, riverine vegetation

1. Introduction

River geometrical data are of prime importance not only for flood protection planning but also river management. Irrespective of their importance conventional survey in relatively big rivers has been carried out to provide the updated information of specified cross sections at the interval of a few years. The cost for 3D mapping by

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conventional survey or conventional aerial photogrammetry has been huge. This situation has been more apparent and serious with medium and small scale of rivers because their number and longitudinal length are quite large. It is also requested from the standpoint of river environment to regularly monitor river topography and land surface cover including riparian vegetation. Hence a strong need has emerged to develop a new measurement platform for river survey, producing precise georeferenced 2D maps and 3D models.

Unmanned Aerial Vehicles (UAVs) has been attractive in many research fields to obtain the latest information of the target areas, owing its high mobility, high resolution and low cost ([1]-[5]). Nowadays UAV-photogrammetry with autonomous navigation function has reached a level of practical reliability and become a useful platform for spatial data acquisition. Hence it is expected that UAV-photogrammetry can acquire river topographical data in a short time and to generate a high-resolution digital model of complex river environment with required accuracy. However, there has been few reports assessing its accuracy under real conditions.

This study aims to evaluate the accuracy of digital surface model (DSM) derived from UAV-photogrammetry applied to river morphological mapping. For this end we carried out UAV-photogrammetry in the Jyoge River in Japan together with ground survey using RTK-GPS and Total Station.

2. Data acquisition

2.1. Data acquisition and processing

The UAV employed in this study is shown in Fig.1 and its specifications are explained in Table 1. It has six arms and rotors with a GPS and a gyro, which support autonomous flight. The UAV flied over a study area at 100 m above the ground at a speed of 4 m/s. It carried a camera of Sony alpha 7R with a 16 mm plastic lens, 35 mm glass

Fig. 1. UAV used in this study.

Table 1. Specifications of UAV

Item	Specification
Weight	3,800 g
Size	950 mm × 950 mm × 400 mm
Wind resistance	15 m/s
Flight time	30 minutes
Payload	4,000 g

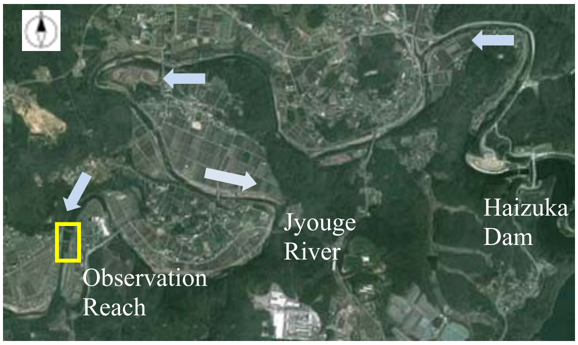
len or a 35 mm glass lens with a polarized lens. The photogrammetry was designed to acquire 90 % forward overlap and 50-60 % lateral overlap. A series of aerial photos were then automatically processed by a photogrammetry software Pix4D Mapper to create orthomosaics, georeferenced Digital Surface Models (DSMs) and 3D mapping.

2.2. Study area

We carried out UAV-photogrammetry in March 2015 before and after a man-made flood in the Jyoge River in Hiroshima Prefecture, Japan. Fig. 2 shows the location of the observation reach located downstream of the Haizuka dam. Fig. 2 explains that the reach consists of a main channel with sandbars covered with dense withered plants and a floodway with short grasses along the left bank. Two small irrigation channels run along the main channel.

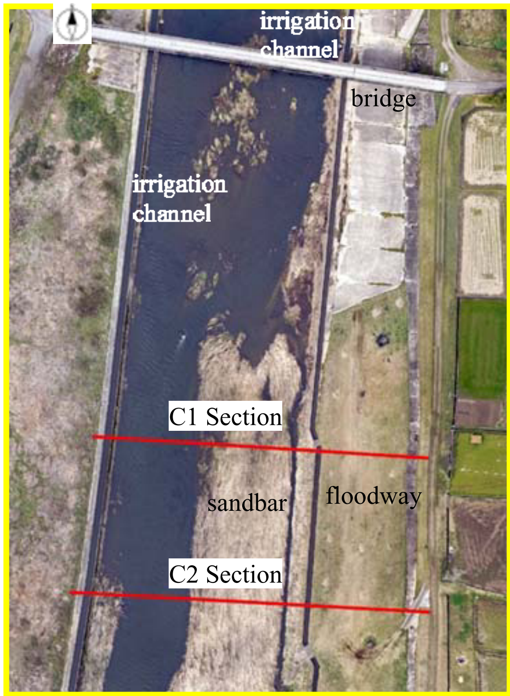
The Haizuka Dam, managed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), has repeated an artificial flood with a peak discharge of 100 m^3/s for fish stocking every March from 2007. The flood has been designed to remove deposited mud and old algae attached to cobbles over the river bed. Since the total volume of water in the reservoir available for the flood is limited, the best practice has been pursued to effectively wash out old algae that juvenile fish does not feed on. We have also observed changes in water level and vegetation during the flood since 2009 and concurrently developed a two-dimensional numerical code for flood flow and sediment transport to discuss more effective flood hydrographs [6,7]. It has been found that plants over sandbars give large effects on the flood because their bending and toppling significantly can change the flow resistance and flow direction. Hence the information on vegetation toppling is important to validate the reliability of the numerical model.

Fig. 3 (a) shows the flow conditions at the initial stage of flood, when the plants downstream of a bridge are emergent, whereas most of the vegetation in the main channel are submerged at the flood peak (Fig. 3(b)). It should be noted the flood did not inundate the floodway.



(a) Location of the observation reach of Jyoge River.

(b) Withered plants over sandbars.



(c) Orthophoto of the observation reach.

Fig. 2. The location of the observation reach in the Jyoge River. Detailed comparison on elevation was made between UAV-photogrammetry and ground survey in C1 and C2 sections.

(a) Flow with emergent vegetation before the flood peak.

(b) Flow with submerged vegetation at the flood peak.

Fig. 3. The change in water depth and plants depending on the flood stage.

3. Assessment of accuracy of UAV-photogrammetry

3.1. Accuracy of GCP

In the observation reach shown in Fig. 2 we carried out UAV–photogrammetry four times with changing the camera lens. Table 2 summarizes the working conditions and the errors of the ground control points (GCPs) assessed by Pix4D mapper. Cases C-1 to C-3 were conducted before the artificial flood while Case C-4 was performed after the flood. Table 1 claims that 35 mm glass lens can provide higher accuracy and resolution that 16 mm plastic lens and that the use of a polarized lens does not improve the accuracy in these cases probably because water reflection plays a minor role in creating DSM above water surface.

3.2. Accuracy of DSM

The river reach consists of water bodies, bars covered with bed materials and vegetation, and man-made structures. Aerial photogrammetric survey with UAV can provide 3D information of the river environment, which is in contrast to and advantageous over the conventional ground survey. We carried out detailed comparison between DSM generated by UAV-photogrammetry and ground survey data to clarify the accuracy and the issues to be improved.

Fig. 4 provides a plan view of the target area and compares the river cross-sectional shape in C-1 section. The orthophoto in Fig. 4 gives a clear and detailed image of the river reach after the flood. The image of submerged river bed is clearly captured due to low concentration of suspended sediment. The comparison between the photogrammetric survey and the ground survey shows that the UAV-DSM creates nearly the same results by ground survey over the floodway where the vegetation grows short and less dense. The maximum difference was 7 cm with the averaged difference of 4 cm. The UAV-DSM, however, fails to detect the ground level over the bar simply because the vegetation was too thick, as shown in Fig. 2 (b). The vegetation height changes from place to place, which are represented in Fig. 4 using bars showing the highest vegetation and the shortest one. The comparison explains that the UAV-DSM gives the level of some vegetation top. The calculated bed level under water shows

Table 2 Working conditions and accuracy of GCPs.

Case	Altitude (m)	Lens (mm)	Ground resolution (cm)	Number of ground control points	Errors (RMSE) (cm)	
					Horizontal	Vertical
C－1	100	16	3.06	11	2.36	2.44
C－2	100	35	1.40	10	2.01	1.88
C－3	100	35 (PL)	1.40	10	2.08	2.01
C－2A	100	35	1.40	10	1.86	1.19

reasonable profile with consistent difference from the reality.

Fig. 5 gives an orthoimage of the reach and a detailed comparison on the river cross-sectional shape in C-2 section. The orthoimage in Fig. 5 is again obtained after the flood. The clear image shows nearly the same characteristics as in Fig. 4. Thus it can be said that UAV-DSM can give accurate ground level unless the vegetation hinders the ground from being detected by photogrammetry. Judging from the difference in elevation over the vegetated bar, the vegetation density is too high for UAV-photogrammetry to capture the ground level.

3.3. Change in DSM due to flooding

Artificial floods may induce the plant bending or toppling, which produces changes in height of DSM. The upper picture in Fig. 6 gives the plan view around the C-1 section before the flood. The lower figure explains the change in

DSM together with the difference in vegetation height. The lower figure claims that no change has occurred over the floodway and little change near the bar edge. The latter phenomenon can be explained in such a way that the river bed was not eroded nor deposited due to the small magnitude of the flood and the existence of short vegetation there. In contrast, vegetation fell down.at the central part of the bar, UAV-DSM reasonably captures the bed level. These results indicate that UAV-photogrammetry can provide orthoimages and 3D mapping with a high level of detail as far as the plant is less dense and the river topography above the water surface is concerned. The bed elevation under water before the flood in Fig. 6 gives unreasonable profile. This result comes from high turbidity of the flow, which makes the river bed patter indistinguishable. The use of polarized lens has shown no effect to improve the situation.

4. Conclusion

This study shows the potentiality of the UAV photogrammetric survey in river morphological mapping. Through the comparison between UAV photogrammetry and ground survey over the river reach with vegetation stands, the following findings are obtained.

1) The error of GCP is around 2 cm and the error over the floodway is around 4 cm, when photos are taken with 35 mm lens attached to Sony alpha 7R at 100 m altitude. The use of 35 mm glass lens is recommended.
2) UAV photogrammetry can provide orthorectified images and 3D mapping whose accuracy is high when the vegetation is short and sparse. UAV-DSM gives the vegetation cover whose level is related to vegetation height and density.
3) The change in ground level and vegetation height can be detectable.

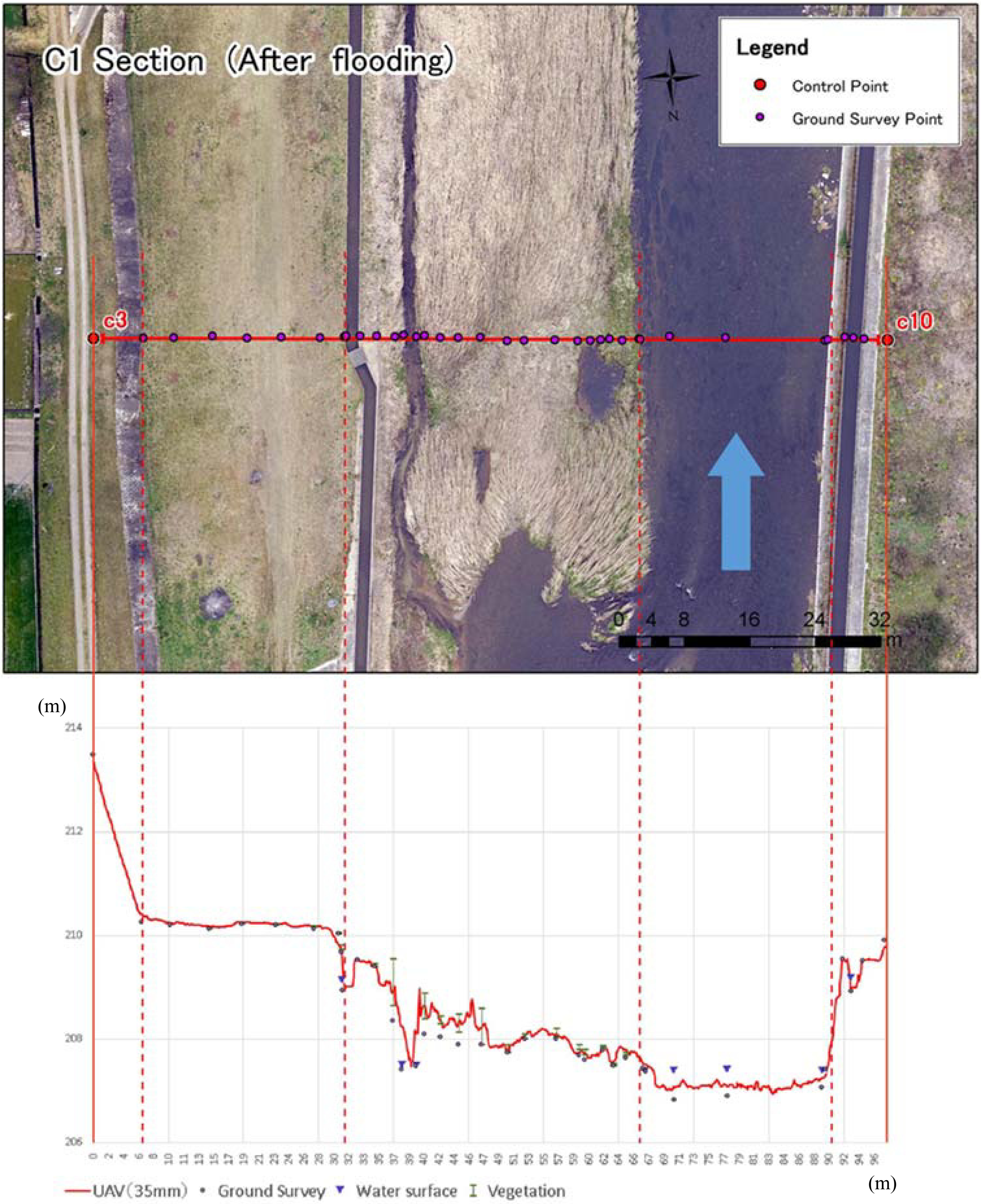


Fig. 4. Orthorectified image and comparison of the cross-sectional shape in C-1 section. The DSM by UAV-photogrammetry precisely captures the floodway ground and gives the level which lies between the vegetation top and bottom. The DSM fails to measure the submerged river bed elevation.

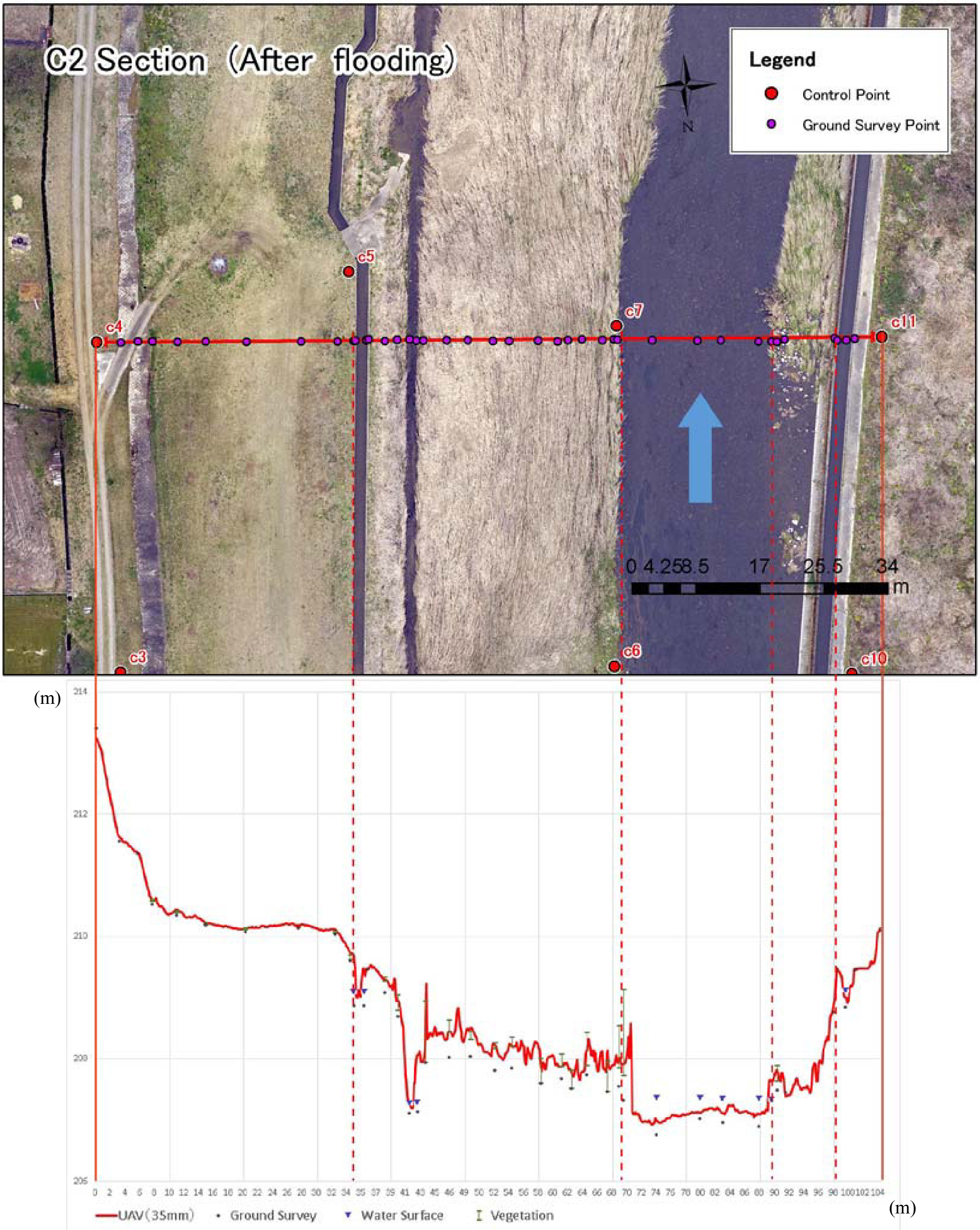


Fig. 5. Orthorectified image and comparison of the cross-sectional shape in C-2 section.

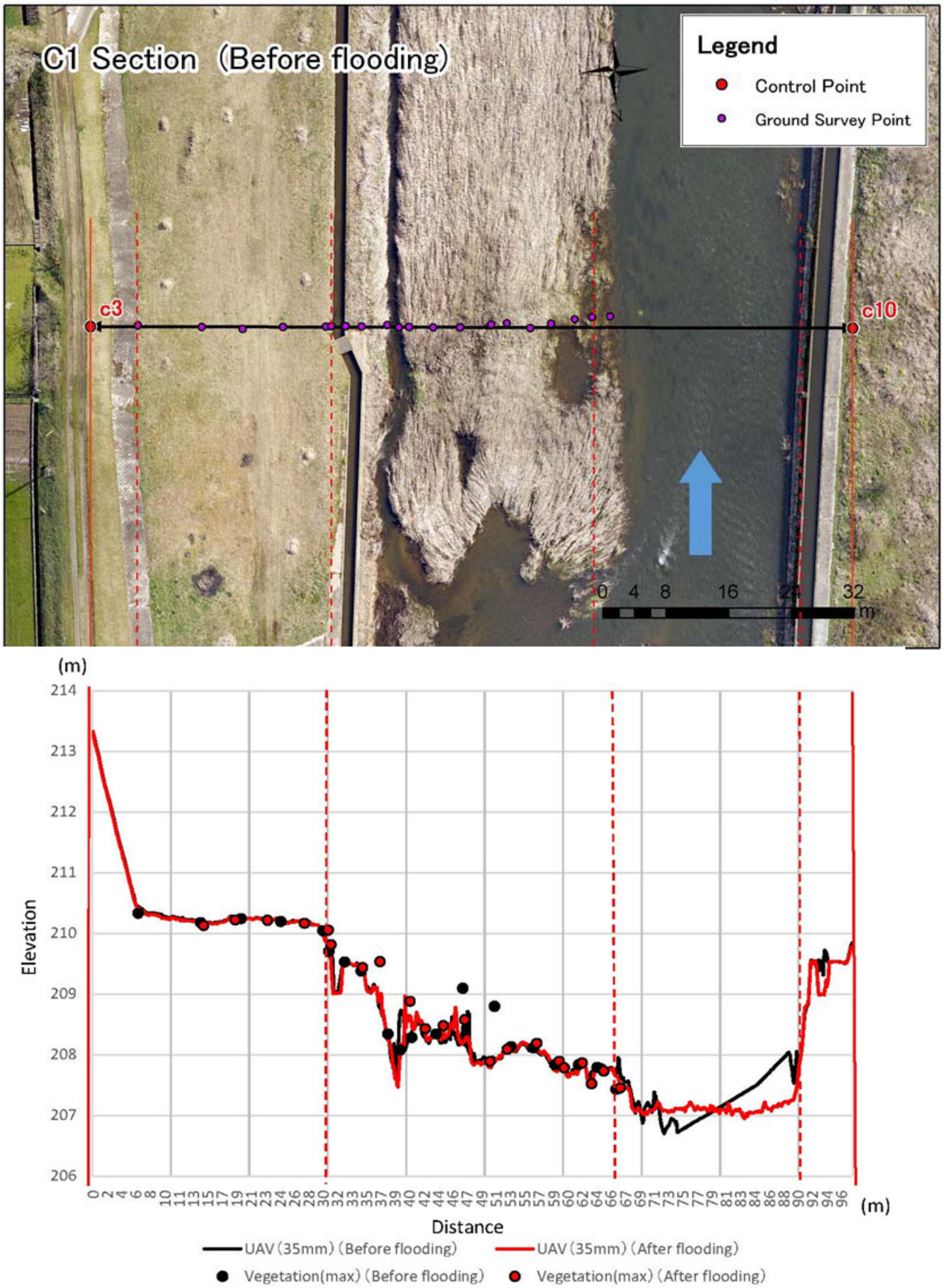


Fig. 6. Orthorectified image before flooding and the change in UAV-DSM at C-1 section. The DSM shows no change over the floodway and some difference at the central part of the bar where some vegetation shows bending and toppling.

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