High Resolution DTM Process to generate accurate River Network for Efficient Water Resource Management

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ملخّص : بلغ إستخلاص المميزة الهيدرولوجيّة الألية التي تستعمل نماذج أرضية رقمية **MNT** شعبية بتوّفر معطيات الكشف عن بعد ذات دقة التمييز العالية . ليست المميزات الهيدرولوجيّة لنماذج الأرضية الرقمية وحدها صحيحة لكنها تعجّل أيضاً سرعة معالجة نمذجة المشاريع كتسيير المورد المائي و خطر الفيضان . هناك عدّة تطبيقات هيدرولوجيّة تحتاج إلى المعلومة ذات مميزة هيدرولوجيّة جدّ صحيحة. هناك مشاكل خطيرة في النماذج الأرضية الرقمية ذات دقة التمييز العالية . إنها أشياء و منخفضات يتزايد عددها و أثارت قبلاً مشاكل مع دقة التمييز لنماذج الأرضية الرقمية المتطورة . ثانيا تستهلك النماذج الأرضية الرقمية ذات دقة التمييز العالية الكثير من الوقت والموارد ، خاصّة عندما يتعلّق الأمر بالأشياء و المنخفضات. تعدّ الأشياء من بناء الإنسان في الجانب الآخر للأنهار وتبين تغلّبها في الأماكن الحضرية. تلعب المنخفضات الطبيعية كالمغارات ، و المنخفضات الشبه دائرية المسطحة دوراً أكبر ، خاصةً في تحويل المميزات الهيدرولوجيّة كشبكة النهر و الحوض الهيدروغرافي . يشكّل وجود الأشياء منخفضات شبه دائرية مسطحة ثانوية تؤدي إلى تعقيدات إضافية . تغيّر المشاكل المذكورة أعلاه المميزات الهيدرولوجيّة من مواقعها الجغرافية الحقيقية وتستهلك الكثير من الموارد والوقت لمعالجتها . بالتّاليّ تعطي نماذج الإنتاج نتائج غير صحيحة . يبيّن هذا المقال واقع الأشياء و المنخفضات و تأثيرها على شبكة النهر المشتقة . يصف أيضا التقنيات التي تحاول أن توّجه / تحل مثل هذه المشاكل ، بتركيز خاص على النماذج الأرضية الرقمية ذات دقة التمييز العالية .

Résumé: L'extraction de caractéristique hydrologique automatisée qui utilise le modèle numérique de terrain MNT atteint une popularité avec la disponibilité de données de télédétection à haute résolution. Les caractéristiques hydrologiques dérivés du MNT ne sont seulement pas exactes mais accélèrent aussi la vitesse du traitement de la modélisation des projets comme la gestion de la ressource de l'eau et le risque de l'inondation. Y compris la modélisation il y a plusieurs applications hydrologiques qui ont besoin d'information de caractéristique hydrologique très exacte. Il y a des problèmes sérieux qui existent dans le MNT à haute résolution. Elles sont des objets et des dépressions qui augmentent en nombre et exacerbent déjà des problèmes existants avec la résolution MNT croissante. Deuxièmement, le MNT à haute résolution consomme beaucoup de temps et de ressources, surtout quand on a affaire à des objets et des dépressions. et leur influence sur le réseau de rivière dérivé. Il décrit aussi les techniques qui essaient d'adresser / résoudre de tels problèmes, avec concentration spéciale sur le MNT à haute résolution.

Abstract : Automated hydrological feature extra-ction using DTM is gaining popularity with the availability of high resolution remote sensing data. The derived hydrological features from DTM are not only accurate but also accelerate the processing speed of modeling of projects like water resource management and flood risk modeling. Including modeling there are various hydrological application that needs very accurate hydrological feature information. There are serious problems that exist in the high resolution DTM. They are artifacts and depressions, which increase in number and exacerbate already existing problems with increasing DTM resolution. Secondly, high resolution DTM consumes lot of processing time and resources, especially while dealing with artifacts and depressions. Artifacts are man made constructions across the rivers and show their dominance in urban location. The natural depressions like pot-holes, sinks-holes play a major role, especially in the derivation of hydrological features like river network and watershed. The presences of artifacts are also create secondary sinks which again lead to further complications. The above mentioned problems are shift the hydrological features spatially from their actual geographical locations and it also consume lot of resources and time to process. Consequently, the output models give inaccurate results. This paper demonstrates occurrence of artifacts and depressions and their influence over derived river network. It also describes the techniques attempting to address/resolve such problems, with special focus on high resolution DTMs.

1. Introduction

The purpose of paper is to demonstrate the extraction of hydrological feature using high resolution Digital Terrain Model (DTM) and address the artifacts and sinks which are two key issues one must consider while deriving hydrological features.

In recent years high resolution DTM have been widely used in automated hydrological analysis. The sources of high resolution DTM are immense due to advan-cement of remote sensing techniques. The derived hydrological feature information is of great help in many hydrological models, some of them are in estimate flood extent and timing, surface water runoff calculations, predict stream discharges.

All hydrologic models ultimately rely on some form of overland flow simulation to define drainage courses and watershed structure. To create a completely connected and labelled drainage network and watershed divide, water outflow at each cell in the DTM has to be routed to the outlet at the edge of the DTM.

The degree of uncertainty in DTM increases with the increase in resolution. The uncertainties that influence the derivation of hydrological features include DTM errors, topographic parameters, the effect of DTM scale as imposed by grid cell resolution, DTM interpolation, and terrain surface modification used to generate hydrologically-viable DTM surfaces (S. Wechsler, 2006). Provided the preprocessing of DTM is perfect, artifacts and sinks are only key elements to treat. In general, the influence of artifacts and sinks is high on derived hydro-features.

The surface depressions (sinks) and spatially structured elevations (artifacts) in DTM are treated as nuisance features in hydrologic modeling. The common practice is to locate and remove these features in the DTM at the very first step of hydrologic analysis.

2. Artifacts and Sinks in DTM

Artifacts, i.e., spatially structured errors of a systematic nature, are often associated with the production of DEMs. The interpolation of DEMs from contour line maps, for example, can produce several kinds of artifacts (Carrara et al., 1997), an example of which is that of contour line "ghosts in USGS Level 2 DEMs (Guth, 1999). But in high resolution DTM spatially structured elevations not only generated from errors but also due to man made constructions like bridges, weirs, culverts, dams, roadways. Artifact removal or breaching lowers the elevation of DTM cells along a stream. This is analogous to creating a trench through the " dam" or obstacle in front of the depression. The result is a breached DTM whose cell elevation values are either the same or lower than the original DTM, never higher.

Sink filling and breaching represent two opposite approaches, and several techniques have been established to independently deal with sinks and artifacts. We have gone for holistic approach to treat both artifacts and sinks in high resolution DTM.

A sink is an area surrounded by higher elevation values, and is also referred to as a depression or pit. This is an area of internal drainage. Some of these may be natural, particularly in glacial or karst areas (Mark, 1988), although many sinks are imperfections in the DTM. These are more commonly natural features, and are less detrimental to the calculation of flow direction. The frequent presence of surface depressions in the DTM prevents simulated water flow from draining into outlets, result in disconnected stream-flow patterns and spurious interior sub-watersheds pouring into these depressions.

The number of sinks, normally higher for coarser resolution DTM as compare to lower resolution DTM. Another common cause of sinks results from storing the elevation data as an integer. This can be particularly troublesome in areas of low relief and urban centres.

3. Methodology

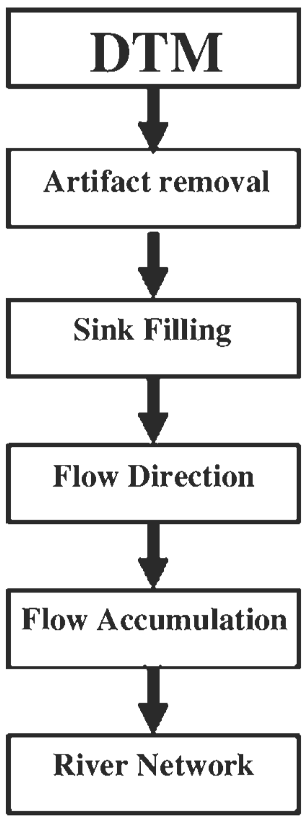


Fig. 1 Methodology followed in current study.

Determining flow direction in low resolution DTM is quite simple if there are less pre-processing errors but while handling high resolution DTM one should exercise more caution.

At RMSI, Spatial Modeling Department, use various resolutions of DTM data. In the present study high resolution DTM of 10 meter was used. We found there were numerous artifacts and sinks which obstruct the water flow. The present methodology explains comprehensively to deal artifacts and sinks in an effective manner without appreciatively altering the original elevation values of DTM. The Hydrology analysis functions in ArcGIS 9X not address the problem of artifact removal. A tool to remove artifacts in systematic manner was thus developed. The Figure-1 depicts the working methodology of present study. All terminologies are subsequently explained.

3.1 Artifact removal

Artifacts are elevation peaks obstruct the water flow in DTM. Removals of such peaks are cumbersome especially if many urban centers in study area. A graphic polygon is drawn over identified artifact (Figure) taking care to place the vertices of the polygon on pixels of lower elevation values. Verification is done through Google Earth and other high resolution remote sensing images.

Artifacts have shown in DTM with high elevation comparatively values of upstream and low stream (Fig.2a). In order to remove obstacle (higher elevation pixel values) draw the graphics around the artifact by carefully placing the all the nodes in lower elevations. This means nodes should be placed in both upstream and lower stream of river valley. We develop a tool to pick up the elevations underlying each node and interpolate all elevation values within graphical element using inverse distance weighted interpolation technique.

3.2 Sink fill

Fill function works to derive depression less DTM. Depression filling has become by far the most widely used approach and several different algorithms have been developed to fill depressions. (Marks, D., Dozier, J. and Frew, J., 1984; O'Callaghan and Mark, 1984; Jenson and Domingue, 1988; Martz and Jong 1988; Planchon an Darboux, 2001; L. Wang and H.Liu 2006). Amongst Jenson and Domingue, 1988, method is best known and widely used in many GIS software packages for sink filling.

The best know method (Jenson and Domingue, 1988) is time intensive method as compared to all latest methods but most of the GIS packages equipped with this technique. For example, the widely used package ArcGIS have utilized of this method. It takes humongous time to fill the sinks, especially in case of high resolution DTM. L. Wang and H. Liu 2006 has been innovated a new method, which is in handling surface depressions as compare to all above methods. It's based on two concepts, termed as cornerstones of the method. They are 1) introduction of a novel concept of spill elevation, and 2) the progressive building of optimal spill paths based on priority queue and least-cost search techniques. The need to introduce fast and accurate sink filling methods in current GIS packages is of utmost importance.

3.3 Flow direction

One of the keys to deriving hydrologic characteristics about a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the Flow Direction function. This function takes a conditioned or depression less DTM as input and outputs a raster showing the direction of flow out of each cell. There are eight valid output directions, relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as a D8 (eight direction) flow model and follows the approach presented by Jensen and Domingue, 1988. The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell.

3.4 Flow accumulation

The Flow Accumulation function calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. If no weight raster is provided, a weight of one is applied to each cell, and the value of cells in the output raster will be the number of cells that flow into each cell.
Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Cells with a flow accumulation of zero are local topographic highs and may be used to identify ridges.

3.5 River network delineation

Flow accumulation in its simplest form is the number of upslope cells that flow into each cell. By applying a threshold value to the results of Flow Accumulation using Map Algebra, a stream network can be delineated.

4. Results

4.1 River network delineation from DTM : Before Artifact Removal

The study window has been clipped from 10 meter DTM. The total area of window is 3.2424 Sq.Km and comprise of 32424 pixels (10m x 10m). We analyze the number of sinks formed, impact of artifacts and behavior of derived river network at three stages. 1. shows the sinks formed at at the very onset prior to any DTM reconditioning 2) shows sinks formed due to D8 method, terrain properties and mainly presence of artifacts. And derivation of river network, 3) shows the advantages of filling sinks after removal of artifacts, and derived river network.

In the first step, the "Sink" (ArcGIS/Spatial Analyst/Hydrology/Sink) tool is run to find out the number of sinks in the study window. A total of 424 pixels as sinks, which constitutes 1.3076% of total area. The sink function of ArcGIS calculates the number of sinks based on D8 method. In the second step, the original DTM is sink filled is calculated. This area is next matched with initial sinks and a remarkable difference is observed. Because sink is not a single cell rather it is combination cells. So, the filling is worked out in an iterative manner. The function calculates the single lower elevation pixel in 3 x 3 window and then extended to whole DTM. Then next phase it again search for the single lower elevate pixel in 3 x 3 window and process continues till DTM satisfy hydrological conditions. It means, filling takes longer time and alters original elevation cells. This is the case of natural terrain and deepest valley do not consist any obstacles.

ut in case of high resolution DTM secondary sinks form due to obstacles (artifacts) across the water flow as shown in the figure (Fig.2b). This is like artificial reservoir between two obstacles. The increase of sink filled area in the figure (Fig.2c) is clearly evident due to artifacts. The sink filled area before artifact removal is more than 27% of study area. Large percent of filling mainly observed in between two marked artifacts (Fig.2b). It is very clear, derived river network falls other than falling in to the deepest valley of DTM (Fig.2d). The deepest valley of the DTM is actual position of river network.

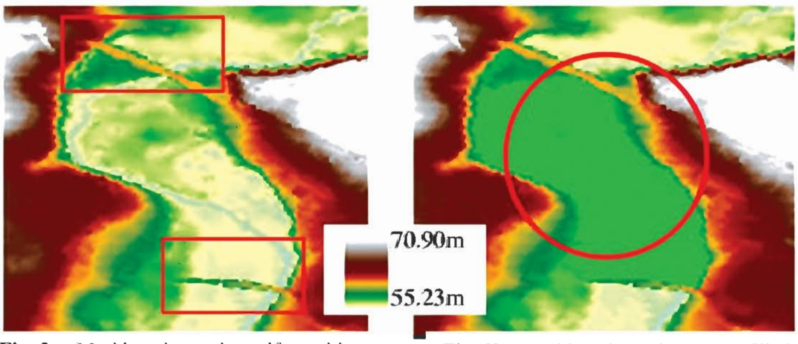


Fig. 2a. Marking shows the artifact with are across deepest valley of DTM

Fig. 2b. Marking shows large area filled between 2 artificats before artifact removal

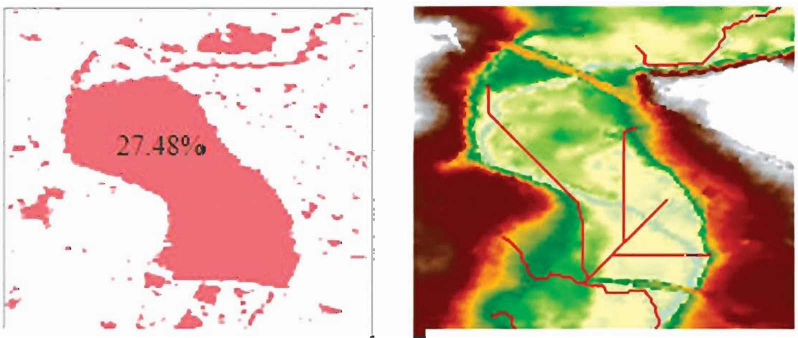


Fig. 2c. Area under fill before removal of artifacts

Fig. 2d. Delineated Rivers shows the shift from deepest valley in DTM

Fig. 2 Show the presence of artifacts forms sinks and shifts are river network.

4.2 River network delineation from DTM: After Artifact Removal

The third step in the procedure is artifact removal. The purpose is to provide a passage for unobstructed flow of water (Fig.3a). This method did not alter the major area DTM. This not only allows water to flow but also effectively reduce the area under sink filling and iterative processes. This is clearly demonstrated in figure (Fig.3b and 3c). The total calculate area under sink filling is found to be around 11% of the total area. Nearly 16 % of fill area is reduced due to artifact removal (Fig.4a). The derived river network after artifact removal match very well with the deepest valley of the DTM (Fig.3d).

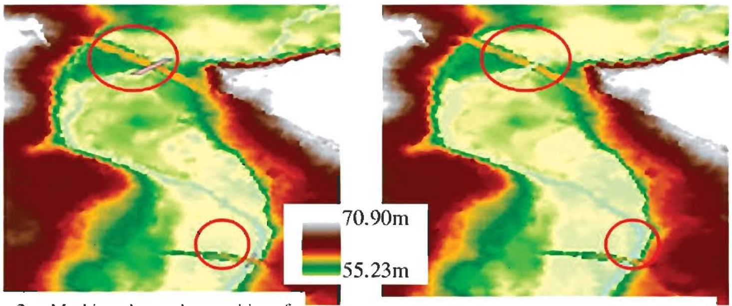


Fig. 3a. Marking shows the graphics of proposed places to remove the artifacts

Fig. 3b. Encircled portion - passage of water flow after artifact removal

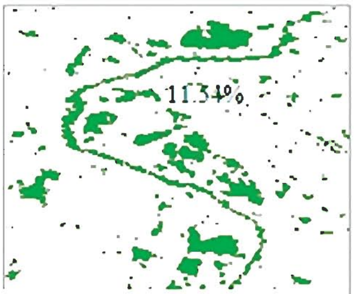


Fig. 3c. Sink Fill area after removal of artifacts

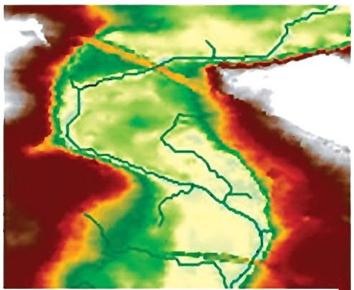


Fig. 3d. Delineated river network fits in to the deepest valley of DTM

Fig. 3 Show the how delineated river network fits in to the deepest valley of DTM and the same is actual path on the ground.

Results depend on many factors such as, DTM resolution, terrain characteristics. Natural sinks have greater occurrence in glacial terrain, krast topography and low relief areas. But secondary forms more in urban morphologies. The figure (Fig.4b) shows clearly the difference in derived river network before and after artifact removals. The table (Table2 and Graph1) indicates clearly effects of artifacts on high resolution DTMs. The present study shows the advantages artifact removal and river network derivation. The current authors recommend usage of more popular GIS packages which incorporate accurate and fast methods of artifact removal as well as sink filling.

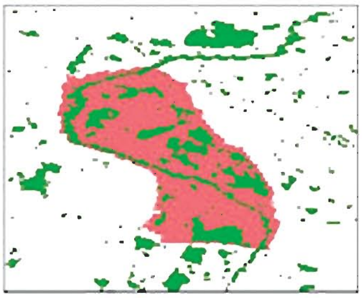


Fig. 4a. Shows the difference of area under fill before and after

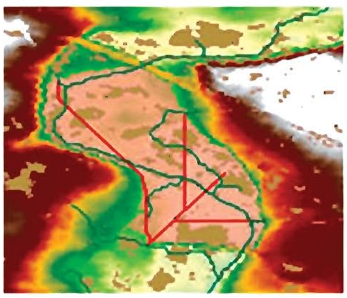


Fig. 4b. Difference of delineated river network before and after

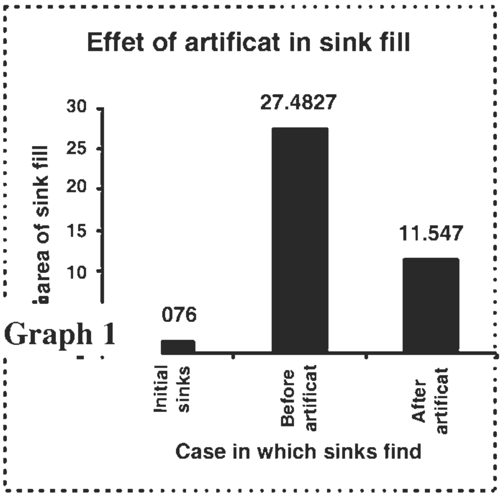
Fig. 4 Show the difference in filling and river networks- before and after removal of artifacts.

Graph1 shows the area under sink fill for three different cases.

Case 1: where there are initial sinks formed about 1. 3% of total area under D 8 method.

Case 2: shows area under sink fill just before artifact removal. This is very, covers more than 27% of total area.

Case 3: Sink area falls down drastically from 27 to 11 % after removing artifacts.



Graph 1

5. Conclusions

Accurate river network derivation is crucial for water resource management and for any hydrological or flood modeling. The nature of high resolution DTM is complex and need to condition. The artifacts are not only structural errors (aberrations) in DTMs but at the same time reflections of man made structures across water courses. Artifacts in DTM increase the sinks and consequently shift the river network from its actual position. Therefore, the need of artifact removal and sink filling is utmost important while deriving river network. There is no need to remove entire portion of artifact rather an outlet is drilled to allow easy passage of water. The sinks formed due to artifacts are called secondary sinks and their impact river network derivation. The exercise of artifact removal and sink fill not only provides accurate river network but saves both resource and time. Unfortunately till date, none of the available GIS packages have incorporated a fast and accurate sink fill method.

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