

Detailed Mapping of Engineering Geomorphologic Classification Using Digital Elevation Model and Satellite Image

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ABSTRACT :

In order to obtain a detailed map of site amplification factors for strong motion prediction, the 50m-mesh engineering geomorphologic classification map is estimated using the existing 250m-mesh map, digital elevation model (DEM) and satellite image for Tsurumi ward, Yokohama, Japan. The resolution of the DEM and the image are 1m and 15m, respectively. The 50m-mesh map is estimated based on the characteristics of the indices computed from the DEM and the image for each geomorphologic unit. The estimated 50m-mesh map is compared with the manually classified map. The result shows that the 84% of the meshes are correctly classified while the accuracy in the lowland zone is relatively low.

KEYWORDS: Engineering Geomorphologic Classification Map, Digital Elevation Model, Satellite Image

1. INTRODUCTION

A distribution of site amplification factors is indispensable to estimate a ground shaking map for a scenario earthquake. A site amplification factor is generally computed from PS logging data. However, since the number of PS logging data is limited, it is difficult to estimate the distribution of site amplification factors in a large area by PS logging data. As a practical method to estimate the distribution of site amplification factors, a geomorphologic classification map whose mesh size is 1 km has been used in Japan [Midorikawa, 2006]. For more detailed mapping, the geomorphologic classification map whose mesh size is 250 m is being developed [Wakamatsu *et al.*, 2006]. However, in order to promote an incentive to citizens' disaster mitigation actions such as seismic retrofit of their own houses, the Central Disaster Prevention Council of Japan is encouraging detailed ground shake mapping with mesh size of 50 m. Therefore, a more detailed mesh map is required for detailed ground shaking mapping.

The detailed mapping requires a high-resolution digital map of soil information such as geomorphologic classification. It is, however, a time and labor consuming task to create such a digital map manually from the existing analog maps. As data for the automated classification in a large area, a digital elevation model (DEM) and satellite image has been used. Characteristics of topography computed from DEM have been used to estimate the geomorphologic classification map [Iwahashi, 1994, Jeong *et al.*, 2003, Matsuura *et al.*, 2005]. In these studies, the geomorphologies were broadly classified, and especially at lowland areas, were not classified in detail. This is because that the spatial resolution of the DEM is 50 m. Recently, in Japan, the high-resolution DEM whose mesh size is 5 m or smaller is being developed in urban areas as the fundamental data for assessment of flood disasters. Such a high-resolution DEM will be widely constructed in highly populated areas.

In urban areas, it would be difficult to estimate the detailed map of soil information only by DEM because landform alterations such as filling and cutting of soil have been widely conducted. Land cover information estimated from the remote sensing data would be helpful to classify the geomorphologies in lowland areas.

Nakai *et al.* [2002] estimated a map of soil information based on changes of land use between recent satellite images and old topographical maps. However, it is difficult to apply this method in a large area because the digitalization of the old topographical maps requires great demand for labor. Bayramin [2000] estimated a landform classification map by using satellite images such as Landsat images. In this study, landform classification is originally defined which does not correspond to the geomorphologies of the existing maps. Therefore, it is difficult to simply apply this method for detailed mapping of the geomorphologic classification.

These studies indicate a possibility for detailed mapping the geomorphologic classification map by using not only topographical information from DEM but also land cover information from satellite image. In this study, a methodology for detailed mapping of the geomorphologic classification with mesh size of 50m is examined using the existing 250m mesh map, DEM and satellite image.

2. TARGET AREA AND DATA

2.1 Relationship between Geomorphology and Land Use

The target area of this study is Tsurumi ward, Yokohama, Japan. Figure 1(a) shows the 250m-mesh geomorphologic classification map constructed by Matsuoka and Wakamatsu [2006] in the target area. In the area, various geomorphologic units are distributed such as the terrace covered with volcanic ash soil (LT), the valley bottom lowland (VL), the natural levee (NL), the back marsh (BM), the abandoned river channel (FR), the delta and coastal lowland (D), the marine sand and gravel bars (SB), the filled land (LF) and the river bed. In order to examine the relationship among the geomorphology, the topography and the land cover, and a 50m-mesh geomorphologic classification map is constructed from the old topographical map in 1922, the land condition maps in 1965 and 1979, and the existing 250m-mesh geomorphologic classification map. Figure 1(b) shows the constructed 50m-mesh map.

In order to discuss the possibility of a satellite image for detailed mapping, the relationship between the geomorphology and land use is examined because land use would be closely related with land cover estimated from a satellite image. Based on the 50m-mesh geomorphologic map (Fig.1(b)) and the digital land use map in 2000 (Fig.1(c)), area proportions of the land use are calculated for each geomorphology as shown in Fig. 2. In the terrace area such as LT and VL, the percentages of the vegetated areas are about 20 %, indicating areas of the vegetation are larger than other geomorphologies. The vegetated areas are mainly distributed in the boundary between the terrace and the lowland. Since steep slopes are located in the boundary and it is difficult to develop built-up area to the slopes, the vegetation such as tree and grasses are still remained in the boundary.

In the lowland area such as NL, FR and D, the area proportions of the vegetated areas are less than 5 % because the built-up area is mainly developed in the lowlands. In NL, the area proportion of the low-rise housing is about 40%. It suggests that the low-rise buildings are densely distributed in NL. In BM and FR, the area proportions of the commercial and the public facilities areas are 30-50%. Because BM and FR had been easily inundated by floods, the residential areas have not been significantly developed in these geomorphologies.

D is covered with multiple land use units not only the low-rise housing but also the commercial and the industrial and the industrial areas. In SB, the area proportions of the low-rise housing and the roads are 40% and 25%, respectively. Since LF is newly developed area, the area proportions of the industrial and the public facilities areas are about 80%. These results show that the characteristics of the land use pattern are different at different site geomorphology. It suggests that there would be some correlation between the geomorphology and satellite images because the land use pattern would be closely related with the land cover from the satellite image.

2.2 Digital Elevation Model and Satellite Image

Figure 1(d) shows the DEM in the target area constructed from airborne laser scanner data observed in 2002.

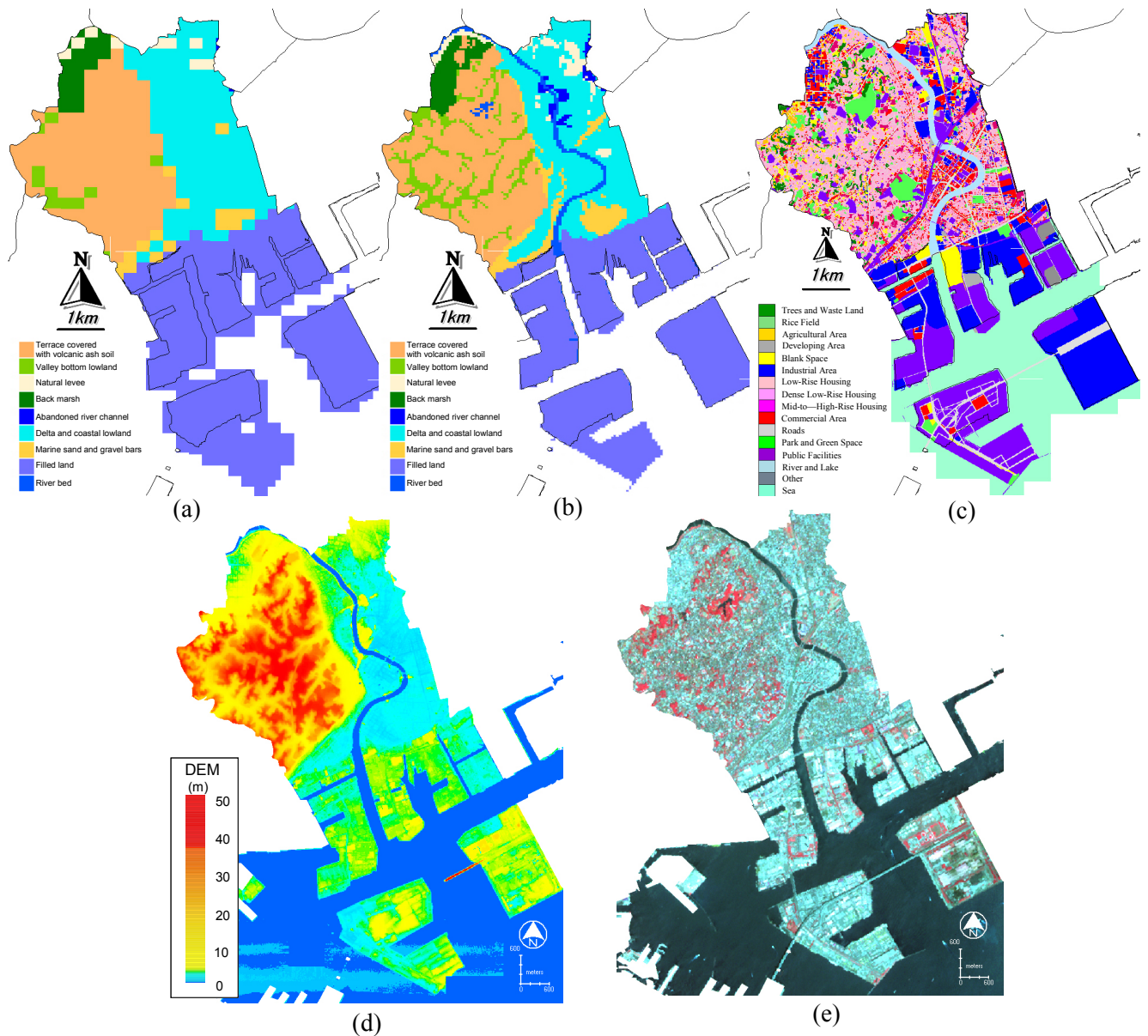


Figure 1 (a) 250m-mesh geomorphologic classification map, (b) Manually constructed 50m-mesh geomorphologic classification map, (c) Land use map, (d) DEM, (e) Satellite ASTER image

The spatial resolution of the DEM is 1m. Relief is defined as the difference of elevation between the highest mesh and the lowest mesh in 50 by 50 meshes. The elevation and the relief in each mesh are used as indices in the next chapter.

Figure 1(e) shows the satellite ASTER image observed in Apr. 28, 2005. The image consists of 3 bands for visible and near-infrared regions, and 6 bands for infrared regions. The spatial resolution of the data is 15 for the band 1 to 3 and 30m for the band 4 to 9, respectively. The distribution of NDVI (Normalized difference vegetation index) is computed from the image by the equation (1).

$$NDVI = \frac{DN_{NIR} - DN_{Red}}{DN_{NIR} + DN_{Red}} \quad (1)$$

Here, DN_{NIR} and DN_{Red} represent the digital number in the near infrared band and the red band image, respectively. A higher NDVI indicates a higher density of green leaves. The digital numbers of the band 1 to 9 and NDVI are used as indices in the next chapter.

3. CHARACTERISTICS OF INDICES IN EACH GEOMORPHOLOGY

3.1 Broad Classification

Characteristics of the indices in each geomorphology unit are examined. The averages and the standard deviations of the indices are calculated for each geomorphology. As the preliminary step, the calculation is conducted for the whole target area. The result shows that the differences of the indices between geomorphologies are small. Therefore, the target area is divided into four zones; hilly zone (A), transient zone (B), filled land zone (C), and lowland zone (D), as shown in Fig. 3.

3.2 Zone A

Figure 4 shows the comparison of the indices with the geomorphologies at each zone. Horizontal axis indicates the average and the standard deviation of each index. Vertical axis indicates each geomorphology. In the zone A, the elevation in LT is higher than that in VL. In LT, the relief is also higher because the distribution of thickness of the volcanic ash soil might be complicated. The differences of other indices are smaller.

3.3 Zone B

In the zone B, the elevation in LT is higher than other geomorphologies, indicating that the difference of the elevation is 5 to 10 m. The NDVI in LT is also higher than that in other geomorphologies. One of the reasons for higher NDVI in LT would be that a lot of vegetated areas are distributed in the slope areas. The differences of other indices between the geomorphologies are rather small. It might be possible to distinguish LT from other geomorphologies by using the indices of the elevation and the NDVI.

3.4 Zone C

In the zone C, the elevation in LF is higher than other geomorphologies. This would be because the ground level in LF is originally constructed higher than the sea level for prevention of high tide water. In addition, the standard deviations of the band 1, 2, 3, 6 and 9 in LF are larger than those in other geomorphologies. As shown in Fig. 2, not only vegetations and roads but also large-scale buildings in the industrial and the public facilities areas are distributed in LF. The digital numbers of the large-scale buildings in the satellite image are much higher than those of other features because the color of the roofs is bright. This might be one of the reasons why the standard deviations of the image in LF are higher than those in other geomorphologies.

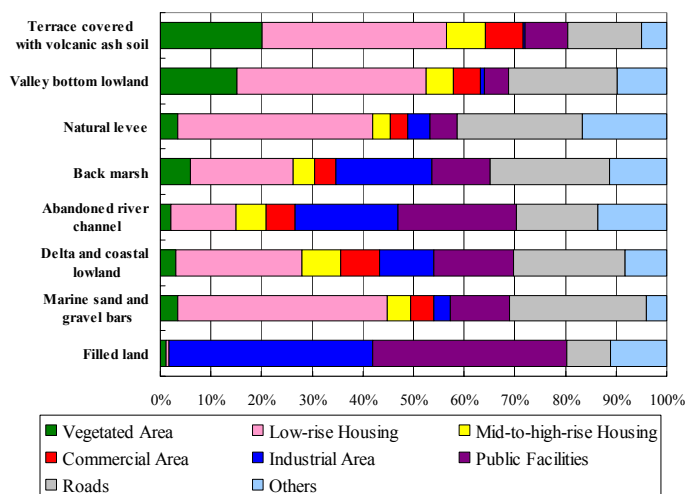


Figure 2 Area proportions of each land use calculated for each geomorphology

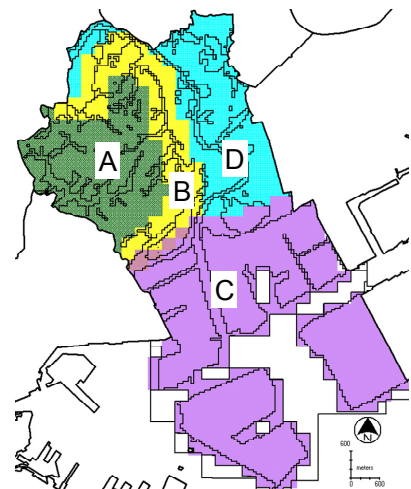


Figure 3 Zoning of target area

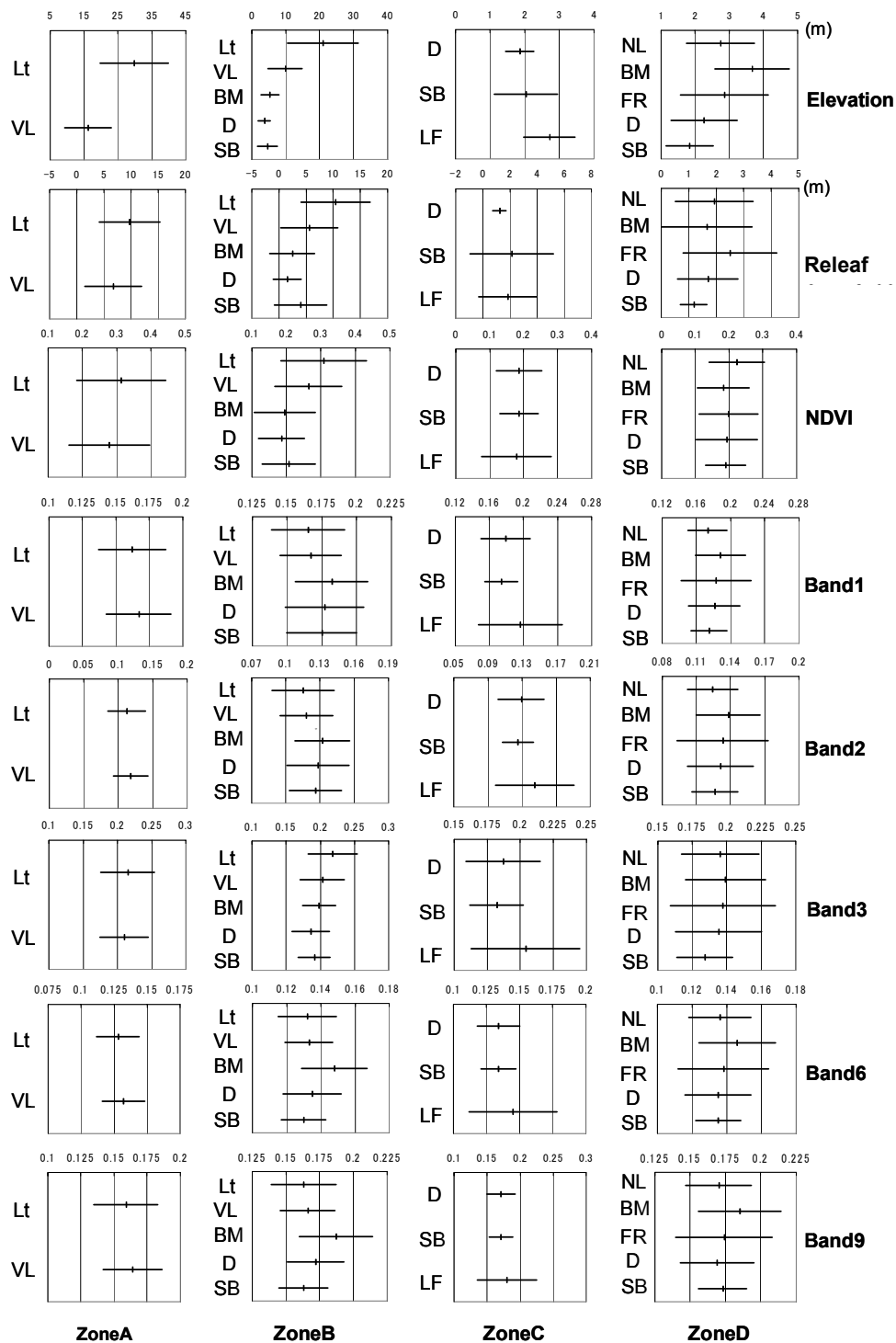


Figure 4 Comparisons of indices at each geomorphologic unit

Zone D

The zone D consists of various classes of the lowlands such as NL, BM, FR, D and SB. The elevation in BM is higher than that in other geomorphologies. This would be because BM is mainly located in the upstream area of the river, and is located close to LT whose elevation is generally high. The NDVI in NL is slightly higher than that in other geomorphologies. As described in the chapter 2.1, the residential zones are widely distributed in NL. One of the reasons for high NDVI in NL might be that a lot of vegetation is distributed in gardens of the residences.

In SB, the digital number of the band 3 (near infrared) is slightly smaller than that in other geomorphologies. Digital number in the band 3 strongly responds to vegetation. Because the residential zones and the roads are densely distributed in SB, amount of vegetation would be smaller. These might be a reason why the digital number of the band 3 is small in SB. In FR, the relief is rather larger than that in other geomorphologies. FR is located close to NL and the elevations in NL are generally higher than FR. One of the reasons for large relief in FR would be that FR areas include the boundary of FR and NL. As shown Fig. 1(b), D areas are widely distributed in the target area. The differences of the indices between D and other geomorphologies are small.

3.5 Classification Rules

Based on the results in the previous chapters, rules for detailed classification are constructed as shown in Table 1. The 50m-mesh map is estimated by using the classification rules. In the zone A, the indices of the elevation and the relief are used to distinguish LT from VL. In the zone B, the indices of the elevation and the NDVI are used to classify LT. In order to classify VL, the relationship of the target mesh and the surrounded meshes is used. When the surrounded mesh is classified into VL, the target mesh is also classified into VL.

Table 1 Classification rules

Zone	Geomorphology	Condition
A (Hilly zone)	River bed	Mesh whose digital number of Band 3 is lower than 0.11 is classified into river bed
	Terrace covered with volcanic ash soil (LT)	Mesh whose elevation is higher than 20m, or Mesh whose relief is higher than 8m is classified into LT
	Valley bottom lowland (VL)	Mesh whose elevation is lower than 20m, or Mesh whose relief is smaller than 8m is classified into VL
B (Transient zone)	Terrace covered with volcanic ash soil (LT)	Mesh whose elevation is higher than 12m, or Mesh whose elevation is between 5~12m and whose NDVI is higher than 0.25 is classified into LT
	Valley bottom lowland (VL)	(1) When a target mesh is adjacent to LT, the mesh is classified into VL (2) When two sides of a target mesh is adjacent to VL, the mesh is classified into VL (3) When all sides of a target mesh is adjacent to LT, the mesh is classified into VL
	Other lowland area	Un-classified mesh
C (Filled land zone)	Filled land (LF)	(1) Mesh surrounded by filled land or sea is classified into LF (2) Mesh whose elevation is between 2~3.5m is classified into LF (3) When a mesh classified into filled land is isolated, meshes located on the landward side to the mesh are classified into LF
	Other lowland area	Un-classified mesh
D (Lowland zone)	Marine sand and gravel bars (SB)	(1) When a mesh is adjacent to LT, meshes whose relief is higher than 2.5m are classified into SB (2) When a mesh is not adjacent to LT, meshes whose elevation is higher than 1.5m or whose relief is lower than 1m or whose digital number of band 3 is smaller than 0.185 are classified into SB (3) When all sides of a target mesh is adjacent to LT or VL or SB, the mesh is classified into SB
	Natural levee (NL)	(1) Mesh whose elevation is higher than 1.7m and relief is higher than 0.5m and NDVI is larger than 0.2 is classified into NL (2) When all sides of a target mesh is adjacent to NL or river bed, the mesh is classified into NL
	Abandoned river channel (FR)	(1) Mesh whose elevation is higher than 1.5m is classified into FR (2) When all sides of a target mesh is adjacent to FR, NL and river bed, the mesh is classified into FR
	Back marsh (BM)	(1) Mesh whose elevation is higher than 2m is classified into BM (2) When all sides of a target mesh is adjacent to BM or NL or LT, the mesh is classified into BM
	Delta and coastal lowland (D)	Un-classified mesh

In the zone C, the target mesh is classified into LF when the target mesh is surrounded by LF or the sea in the existing 250m-mesh map. The index of the elevation is also used to classify LF.

In the zone D, the indices of the elevation, the relief and the digital number of the band 3 are used to classify SB. The relationship of the target mesh and the surrounded meshes is used. When the target mesh is surrounded by SB, LT or VL the target mesh is classified into SB. The indices of the elevation, the relief and NDVI are used to classify NL. The relationship of the target mesh and the surrounded meshes is used. When the target mesh is surrounded by NL, FR or the river bed, the target mesh is classified into NL.

The index of the elevation is used to classify FR. The relationship of the target mesh and the surrounded meshes is used. When the target mesh is surrounded by FR, NL or the river bed, the target mesh is classified into FR. The index of the elevation is used to classify BM. The relationship of the target mesh and the surrounded meshes is used. When the target mesh is surrounded by BM, NL or LT, the target mesh is classified into BM. Finally, the un-classified meshes are classified into D.

4. DETAILED MAPPING OF GEOMORPHOLOGIC CLASSIFICATION

Figure 5 shows the 50m-mesh map estimated by the proposed method. The accuracy of the classification is computed by comparing the result of this study with the manually classified 50m-mesh map (Fig. 1(b)). Table 2 shows the accuracy of the classification. In Table 2, *a* indicate the number of meshes for each geomorphology classified in Fig. 1(b), and *b* indicate the number of meshes correctly classified in this study. The comparison of the 50m-mesh maps of between this study and the manually classification shows that the distribution of the hilly zone and the filled land zone is correctly classified. The accuracies in LT and LF are more than 80 %. As shown in Table 2, the total accuracy of the proposed method is about 84 %. However, the classification in the lowland zones does not well corresponds to the manually classified map. Especially, the accuracies in FR, SB and NL lower than 30 %.

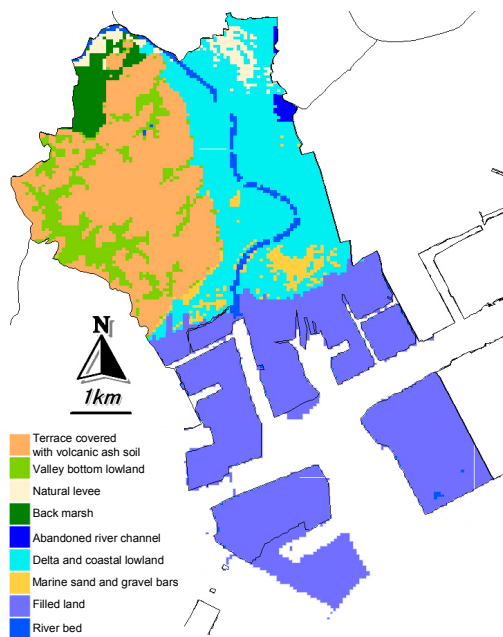


Figure 5 50m-mesh map estimated by the proposed method

Table 2 Accuracy of classification

Geomorphology units	Manually classified (a)	This study (b)	Accuracy rate(%) (b)/(a)
Terrace covered with volcanic ash soil (LT)	3137	2561	81.6
Valley bottom lowland (VL)	705	418	59.3
Filled land (LF)	5565	5315	95.5
Delta and coastal lowland (D)	3102	2749	88.6
Back marsh (BM)	523	464	88.7
Abandoned river channels (FR)	221	56	25.3
Marine sand and gravel bars (SB)	568	172	30.3
Natural levee (NL)	343	105	30.6
River bed	1870	1620	86.6
Total	16034	13460	83.9

One of the reasons for these low accuracies in the lowland areas is that the differences of the indices among the geomorphologies are not significant. Because the difference of the topographic information is small in the lowlands, the land cover information from the satellite image might be necessary to be examined in more detail to improve the accuracies. In this study, the ASTER image whose spatial resolution is more than 15 m is used. A higher resolution image could provide more information on land cover for each geomorphology. Recently, high-resolution satellite images whose resolutions are smaller than 1 m such as QuickBird and IKONOS are easily available. In the future study, the high-resolution satellite image would be used to evaluate the characteristics of the land cover in each mesh in detail.

5. CONCLUSIONS

A methodology of semi-automatically detailed mapping of geomorphologic classification using the existing 250m-mesh map, the DEM and the satellite image is introduced in this study. Firstly, the characteristics of the DEM and the satellite image are examined at different site geomorphologies in Tsurumi ward, Yokohama, Japan. The classification rules based on the characteristics in each geomorphology are applied to estimate the detailed 50m-mesh map. The estimated 50m-mesh map is compared with the manually classified map. The result shows that the 84% of the meshes are correctly classified while the accuracy in the lowland zone is relatively low.

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