Building Landform Classification Maps from DEM: Alluvial Fan Extraction Method

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Abstract: Landform Classification maps are used in many areas such as disaster damage assessment, developmental conformity evaluation, and environmental study. For the high resource demand of the classification processes, such maps are not available in many regions including developing countries. Our ongoing research focuses on providing Landform Classification maps for those regions using DEM which is easily obtainable by remote sensing technology. In this paper, we propose an algorithm that extracts alluvial fans, an element of our landform classification, from readily available DEM supplied by SRTM. Then we tested the algorithm over the entire area of Japan, and found that the results were consistent with existing classification maps in terms of the number, size, and location of the alluvial fans extracted, thus confirming the applicability to the regions without classification maps.

Keywords: alluvial fan, DEM, landforms

1. Introduction

Landform classification maps based on DEM are useful in earthquake damage estimation that is important in the initial response to earthquakes (Jeong *et al.*, 2008), while these maps or databases are hardly available in many developing countries. Our prior work demonstrated algorithmic classification of landforms using DEM (Kim *et al.*, 2009), but it did not include alluvial fans.

Alluvial fans are fan-shaped landforms constructed from loose deposits of sediments (Figure 1). They form at where streams exit steep mountains onto low-gradient plains. Streams shift around in the fan accumulating and distributing sediments over the fan. The head of a fan is the area where the stream exits mountains and begins to shift. Fan toe is the outermost or lowest zone of the fan. The highest point of an alluvial fan is called the apex and is located at the fan head. The fan radius varies from hundreds of meters to more than a hundred kilometers (Charlton, 2008).

The intensity and form of a natural disaster tend to shift at alluvial fans. Alluvial fans may exhibit hazard of avalanche of earth and rocks in flooding and, in case of earthquake, the site amplification factors of peak ground velocity may also shift at alluvial fans. The damage caused by earthquake is closely related to the amplification factors. Matsuoka *et al.* (2005) showed

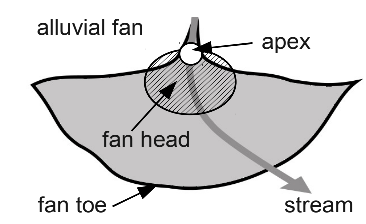

Figure 1. The structure of an alluvial fan (Jeong, 2009)

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that the shear-wave velocity, which is a predictor for estimating amplification factors, is higher at alluvial fans.

In one of our prior studies to find alluvial fans from DEM (Jeong, 2009), we employed the apex-growth strategy of Millaresis and Argialas (2000), but in contrast to Millaresis and Argialas' work that also used surface spectral signature of the area to identify the fan toes, we relied on height differences in the *Apex Expansion* process, not taking account the geometry of fans. In this study, we further improved the algorithm by developing a different method for Apex Expansion which recognizes the fan-like surface structures and therefore more suitable in finding alluvial fans.

2. Algorithm

The algorithm presented in this paper tries to find alluvial fans by growing fan areas from each apex cells. To grow fan areas, it is important to know if a given cell is in a fan area. For this, we developed *Aspect Consistency Test* based on the characteristics of aspect distribution on alluvial fans.

2.1. Aspect Consistency

On an ideally shaped alluvial fan, the cells on the fan area have their aspect pointing outward from the directional origin, the apex. To visualize this feature, one can think of aspect as an arrow mark placed on each cell in the grid. Then, we can observe distinctive pattern of arrow rays radiating outward from the apex throughout the alluvial fan surface surrounded by unorganized and loosely directed flow of arrows on the cells beyond the fan toe and therefore outside the fan (Figure 2). It is this difference in aspect distribution between alluvial fan and its surroundings that we used to delineate alluvial fans. To quantize such behavior of aspect distribution, we introduce the *Aspect*

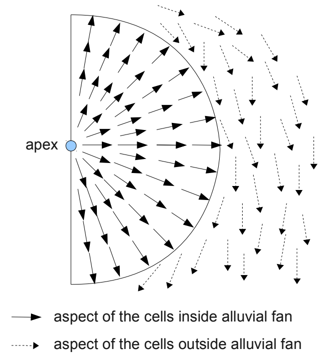

Figure 2. Aspect distribution of alluvial fan

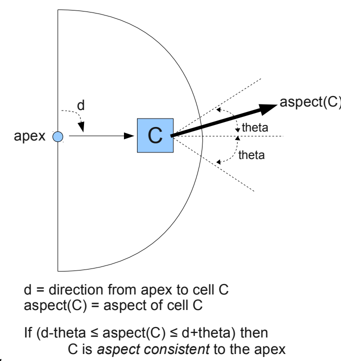

Figure 3. Aspect Consistency Test

Consistency. Aspect Consistency of a cell *C* measures how diverse the aspect of C from the direction from the apex to C. As shown in Figure 3, C is aspect consistent to the apex if the aspect of *C* is in *d* ± *theta* range, where d is the direction from the apex to C and theta is a threshold value.

A *processing window* was used to average aspect consistency values to deal with local aspect variations, and the size of the processing window along with the threshold value theta must be assigned some values to run the algorithm. We confirmed that increasing these values also increases the size of all alluvial fans found by running the algorithm with about 200 different combinations of these values on Kofu Basin area, Japan. Then we chose window size of 4(cells, in radius) and theta of 30 degrees because these were the lowest value pair that stabilizes the rate of increase in total size of alluvial fans found by the algorithm. Figure 4 is the resulting alluvial fan classification of Kofu Basin with processing window size = 4 and theta = 30.

3. Test Setup

The algorithm was ran on a DEM covering the entire Japan area, which was extracted from SRTM3. The resulting classification map was compared to Japan Engineering Geomorphologic Classification Map with 7.5 arc seconds in cell size, which was obtained from

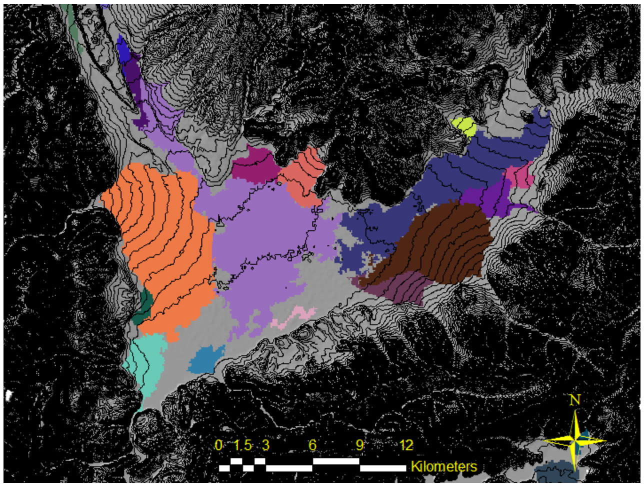

Figure 4. Alluvial fans found by the algorithm in Kofu Basin area. Each fans originated from different apices are colored differently.

National Research Institute for Earth Science and Disaster Prevention, Japan Seismic Hazard Information Station, through the Internet address: http://www.j-shis.bosai.go.jp (called JEGM hereafter).

4. Result

We compared JEGM to our result in two ways: size and location of alluvial fans. Size matching is done by counting the matching number of cells classified as alluvial fans in both maps, multiplied by the size of the cell, and represented with km^2 unit. In location comparison, two areas from each map are said to match in location if any part of the these areas overlap. As shown in Table 1, JEGM has 1,357 alluvial fans occupying 8,852km^2, and this is 2.41% of the total land area(367,673km^2). When this is compared to our result, the size matching rate is 31.5% and location match 31.83%.

Looking closer to the size and number of alluvial fans ,we found that large-sized fans occupy most of the total fan areas and this is illustrated in Figure 5. The chart shows the distribution of alluvial fans in terms of their sizes. The x-axis indicates the total size of the alluvial fans in the map, and y-axis the number of fans. As we delete the smallest fans one by one from the map, the total size and number of the fans decrease and are plotted on the chart. For example, we can see that with JEGM, when x=5, y is around 21, meaning that smaller fans account for 5% of the total fan area occupies about 79% of the fans in number. In other words, only about 21% of total 1357 fans occupies 95% of total fan area. The map generated in this study also displays similar behavior, with larger fans occupy even more fan area.

Table 1. Comparison of JEGM and the alluvial fans found in this study

	alluvial fans		match		match rate	
	size (km^2)	number	size (km^2)	number	size (%)	number (%)
JEGM	8,852	1,357	2,788	432	31.50	31.83
this study	7,987	9,234	2,788	1,447	34.91	15.70

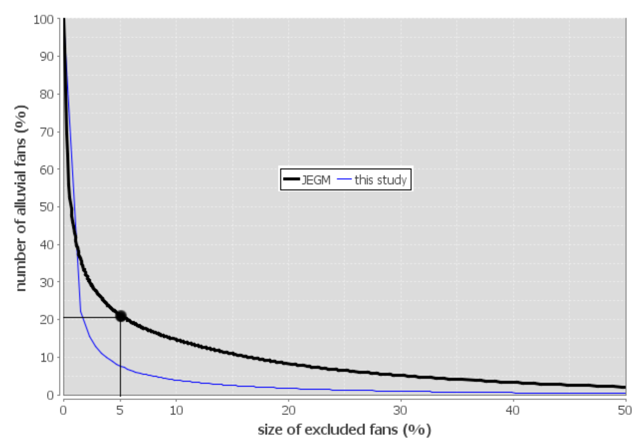

Figure 5. Number of fans vs. total size of fans. Represented as rate to

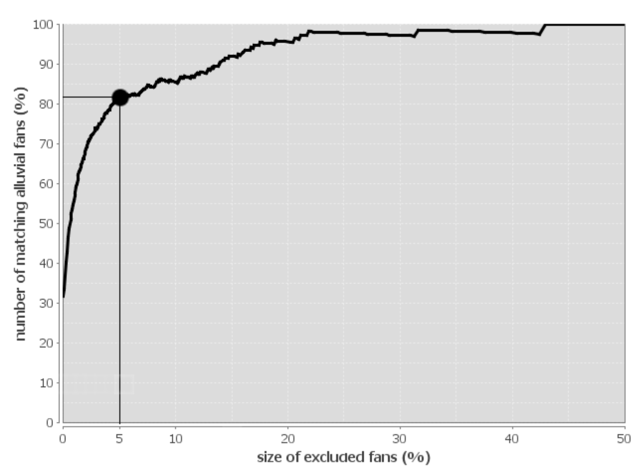

Figure 6. Number of location match vs. total size of fans. Represented as rate to their maximum values.
their maximum values.

Excluding these small fans increases the location match rate significantly. As in Figure 6, the location match rate quickly rises if we remove small fans that occupy only a small fraction of total alluvial fan area. If we remove smaller fans that is about 5% of total area, the location match rate becomes 82% and it continues to increase as we remove more fans. The largest fan removed is smaller than $3km^2$ in this case. Therefore, we can say that for the fans larger than $3km^2$, the result of our alluvial fan classification algorithm is 82% (235 out of 287 fans) consistent with JEGM in terms of location.

The false-positive results that the algorithm classified as alluvial fans but belongs to other landforms in JEGM are listed in Table 2, from the largest to smallest. In the table, gravelly terrace takes up 32% of total false-positive areas, followed by valley bottom lowland, etc. The top 5 in the list that adds up to almost 87% of total false-positives are the landforms of near flat surface or very gentle slope changes, which resembles the surface characteristics of alluvial fans. When they are next to fan toes and their aspect values happen to be aligned with the ones on the fan toes, it is hard for the algorithm to stop but keep expanding over to fan toes because the fan expansion strategy relies on aspect differences only. We expect that extracting these landforms separately and subtract them from alluvial fans will lower the false-positive rates.

The number of fans found by the algorithm(9,234) is much greater than JEGM(1,357) as we can see in Table 2, which is due to the number of apex found prior to the fan expansion process since logical search for apex finds "possible" apices but does not confirm them in the real world. Most of these 9,234 fans are small but still contribute to false-positive cases. How to remove these unneeded apices is to be addressed in our future study.

Table 2. JEGM landforms identified as alluvial fans by the algorithm

%	size(km^2)	ID	landforms
31.97	1662	8	gravelly terrace
17.90	931	10	valley bottom lowland
16.87	877	13	back marsh
10.57	549	5	volcanic foot slope
9.31	484	9	terrace covered with volcanic ash soil
2.98	155	#	nodata
2.84	147	15	delta and coastal lowland
1.84	96	22	river bed
1.52	79	12	natural levee
4.20	218		other landforms less than 1 %

5. Conclusion

In this paper, we proposed an alluvial fan classification algorithm using DEM. Sufficiently high location match rate could be obtained by controlling the size of the fans to be included in the classification. This method requires only DEM as an input and consumes relatively low resources in processing, it can be used in producing landforms classification rapidly when an immediate damage assessment is required over a large area in the situation such that a large scale natural disaster occurs.

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