研 究 解 説

Effect of DEM Accuracy in Flood Inundation Simulation using Distributed Hydrological Models

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1. Introduction

Mathematical models play a great role in flood disaster mitigation. Flood inundation simulation using distributed physically based hydrological model is one of such modeling approaches. High level of accuracy of outputs of such models is of utmost importance for any decision making process in flood risk management. Regular grid or raster digital elevation models (DEMs) have become the basis for recent approaches to process modeling of the earth's surface including hydrological modeling (Abott et al, 1986a (1), 1986b (2) and Rohdenburg et al., 1986 (3)). In flood inundation modeling, DEMs greatly influence the model outputs. Drainage networks used as input dataset in such models are derived from DEM by connecting each cell to its neighbour in the direction of principle slope. DEM resolution has a direct influence on the total drainage length and slope. Too coarse resolution causes an undersampling of the hillslopes and valleys where hilltops are cut off and valley filled. Two principal effects result: drainage length is shortened by short-circuiting; and slope is flattened. Truly flat landscapes (with zero slope) seldom occur in nature. Yet, when a landscape is represented by a DEM, areas of low relief can translate into flat surfaces. This flatness may also be a result of quantization of the elevation data. Flat surfaces typically are the result of inadequate vertical DEM resolution, which can be further worsened by a lack of horizontal resolution. Such surfaces are also generated when depressions in the digital landscape are removed by raising the elevations within the depressions to the level of their lowest flow.

A variety of methods have been proposed by many researchers to address the problem of drainage analysis over flat surfaces. Methods range from simple DEM smoothing to flow direction assignment. One of the most satisfactory methods addressing this issue is assigning drainage directions, which was developed by M. Hutchinson (1989 (4), 1991 (5)). The principal innovation of the procedure is a drainage enforcement algorithm, which automatically removes spurious sinks or pits from the fitted grid. The algorithm is adopted in popular GIS software ARC/INFO for interpolation of topography data for creation of hydrologically improved DEM.

This paper presents a study that was carried out to analyse the effect of the hydrologically improved DEM in the outputs of flood inundation model in comparison with the existing DEM.

2. Hydrological Improvement of DEM

The area selected for conducting this study was a moderate size Japanese river basin, known as Ichinomiya river basin with an area of 220 sq. km, located in the Chiba prefecture between longitude 35°18'N to 35°30'N and latitude 140°10'E to 140°25'E (Fig. 1). The topography of the basin varies from hilly areas in the western part with maximum elevation of about 155 m to lowland flat areas

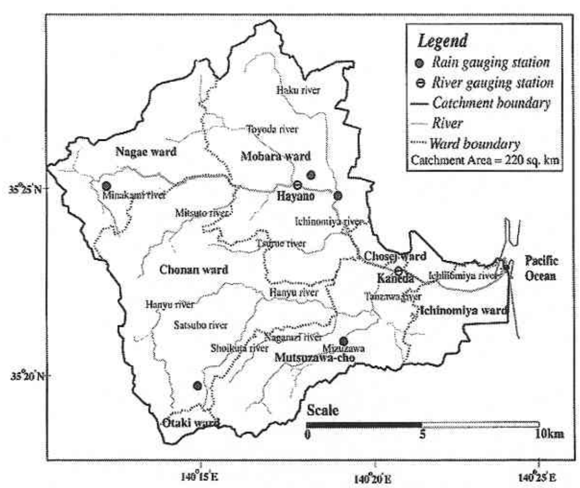

Fig. 1　Study area map

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in the eastern part with minimum average elevation of about 1m from mean sea level.

The topography data for the study area was obtained in the form of 50m resolution DEM from Japan Map Center, which was originally derived from 1:25,000 scale contour maps with 10m contour intervals. The digital data provides the elevation value in the level of 0.1m. Based on the concept that flow direction follows the steepest slope direction from a grid to the eight neighboring grids, drainage network is generated from this 50m DEM dataset. The generated drainage network together with the actual drainage network is shown in Fig. 2. From this figure, it can be seen that the generated river network agrees well with the actual flow paths in the upstream hilly areas, however in the downstream flat areas, generated drainage paths significantly deviate from the actual flow paths. In some locations, the generated rivers deviate from the actual rivers greatly and there are more than one outlets of this generated river network, which make it impossible to use this river network in the hydrological model application in the basin.

The 50m resolution DEM was generated from 10m interval contours. In the flat areas with a few meters of elevation differences, the generated DEM was not able to capture the variation adequately and thus, it was not possible to obtain adequate river network from this DEM based on the concept of slope. For the improvement of the drainage network to be used for the modeling, the existing DEM was improved by adding contour data with 1 m interval obtained from 1:2,500 scale maps in the flat areas as shown in Fig. 3. The river network is further generated with the improved DEM. As can be seen from Fig. 4, the generated river with the improved DEM is much closer to the actual flow paths than the previous case.

However, still the agreement of generated river network with actual one is not satisfactory in some of the downstream flat areas. In the study area, there was no further scope of improving the DEM, as additional finer topography details were not readily avail-

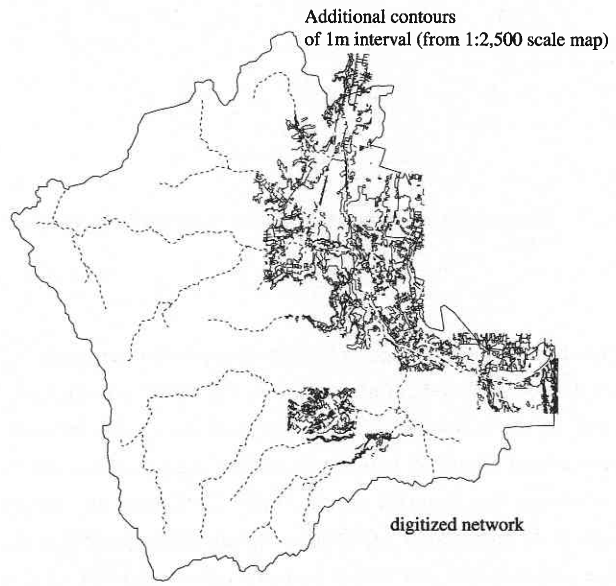

Fig. 3　Areas where additional contours of 1 m Interval added in the study area

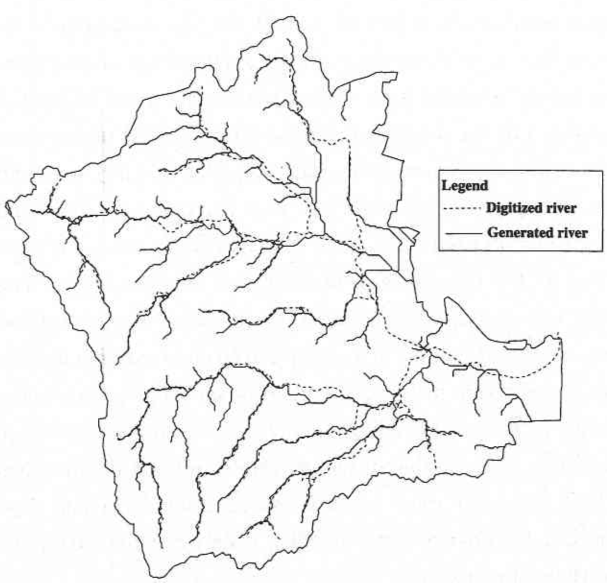

Fig. 2　Generated river network from 50 m resolution DEM together with actual river network

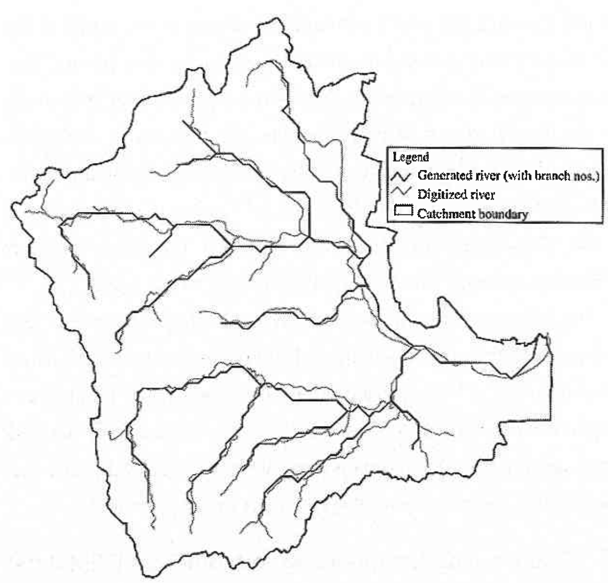

Fig. 4　Generated river network from the improved DEM together with actual flow paths

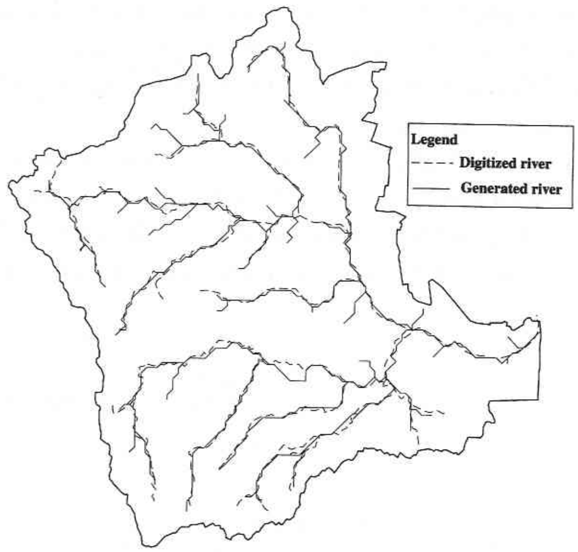

Fig. 5 Generated river network from the hydrologically modified DEM

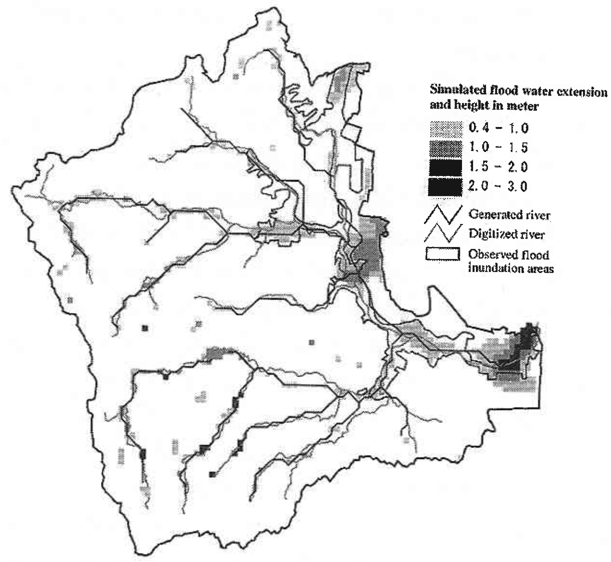

Fig. 6 Simulated flood Inundation map using the DEM without any drainage-enforced enhancement

able. Hence, the drainage enforcement algorithm designed by Hutchinson was used to further improve the DEM hydrologically based on the actual streamline. The essence of the drainage enforcement algorithm is to recognize that each spurious sink is surrounded by a drainage divide containing at least one saddle point. If the sink is associated with an elevation data point then the lowest such saddle, provided it is not also associated with an elevation data point, identifies the region of grid which is modified in order to remove the spurious sink. If on the other hand the lowest saddle point is associated with an elevation data point but the sink is not, then the sink and its immediate neighbors are raised above the height of the data point saddle. If neither the sink nor the lowest saddle are associated with elevation data points then grid points in the neighborhood of both the sink and the lowest saddle are modified to ensure drainage. Finally, if both sink point and saddle point are associated with elevation data points, then a choice is made, depending on the a user-supplied tolerance, between enforcing drainage and maintaining fidelity to the data.

The generated river network from the drainage-enforced DEM using the above mentioned algorithm is compared with the actual river network in Fig. 5. From the figure it can be seen that generated river network in this case follows the actual river network from upstream to downstream very closely compared to the previous two generated networks as shown in Figs. 2 and 4.

3. Flood inundation modeling with different DEM data

The flood inundation model used in this study is a physically based distributed hydrological model. The model consists of various hydrological components and governing equations for flow propagation in different components are solved using finite difference schemes. The model is designed to simulate flood inundations including urban flooding taking into consideration of boundary conditions of existing river embankments. The detailed description of the model was given elsewhere (Jha *et al.*, 1997 (6) and Dutta et al., 2000 (7)) and not described in detail in this paper.

For the model application, a past flood event of September 1996, was considered in which the basin suffered from a big flood disaster due to the heavy rainfall. During a span of 24 hours, the basin received about 360mm rainfall and was under floods for about two days. Using the available temporal and spatial input parameters obtained from various sources, the flood event was simulated by the model twice, once with the DEM of the study area before any enhancement using streamline and next was with the drainage-enforced DEM. For these two cases, the generated river networks from the respective DEMs were used (refer to Figs. 4 and 5). For the two cases of simulation, remaining input data were kept same. Figure 6 shows the simulated maximum flood inundation maps for the first case. It can be observed from this figure that although the general pattern of simulated inundation is similar to the actual flooding as represented by the surveyed map, there was clear shifting of the inundation areas in the locations where generated river network shifted from the actual flow paths. It was obvious as the flooding mainly occurred due to the overflow of rivers.

The simulated flood inundation areas using the drainage-enforced DEM are shown in Fig. 7. From this figure it can be seen

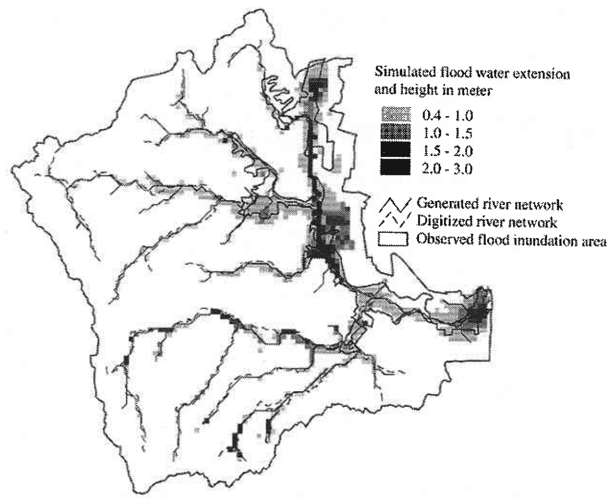

Fig. 7 Simulated flood Inundation map using the drainage-enforced DEM

that in this case, there was no shift of the inundation areas from the actual inundation areas as there was no shift of the generated river network. Also, it can be observed that the simulated inundation areas in upper part of the basin agree well with the surveyed one compared to the previous simulation. In the previous simulation, inundated area was much less compared to the survey map. Like the first case, in this case also, in several locations, much more areas were shown as inundated areas in the simulation compared the surveyed map. It was due to the negligence of the locally elevated lands such as highways, etc in the model. In real situation, these elevated lands blocked the movement of flooding from river side to other side. However, in simulation the 200m resolution DEM data could not capture such local elevation of few meter widths and thus simulation results were affected.

4. Conclusions

In this paper, a study to analyses the impact of accuracy of DEM model in flood inundation simulation is presented. The accuracy means the hydrological accuracy of the DEM, such that generated drainage networks from the DEM model represents the actual flow paths adequately. It can be seen from the analysis that with the improvement of the DEM, improvement occurs in the generated drainage network. As with the existing topography data, it was not possible to improve the DEM beyond a certain extent, an algorithm is used to improve the DEM hydrologically using the existing streamlines. The simulated results of the flood inundation model show that flood inundation simulation can be improved by hydrologically improving the DEM model. Such an approach of DEM improvement is required for large catchments where existing DEM data are not adequate to generate a drainage network that can represents the actual flow paths.

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