SUBCATCHMENT EXTRACTION AND RUNOFF SIMULATION UTILIZING REMOTE SENSING DATA

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BẢN TÓM TẮT

Lưu vực con cũng như các thông số có vai trò rất quan trọng trong việc dự đoán nguy cơ lũ và quản lý tài nguyên nước vì chúng cần thiết cho việc phân tích và mô phỏng các con sông. Tuy nhiên, những thông số này chỉ có được do khảo sát thực địa ở những nơi địa hình đơn giản, còn những khu vực có địa hình đồi núi phức tạp hay trong rừng sâu thì chưa có được những số liệu này hoặc dữ liệu không chính xác mặc dù đã tiến hành thực địa. Ngoài ra, việc tiến hành đo thực địa như vậy tốn rất nhiều thời gian và chi phí cũng như các thông số thu thập được không có độ chính xác cao.

Trong bài báo này, chúng tôi đề cập đến phương pháp trích xuất các lưu vực con và các thông số từ dữ liệu vệ tinh viễn thám. Do tách lưu vực con bằng dữ liệu DEM từ vệ tinh viễn thám mà không cần phải đi thực địa nên ta có thể có được các lưu vực con ở mọi khu vực có dữ liệu DEM. Các thông số địa hình của subcatchments được tính dựa trên DEM. Bằng cách sử dụng dữ liệu bề mặt có được nhờ cảm biến quang đa phổ, ta có thể xác định được hiện trạng lớp thực phủ. Phương pháp này có thể dùng để đạt được các thông số lưu vực con ở những địa hình đồi núi hoặc rừng sâu.

Để sử dụng triệt để những thông số tách được, chúng tôi cũng đưa ra chương trình mô phỏng ngập. Dùng những thông số nói trên và một số thông số khác, chương trình này sẽ mô phỏng tháo rút nước. Nhờ có được mô phỏng ngập trước đây và thuật toán thích hợp sẽ có được các thông số chính xác và phù hợp hơn.

ABSTRACT

In the fields of flood hazard prediction and water resource management, subcatchments and their parameters play very important roles because they are needed for almost all analyses and simulations related to rivers. However, they are prepared by field surveys in usual cases, so they have not yet been prepared for mountainous or deep forest areas difficult to survey, or they are not so accurate although they have been already prepared for those areas. In addition, such kinds of field surveys spend much time and costs, so it seems stalled to prepare subcatchments and their parameters with high accuracy in those areas.

In this research, we developed the methods to extract subcatchments and their parameters from satellite remote sensing data. Our method to extract subcatchments needs only DEM obtained by satellite remote sensing, without any field surveys, so we can extract subcatchments anywhere if only DEM exists for there. Topographical parameters of extracted subcatchments are calculated also only from DEM. Using surface data obtained by multi band optical sensor, landcover is determined. These methods will enhance the preparation of subcatchments' parameters for mountainous or deep forest area.

As a practical way to use of those extracted parameters, we developed a runoff simulation program too. It simulates draining discharges, using the extracted parameters above and some other parameters. By the simulation for past runoff, with fitting algorithm, it can correct parameters into more suitable.
Keywords: Flood Hazard, Runoff, Discharge, Simulation, Remote Sensing

1. INTRODUCTION

According to increase of flood hazards occurred by heavy rain related to abnormal weather, importance of flood hazard prediction and water resource management has been increasing. In those fields, subcatchments and their parameters often become the basis of analysis and simulations so importance of them has also been increasing.

However, there are a lot of areas that subcatchments and their parameters have not been prepared yet because of the difficulties to survey. They are measured and determined by field survey in usual case, but it is not so easy especially for mountainous or deep forest areas. Although they have been already prepared, they are often without accuracy. In addition, field survey spends a lot of costs since it requires specialists, engineers, some expensive implements, and long term to execute, so it seems stalled to prepare subcatchments and their parameters with high accuracy for such "difficult" areas.

In order to solve these problems, utilization of satellite remote sensing data will be good solution. It is expected as new way for survey or replacement of measurement in the field of cartography, and actually some features measured by field survey can be obtained from it. So there are enough possibilities to extract subcatchments and some of their parameters from satellite remote sensing data.

In this research, we developed the methods to extract subcatchments and their parameters from satellite remote sensing data, easier and cheaper than usual field survey. Our methods to extract subcatchments and their topographical parameters require only DEM (Digital Elevation Model) obtained by satellite remote sensing, and ones to extract landcover require only surface data obtained by multi band optical sensor of satellite.

We also developed runoff simulation program as a practical way for use of those extracted parameters. It simulates draining discharges, using parameters extracted by our methods and some other parameters. It has function fitting input-output so it is able to correct parameters into more suitable through simulation of past runoff.

As the satellite remote sensing data, we use ASTER (Advanced Spaceborne Thermal Emission and Reflection radiometer) 3A01 products. This data is raster DEM obtained by 2 line sensing with resolution 15m and has a set of reflectance obtained by 14 bands (3 visible near infrared, 6 short wave infrared, and 5 thermal infrared radiometers) of optical sensor. So we can use it not only for the topographical information by DEM, but also for the land surface information by the composition of reflectance (see Fig.1). In addition, this data is very good at cost performance so suitable for our purpose.

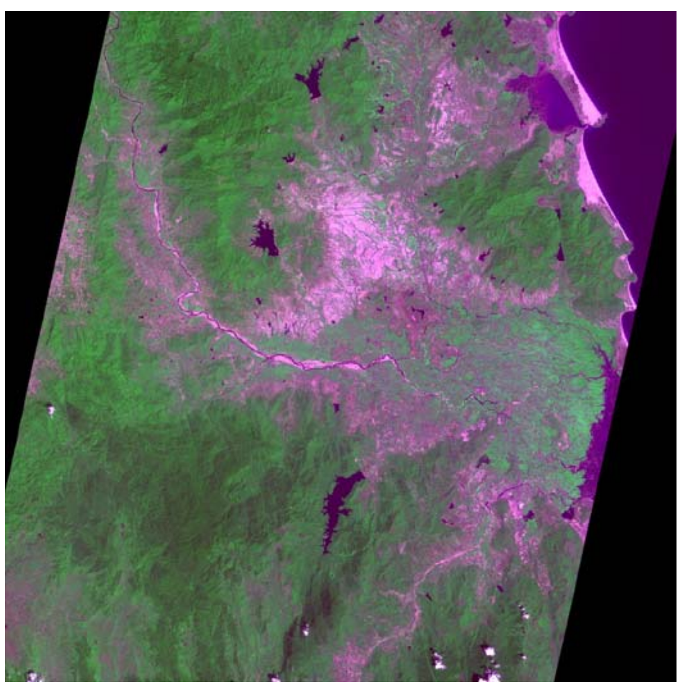

Fig. 1 Natural colored image (R : G : B = band2 : 3 : 1) of ASTER 3A01 product obtained for Kon-Ha Thanh River Basin in the mid of Vietnam

2. EXTRACTION OF SUBCATCHMENTS

The method to extract subcatchments from DEM obtained by satellite remote sensing is done through several steps. In the order of the steps, we extract aspects, steepest paths, drainage systems, and subcatchments at last.

2.1. Aspects

The aspect means which direction a point slopes most strongly. This is determined by comparison of height (referring DEM) among the targeted point and all of its nearby points. If one of the nearby points is lower than the targeted point, the aspect of the center point is selected as the direction to the nearby point with the lowest height. In the other case, the center point becomes a pit.

Those pits disturb the extraction of steepest paths after this step, so we must fill them and smooth the surface. The way to fill them is simply to rewrite the height of each pit higher and re-extract aspects from rewritten heights. Repeating this process until there become no pits, smooth aspects are extracted.

Aspects are usually indicated by colors as in Fig. 2.

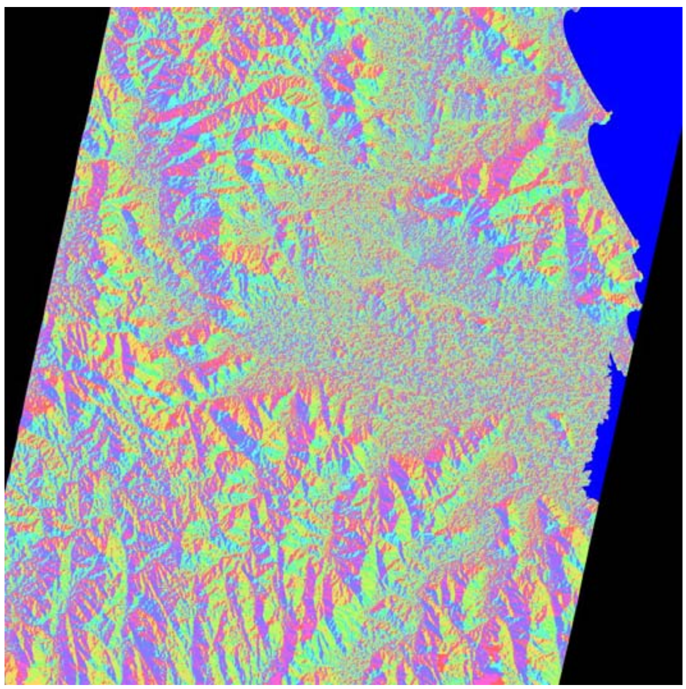

Fig. 2 Color indication of extracted (smoothed) aspects

For flat areas, the aspects extracted above method are often incorrect because heights' errors of DEM affect the comparison of heights much in such areas. We discovered that river shape and its flowing direction are effective to prevent such incorrect aspects. At the extraction of aspects, by using -9999m (or some other suitable value) as the height of the river instead of its original heights and excluding river itself from extraction of aspects (to avoid the river become filled by filing pit process), all aspects of riverside points become directed into river. After that, by rewriting the aspects of river according to flowing direction of it, resulted aspects finally become more correct ones.

2.2. Steepest Paths and Drainage Systems

The steepest path means the path where a ball goes through if it is putted on a point. Replacing the ball to rainwater, the steepest path is understood as streaming path of rainwater.

As you see in Fig. 3, steepest paths are determined by bonding points according to aspects. In this figure, each one square is one point (grid) of ASTER 3A01 and its color means its aspect.

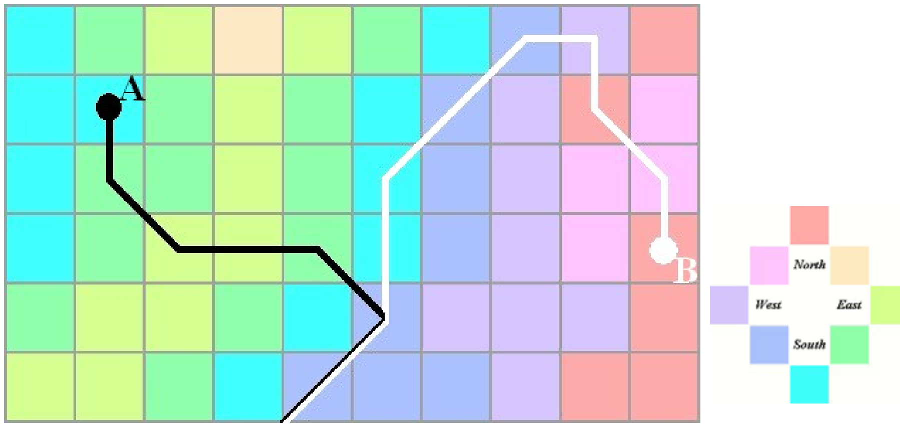

Fig. 3 Steepest paths from point A and B (determined according to aspects)

The drainage system is main streaming path of gathered rainwater, so it is extracted by bonding points where lots of steepest paths go through. Extracted drainage systems are indicated as in Fig. 4.

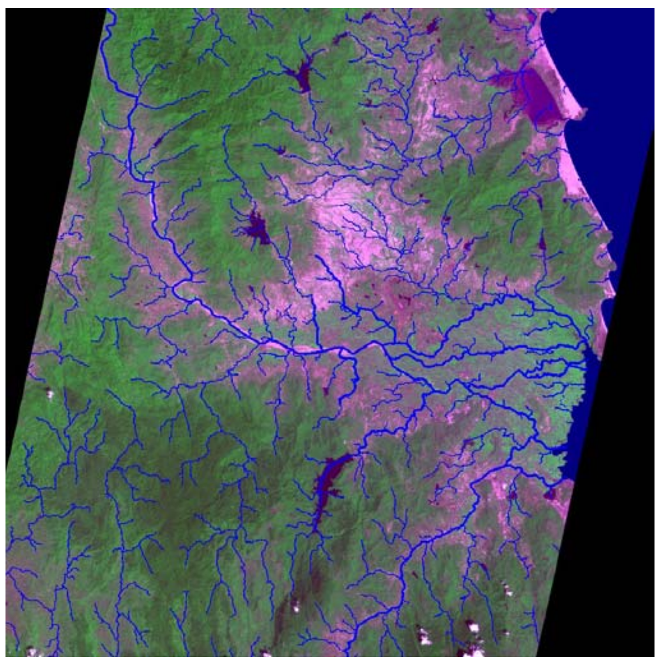

Fig. 4 Drainage systems (blue lines) extracted from steepest paths

2.3. Subcatchments

The subcatchment is area where rainwater is gathered from to a point, so it is extracted by bonding points that steepest paths from reach the point. Usually, choice of the extraction point of the subcatchment is not so easy because it should be the end point of draining in the subcatchment. But in our method, since we have already extracted drainage systems, we can correctly and easily choose the extraction points by choosing a point on those drainage systems.

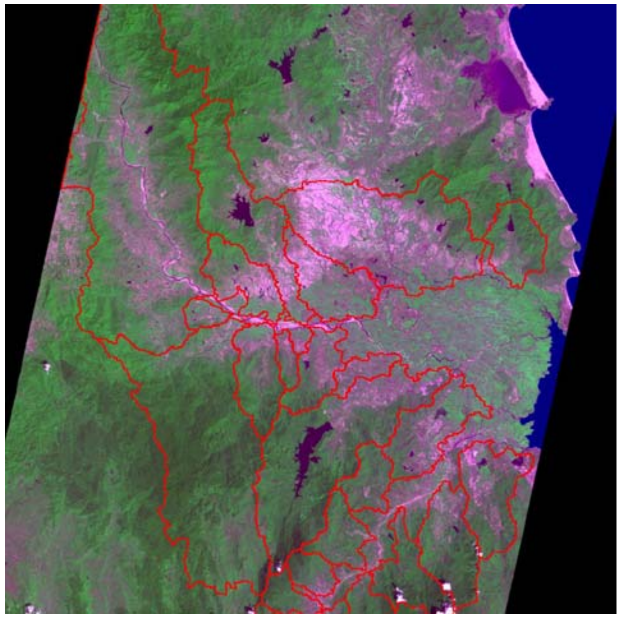

Fig. 5 Subcatchments extracted from steepest paths and drainage systems

3. Calculation of Topographical Parameters

By using DEM obtained by satellite remote sensing, topographical parameters of extracted subcatchments are calculated.

3.1. Length

Horizontal lengths are calculated by simple geometry with unit length defined for grids of the DEM. For example, in the case that one grid has latitude 10m and longitude 12m, the length of a line across a grid from West to Northeast is calculated as $\sqrt{(10 \div 2)^2 + 12^2} = \sqrt{169} = 13$ (see Fig. 6). Shapes of extracted elements are all defined as raster, so lengths related to them are calculated as sum of lengths of such short lines.

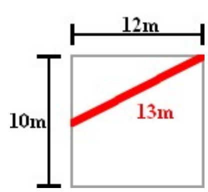

Fig. 6 The length of a line across a grid from West to Northeast

3.2. Area

As already mentioned, shapes of extracted elements are all defined as raster, so horizontal areas related to them are simply calculated as product of unit area defined for grids of the DEM and number of grids included in them.

3.3. Slope

It is technically possible to calculate slopes for each grid by using differential heights and horizontal lengths, but this way is often not accurate because of heights' errors (especially sudden extreme values) of DEM. In many cases, since calculation of mean slope of wide-area is not so sensitive for such errors, it is better way to determine slopes.

From this reason, we calculate slopes for each subcatchment (or such wide-area) as mean slope of whole that area, not for each grid. In our method, mean slope of subcatchment is calculated as $\left(\Delta h \cdot L \cdot \sum r_i\right)/\left(A \cdot r_n\right)$ in tangent, where Δh is n-divided value of the differential height between the highest and the lowest point in the subcatchment, A is area of the subcatchment, L is the length of boundary of the subcatchment, r_i $(i = 0, \cdots, n)$ are radiuses of each circles with the area same to cross-section per height Δh (r_0 for the top cross-section 0, and r_n for the bottom cross-section A).

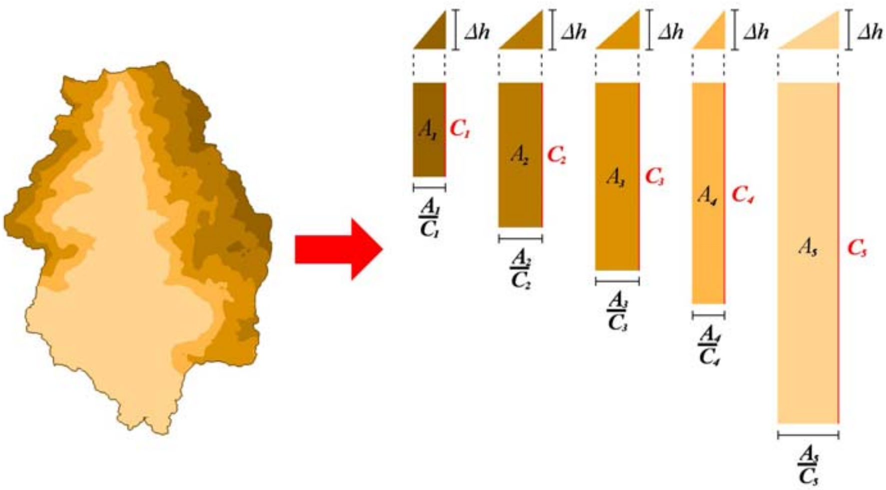

Fig. 7 Calculation of slopes (left: color indication of heights per Δh, right: slopes for each Δh)

This calculation is based on the relation between the strength of slopes, areas and the contours' lengths (per a unit height). Let A_i be areas per Δh and C_i be contours' lengths per Δh, then each A_i/C_i means the horizontal length that it need to go up until Δh (see Fig. 7). Therefore $\Delta h \cdot C_i / A_i$ are slopes for each height per Δh, and so $\Delta h \cdot \sum C_i / A$ the average of all $\Delta h \cdot C_i / A_i$ with weights of area ratio becomes the mean slope. In addition, we use $L \cdot r_i / r_n$ instead of C_i because lengths of contours are also affected by heights' errors of DEM, so the formula is resulted in above form $(\Delta h \cdot L \cdot \sum r_i)/(A \cdot r_n)$.

3.4. More complicated parameters

Combining above three parameters, lengths, areas, and slopes, we can calculate many topographical parameters. For example, we calculate subcatchments' width, one parameter of inputs for runoff simulation (mentioned later) as $L \cdot (A_1 + 3A_2)/(A_1 + A_2)$, where L is the length of the main stream of drainage system in the subcatchments, A_1 and A_2 are areas of the subcatchment divided by the main stream with $A_1 \geq A_2$.

4. EXTRACTION OF LANDCOVER

The landcover is information of surface of the land. It is extracted from spectrums obtained by multi band optical sensor equipped to satellites. In our method, we use the training data, which is index for classification of landcover.

At first, choosing several ranges where we already know about the landcover, the averaged value of each band in that range calculated. They are the training data of landcover classification. Then the landcover class of each grid is determined as same one of training data nearest (in the Euclidean distance for all bands) to the grid. It may be effective to make choice about which bands to use, according to the purpose of classification.

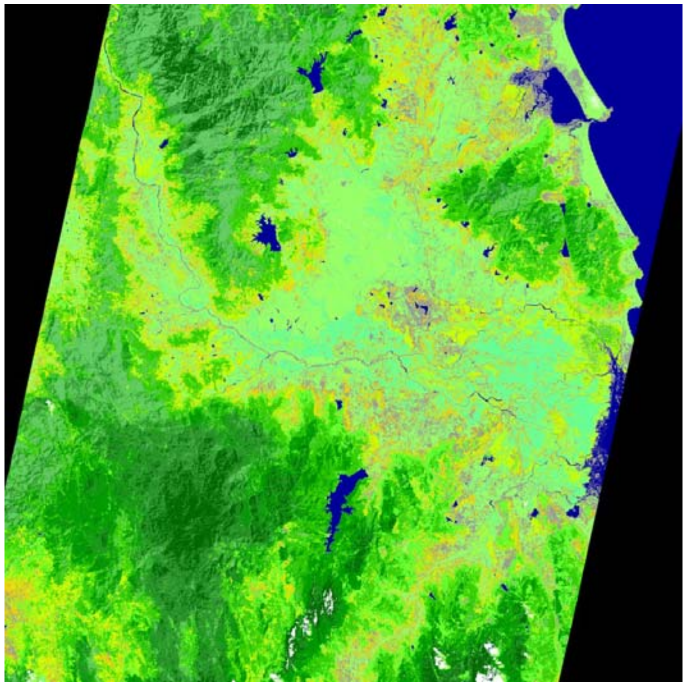

Fig. 8 Landcover extracted from 14 bands of ASTER

5. SIMULATION OF RUNOFF

As a practical way to use of those extracted parameters above, we developed a runoff simulation program. It simulates draining discharges from each subcatchment by infiltration calculation with Green-Ampt equation and flow-rate calculation with non-linear reservoir equation (based on Manning's equation). And its inputs are the extracted parameters and some other parameters (roughness and storage for each landcover class, geological distribution and its features about infiltration, and meteorological data).

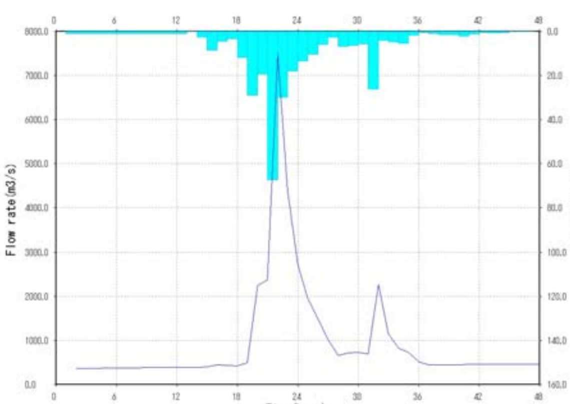

Fig. 9 Hyeto-hydrograph calculated by runoff simulation

This program has fitting algorithm for input data. The input parameters that the fitting process executed to are "area", "slope", "width", "imperviousness rate", "roughness", "depression storage", "soil moisture", "capillary suction", and "hydraulic conductivity". Executing the simulation with them and meteorological data observed at past runoff as input data, and comparing its output and discharge data observed in the same runoff, the fitting function corrects them to suitable values. By repeating the fitting process through a lot kinds of past runoff events, the input parameters become more correct.

6. CONCLUSION

Our methods are revolutionary ones as the way to extract subcatchments from satellite remote sensing data because they are arranged to be less affected by errors of remote sensing data. Therefore we can apply them with "rough" data, and so we can execute the extraction of subcatchments economically by them.

As a future task to improve them, we should examine to apply them to a lot kinds of basins and feedback the results. By the runoff simulation for those different basins and the fitting process of their input parameters, we can find the points to improve about our methods. Through this task, we will improve our methods more effective for flood hazard prediction and water resource management.

7. ACKNOWLEDGEMENTS

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