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The impact of farmland reclamation on soil distribution in Japan: the case of Andosols in Nagano prefecture

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Abstract:	Purpose In modern times, farmlands have been reconstructed on a large-scale by cutting and filling of soils with governmental support in Japan. Principally, the reconstruction process should be conducted with minimum transportation of soils to decrease environmental impacts and cost. Then, the reclamation process can influence on the soil classification and soil properties. Therefore, this study tried to evaluate an impact of the farmland reclamation on soils. Materials and methods Farmland soil in the reconstructed area was surveyed from the pedological point of view and using geographic information system (GIS). For simple comparison of surface soil thickness and soil distribution before and after farmland reclamation, we selected survey soils classified as “High-humic Cumulic Allophanic Andosols”, which have more than 50cm thickness of Melanic horizon, in the Japanese soil classification system. Changes in the thickness of the surface horizon was evaluated by direct measurement on the field survey. The farmland area, where was affected by the reclamation with large-scale, have been calculated using GIS by comparison of data of digital elevation model (DEM) between two time periods made by topographic maps. Results and discussion As a result, the thickness of Melanic horizon of Andosol was decreased from over 50cm to 26.9cm in average. Calculation by GIS showed that over half of the area occupied by“High-humic Cumulic Allophanic Andosols”, was reclaimed. This indicates that soils originally distributed possibly lost the feature of “Melanic”. Reclamation processes always influence soils at the site. Soil profiles before and after reclamations tell us drastic changes of soil properties at the site. Although surface soil conserved through farmland reclamation processes corresponding to the Japanese guideline, this study showed the influence of farmland reclamation process on soil classification by decrease of surface soil thickness and mixing with subsurface soils. The soil distribution in study area is required to revise. Conclusions We confirmed that farmland reclamation corresponding to the guideline influence on soil classification by modification of surface soil horizon. There is an

	overlooking of soil disturbance area in prediction by calculation of elevation change by simple comparison using DEM before and after farmland reclamation. However, we suggested that this methodology is effective to predict the area where soil distribution was changed especially for area original soils with thick diagnostic surface horizons occupied.
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SUITMA+20: VISIONING THE FUTURE BY REFLECTING ON 20 YEARS OF SUITMA SINCE ITS BIRTH IN 1998

The impact of farmland reclamation on soil distribution in Japan: the case of Andosols in Nagano prefecture

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Abstract

Purpose In modern times, farmlands have been reconstructed on a large-scale by cutting and filling of soils with governmental support in Japan. Principally, the reconstruction process should be conducted with minimum transportation of soils to decrease environmental impacts and cost. Then, the reclamation process can influence on the soil classification and soil properties. Therefore, this study tried to evaluate an impact of the farmland reclamation on soils.

Materials and methods Farmland soil in the reconstructed area was surveyed from the pedological point of view and using geographic information system (GIS). For simple comparison of surface soil thickness and soil distribution before and after farmland reclamation, we selected survey soils classified as “High-humic Cumulic Allophanic Andosols”, which have more than 50cm thickness of Melanic horizon, in the Japanese soil classification system. Changes in the thickness of the surface horizon was evaluated by direct measurement on the field survey. The farmland area, where was affected by the reclamation with large-scale, have been calculated using GIS by comparison of data of digital elevation model (DEM) between two time periods made by topographic maps.

Results and discussion As a result, the thickness of Melanic horizon of Andosol was decreased from over 50cm to 26.9cm in average. Calculation by GIS showed that over half of the area occupied by “High-humic Cumulic Allophanic Andosols”, was reclaimed. This indicates that soils originally distributed possibly lost the feature of “Melanic”. Reclamation processes always influence soils at the site. Soil profiles before and after reclamations tell us drastic changes of soil properties at the site. Although surface soil conserved through farmland reclamation processes corresponding to the Japanese guideline, this study showed the influence of farmland reclamation process on soil classification by decrease of surface soil thickness and mixing with subsurface soils. The soil distribution in study area is required to revise.

Conclusions We confirmed that farmland reclamation corresponding to the guideline influence on soil classification by modification of surface soil horizon. There is an overlooking of soil disturbance area in prediction by calculation of elevation change by simple comparison using DEM before and after farmland reclamation. However, we suggested that this methodology is effective to predict the area where soil distribution was changed especially for area original soils with thick diagnostic surface horizons occupied.

Keywords Contour shape • Land consolidation • Paddy • Soil transportation • Surface soil thickness • Upland field

1 Introduction

Farmland reclamation has been traditionally conducted in Japan, mainly to open agricultural areas. The reclamations for agriculture have still been conducted on a tremendously large scale with civil-engineering works in modern times. Traditional reclamations for agriculture with man-powered work changed the land little with winding boundary and narrow passes along the original topography, resulting in no change affecting to soil classification. In modern times, farmlands have been reconstructed on a large-scale like as civil engineering using a large agricultural machinery by transportation of soils within the reclaimed area and from outside to inside of the reclamation area. Such farmland reclamations have been encouraged by governmental support which established in 1960s (Kikuchi et al. 1999). Application of large agricultural machinery enables us the land consolidation accompanied by increase in a unit area surrounded by straight lines by civil engineering works and construction of broader agricultural passes. The land consolidations on a large scale have been conducted in the world (Hiironen and Riekkinen 2016; Karásek et al. 2018). However, the reconstruction process should minimize transportation of soil mass to decrease environmental impacts and to save the cost. Then, all of the reclamation process could not directly influence on the soil classification but soil profiles and properties. Moreover, according to Japanese guidelines for farmland reclamation, original surface soils, those are historically improved by farmers, are recommended to conserve to maintain the productivity (The Japanese Society of Irrigation, Drainage and Rural Engineering 2006, 2013). The recommended thickness of the surface horizon as a plow layer, which ideally includes conserved surface soils, were defined in the guidelines as over 15cm for a paddy field and over 25cm for an upland field including the field for crop rotation consisting of paddy and upland field. The redistribution of the surface soils is a specific management for farmlands by the land consolidation shown in Fig. 1 (The Japanese Society of Irrigation, Drainage and Rural Engineering 2006, 2013). On the other hand, the

Japanese guideline of engineering for settlements and roads have no rules for surface soil conservation (MLIT 2019). In the case of civil engineering in an urban area, removal of surface soils containing much organic carbons are recommended to improve the load capacity for constructions (The Japanese Geotechnical Society 1999, 2000; Scheyer and Hipple 2005; Trammell et al. 2017). Thus, surface soil thickness of reclaimed farmland can be a specific feature to consider their impacts on soil distribution. Since actual condition of soil distribution and soil surface horizons modified by land consolidation according to this definition is still unclear, the revision processes of Japanese soil maps have not taken it into account (Takata et al. 2009, 2011; Kanda et al. 2017). Therefore, this study tried to evaluate an impact of the farmland reconstruction on soils, by focusing on thickness of surface soil horizons and soil transportation by elevation change, in a region of Nagano prefecture, which is an inland prefecture in Japan and where Andosols largely occupy. The evaluation process of soil distribution proposed in this study can be applicable for further revision of Japanese soil map using geographic information system (GIS) coupled with old and recent issued geographical maps. To clarify the impact of farmland reclamation on soil distribution, farmland soil in the reconstructed area was surveyed from the pedological point of view and using GIS.

2 Materials and methods

2.1 Study site

The study site was set on Nagano Prefecture where is located in the central Japan and an inland prefecture without seacoast. One of the major soil types of Andosols are distributed in this region, especially on the mountain foot slope and the river terrace. The geographical location of Andosols is common in the other areas in Japan. The Nagano prefecture is also characterized by famous mountain ranges called as Japanese Alps. These mountain ranges include many active volcanos, such as Mt. Ontake, Mt. Yakedake, Mt. Yatsugatake, Mt. Asama, Mt. Norikuradake and so on located on west side, the central part and the southern part in the prefecture (Fig. 2). Since volcanic activities during the Holocene have frequently released volcanic products to surrounding regions, the mountain foot slope and the river terrace have been covered with volcanic ash. Westerlies also promote accumulation of volcanic ash inside of Nagano. That is the reason why different types of Andosols are distributed in Nagano prefecture. Chino-City located in the western foot slope of Mt. Yatsugatake was chosen as the study site. Topography of the city is relatively flat and most of the area in the city is occupied by Andosols. Although this region has already opened as a common Japanese farmland in the Medieval time, the large-scale land consolidation has been tackled after 21st century to extend a unit of farmland accompanied by the farmland readjustment. This type of land consolidation is getting common in Japan due to decrease in population of farmers and to achieve cost effective management in the local regions. In this area, farmland reclamation was conducted on paddy and upland field since 1990 to 2002 (Chino-City Board of Education 1993; Land Improvement and Consolidation Division, Suwa Region Promotion Bureau of Nagano Prefecture 2016).

2.2 Soil map

The soil map used in this study was expressed by the latest version of the soil classification system. That was the cultivated soils in Japan according to the comprehensive soil classification system of Japan-First approximation" (Kanda et al. 2017). The soil map has been continuously translated on each time when the soil classification systems for cultivated land was revised (Takata et al. 2009, 2011; Kanda et al. 2017). The first soil map was prepared according to the soil survey during 1959 to 1978 using the first soil classification systems. Based on this revision system of the soil maps, changes in soil properties by the land consolidation have not been taken into account.

The target area was extracted from the digital soil map with 1/50,000 scale. This study area was mainly occupied by "High-humic Cumulic Allophanic Andosols". These soils have an advantage to identify change of soil property due to land consolidation from the diagnostic character. Changes in thickness and color of the surface horizon can be easily identified from the soil horizon. The qualifiers as "High-humic" means the soil horizon with high organic carbon content (over 6%) and "Cumulic" means thicker than 50cm surface soil horizon with "High-humic" or "Humic" (over 3% of soil organic carbon) feature. The combination of "High-humic with Cumulic" corresponds to "Hyperhumic" and "Melanic" in WRB (IUSS Working Group WRB 2015), and of "High-humic Cumulic" corresponds to "Melanic epipedon" in Soil Taxonomy (Soil Survey Staff 2014).

2.3 Evaluation of the effect of land consolidation on the soil distribution

The farmland area, where was affected by the farmland reclamation on a large-scale, have been calculated using GIS (Arc GIS 10.2.2 ESRI Japan, Tokyo) by comparison of 10m digital elevation models (DEM) made from contour maps in 1 to 25000 scale published in two time periods, 1988 (GSI 1997) and 2014 (Geospatial Information Authority of Japan 2018), using the “Topo to Raster” tool of Arc GIS. The calculated area was shown in Fig.3. Contour map in 1 to 25000 scale are basic maps covering all area of Japan since 1983 (Akeno et al. 2002). Thickness of surface horizons affecting to the qualifier of soil classification was surveyed within the study area by direct measurement using a boring stick (W10mm, L300mm, H10mm, DIK-1641 Daiki Rika Kogyo Co., Ltd.) at the research area where farmland was reclaimed on a large scale. The total survey of area was approximately 30 ha depending on land uses. The surface soil thickness of 30 points was checked by each farmland lot at approximately 40m intervals within the research area (Fig. 4).

3 Results

Surface horizon thickness was shown in Fig. 5 and Table 1. Despite of our selection of survey points in this study area where was occupied by soils classified as “High-humic Cumulic Allophanic Andosols”, which has ”Melanic” horizon thicker than 50cm, our result showed 26.9cm ± 9.4cm in thickness.

Exceptionally just one surveyed points reached to 50cm thickness due to mechanical disturbance by deep cultivation after reclamation. The minimum thickness of surface horizon, observed in two points, was 15cm thickness, which equals to the minimum thickness recommended to conserve according to the guideline of farmland reclamation (The Japanese Society of Irrigation, Drainage and Rural Engineering 2006, 2013). Approximately one-third of soil color data of surface horizons on the field survey was brighter than the criterion of “High-humic” in the comprehensive soil classification system of Japan-First approximation. The following is the criterion of soil color for “High-humic” horizon, the Value is not higher than 3 and Chroma is not higher than 3 and not both of Value and Chroma is 3 in the Munsell color chart. From these two features (thickness and color of surface soil horizon), farmland reclamation changed soil distribution in the surveyed area. The diagnostic surface horizon, “High-humic Cumulic” in Japan, “Hyper humic” and “Melanic” in WRB, and “Melanic epipedon” in Soil Taxonomy, was lost through farmland reclamation processes.

Around surveyed area, we estimated soil thickness affected by soil cutting and filling by land consolidation using GIS and two period of topographical maps. The result of estimation was illustrated in Fig. 6 at more than 50cm topographical change. The overlaying of this map and soil map indicates that over half of “High-humic Cumulic Allophanic Andosols” classified in the soil map of cultivated soil potentially lose their “Cumulic” and “High-humic” features through land consolidation processes (Figs 3 and 6). The 18 field survey points were distributing in the area which consolidated by cutting, the 7 survey points were distributed in the area consolidated by cutting, and the 5 survey points were distributed in area consolidated within 0.5m filling or cutting. We did not find any relations between thickness of surface soil horizons and type of elevation change (cutting or filling).

4 Discussion

The soil classification system (Obara et al. 2011) used for the soil map has a soil group named as "Reformed soils" for soils filled with transported materials. Since this soil group is defined by import of alien soil materials thicker than 35cm, which identified by unusual pairs of vertically continuous soil horizons, some of soils reclamed by on-site transportation were not classified as "Reformed soils". It is difficult to judge whether soil materials redistributed by farmland reclamation can fulfill the definition of "Transportic" in WRB (2015), because we can't trace the redistribution of surface soil materials and we can't distinguish that redistributed soil materials, that "have been moved from a source area outside the immediate vicinity" or not. According to Soil Taxonomy (2014), most of these redistributed soil materials can be identified as "Human–Altered Materials" and some of these soil materials likely to identify as "Human-Transported Materials". Soils modified by farmland reclamation should be represented with qualifiers for human activities. On the other hand, most of those soils could not be classified by features of human activities at the highest or second highest category ("Reference Soil Group" (RSG) in WRB and "Soil Order" in Soil Taxonomy). Thus, classification of soils in reclaimed farmland usually require field survey.

Thickness of the field survey indicates that soils originally distributed have already lost the feature of “Melanic” (in WRB and Soil Taxonomy) by the farmland reclamation in thickness and color criteria. Change of soil color can be explained by contamination of sub-surface soil materials with brighter color through soil transportation process. We have a guideline about thickness of reclaimed surface soil horizon for cultivation. In Japanese guideline for farmland reclamation, original surface soil conservation is recommended because of effective soil resource utilization for plant growth and cost saving (The Japanese Society of Irrigation, Drainage and Rural Engineering 2006, 2013). In this guideline, the required soil thicknesses for cultivation, which is almost same as recommended thickness of original surface for soil conservation, are 15 cm in paddy and 25 cm in upland field and rice-crop rotation farmland at least. These are general plowing thickness for rice and major crops except for root crops. Averaged surface soil thickness in this study (26.9 cm) including paddy fields were well fitted to the case for rice-crop rotation fields. Our results showed a case that the land consolidation project complied the guideline and a case of land consolidation changed soil distribution classified as thick “Melanic” horizon, that is one of diagnostic surface horizons. If all of farmland reclamations in Japan were conducted according to the guideline, originally distributed surface soil horizons thicker than 25 cm were uniformed into approximately 15 cm thickness in paddies and 25 cm thickness in upland field same as the surveyed area. The thickness for upland field is also same as the required thickness of diagnostic surface soil horizons in the Japanese soil classification systems. Therefore, according to this precondition, information about farmland type and identification of topographical change between before and after farmland reclamation enable prediction of soil distribution changes classified by diagnostic surface soil horizons.

The farmland reclamation should impact on sub-surface horizons as well. In the case of minimum transportation of soil materials to be less impact on the agricultural land, the sub-surface horizon might not be changed from the original one, even if we can observe any anthropogenic alteration in the surface soil s. Although depth of diagnostic sub-surface horizons is changed by the reclamation, properties and classified soil names are not changed in such cases. On the other hand, our results in the case of land cutting indicated that the soil distribution might be changed at the highest category (“RSG” and “Soil Order”) by farmland reclamations. A geological study reported that about 3m thickness of volcanic material layers distribute in the study area (Kitazawa and Kawachi 1967). Although the reported thickness has large uncertainty, our estimation indicated that whole diagnostic horizons of “Andosols” might be removed in area identified as over 3.5m cutting. More precise estimation of elevation changes by soil transportation using large-scale contour maps and other geographical data can help more certain prediction of soil distribution change at the highest category by alteration in deeper horizons. Therefore, we can’t predict that soil names classified from before farmland reclamation and after reclamation are different or not. Thus, our prediction methodology for soil distribution change by farmland reclamation should be limited in area with soils classified by diagnostic surface horizons showed by soil map.

In Japan, exploitation and reclamation of farmland have been managed on a small scale depending on original topography before establishment of a governmental supporting law for land consolidation until 1960s (Kikuchi et al. 1999). Now, farmland reclamation project accompanies construction of infrastructures for the farmland and villages on a larger scale as compared to the period before 1960s. Large-scaled reclamation on the farmland involve a topographical modification with a larger civil engineering process. In the study area, we can find differences in shape of contour lines on maps before and after the reclamation. In Japan, the scale of maps used in this study (1 to 25000) is standard and we can easily get maps which have periodically revised since 1983. Although this scale of contour maps was too small-scale to precisely calculate elevation in the order of centi-meter which is required for soil classification, it was enough to identify land consolidated area and soil distribution change through the consolidation processes. Therefore, this study suggested that maps in 1 to 25000 scale is enough for prediction of loss of “High-humic Cumulic” (“Melanic” in WRB and Soil Taxonomy) surface horizons.

There was no relationship between surface soil thickness and changes in elevation through the process of filling and cutting. This result indicated that the thickness of surface horizon after the reclamation was uniformed through the land consolidation processes regardless of the filling or cutting. When the farmland reclamation conduct taking the minimum soil transportation into account, less changes in elevation will be detected from the comparison between before and after the reclamation using the DEM of the project area. However, severe disturbance on soil can be included after the reclamation. This overlooking of the soil disturbance is one of the defects of the proposed calculation using DEM.

We can identify the area, where farmland reclamation was conducted, by comparison of the shape of contour line at farmland in two period of topographical maps before and after the farmland reclamation. The contour line has been changed from the winding shape under traditional land uses to the straight contour line after a large-scale farmland reclamation (Fig. 7).

Although we need more examples and studies, our results suggest that identification of land consolidated area by comparison of topographical maps or aerial photos before and after reclamation might be enough to extract the area. Soils classified by diagnostic surface horizons in the reclaimed area should be taken into account for revision of soil maps. Thus, this study can contribute to simplify revision of soil maps of farmland without analyzed dataset and detailed soil survey in the human altered area on a large scale. Since the thickness of surface soil horizons recommended to conserve for upland field is same as the thickness required for diagnostic surface horizons, information of farmland types (paddy or upland) is important for prediction of soil distribution change by surface soil redistribution. Actually, it is difficult to get large-scale geographical data especially published in older periods, but more precise estimation of elevation change caused by farmland reclamation using large-scale maps with combination of other geographical data such as geological maps might enable to identify the deeper soil transportation and soil distribution changes classified by diagnostic subsurface horizons.

5 Conclusions

In this study, the thickness of Melanic horizon of Andosol was decreased from over 50cm to 26.9cm in average (no points over 50cm and less than 15cm). We confirmed that farmland reclamation was conducted corresponding to the guideline in the surveyed area. Calculation by GIS indicated that over half of the area, where “Melanic Andosols” originally distributed, was reclaimed with elevation change more than 50cm. Thickness of surface soil horizons we surveyed were not related to reclamation type (filling or cutting). In cases of soils classified by diagnostic surface soil horizons, we suggest that if all large scale farmland reclamations for upland field were fulfilled to the guideline quality, comparison of contour lines in topographical maps or aerial photos before and after farmland reclamation might be enough to predict soil distribution change into classification as 25cm same surface soil materials. Reclamation processes always influence soils at the site. Soil profiles before and after reclamations tell us drastic changes of soil properties at the site. Although this study showed the case that reclamation process influences soil classification, it is still unclear that soils classified by thinner diagnostic surface horizon than this study and diagnostic subsurface soil horizons also have been changed or not. More precise estimation of topographical changes by farmland reclamation and geological information might reveal influences of the reclamation on soil distribution classified by diagnostic subsurface horizons.

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Table 1 Land use type and results of field survey. The "○" fitted to criteria of written features and the "×"didn't fit to the features. The “Cumulic” required more than 50cm thickness of “High -humic” surface soil horizon

Survey points	Land use	Thickness of surface soil horizon(cm)	Decision of Soil color for High-humic	Decision of Cumulic
1	paddy	45	○	×
2	paddy	50	○	○
3	paddy	45	○	×
4	paddy	22	○	×
5	paddy	20	○	×
6	paddy	25	○	×
7	paddy	40	○	×
8	paddy	20	○	×
9	paddy	20	○	×
10	paddy	40	○	×
11	paddy	20	×	×
12	paddy	20	○	×
13	paddy	15	○	×
14	upland field	20	○	×
15	paddy	20	×	×
16	paddy	30	×	×
17	paddy	30	○	×
18	paddy	20	×	×
19	paddy	20	×	×
20	upland field	18	×	×
21	paddy	15	○	×
22	paddy	30	○	×
23	paddy	30	×	×
24	paddy	22	○	×
25	upland field	29	×	×
26	paddy	37	×	×
27	paddy	23	×	×
28	upland field	27	×	×
29	upland field	25	×	×
30	upland field	30	×	×

Figure Captions

Fig. 1 Schematic diagram of surface soil conservation method for farmland reclamation (The Japanese Society of Irrigation, Drainage and Rural Engineering 2013). Shaded polygon indicates surface soils. Surface soils return on farmland after reclamation

Fig. 2 Distribution of Andosols in Nagano Prefecture and several volcanos. Base map satellite image from (c) ESRI Japan, ESRI, HERE, Garmin, © Open Street Map contributors, and the GIS user community, Sources; Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Fig. 3 Distribution of Andosols in Farmland of Chino-City. Surrounded area by red line is calculation area of elevation change using DEM. Base map satellite image from (c) ESRI Japan, ESRI, HERE, Garmin, © Open Street Map contributors, and the GIS user community, Sources; Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Fig. 4 Field survey points in "High-humic Cumulic" Andosols. Numbers mean the survey points in Table 1. Orange color indicates soil filling more than 0.5m, blue color indicates soil cutting more than 0.5m, and grey color indicates soil cutting or filling within 0.5m. Base map satellite image from (c) ESRI Japan, ESRI, HERE, Garmin, © Open Street Map contributors, and the GIS user community, Sources; Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Fig. 5 Thickness of surface soil horizons

Fig. 6 Elevation change in farmland area of Chino-City calculated by DEM comparison between 1988 and 2016. Base map satellite image from (c) ESRI Japan, ESRI, HERE, Garmin, © Open Street Map contributors, and the GIS user community, Sources; Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Fig. 7 Change of winding contour line into straight after farmland reclamation. Left map was published in 1988 (JSI 1997), right map was published in 2016 (Geospatial Information Authority of Japan 2018).

Figure Captions

Figure 1

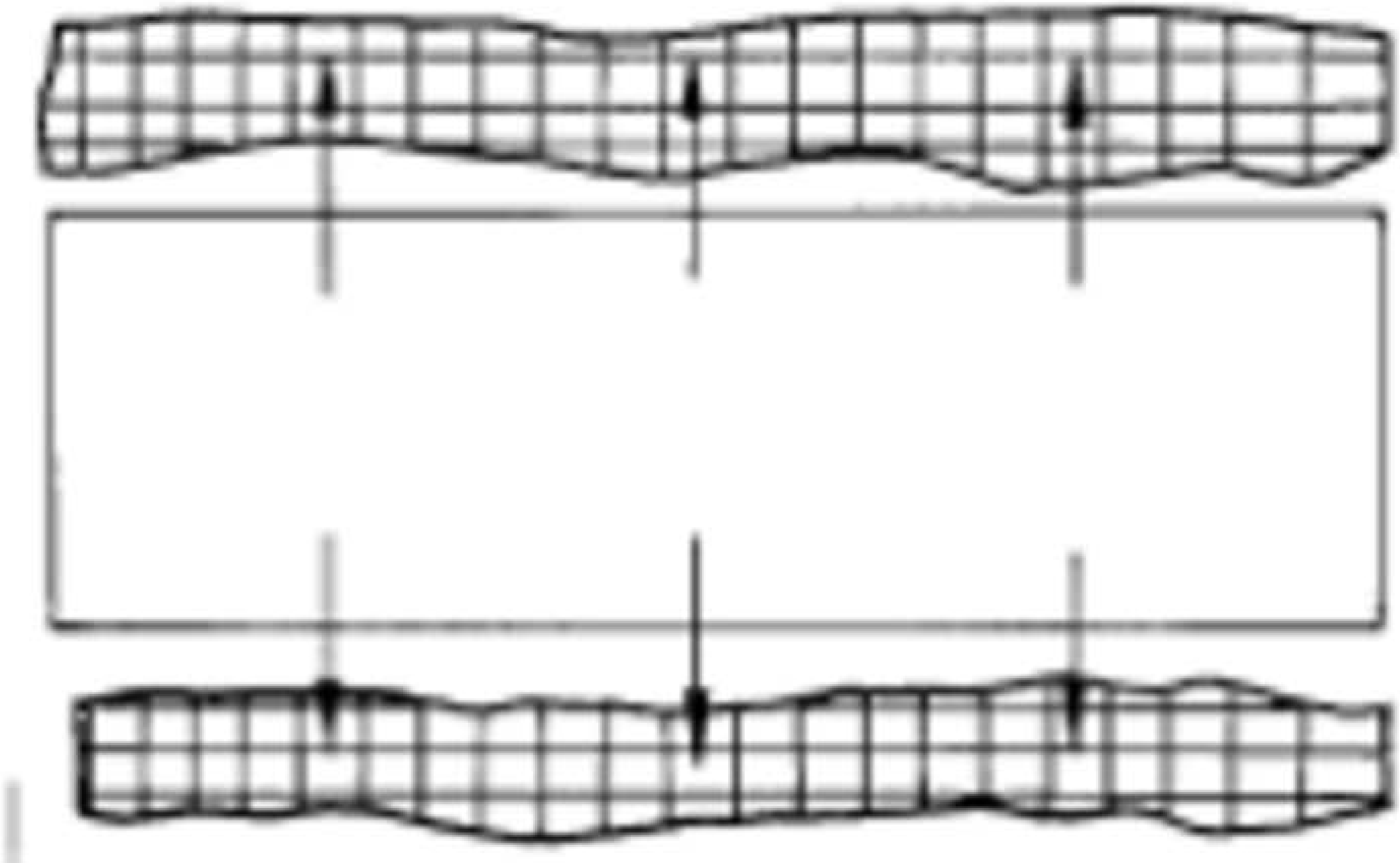

Figure 2

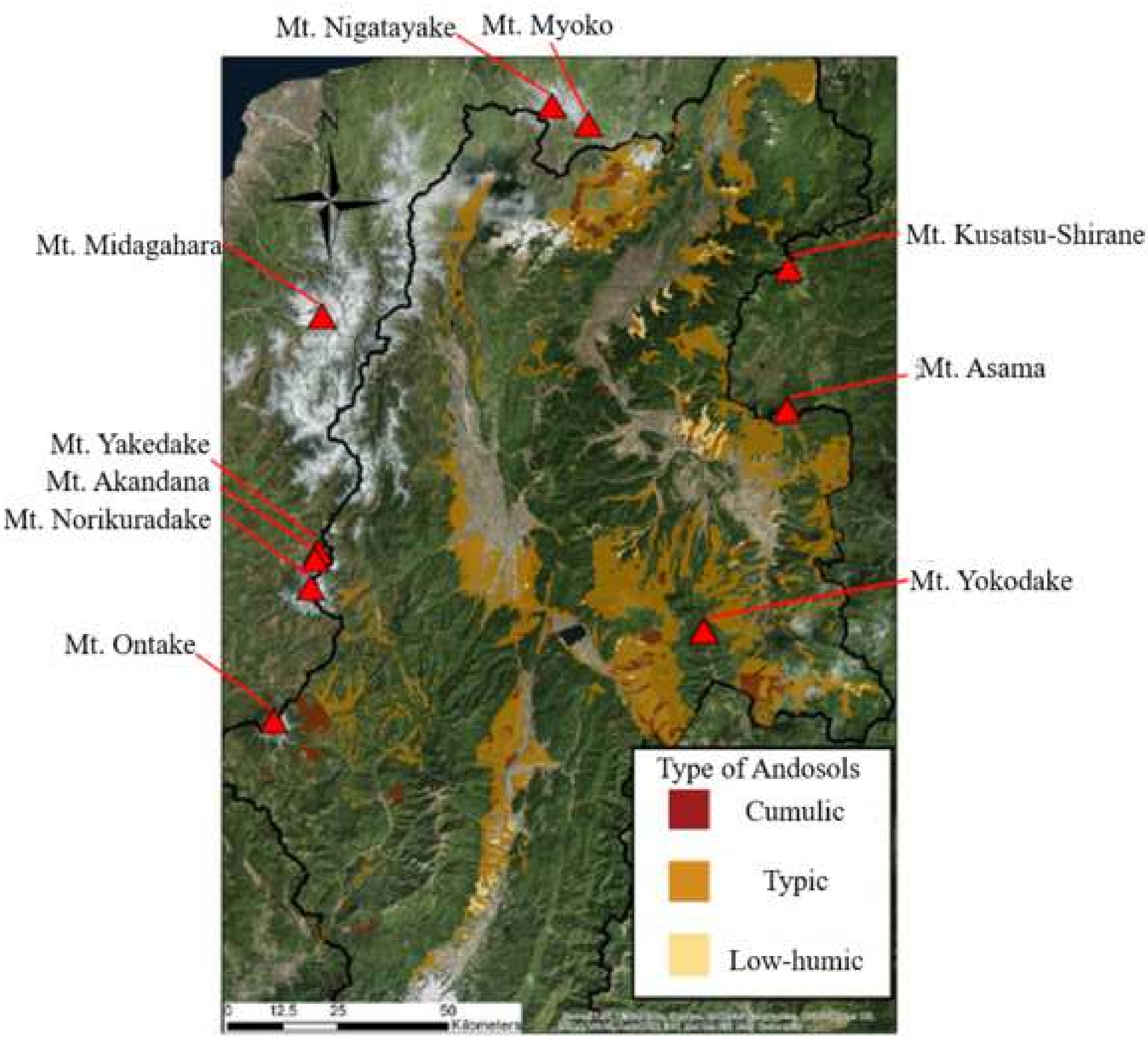
Mt. Nigatayake
Mt. Myoko
Mt. Midagahara
Mt. Kusatsu-Shirane
Mt. Asama
Mt. Yakedake
Mt. Akandana
Mt. Norikuradake
Mt. Yokodake
Mt. Ontake
Type of Andosols
Cumulic
Typic
Low-humic
0
12.5
25
50
Kilometers

Figure 3

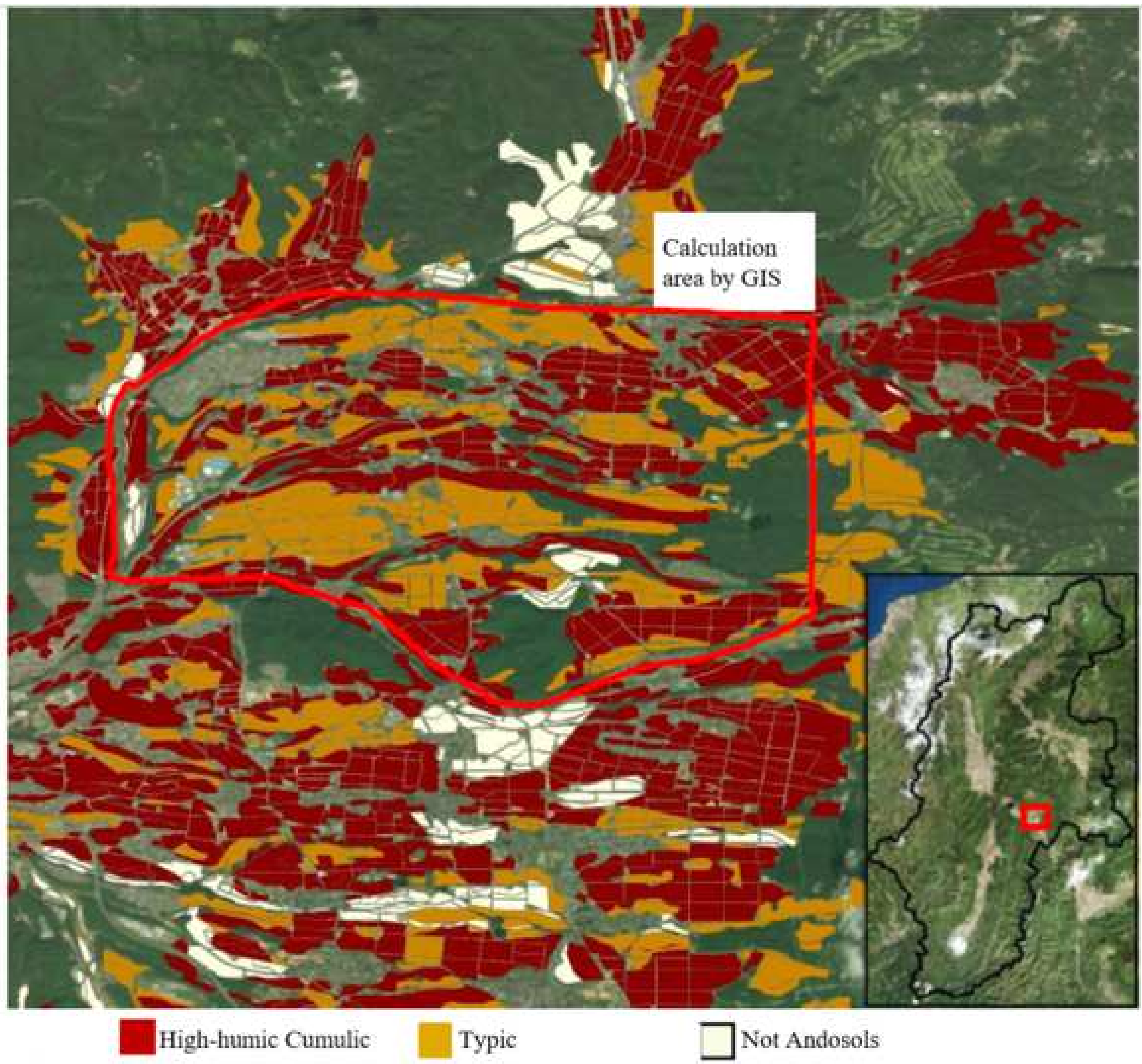
Calculation
area by GIS
High-humic Cumulic
Typic
Not Andosols

Figure 4


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
N
0
100
200
400
Meters
Field survey points
High-humic Cumulic Andosols

Figure 5

Click here to access/download;Figure;Fig. 5 Thickness of surface soil horizons.tif

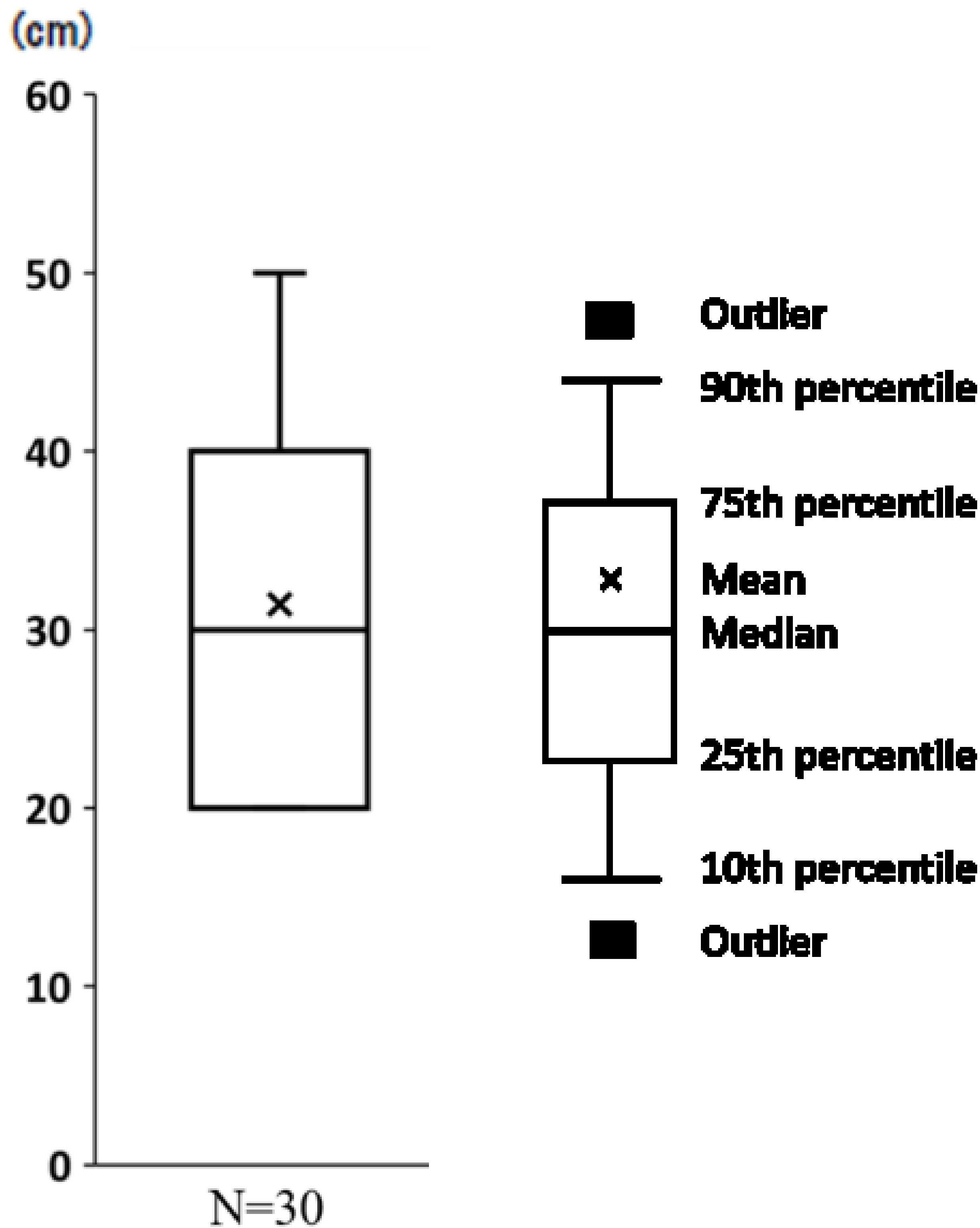

Table 1

Survey points	Land use	Thickness of surface soil horizon(cm)	Decision of Soil color for High-humic	Decision of Cumulic
1	paddy	45	○	×
2	paddy	50	○	○
3	paddy	45	○	×
4	paddy	22	○	×
5	paddy	20	○	×
6	paddy	25	○	×
7	paddy	40	○	×
8	paddy	20	○	×
9	paddy	20	○	×
10	paddy	40	○	×
11	paddy	20	×	×
12	paddy	20	○	×
13	paddy	15	○	×
14	upland field	20	○	×
15	paddy	20	×	×
16	paddy	30	×	×
17	paddy	30	○	×
18	paddy	20	×	×
19	paddy	20	×	×
20	upland field	18	×	×
21	paddy	15	○	×
22	paddy	30	○	×
23	paddy	30	×	×
24	paddy	22	○	×
25	upland field	29	×	×
26	paddy	37	×	×
27	paddy	23	×	×
28	upland field	27	×	×
29	upland field	25	×	×
30	upland field	30	×	×

Figure 6

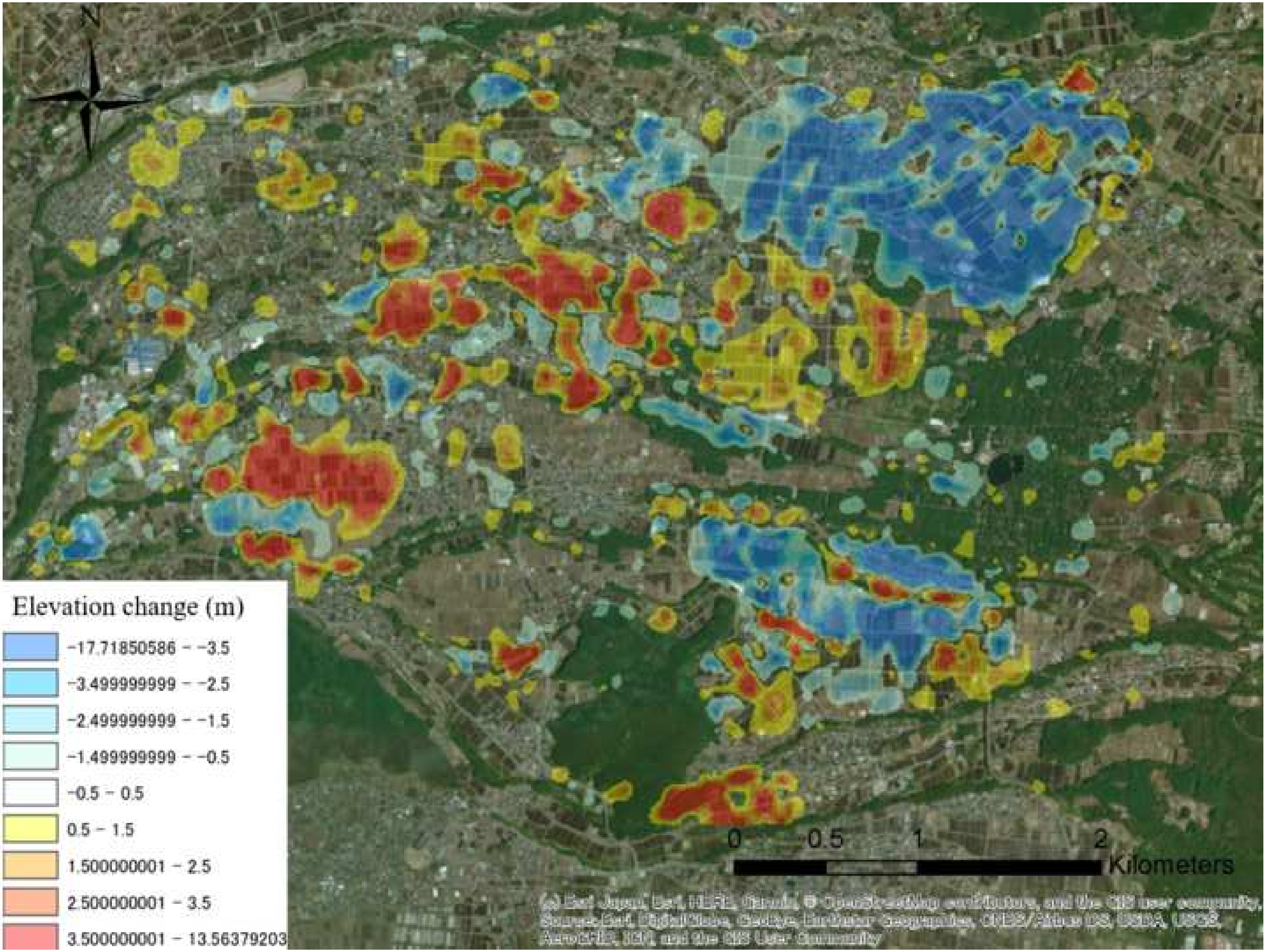
N
Elevation change (m)
−17.71850586 − −3.5
−3.499999999 − −2.5
−2.499999999 − −1.5
−1.499999999 − −0.5
−0.5 − 0.5
0.5 − 1.5
1.500000001 − 2.5
2.500000001 − 3.5
3.500000001 − 13.56379203
0 0.5 1 2
Kilometers
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Figure 7

Click here to access/download;Figure;Fig. 7 Change of winding contour line.tif