Geomorphological analysis of wetland distribution on various spatial scales

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Abstract: This study introduces some case analyses of wetland distribution on various spatial scales, from nationwide to the area of a wetland group, with a focus on geomorphological feature. Then described the usefulness of GIS analysis in wetland research. The nationwide wetland distribution in Japan showed that wetland density was high at less than 200 m and around 1600–2000 m. Wetlands in mountainous regions were concentrated in snowy Quaternary volcanic regions from the center to the northern part of Japan. This implied snow accumulation and topography of volcanic mountains are important for wetland formation. Secondly, we clarified that wetlands were mainly distributed on the gentle slope of original volcanic surfaces and in landslides in the Hachimantai volcanic groups, in the northern Japan, using 10-m grid DEM and aerial photo interpretation. With the higher-resolution data, it was clear that wetlands were arranged depending on the microtopography of landslides and volcanic surfaces and groundwater. Using data with resolution suitable for the target topographical size and combining the results of multiple spatial scales/resolutions, we can understand the origin of wetlands in more detail.

Keywords: mountain wetland, geomorphological control, GIS, DEM

1. Introduction

Over the past few years, many studies have shown an interested in wetland responses under the impact of climate changes and human activities (Erwin, 2008; Thorne et al., 2018). One of the most important factors affecting wetland vulnerability is the fluctuation of recharge water. The amount of recharge water is greatly affected not only by the change of precipitation around the wetland, but also by the change of inflow of groundwater and surface water from the surrounding area. Particularly, it is considered that the mountain wetlands in the narrow catchment area are more sensitive to fluctuations in recharge water. Adding to enough precipitation, the presence of a concave topography for storing water is also an important factor for the wetland formation. Moreover, the hydrological environment around the wetland needs to be considered as a system of climate and topography (Daimaru and Yasuda, 2009). However, , few studies focus on geomorphological control on wetland distribution (Łajczak, 2013; Takaoka, 2015).

With the consolidation of the nationwide GIS dataset on terrain and climate, studies on geographical distribution from broad perspectives have increased. On the other hand, with remarkable progress of UAV-SfM (unmanned aerial vehicle and structure from motion) technique in recent years, high resolution geomorphological analysis has been easily available although limited to narrow area.

This study introduces four case analyses of wetland distribution on various spatial scales, from nationwide to a wetland group in a mountain region, with a focus on geomorphological feature surrounding wetlands. Then describes the usefulness of GIS analysis in wetland research.

2. Wetland distribution on various spatial scales

2.1 Wetland distribution in Japan

Many wetlands of various sizes and origins are distributed from low to mountain regions in Japan, where the East Asian monsoon brings much precipitation through the year, and topographic changes associated with tectonic and volcanic activities, mass movements and river and coastal processes are active.

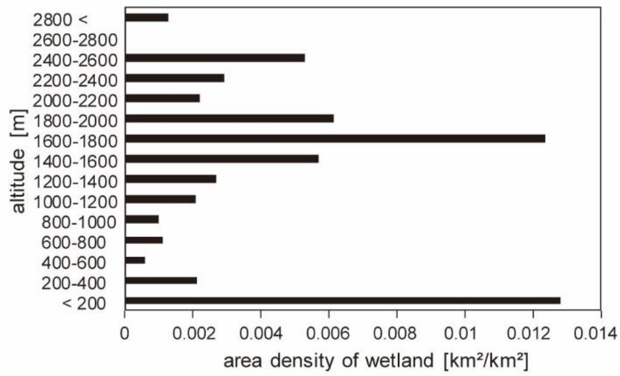

Figure 1. Area density of wetlands in each elevation in Japan.

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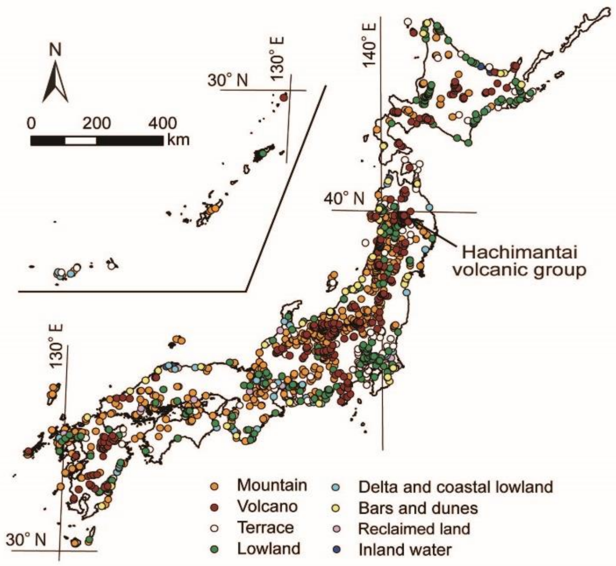

Figure 2. Wetland distribution in each topographic surface in Japan. The 21 topographic surfaces in Wakamatsu et al. (2005) were edited into 8 as the legend.

Firstly, we describe the nationwide wetland distribution in Japan. We used the wetland inventory of the National Survey on the Natural Environment conducted by the Environment Agency in 1993, which covered natural inland wetlands with an area of 1 ha or more (total area for a wetland group). Of the wetland data, the analysis was conducted on 2114 inland wetlands excluding rivers, tidal flats, and wetlands with a defect in area value. The wetland density (wetland area/surface area) at each altitude exhibited a bimodal pattern, high at less than 200 m and around 1600–2000 m (Figure 1). The formers are large and a few, including lagoons, peatlands on alluvial lowlands and large tectonic lakes. Wetlands in mountainous regions are smaller, but numerous wetlands characterized the mountain landscape in Japan.

Mountain wetlands in Japan concentrate from the center of the northern part of Japan, along the snowy backbone range (Figure 2). As a result of superposing the wetland distribution on a topographical map by Wakamatsu *et al*. (2005), the number density of wetlands in Quaternary volcanoes and the other mountains are calculated as 9.41 $\times 10^{-3}$ wetlands / km^2 and 2.55 $\times 10^{-3}$ wetlands /km^2, respectively. This indicates volcanic mountains are one of the most typical regions where wetlands are prevalent. Many Quaternary volcanoes located in the central and northern parts of Japan are about 1500 to 2000 meters above sea level and their altitude is correspond to the peak of area density of wetland (Figure 1). It is implied that high altitude areas of volcanoes have environmental conditions suitable for wetland formation.

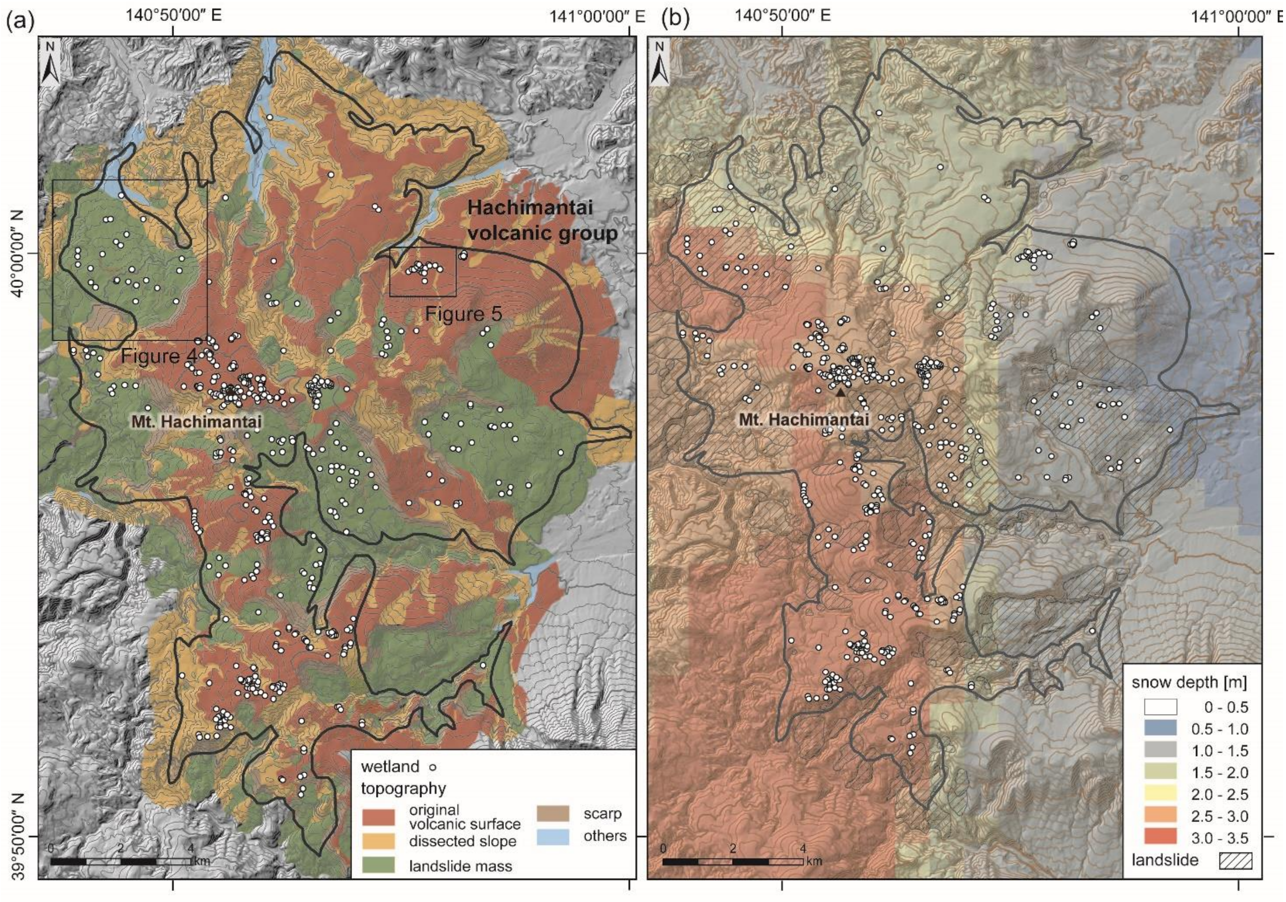

Figure 3. (a) Distribution of wetlands and geomorphic classification of the Hachimantai Volcanic Group (after Sasaki and Sugai, 2015). Scarps, landslide mass are based on the Landslide Distribution Maps Database (National Research Institute for Earth Science and Disaster Prevention 2013) (b) Wetland distribution and maximum snow depth which is published by the Ministry of Land, Infrastructure, Transport and Tourism (http://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-G02.html). Basement maps were derived from 10 m grid DEM.

2.2 Wetland distribution in the Hachimantai volcanic group

To interpret the distributions of mountain wetlands in relation to topography and snow depth as their establishment requirements, we focus on the Hachimantai volcanic group, which consists of a set of quaternary stratovolcanoes and contains many wetlands. We conducted a GIS analysis with wetland distribution map and geomorphological classification map made by aerial photogrammetry (Sasaki and Sugai, 2015) and the 1-km grid maximum snow depth distribution published by the Ministry of Land, Infrastructure, Transport and Tourism (http://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-02.html).

Wetlands were mainly distributed on three conditions (Figure 3). Firstly, many wetlands are along the north-south ridge line, where is the smooth gentle slope of original volcanic surfaces with much snow. Secondly, some are at the foot of lava flows despite little snow in the northeastern part of the volcanic group, although the number of wetlands is small on the volcano surface with little snow. Finally, wetlands tend to be dispersed over large-scale landslides independently of snow depth.

To summarize in the spatial scale targeting one volcanic group, it was possible to capture how wetlands were unevenly distributed on several topographical surfaces. We found there are also two types of wetlands on the volcanic surface, those that are highly dependent on snow depth or not.

2.3 Wetlands on landslide and volcanic surfaces in Hachimantai volcanic group

2.3.1 *On large-scale landslide: Komonomori Landslide*

Landslide wetlands tend to be dispersed over landslides, while those on the original volcanic surfaces tend to be concentrated along the mountain ridge (Figure 3a). Control factors of the wetland distribution in a large-scale landslide, the Komonomori Landslide in the Hachimantai volcanic group, could be explained using a landslide topographic map created from a 5-m grid hillshade map and aerial photo interpretation. In the upper part of the landslide, secondary scarps and linear depressions are aligned parallel to the main headscarp, and elongated wetlands are formed at the foot of scarps. The lower part of the landslide is deformed by secondary landslides. In the secondary landslide, wetlands are located also at the foot of the scarp and in the depression, which may represent the shape of the surface rupture as Massay *et al*. (2018) illustrated.

Wetland distribution in a large-scale landslide is controlled by the microtopographic pattern of the landslide. Moreover, the topographic feature of nested structure causes the dispersed distribution pattern of wetlands.

In the hillshade map derived from 5-m or 1-m grid DEM, microtopography of the landslide including linear depressions parallel to the main scarp and radial cracks in the accumulation zone of landslide could be clearly recognized, wherever ground surface is covered by forest. These topographic features help to understand not only its landslide type and internal structure of the landslide but also the relation to the wetland distribution.

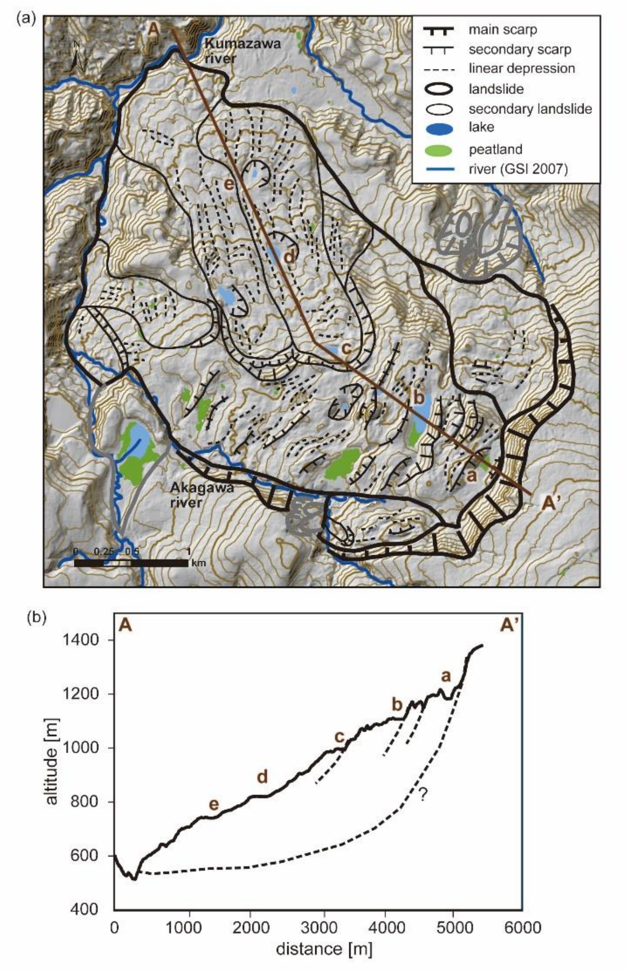

Figure 4. Map of Komonomori Landslide showing geomorphology and wetland distribution (a) and longitudinal profile A-A' (b) (after Sasaki and Sugai, 2015).

2.3.2 *On original volcanic surfaces*

In the case of a wetland group at a flat grassland, Okuno-makiba Ranch, on the toe of a lava flow, we analysed using 5-cm grid digital elevation model (DSM) and orthophoto constructed with UAV-SfM approach. We identified 136 wetlands with the orthophoto in June 2018 (Figure 5). They are formed in slight depressions on the ground surface, and some of them have connected each other by small unclear channels(Figure 6).

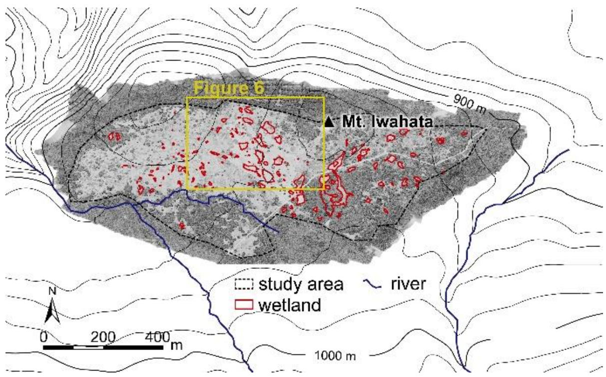

Figure 5. Wetland distribution of the Okunomakiba Ranch, on the original volcanic surface in the Hachimantai volcanic group. The base layer is the 5-cm digital surface model constructed with the UAV-SfM approach. Contour is derived from the 10-m DEM and the rivers are from GSI (2007).

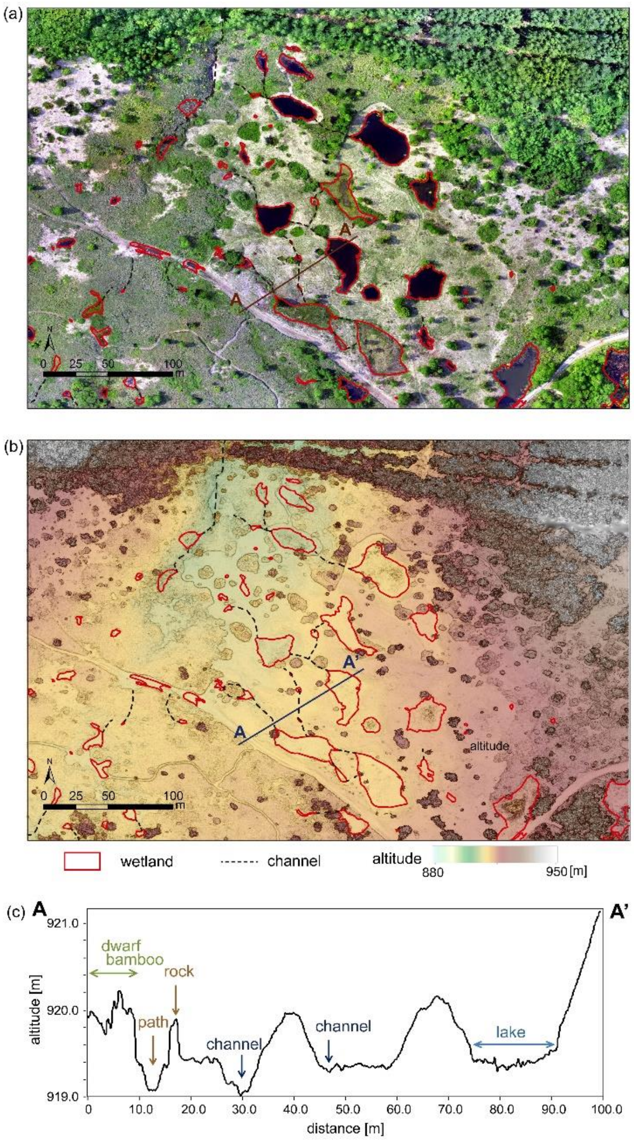

Figure 6. Wetlands formed in small depression connected by unclear channel in the Okunomakiba Ranch. (a) On the 5-cm orthophoto in June 2018. (b) On the 5-cm DSM. (c) Profile of a wetland and channels along A-A'.

Based on this result coupled with previous mountain wetland studies in other areas, we could interpret why so many small wetlands are formed in the Okunomakiba Ranch. The annual maximum snow depth is less than 2 m around this study area (Figure 3b), and snow disappeared until late April in 2018. In the case of the snow recharged type wetlands in the other area, the last snow cover in the snowpatchs disappears around August to September (Daimaru et al., 2002; Kariya, 2002). In the south of the study area, an undissected lava flow covers the mountain. The shallow groundwater from the undissected lava flow layer can be judged as the main recharge source in the Okunomakiba Ranch. We concluded that the wetlands emerge depending on whether the groundwater level was higher than the micro-topographic surface.

The high-resolution DSM created by the UAV-SfM approach helped to identify the wetland and interpret the topography in the study area in more detail. By combining the results at two spatial scales, we can understand the formation environment of the wetland in more detail.

3. The usefulness of GIS analysis on various spatial scales in wetland research

In the previous chapter, we introduced the results of examining the formation environment of wetland with the geomorphological perspective, using data of several different spatial scales and spatial resolutions. By targeting many samples in wider areas as the case of wetland distribution in Japan, we could draw more generalized conclusions. Using data with resolution suitable for the target topographical size, we could clarify geomorphological control on wetland formation. When dealing with the different spatial scales including hydrological environment and micro-topography, combining the results of multiple spatial scales/resolutions can deduce the origin of wetlands in more detail.

4. Conclusions

This study introduces some case analyses of wetland distribution on various spatial scales, from nationwide to the area of a wetland group, with a focus on geomorphological feature. The nationwide wetland distribution in Japan showed that snow accumulation and topography of volcanic mountains were important for wetland formation in mountainous regions. Secondly, we clarified that wetlands were mainly distributed on the gentle slope of original volcanic surfaces and in landslides in the Hachimantai volcanic groups, in the northern Japan, using 10 m grid DEM and aerial photo interpretation. With higher-resolution data, it was clear that wetlands were arranged depending on the microtopography of landslides and volcanic surfaces and groundwater. Using data with resolution suitable for the target topographical size and combining the results of multiple spatial scales/resolutions, we can deduce the origin of wetlands in more detail.

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