DEMを用いた扇状地分類情報を抽出するアルゴリズム研究

Study on Alluvial Fan Identification Algorithm Based on DEM

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Landforms classification maps are used in estimating potential damage by natural disasters. For some landforms in the map such as alluvial fans, the mode of damage tend to shift at the boundaries, therefore accurate identification of such landforms are vital to the damage estimations. In this study, an algorithm of identifying alluvial fans from Digital Elevation Models was developed, implemented, and demonstrated on a selected region of Japan. The result was found to be effective under visual inspection.

Keywords: *landforms classification, alluvial fan identification, DEM*

1. Introduction

It is known that 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 an earthquake, the site amplification factors of peak ground velocity(for short, amplification factors) may also shift at alluvial fans. The damage caused by an earthquake is closely related to the amplification factors. Matuoka et al.[4)] mapped the distribution of the average shear-wave velocity in the upper 30m, which is a useful predictor for estimating the amplification factors, to geomorphologic classification and showed that the shear-wave velocity is lower at alluvial fans compared to mountains and valley bottom lowlands and therefore suggesting that the site amplification factors of peak ground velocity would also be lower. Thus, accurate identification of alluvial fans will improve the reliability of damage estimation of earthquakes.

Traditionally, landforms classification maps are built through site surveys requiring both compositional and morphological data. In this study, we developed an algorithm to identify alluvial fans from elevation data of the area, by using Digital Elevation Model(DEM). Identifying landforms by DEM only may degrade the quality of the classifications compared to the traditional methods, however it can be advantageous for the remote areas and for the cases with limited budget.

The fan-growing strategy of Millaresis and Argialas[6)] is employed for the identification algorithm. The strategy constructs an alluvial fan from the apex to fan toe reflecting the concentric structure of its contour lines. Unlike Millaresis and Argialas who made use of the surface spectral signature to delineate fan toes, surface gradient threshold is used in this paper to decide when to stop growing the fan.

2. Alluvial fans

Figure 1 shows a typical alluvial fan. Alluvial fans are fan-shaped landforms constructed from loose deposits of sediments. 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 apex and is located next to the fan head(Figure 1-b).

Alluvial fans are common in arid areas surrounded by mountains where occasional rainstorms cause high sediment loads. However, alluvial fans also occur in humid conditions. The fan radius varies from hundreds of meters to more than a hundred kilometers, increasing with the rate of supply of water and sediment from the catchment.

The long profile of fans is normally concave upwards. Slope is steepest at the fan head, progressively decreasing along the length of the fan. The average slope generally decreases as water and sediment supply increase. Cross-valley profiles of fans are convex-upwards.

Fan surface has complicated topography by incisions caused

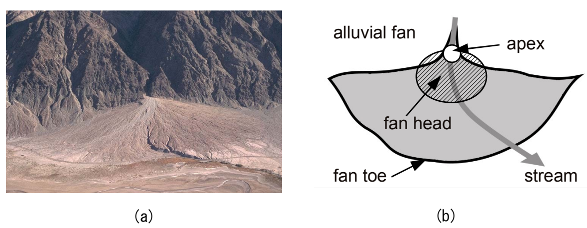

Figure 1. Alluvial fan

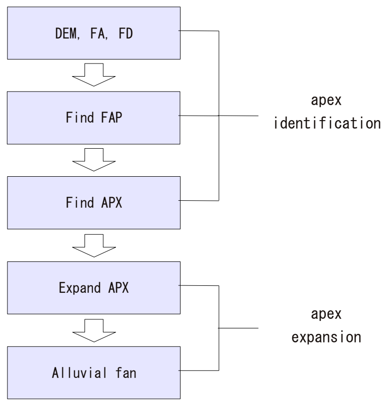

Figure 2. Alluvial fan identification

by migrating streams. When many individual fans develop in the same area, they may coalesce to form a bajada, an extensive apron of sediment that covers the foot of a whole range.

3. Alluvial Fan Identification

The algorithm presented in this paper tries to find alluvial fans from a given DEM. It largely consists of two parts: identifying apex cells that are located at the heads of alluvial fans and growing alluvial fan areas from each apex cells (Figure 2).

1) Apex identification

Finding correct apex cells hugely affect the performance of the algorithm as well as knowing when to stop growing an alluvial fan area. Fans grow from apex points, therefore if no apex point is found for a fan then it will have no chance to be identified. Likewise, if incorrect apex is found, then it results in a false alluvial fan.

The basic idea of apex identification is to trace up a stream flow and find where it enters into mountains; where the width of the plain the stream belongs to becomes dramatically narrower. This requires identifying the plain area containing alluvial fans(hereafter, AFP for alluvial fan plain) and the rest of the area(conveniently, call it mountains). Flow direction(FD) and flow accumulation(FA) which represent the direction and shape of stream flow need to be calculated too. And with these AFP, FD and FA provided, the positions of apex cells(APX) in a DEM are then calculated.

The gradient of AFP is less than 7° to sufficiently include alluvial fans.[6] Therefore, plain areas with gradient less than 7° are searched and used as AFP. Uplands of moderate height and their side slopes are also added to AFP since it is observed that large alluvial fans often display topological similarities with uplands of gentle slopes. The goal is to exclude steep and high mountains from AFP, so that the width of AFP measured perpendicular to the streams gets smaller near the mountains. In Figure 3, the width measured at the cells on the stream becomes smaller close to the APX, where the stream exits mountains. In finding AFP, a modified version of the slope-profiling algorithm introduced in the work of Matsuura et al.[5] was used to identify the borders of uplands and lowlands.

FD and FA are computed using ArcGrid commands. FD grid is a grid in that each cell has a direction value pointing to its steepest downslope neighbor, and using this, FA grid is calculated in that each cell has a value of accumulated flow to it, by iteratively accumulating the weight for all cells that flow into each downslope cell. Thus the cells with higher values collectively describes a network of streams in the area.

A search for APX starts from the cell at the end of a stream and proceeds toward upstream. At each cell on the stream, the AFP width is measured in the direction perpendicular to the flow direction that can be obtained by refering to FD. The maximum width is kept recorded and compared to the smaller widths. When the width measured is significantly smaller than the maximum width(1/20 of the maximum in this paper), the cell at where the measurement was made is marked as an APX and a new search starts from the end point cell of the next stream.

2) Apex expansion

For each APX, an identification number is given to represent the alluvial fan to be grown from it. So at the initial state, every alluvial fan consists of only one cell, the APX of the fan. Fan-growing is then performed by testing and adding the surrounding cells to the fan repeatedly until no more cells can be added. The growth occurs at the bordering cells of the fan, and in this algorithm, they are managed in a queue-styled list and expanded sequentially. The expansion process is illustrated in Figure 4 and bellow are the description of each steps of the expansion procedure.

a) Select an APX(A in Figure 4), assign an alluvial fan ID, and add it to the border-cells list for this alluvial fan. The list now contains an APX only.
b) A cell P is removed from the list. For each neighboring cell C of P, a test is performed to see if C can be added to the alluvial fan. If it is eligible to be included in the fan, P's ID is copied to C and C is added to the list.
c) Repeat b) until the list becomes empty. An empty list indicates that there is no more border cells eligible for growth. At this point, the alluvial fan contains a number of cells that share same ID, thus identifying the alluvial fan with the ID.
d) Repeat a)-c) for every APX.

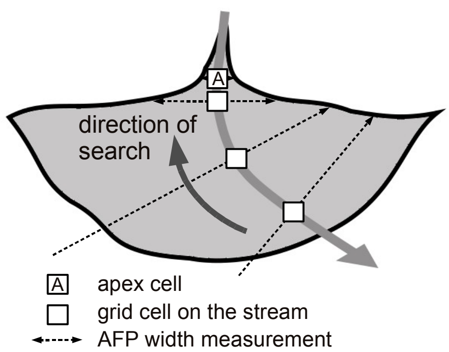

Figure 3. Apex identification

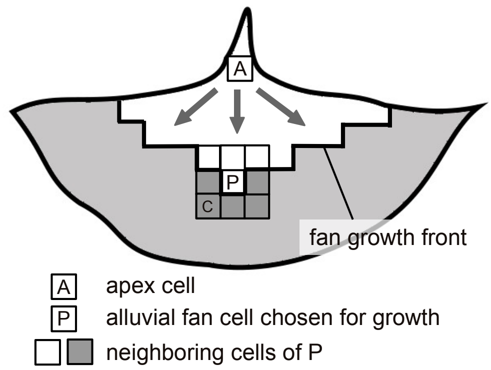

Figure 4. Apex expansion

Testing a cell for alluvial fan eligibility affects the overall shape of the alluvial fan found, so the test must be constructed carefully. The testing strategy is described in the following section.

3) Test of a cell for alluvial fan eligibility

Since the algorithm grows an alluvial fan top-down, that is, from the highest point(APX) to the fan toe, a neighboring cell C cannot be higher than the center cell P to be added to the fan. Also its gradient must be less than 7° and greater than some number greater than 0°. If it is 0° or close to 0°, then the cell must be in a flat plain. A cell C which is a neighboring cell of a fan-bordering cell P must satisfy the followings requirements to be added to the fan:

a) C is not already assigned an alluvial fan ID, meaning not in any alluvial fan.
b) The height of C is less than or equal to the height of P.
c) The gradient of C is in the range of 1° to 7°. (The best result was obtained when the lower bound was set to 1° in our tests.)

Direct comparison of height and gradient for b) and c) above does not perform well if P or C is in local dent or rise. Because the stream at the apex of the fan is commonly entrenched,[1) 2)] APX cells have lower height than the surrounding cells due to the APX search strategy that traces flow streams. At the initial state of the fan growth, the APX is taken as P and compared to the height of the neighboring cells that are mostly higher than P, and therefore, it tends to grow along the narrow flow stream. To allow it to grow wider to be a fan-like shape, small local variations in height need to be mitigated. For gradients, local noise(very steep or very flat) results in many small holes in the identified fan because alluvial fans have uneven surface incised by migrating streams in most cases.

To mitigate these local value effect, averaging the value with surrounding cells is performed to obtain a smoothed height and gradient values to compare. In the algorithm, following steps are taken to get average height and gradient for a cell P.

a) Let sum = 0
b) Add the value of P(height or gradient accordingly) to sum.
c) Select C. The distance between P and C is less than or equal to twice the value of the cell spacing of the grid.
d) Add the value of C to sum
e) Repeat c) and d) for all C.
f) Then the average value = sum / (number of C + 1)

4. Algorithm demonstration

The algorithm was demonstrated on Yamanashi Prefecture, Japan, a neighbor of Tokyo, Kanagawa, Saitama, Shizuoka, and Nagano. Due to the rain shadow effect provided by Mt. Fuji located to the south, the prefecture receives only a little over 800mm of rainfall a year. Surrounded by mountains in this dried region, the central Kofu Basin was chosen for algorithm demonstration because alluvial fans are commonly found in dry mountain regions.[1) 3)] The result was analyzed for the two selected areas: the west part and east part of the basin (Figure 5-a).

The test procedure is as follows: First, alluvial fans are manually delineated based on hillshade and 40-meter contour lines. These manually found alluvial fans are shown in Figure 5-b and e, numbered from 1 to 8. Next, AFP is computed and with FA and FD, APX searches are performed (Figure 5-c and f). APX cells are then grew to be alluvial fans. Generated alluvial fans are colorized by their IDs. Figure 5-d and g shows the alluvial fans found by the algorithm (colored areas) with the manually delineated fans and APX points projected onto them for comparison.

A grid-based DEM with 50m cell-spacing was used for the area. The DEM contained over 11 million cells each of which stores the height, or elevation value at the cell's position. The plain-text ESRI ASCII Grid format was chosen as the container of grid data including DEM for computation. ArcGIS software was used to calculate FD, FA, and contour lines as well as to visualize the result. The algorithm was implemented in Java programming language to take advantage of its multi-threading ability and portability .

5. Result and Conclusion

As shown in Figure 5-a, two areas A and B are selected for discussion. Area A is considered to be simpler than B for that the fans are more apart from each other and the fan toes are clearly defined by Kamanashi-gawa, a tributary river of Fujigawa. B includes more composite fan structures that make the identification harder than on A. There are 3 fans in A, Fan1, Fan2 and Fan3, and 5 fans in B, Fan4 to Fan8.

In A, the Fan1, 2, and 3 are all found and mostly colored accordingly. However, the fan toe of Fan2 is colored by Fan1. Similar phenomena are observed in Fan3 where two APXs are located very close, and the most fans in B. This is due to the algorithm's inability to recognize the border when two or more fans are developed and merged together. More specifically, the alluvial fan eligibility test for a cell conducted when expanding the fan need to incorporate some type of surface profile test which covers wider area to delineate coalescing fans correctly. Most areas of Fan5 and 6 are colored but not by their own colors. The algorithm seem to be failing in relating fan IDs to their APXs in these areas with complex geometry. Fan 6 is not colored at all since no APX was found for it. As it can be seen in Figure 5-f, AFP does not include the fan head of Fan6, and that prevented the APX to be found. Fan7 and 8 are identified correctly but the fan toe leaking is occurred as seen in Fan 1 and 2. In overall, the algorithm is effective in finding the fan surface but not accurately defines fan borders between coalesced fans.

In this study, we developed an algorithm for alluvial fan identification from a DEM. It was demonstrated on the central Kofu Basin in Yamanashi Prefecture and the results are inspected for two distinct areas. The algorithm performance was satisfactory in the area with well-defined alluvial fans while it requires further improvement to process combinations of the fans with complicated geometries.

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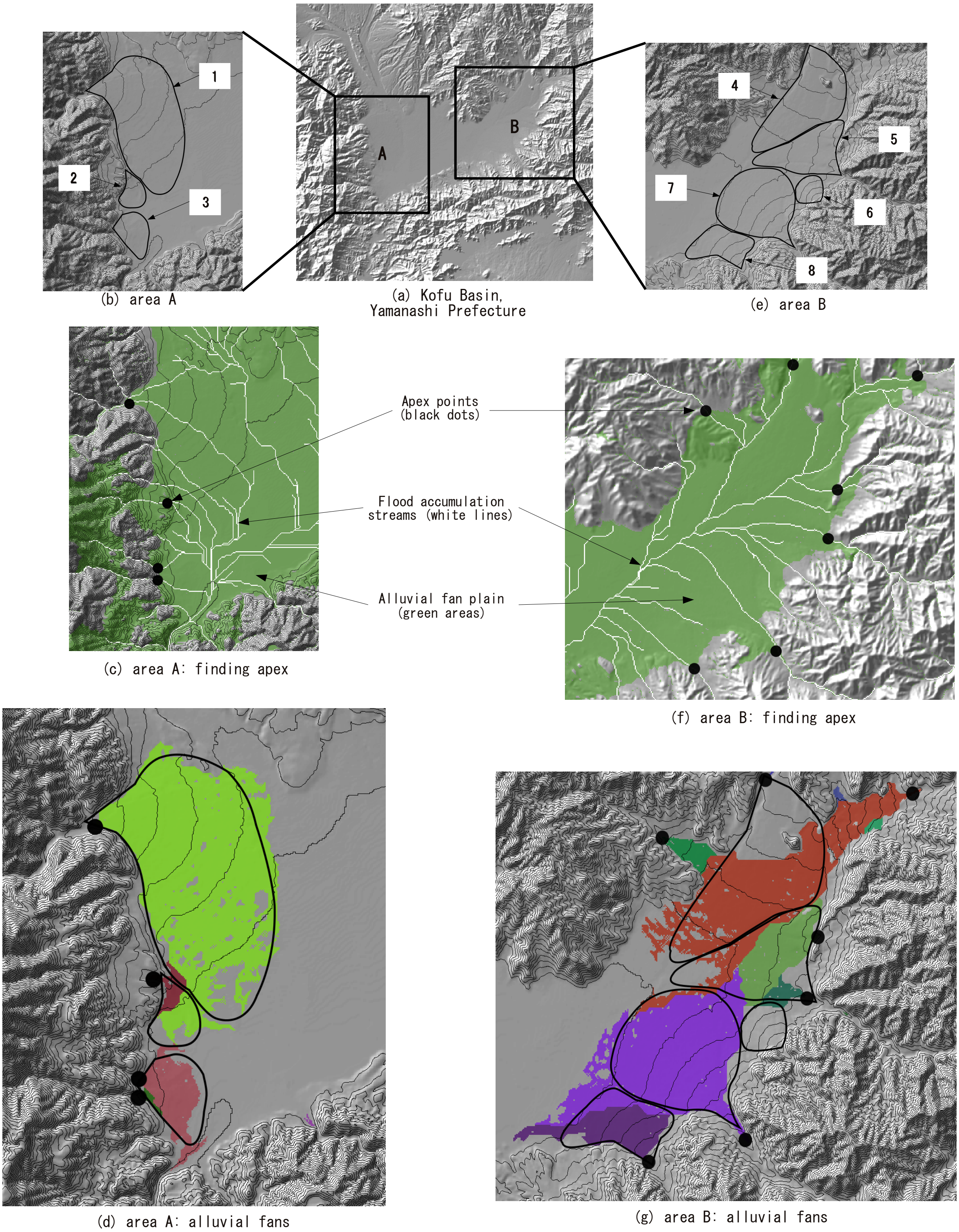

Figure 5. Alluvial fan identification in Yamanashi Prefecture