Classification of Land Cover in Kumamoto Area, Japan to Evaluate Infiltration and Surface Runoff

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Abstract. Almost 100% of domestic water is covered by groundwater in the Kumamoto region, Japan. However, in recent years, the groundwater recharge area (particularly paddy fields) has been significantly decreasing, and the groundwater level has been gradually dropping in some places. Aside from this, the groundwater level was abnormally changed as an impact of the 2016 Kumamoto earthquake. Our final goal is to build a model to represent the groundwater level change including the abnormal change. For this purpose, we generated a land cover map by using temporal Normalized Difference Vegetation Index (NDVI) changes based on Landsat-8 satellite images and Geographic Information System (GIS) data. Our classification results well expressed the actual land cover especially around rivers, lakes and buildings compared with the existing land cover map. The calculated infiltration and surface runoff amounts from grasslands with different land uses indicated the importance of understanding not only land covers but also land uses to evaluate infiltration and surface runoff amounts.

1. Introduction
Kumamoto region in Japan has been using groundwater for the public water of almost 100%. Therefore, conserving groundwater is crucial from the viewpoint of both quantity and quality. In recent years, the nitrate pollution mainly due to the application of fertilizer [1] and the decline in groundwater level and spring volumes [2] are serious issue. The land use changes caused the decrease in groundwater recharges. In 1965, the total recharge area such as paddy fields, upland fields, grasslands, and forests was 947.89 km\(^2\) [3]. However, that area significantly decreased to 844.30 km\(^2\) in 1991. For example, the area of paddy fields decreased from 262.22 km\(^2\) to 236.56 km\(^2\). The prime reason of decrease in paddy fields is the rice production adjustment policy of Japanese government [2] and urbanization. To improve this situation, a project aiming to increase groundwater recharges started in 2004. In this project, the local famers flood their fields during the fallow periods. Consequently, the groundwater levels and spring volumes have been gradually recovering [2].
In 16 April 2016, the earthquake (main shock) of \(M_w\) 7.0 attacked Kumamoto region. Because of the earthquake, the unusual changes in groundwater level were observed. According to Hosono et.al [4], the water level drop was caused by most likely water transfer downwards through open cracks. On the other hand, the coseismic abnormal water level increase was explained by mountain water release [5]. This abnormal water level rise propagated to the downstream water level. It is important to build a model that can express such groundwater level changes and their propagation processes in order to
predict water level changes due to future weather conditions and land uses. One of the important matters to build a model is the distribution of groundwater recharge and not-recharge areas classified into each land cover. Thus, in this study, firstly we attempted to generate a land cover map by using temporal Normalized Difference Vegetation Index (NDVI) changes and Geographic Information System (GIS) data. NDVI has been often applied to classification of land cover and assessment of land cover changes [e.g., 6, 7]. In addition to land cover, understanding land use is also an important matter. For example, there are some places in the grasslands where cattle are grazed, while only open burning are performed in the other area. Infiltration tests that we practiced by the double-ring method revealed that the grasslands in which grazing was performed had a lower infiltration capacity. Therefore, based on the results of land cover classification, secondly, we quantified and evaluated the difference of infiltration and surface runoff amounts due to the difference in land uses of grasslands.

2. Materials and Methods

2.1. Study area

Figure 1 shows the analysis target area. The analysis area is located in the center of Kyushu Island, Japan. This area constitutes of 11 municipalities, which has total 1,245 km². This analysis area is larger in the north than the area generally called the Kumamoto region. It is because that it can respond to any model area. Annual averaged precipitation and temperature from 1990 to 2019 in Kumamoto observatory were 1,990 mm and 17.2 °C, respectively [8]. June and July are rainy seasons, often causing heavy rainfall disasters.

![Figure 1. Location map of the Kumamoto area in Japan.](image)

2.2. Satellite images

Three Landsat-8 satellite images on 16 January, 20 March, 23 May 2016 were downloaded from LandsatLook Viewer [9]. We excluded satellite images at the other periods in 2016 because they were covered by clouds. Landsat-8 was launched in 2013 and has two observation sensors: Operational Land Imager (OLI) of 30 m resolution, and Thermal Infrared Sensor (TIRS) of 100 m resolution. The NDVI was calculated by equation (1) using the band 4 (visible red band) and band 5 (near-infrared band) of OLI sensor.

\[
\text{NDVI} = \frac{(NIR - R)}{(NIR + R)},
\]
where \( \text{NIR} \) is the reflectance of the near-infrared band, and \( R \) is the reflectance of the visible red band. The NDVI outputs the values between -1.0 and 1.0 which represents the activity level of vegetation.

### 2.3. Classification of land cover

Kumamoto area (Figure 1) was classified into 9 categories: Grassland, Paddy field, Damaged paddy field, Forest (Conifer and Hardwood), Upland field, Bare land, Building, Golf, Water area (river, lake, and pond). Damaged paddy field means the field which cannot be used because of the 2016 Kumamoto earthquake. The locations of Damaged paddy field were identified by using an account book of paddy field that the address and crop species of each filed were registered and Navigation system [10] which searches the location of field by address. Golf and Water area were identified by using google map. The classification of the other land covers was performed by using temporal NDVI change and GIS. Firstly, the NDVIs were extracted for each land cover by using the polygons of vegetation map (vg67) [11]. Vegetation map (vg67) is a 1/25,000 scale map of land cover, and has been made and updated by field surveys and interpretation of satellite images since 1999. Figure 2 shows extracted NDVIs in mean values for each category. Since Conifer and Hardwood represented almost same trends, it is too difficult to distinguish these land covers. Thus, Conifer and Hardwood were classified as Forest. In the Paddy field, the NDVI decreased from March to May because wheats are harvested before rice planting begins. The NDVI of Grassland cannot show seasonal change like Conifer and Hardwood because of open burning (Noyaki) in March. Utilizing such characteristic changes depending on land cover, the classification was carried out by the following procedure:

1) Grassland; within the grassland area of the vegetation map (vg67), the difference in NDVI between May and March is 0.243 or more.
2) Building; within the building area of the vegetation map (vg67 and vg3) and high-resolution land use and cover map of Japan Aerospace Exploration Agency (JAXA) [12], the NDVI on May is less than 0.319.
3) Paddy filed; within the paddy and upland fields of the vegetation map (vg67 and vg3), the difference in NDVI between May and March is less than -0.017.
4) Upland field; within the paddy and upland fields of the vegetation map (vg67 and vg3), the difference in NDVI between May and March is -0.017 or more.
5) Bare land; excluding the building area of the vegetation map (vg67 and vg3) and high-resolution land use and cover map of JAXA, the NDVI on May is less than 0.319.
6) Forest; the rest area.

![Figure 2. Temporal change of NDVIs for each land cover.](image-url)
the area of vg67. High-resolution land use and land cover map is the averaged land cover for 2014-2016, which generated by JAXA and has 30 m resolution. According to the Confusion Matrix, the overall accuracy is 81.6% for 10 categories [12]. In the least accurate category, the accuracy is 56.3%.

2.4. Soil surface model
In this study, we applied the soil surface model (Figure 3) [13], which expresses surface runoff, retention and infiltration, to grasslands area in the outer rim. Infiltration I from the soil surface can be expressed as following equation:

\[ I' = \min \left( P' + x', I_c \right), \]  

where \( P \) is the precipitation (mm), \( x \) is the storage of soil surface model (mm), \( I_c \) is the infiltration capacity (mm/hour), and \( i \) is the time. Time steps of the model were assigned to 1 hour. When the sum of rainfall and storage exceeds infiltration capacity \( (P' + x' > I_c) \), the water is retained in the soil surface model expressed as following equation;

\[ x'^{+i} = \min \left( P' + x' - I_c, S \right), \]  

where \( S \) is the storage capacity (mm). The water exceeding storage capacity is discharged as the surface runoff \( D \). The infiltration capacity was referred to the data [14] in Aso caldera adjacent to the east. Depending on the locations, the infiltration capacity varies from 40 to 118 mm/hour. As mentioned above, the infiltration capacity in the grasslands where grazing has been performed is significantly low. Thus, the calculations were performed in two cases with the high infiltration capacity of 118 mm/hour and the low infiltration capacity of 7.8 mm/hour. According to the soil composition investigated by column sampling of undisturbed soil in the grasslands of Nishihara Village [15], the averaged porosity was 62.9%. Converted from the column volume and cross-sectional area, the porosity corresponds to 64.9 mm. Generally, since the effective porosity is lower than porosity, the half of porosity was used as the storage capacity. For precipitation, the data at the precipitation observatory where is the closest to the location of classified grasslands was used [16].

![Figure 3. Summary of soil surface model.](image)

3. Results and discussions

3.1. Land cover
Figure 4 shows the results of land cover classifications, and the high resolution land use and cover map of JAXA. The distributions for each category of classification result and JAXA’s map are almost the same. However, there is not the category of Golf and Damaged paddy field in JAXA’s map. Golf seems to be classified into grasslands. In the center of Ozu and Kikuyo region, actually, paddy agriculture could not be practiced because of the broken irrigation canal induced by the 2016 Kumamoto earthquake. However, our classification method classified these regions into paddy filed. The main reason of this misclassification is that the NDVI change of wheat cultivated before rice was applied because the available satellite image was limited. In paddy fields, the characteristics of NDVI changes are appeared in rice planting and rice growth seasons [17]. Thus, as satellite images in these
periods seem to be able to modify paddy fields classification, we plan to purchase SPOT-6/7 satellite images with high resolution of 6 m. The differences in classification results are noticeable around rivers, lakes, and buildings (Figure 5). In the JAXA’s map (Figure 5 (b) and (d)), the areas surrounding rivers and lakes are misclassified into the paddy and upland fields. In fact, the riverbed is covered with a vegetation and the area around the lake is a park. Our results successfully classified these areas into forests or bare lands (Figure 5(a) and (c)). Then, JAXA’s map could not express the buildings lined up along the fields near the coast (Figure 5(f)). Instead, the paddy fields are distributed. Such misclassification of the paddy fields can overestimate groundwater recharge because the paddy fields are flooded to grow rice, so that water always infiltrates underground regardless of precipitation. In order to evaluate a validity of our classification results, the area of each category was compared with JAXA’s map (Figure 6). In addition, the area of Golf was added to the area of Grassland, and the area of Damaged paddy field was added to the area of Paddy field. As mentioned above, although the misclassification of JAXA’s map were confirmed, the overall accuracy of classification is high. Although the coefficient of determination $R^2$ of 0.94 was obtained, there is the significant difference in Paddy field and Building. The area of paddy fields of JAXA’s map is higher than that of our classification mainly because of the misclassification as shown in Figure 6. On the other hand, the area of building of our classification is higher than that of JAXA’s map. The difference of distribution can be observed especially in the paddy fields of south-west area and north area (Figure 4). It is because that JAXA’s map could not extract slender and/or small buildings area between paddy fields (Figure 5(e) and (f)).

![Figure 4. Land cover map: (a)NDVI and GIS, (b)JAXA*.](image)

*Provided by high-resolution land use and land cover 30m resolution map of Japan [2014 – 2016] (ver.18.03: 10 categories) (Japan Aerospace Exploration Agency)
3.2. Infiltration and surface runoff

Figure 7 shows the calculated infiltration and surface runoff amounts in two patterns from 1 June to 31 July (rainy season in Japan). As shown in Figure 7(a), when the infiltration capacity was assigned to
118 mm/hour, the runoff did not occur, which means that all of precipitation infiltrates into underground. On the other hand, when the infiltration capacity was assigned to 7.8 mm/hour, the runoff occurred in some precipitation events. The cumulative surface runoff amount reached about 2.1 million m$^3$. These calculations show the difference in land use of grasslands as an example, but the difference in land use is also recognized in the building area. The building area is usually considered as an impermeable area. However, a part of site in Kumamoto prefectural office, a permeable paving is applied to promote infiltration of precipitation. Namely, if the land cover is the same but the land use is different, it is important to assign the parameter values corresponding to the land use when a model is created.

![Figure 7. Cumulative infiltration, runoff, and precipitation from 1 June to 31 July 2016: (a)Infiltration capacity is 118 mm/hour, (b)Infiltration capacity is 7.8 mm/hour.](image)

4. Conclusions
In this study, we classified Kumamoto area where groundwater is the important water resource into 9 land cover categories for 2016 by using temporal NDVI change depending on each land cover and GIS data. The classification results are almost corresponding to the land cover map of JAXA. In some places, our classification results well represented the actual land covers. However, the paddy fields were misclassified because of the limited satellite images so that we plan to purchase SPOT-6/7 satellite images with high resolution of 6 m in the suitable periods to classify paddy fields. The soil surface model indicated that the different land use should be considered in the same land cover to evaluate infiltration and surface runoff amount.

5. References
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