Impact Analysis of Different Spatial Resolution DEM on Object-Oriented Landslide Extraction from High Resolution Remote Sensing Images

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***Abstract*—Information extraction of landslides is a critical issue for the disaster hazard analysis. Although DEM (Digital Elevation Model) is an important feature for landslide recognition, it's difficult to obtain the high-resolution DEM in study areas in practical application. In order to analyze the impact of DEM resolution on landslide extraction and to determine the resolution to the meet application requirements, we resample the DEM data into five groups on different spatial resolution and then adopt the object-oriented method to extract the landslides information to combine with high-resolution images. The experimental results show that, when the DEM resolution is greater than 30 meters, we can obtain better recognition and classification results for the landslide with area greater than 5000m^2. When the resolution is less than 30 meters, it is difficult to distinguish between landslide types, but by adjusting parameter values we can still achieve the detection of landslides. This research has certain guiding significance and reference value for the selection of DEM spatial resolution on the landslides information extraction.**

Keywords—landslide extraction; Digital Elevation Model (DEM); remote sensing images; object-oriented; high resolution

I. INTRODUCTION

The landslide is a devastating geological disaster, which often happens suddenly and causes huge economic losses and casualties. The development of modern remote sensing technology provides new ways with landslides in surveys and studies [1]. Most of the traditional extraction methods of landslides are based on pixel, only using the spectral features of the landslide, so it cannot give a good performance of landslide geological processes, and the results of extraction are like pepper shapes. The object-oriented image classification technology is mainly through multi-scale segmentation, and doing the fuzzy classification according with the characteristics of the object. This method can make good use of image context information and improve the classification accuracy, compared with conventional methods, having significant advantages [2].

There are many successful examples of the use of object-oriented method of landslide survey and mapping. In 2003, Barlow et al. used the object-oriented method carried out landslide detection in Cascade base on the Landsat ETM+ image, identification and mapping of landslide remote sensing in the aid of Digital Elevation Model (DEM) data [3]. In 2007, Iwahashi and Pike use the slope, terrain texture and the convexity, achieving from DEM data, to classificatory the terrain automatically [4]. In 2008, Yao Xin et al. take the Biluoxueshan an alpine gorge area as an example, using the SPOT-5 multispectral image of 10m spatial resolution and DEM data which generated by 1:50000 topographic maps as source data, using the decision tree method to test the effect of shallow landslides in the automatic identification [5]. In 2008, Hu Deyong et al. take the rainforest areas in the Cameron Highlands of Malaysia as an example, proposing an object-oriented landslide detection method, and proving this method is suitable for the information extraction in rainforest areas [6]. In 2010, Martha et al. carried out an object-oriented information extraction experiment in India Mandakini, that is based on multi-source data (including multispectral images, DEMs, DEM derivatives) [7]. It can be seen that DEM plays an important role in landslides information extraction, but, in practical application, it is hard to get high-resolution DEM data of the study areas.

Considering the importance of the DEM data in landslide information extraction and it is hard to get high-resolution DEM data of the study areas, this paper formulates an object-oriented landslide information extraction process of DEM data and its derivatives auxiliary high-resolution remote sensing images, then resample the DEM data and divided the different spatial resolution into five experiment groups. Finally, we analyze the impact of DEM spatial resolution changes on landslide information extraction. We found that, in the case of high-resolution DEM in study area being unable to obtain, using a lower resolution DEM product is also available to achieve the landslide detection.

II. EXPERIMENTAL DATA

An area covering 28 km^2 in parts of the Mandakini river catchment in the High Himalayas around Okhimath town in the Uttarakhand state of India is selected for this study. Lithological units exposed in this area are granite gneisses, quartzite-sericite schist, quartzite, garnetiferous mica schist, marble and occasional basic intrusive. In August 1998, a total of 466 landslides triggered due to rainfall killed 103 people and damaged 47 villages in the Mandakini valley alone [7].

When we extract the landslide information, we always use multispectral data and DEM in general. Multispectral data acquired on 16 April 2004 by Linear Imaging Self-scanning

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System IV (LISS-IV) sensor onboard the Indian Remote Sensing Satellite (IRS) P6 (also known as Resourcesat-1) [8]. These data have 5.8 m spatial resolution and three spectral bands viz. green (0.52 to 0.59 μm), red (0.62 to 0.68 μm) and near infra-red (0.76 to 0.86 μm). They were mainly used for image segmentation and spectral diagnostic features extraction. DEM created from a stereopair Cartosat-1 data was acquired on 6 April 2006 in photogrammetric processing [9]. These data have 10 m spatial resolution and could achieve a vertical root mean square error (RMSE) of 2.31 m. They were mainly used to calculate the DEM derivatives contain slope, aspect, hill shade, terrain curvature, profile curvature, stream order (Figure 1).

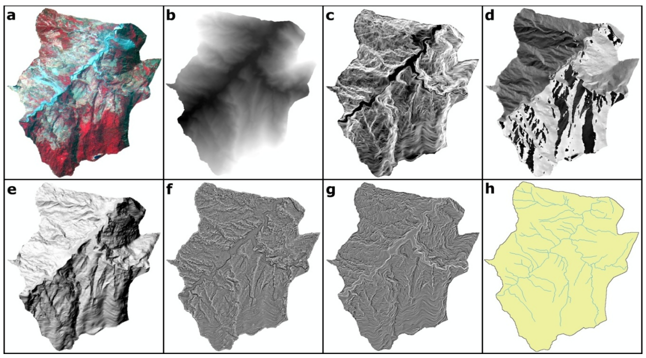

Figure 1. Multi-source experimental data. (a)Multispectral images, (b)DEM, (c)Slope, (d)Aspect, (e)Hill Shade, (f)Curvature, (g) Profile curvature, (h)Stream order.

III. Object-Oriented Landslide Extraction Method

The approach for landslide information extraction is mainly derived from the knowledge developed by experts for detection of landslides during image interpretation, so it mimics the cognitive approach of landslide experts in image interpretation. In this paper, we improve landslide information extraction rules of Tapas R. Martha, which was put forward in 2010 based on the object-oriented [7]. The steps of the landslide information extraction were shown in Figure 2.

Landslide recognition and classification process is mainly described in the following four steps:

- Image objects creation. We use multi-scale segmentation method according to the homogeneity of the pixel values of the image, divided the image into different areas.
- Landslide candidate objects identification. Bare rock or debris is exposed after a landslide event, which makes a clear distinction between landslides and vegetation. Therefore, we use Normalized Difference Vegetation Index (NDVI), which is sensitive to low levels of vegetation cover, as a first criterion to identify landslide candidates.
- Landslide confusable objects elimination. Since NDVI is used as a cut-off criterion, objects with similar or lower NDVI values, such as shadows, water bodies, river beds and roads, are likely to be misclassified as landslides. After eliminating the landslide confusable objects from the landslide class sequentially by integrating their spectral, morphometric and contextual information in Object-Oriented Analysis (OOA), we can get the landslide objects.
- Landslide types classification. The classification of landslides based on material and types of movement was developed using the adjacency condition for source area [10]. Morphometric criteria, quantified from D. J. Varnes' definition and local field knowledge, were used to classify landslides according to their failure mechanism. Our experiment combined the characteristics of the study area, selecting five typical landslides to classify the landslide object.

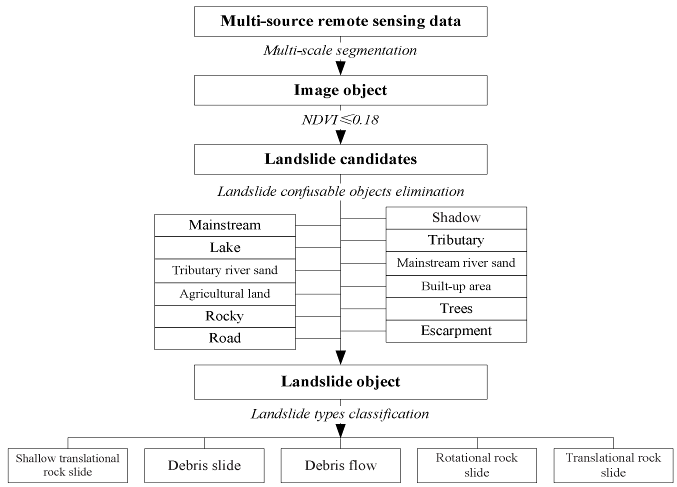

Figure 2. Object-oriented landslide information extraction.

We completed this study in Definiens eCognition Developer 8 software environment. Some custom features used in this study such as Normalized Difference Vegetation Index (NDVI), the differences of height between hills and valleys (Relief) and the relatively angle between the slope aspect and the main direction (longest axis direction) of objects (Aspect-MainDir) are expressed by the following equations:

$$\mathrm{NDVI} = ([\mathrm{Mean\ Layer\,3}] - [\mathrm{Mean\ Layer\,2}])/([\mathrm{Mean\ Layer\,3}] + [\mathrm{Mean\ Layer\,2}]) \tag{1}$$

$$\mathrm{Relief} = [\mathrm{Max.pixel\ value\ DEM}] - [\mathrm{Min.pixel\ value\ DEM}] \tag{2}$$

$$\mathrm{Aspect\text{-}MainDir} = \mathrm{abs}([\mathrm{Mean\ Aspect}] - [\mathrm{Main\ direction}]) \tag{3}$$

IV. Impact Analysis of Different Resolution DEM on Landslide Extraction

Importing the 5.8 m resolution multispectral image, 10 m resolution DEM and the DEM derivatives to eCognition software for extraction landslides. The classification rules which optimized based on rules in article [7] shown in TABLE I.

TABLE I. CLASSIFICATION RULES OF LANDSLIDE INFORMATION EXTRACTION.

Landslide type	features and rules
Shadow	Hill_shade≤92; NDVI≥0.1
Mainstream	Stream order≥5
Tributary	Length/Width≥3.6; Slope≤17.5;NDVI≤0.067; Layer 3≤74
Lake	NDVI≤0.08; Slope≤15; Relief≤20
Mainstream river sand	Brightness≥65; Distance to Mainstream≤100m; Slope≤20; Relief≤30
Tributary river sand	NDVI≤0.08; Slope≤15; Relief≤20
Built-up area	Compactness＜2.5; GLCM Homogeneity Layer 2:[0.15,0.2]; Slope≤12
Agricultural land	GLCM Mean Layer 2:[60,90]; NDVI≥0.094; Slope≤30
Trees	GLCM Mean Layer 2 :[55,60]; NDVI≥0.094; Slope≤30
Rocky	Brightness≤95; NDVI≥0.123; Slope:[29.5,45]
Escarpment	Brightness≤90; NDVI≥0.12; Slope≥45
Road	Aspect-MainDir:[65,115]; Length/Width≥4.5; Layer 3≥76.5
Shallow translational rock slide	Asymmetry≥0.95; Slope≥25
Debris slide	Rel. border to agricultural land≥0.5
Debris flow	Length≥500; Slope≥25
Rotational rock slide	curvature≤-1
Translational rock slide	prof_curv≤1
Built-up area	Compactness＜2.5; GLCM Homogeneity Layer 2:[0.15,0.2]; Slope≤12

The landslides extraction result is shown in Figure 3 using above classification rules.

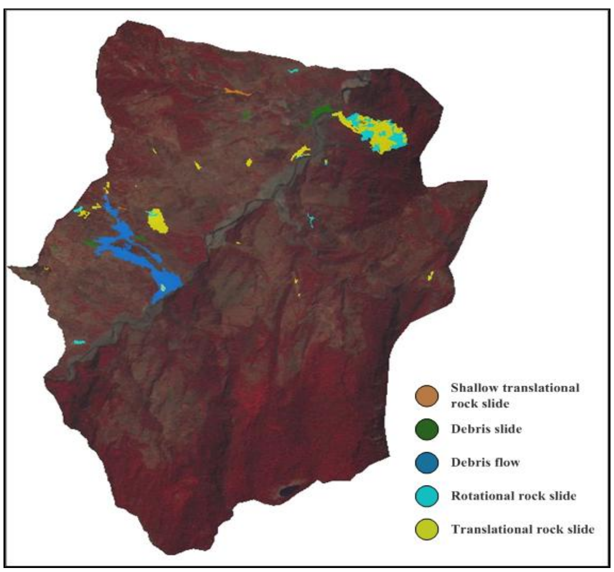

Figure 3. Extraction results using 10 m resolution DEM.

A. DEM Resampling

DEM resampling will weaken the characteristics of the original DEM data, and the nearest neighbor (NEAR) method has a greater effect, the bilinear interpolation (BIL) method and cubic convolution (CUB) method have a little effect [11]. In order to study the impact of DEM spatial resolution on landslides information extraction, we use the BIL method to resample the 10m resolution DEM into 20m, 30m, 60m and 90m. By using the spatial analysis method in ArcGIS software, we calculate the six different resampling DEMs, and get the slope, aspect, hill shade, terrain curvature, profile curvature, stream order, respectively, in their resolution.

Resampling process makes the DEM smoothly, resulting in some low-lying areas sampled value on the high side under the influence of the surrounding high areas, and affecting the calculation of flow accumulation. Consequently, the stream order maps used in the experiment are calculated by the original 10m resolution DEM.

B. The Landslide Extracted on Different Resolution DEM

Keeping the multispectral image unchanged, replacing the original DEM data and its derivatives with the resampling ones, we use the optimized feature rules listed in TABLE I to extract the landslide information. The extraction results obtained by this method are not ideal, and there are many misclassification phenomenons. Due to the change of DEM features, some landslide objects are not identified. Thus, we adjust the extraction parameter values of each feature according to the different resolution DEM. The parameter value which we adjusted list in TABLE II, the final classification results that we obtained are shown in Figure 4.

TABLE II. PARAMETER ADJUSTMENTS OF LANDSLIDE INFORMATION EXTRACTION.

Landslide type	**Object features**	**Rules**				
		10m	***20m***	***30m***	***60m***	***90m***
Tributary	Slope	<=17.5	<=18.5	<=18.5	<=18.5	<=18.5
Lake	Slope	[0,5]	[0,5]	[0,5.9]	[0,5.9]	[0,5.9]
Mainstream river sand	Slope	[0,20]	[0, 19.75]	[0,16]	[0,16]	[0,16]
	Relief	<=30	<=38.95	<=38.95	<=38.95	<=38.95
Tributary river sand	Relief	<=20	<=18.4	<=18.4	<=18.4	<=18.4
Agricultural land	Slope	[0,30]	[0,29.5]	[0,29.5]	[0,29.5]	[0,29.5]
Trees	Slope	[0,30]	[0,29.5]	[0,29.5]	[0,29.5]	[0,29.5]
Rocky	Slope	[29.5,45]	[29.5,44.5]	[29.5,44.5]	[29.5,44.5]	[29.5,44.5]
Escarpment	Slope	>=45	>=44.5	>=44.5	>=44.5	>=44.5
Road	Aspect-MainDir	[65,115]	[65,115]	[65,115]	[65,115]	[63.5,115]
Shallow translational rock slide	Slope	>=25	>=25	>=25	>=25	>=22.5
Debris slide	Rel. Border To Agricultural Land	>=0.5	>=0.4	>=0.4	>=0.4	>=0.4
Debris flow	Slope	>=25	>=25	>=25	>=24	>=24

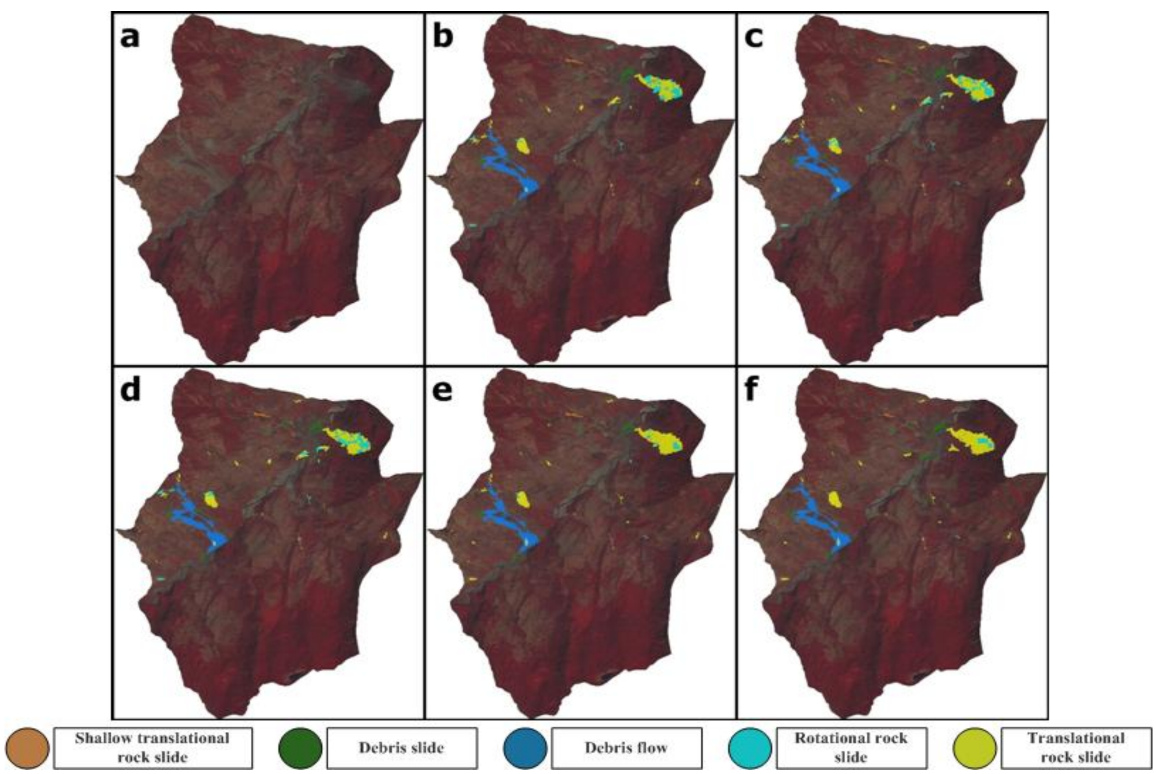

Figure 4. The landslide information extracted results of different spatial resolution DEM. (a)Original images, (b)10m, (c) 20m, (d)30m, (e)60m, (f)90m.

C. *Analysis of experimental results*

As the DEM spatial resolution reduction, landslide information extraction will gradually be affected. Adjusting the characteristic parameter values for each feature extraction process, you can reduce the misclassification phenomenon to the least. It can be seen from TABLE II that parameter adjustment that the changes of characteristic mainly include: Slope, Relief, Aspect-MainDir, Rel. border to agricultural land. The common of these feature rules is that they are associated with DEM. The DEM resolutions changes lead to the changes in the value of these characteristics correspond. The feature Slope is calculated by DEM data using the digital terrain analysis in GIS (Geographic Information System) software. The feature Relief describes the differences of height between hills and valleys, and it is calculated by the maximum elevation minus minimum elevation in DEM images. The feature Aspect-MainDir describes the relatively angle between the slope aspect and the main direction of objects, and the aspect is calculated by DEM data. The feature Rel. Border to Agricultural Land describes the relative border length an object shares with the Agricultural Land border, and the Agricultural Land is identified under the participation of slope feature (TABLE I) which is calculated by DEM data.

Comparing the landslide information results (Figure 4) extracted under the participation of different spatial resolution DEM, we can see that, the landslides in the study area can basically be detected when the parameter values adjusting. Comparing with the low-resolution DEM extraction results in Figure 4(f) and the high-resolution the DEM extraction results in Figure 4(b), apart from a few landslides with small area cannot be detected and a majority of the landslide with large area can be identified. However, in the case of landslide type, when the DEM resolution is down to 30 meters, it is difficult to distinguish between the boundaries of rotational rock slide and translational rock slide, because the process needs the landslide objects resegmentation by curvature data shown in Figure 1(F). The curvature data is calculated by DEM data, it is the same resolution with DEM. The area of the rotational rock slide in the study area is in the 5000-40000 m^2. Form Figure 5, we can find the following phenomenon: (1) The rotational rock slide can be correctly represented by image objects with the 10 m resolution DEM. (2) With the 30 m resolution DEM, the rotational rock slide can barely be represented. (3) When the DEM resolution down to 60 meters, the rotational rock slide showed only a few pixels, it cannot be represented.

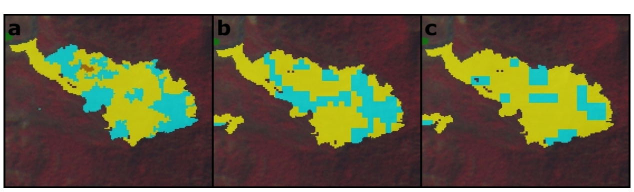

Figure 5. The comparison chart of different spatial resolution DEM. (a)10m resolution, (b)30m resolution, (c)60m resolution.

V. CONCLUSIONS

With the full application of high-resolution satellite remote sensing technology, object-oriented information extraction has been rapid development. Firstly, in this paper, we use DEM data and its derivatives data to auxiliary high-resolution remote sensing images, achieving comprehensive spectrum shape and terrain characteristics of object-oriented landslide information extraction. Then we resample the DEM data into five levels and involved in the landslide information extraction. Finally, we analyze the impact of DEM spatial resolution changes on object-oriented landslide information extraction. Our experiment shows that: (1) With the reduction of DEM spatial resolution, landslides information extraction accuracy will gradually decrease. (2) When the DEM spatial resolution is better than 30 meters, the landslide area being greater than 5000m^2 can get a better identification and classification results. (3) When the DEM spatial resolution is less than 30 meters, although it is more difficult to distinguish the type of landslide, we can detect the landslide by adjusting the value of the characteristic parameters of the feature.

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