Method for 3D virtual reality dynamic display of flood area and Damage Evaluation in GIS

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Abstract : Using GIS to study flood area and damage evaluation has been a hotspot in environmental disaster research for years. But there is a lack of the articles discussing computer algorithm for the subject. In this paper, a model of flood area display and damage evaluation is discussed, which adopts seed spread algorithm to calculate and visualize flood area based on a DEM data set and under the condition of a given water level of flood. Then the raster image containing flood area is overlaid with raster data converted from thematic vector maps such as land-use map and related to other social and economic data, and then the quantitative evaluation of flood damage is achieved. Developing this model by VC++ programming is partly because commercial GIS platforms such as Arc/Info and Erdas are too expensive to most counties in China and other developing countries. Besides, to determine flood area based on the given water plane is just an approximate method, but it is easy-to-use and run-fast for doing overlay analysis, and thus has an important significance in actual flood fighting and control.

There are two different cases so-called "non-source flood" and "source flood" when determining flood area based on DEM and under the given water level condition. Non-source flood corresponds to the case with well-distributed and large-area rainfall where all the low-lying land may have a flood disaster, and in this case all the points with elevations below the given water level should be included in the flood area. The "source flood" is the case of flood (e.g. from bank burst) flushing through the nearby regions and needs to consider "circulating" condition. It is because flood may be obstructed by ring structures or high lands and thus can only covers the place where it can flow and reach. One of computer processing methods suitable for source flood is the seed-spread algorithm. The principle of this method is to select a representative pixel as a seed and to examine its contiguous pixels outward along 4 or 8 directions. The pixels, contiguous to it and meeting the given conditions, become seeds, and then contiguous pixels to the new seeds will be examined in the same way. This process repeats until an aggregation of the pixels which meet the given conditions on a certain plane are obtained. Adopting seed spread algorithm for source-flood area calculation is just to achieve an aggregation of pixels, which satisfies the connectivity requirement and the given conditions of water level. The initial position of seed pixel should usually be selected on the characteristic points, e.g. adjacent to reservoir dam or stream boundary.

The precision of flood area calculation is mainly determined by spatial resolution of the DEM, the area on the ground represented by each pixel; whereas the accuracy of flood area calculation, to a great extent, is dependent on the precision of the DEM's pixel value or elevation. In order to raise computing efficiency it is useful to skip several pixels to perform seed spread algorithm if *necessary.*

Once the flood area below the water plane has been calculated, the flood damage evaluation can be calculated by overlaying the flood range with thematic maps and by relating to other social and economic data. All thematic maps were converted to raster data because algorithm of the overlay analysis implemented in raster format is relatively simple and computing is fast. In order to improve accuracy of the flood damage evaluation it is necessary to accurately register and georeference all raster layers before overlay analysis.

The calculation results of flood damage evaluation are generally represented by tabulation, which is a kind of classified statistics of flood damage data, e.g. a table representing total area of every land-use type in different administrative divisions. The results of the flood area Calculation and damage Evaluation can also be visually and dynamically provided in the forms of graph, image, 3D or virtual reality.

The model of flood area calculation and damage evaluation proposed in this paper, adopting Microsoft VC^{++} 6.0 programming language and Microsoft SQL Server 7.0 DBMS platform, has been successfully applied in the "Zhejiang Provincial Water Conservancy Management System" developed for a national project.

***Keywords*:** Model, Flood area calculatoin, Damage evaluation, Seed spread algorithm

Introduction

Flood simulation and damage evaluation has been paid attentions in environmental disaster research fields for many years. Since 1990s, especially in recent years, using geographic information systems (GIS) technology and its powerful functions of spatial analysis and visualization to simulate and display flood area and to evaluate disaster damage has become a research hotspot. The papers involved in this field, however, mostly present from hydraulic & hydrology's angle of view and based on GIS commercial software. And there is a lack of the articles discussing computer algorithm for flood area display and damage evaluation. This paper discusses a model of flood area display and damage evaluation, which adopts seed spread algorithm to calculate and visualize flood area, based on a DEM data set and under the condition of a given water level of flood. Then the raster image containing flood area is overlaid with thematic maps converted from vector format such as land-use map and is related to other social and economic data, and then the quantitative evaluation of flood damage is achieved.

The given water level here can be water level of real time or the calculation and prediction result of a hydraulic & hydrology model. In the national project related to this paper, authors adopted the results from a hydraulic & hydrology model as the given water levels for defining flood area, which vary with different falls of the river reach in mountainous area. It should be noted that to determine flood area based on the given water plane is just an approximate method and the more accurate flood area calculation should take account of the hydrodynamic simulation and the changes of water plane shape in the flood process. However, the approximate method here is practical, easy-to-use and run-fast, and thus has an important significance in actual flood fighting and control.

Besides, the simulating flood area and evaluating disaster damage can also be done by means of commercial GIS software such as Arc/Info and Erdas. In fact, the author did so in the project mentioned above. For example, the flood area extent in vector format converted from Arc/Info GRID can directly be overlaid with land-use coverage or other data. However, powerful GIS platforms such as Arc/Info are too expensive to most counties of China and other developing countries. For this reason, the author also developed a model for simulating flood area and evaluating disaster damage by VC^{++} programming.

Two critical precondition required in this research are: 1) To establish quality spatial databases, including digital elevation model (DEM) with resolution high enough, corresponding digital orthophoto map (DOM) and thematic map, and to match them precisely. 2) To establish attribute database which includes flood, water facilities, land use and other related social and economic data, and to establish linkage between spatial and attribute databases. The precision of the DEM’s pixel value and spatial resolution of the DEM can basically determine the accuracy of flood area calculation while the accuracy of damage assessment will further rely on the match accuracy of DEM and thematic data and on the accuracy of the social and economic data in the attribute database. The operation speed of seed spread algorithm and spatial overlay will determine the efficiency of the whole model.

Flood area Calculation

“non-source flood” and “source flood”

There are two different cases when determining flood area based on DEM and under the given water level condition. The first case is that all the points with elevations below the given water level are included in the flood area; and the second case needs to consider “circulating” condition, that means that flood only covers the place where it can flow and reach. For example, in a ring structure, a landscape low-lying in the middle and high-rising in the periphery, the first case may result in the calculated flood area including both inside and outside areas of the ring mountain, whereas in the second case flood area only covers the outside of the mountain because flood can not reach and overpass the summit.

Both cases have the practical significance. The first corresponds to the case with well-distributed and large-area rainfall where all the low-lying land may have a flood disaster; the second is the case of violent flood flushing through the nearby regions; For example, bank burst or local rainstorm causes a flood suddenly deluging all around. For convenience, we call these two cases respectively “non-source flood” and “source flood”. In the type of “source flood”, flood may not only be obstructed by a ring structure, but also maybe by any high lands. For instance, Flood in a watershed usually does not overpass its mountain to form flood in the adjacent watershed. In southeast China there are a lot of mountainous and hilly lands and “source flood” occurs quite often. Even in the plain region with a stream network the case can not be ignored. As an example, Hang-jia-hu region of China has got a lot of historically formed embankments forming a circle-wise topography.

Seed spread algorithm for source flood area calculation

The programming for non-source flood is relatively simple, so is not discussed here. The source flood, as mentioned above, needs to deal with the connectivity problem for “circulating”. One of computer processing methods suitable for source flood is the seed-spread algorithm, a kind of spread-detect algorithm based on seed spatial character. The principle of this method is to select a representative pixel as a seed and to endow it with the particular attribute, and to examine its contiguous pixels outward along 4 or 8 directions. If some of the pixels contiguous to it can meet the given conditions, they become seeds, too. And then contiguous pixels to the new seeds will be examined in the same way. The pixels which meet the given conditions are stored into the computer buffer and continuously accumulated so that the flood area expand continuously. This process repeats until an aggregation of the pixels which meet the given conditions on a certain plane are obtained.

Adopting seed spread algorithm for flood area calculation is, in fact, to achieve an aggregation of pixels, which satisfies the connectivity requirement and the given conditions of water level. The area, which satisfy the water level condition but do not have connectivity with seed point, will not enter into the aggregation. The initial position of seed pixel should usually be selected on the characteristic points, for example, adjacent to reservoir dam or stream boundary.

Accuracy and efficiency of flood area calculation

The precision of flood area calculation is mainly determined by spatial resolution of the DEM, the area on the ground represented by each pixel; whereas the accuracy of flood area calculation, to a great extent, is dependent on the precision of the DEM's pixel value or elevation. The given water level is usually precise to 1 centimeter. If the precision of DEM's pixel value is too low (e.g. 1 meter), the flood area may be inaccurately calculated, especially in plain region. For example, if the given water level is 126.64m (float point) or 12664cm (integer) and the pixel elevation is precise to 1 m, then only the pixels whose elevation is lower than 126 m or 127 m, instead of 126.64m, can be count in flood area. In our project, the spatial resolution of the DEM is 3 m and the precision of pixel value is 5 cm.

In order to raise computing efficiency it is useful to skip several pixels to perform seed spread algorithm if necessary. The skip factor, or so-called detect-step-length of seed spread, is among 3-8 in our case dependent on the DEM's resolution, precision and the terrain characteristics within the selected flood analysis area.

The calculation model of flood area is shown in fig.1.

Fig.1 model for flood area computation

Damage evaluation

After range of the flood area below the given water plane has been calculated, the flood damage evaluation can be calculated by overlaying the flood range with digital topographic and thematic maps of this area (e.g. land use map, cadastral map and administrative division map) and by relating to other social and economic data. In the practice of our project, all the topographic and thematic maps with vector format were converted to raster data because algorithm of the overlay analysis implemented in raster format is relatively simple and computing is fast.

In order to improve accuracy of the flood damage evaluation it is necessary to accurately register and georeference all raster layers before overlay analysis. The raster layers include DEM data, orthographic image (DOM) and those converted from vector data of topographic and thematic maps. The orthographic images are used for better visualization of flood area. In our project, all these raster layers were conformed to each other and transformed to Chinese national map coordinate system by means of selecting ground control points (GCPs), adopting abundant observation adjustment theory.

The calculation results of flood damage evaluation are generally represented by tabulation, which is a kind of classified statistics of flood damage data in different administrative divisions. For example, overlaying the flood range with land use map and administrative division map, a table representing total area of every land-use type in different administrative divisions can be obtained. Fig.5 just is such a table. Relating the result to other social and economic data, the flood damage can be further evaluated.

The results of the flood area Calculation and damage Evaluation can also be visually and dynamically provided in the forms of graph, image, 3D or virtual reality (e.g. Fig.6).

Fig.2 gives basic frame of the entire model for flood area calculation and disaster evaluation.

Fig.2 Model for flood area calculation & damage evaluation

Applications

The model of flood area calculation and damage evaluation proposed in this paper, adopting Microsoft VC^{++} 6.0 programming language and Microsoft SQL Server 7.0 DBMS platform, has been successfully applied in the “Zhejiang Provincial Comprehensive Water Management System” developed for the national project mentioned above. Fig. 3, 4, 5 and 6 are some application samples.

Fig.3 is a sample of non-source flood of Tongxiang City located in the Hang-jia-hu Plain, Zhejiang province. In the legend each color represents a land-use type and blue (or dark) area shows the flood region.

Fig.3 A sample of non-source flood

Fig.4 is a sample of source flood, in which (a) shows DEM image of Zhoushandao city, Zhejiang province (the dark areas are mountain ranges), and (b) shows the situation after a source flood.

Fig.4 A sample of source flood

Fig.5 gives a screen showing a statistics of flood damage in Zhoushandao city. On the left

Fig.5 flood statistics

there are the city's different administrative divisions (analogies of township). Selecting any township division, the table on the middle and right will give the statistics of the total area and inundated area of every land-use type for the selected township. For example, in the case of Fig.5 the fifth township, Baiquanzhen, is highlighted, so the table here shows the statistics of flood damage of the selected Baiquanzhen township.

Fig.6 gives two pictures of a 3D virtual reality dynamic display of a flood area in a watershed of northern Zhejiang province.

Fig.6 3D virtual reality dynamic display of flood area 3 Conclusion

Conclusion

The model of flood area display and damage evaluation discussed in this paper is useful for China and other developing countries considering commercial GIS platforms such as Arc/Info and Erdas are expensive to them. Although the method determining flood area based on the given water plane is an approximate method, but it is easy-to-use and run-fast and thus has practical significance in actual flood fighting and control.

When calculating flood area, two cases: *non-source flood* and *source flood*, should be distinguished and the later is complicated comparatively. Seed-spread algorithm is one of the best suitable methods for source-flood. The precision of flood area calculation is mainly determined by spatial resolution of the DEM; whereas the accuracy of flood area calculation, to a great extent, is dependent on the precision of the DEM's pixel value or elevation. In order to raise computing efficiency it is useful to skip several pixels to perform seed spread algorithm if necessary.

The flood damage evaluation can be calculated by overlaying the flood area range with thematic maps and by relating to other social and economic data. All thematic maps are converted to raster data because overlay algorithm running in raster format is relatively simple and fast. To insure accuracy of the flood damage evaluation, it is necessary to accurately register and georeference all raster layers before overlay analysis.

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Legends for illustrations

Fig.1 model for flood area computation

Fig.2 Model for flood area calculation & damage evaluation

Fig.3 A sample of non-source flood

Fig.4 A sample of source flood

Fig.5 flood statistics

Fig.6 3D virtual reality dynamic display of flood area 3 Conclusion

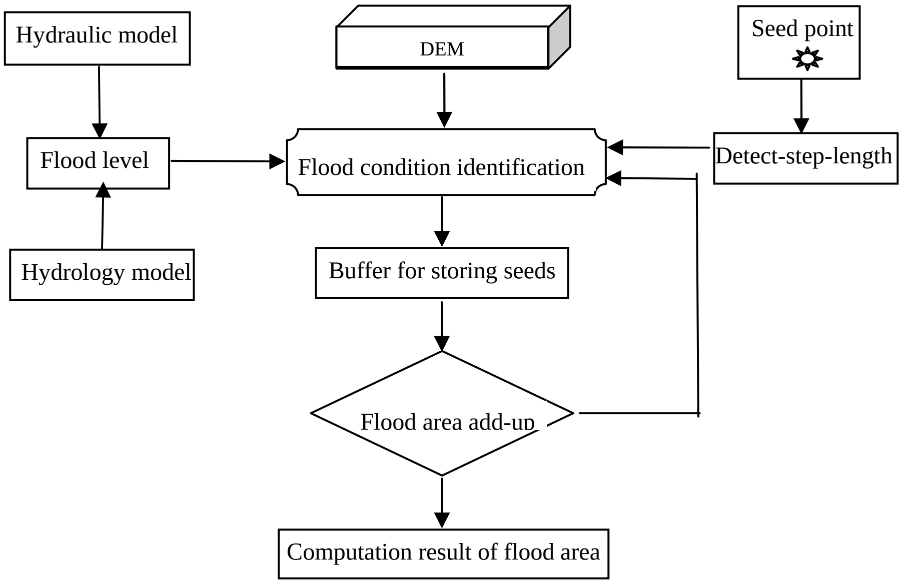


Fig.1 model for flood area

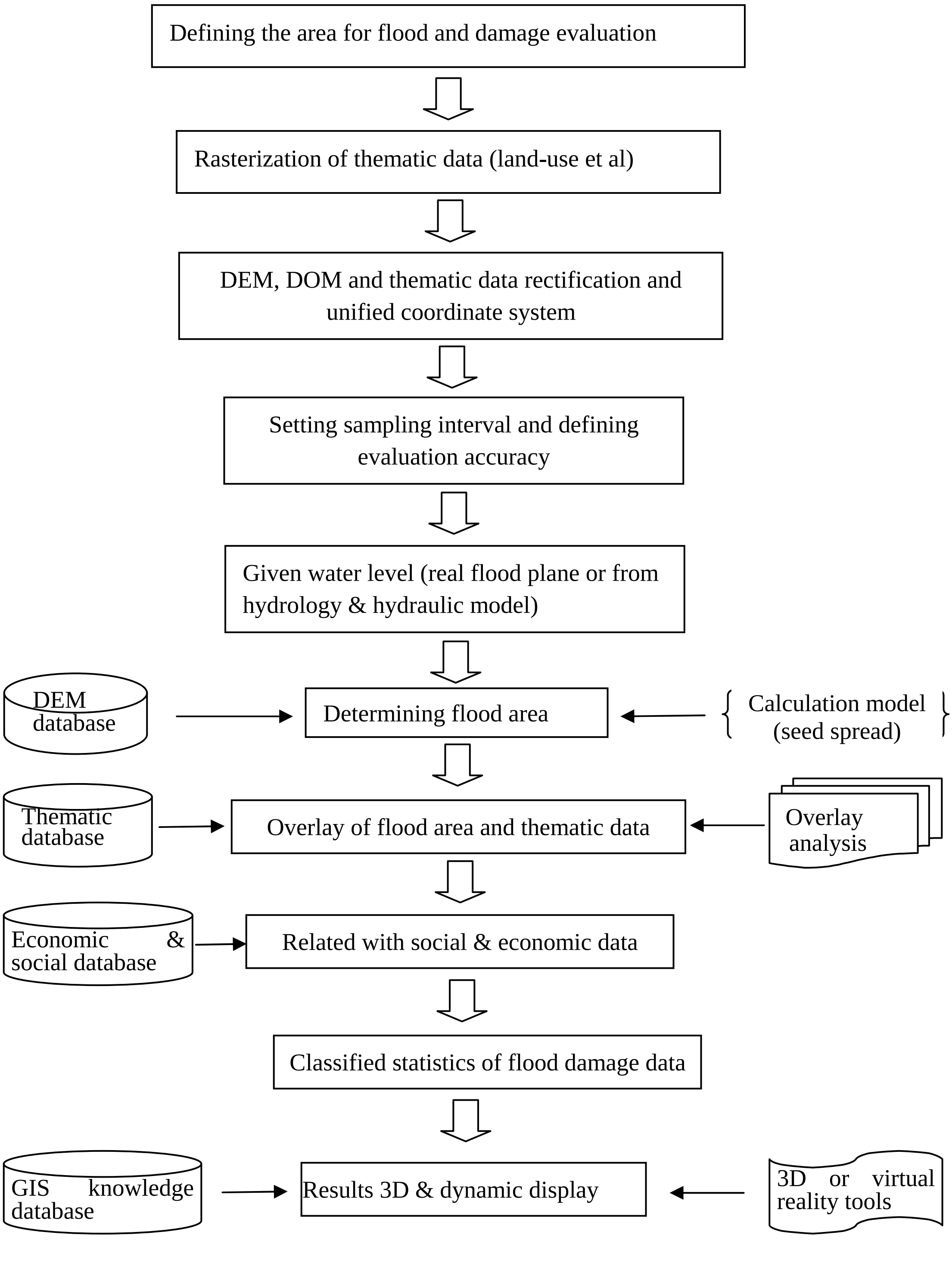


Fig.2 Model for flood area calculation & damage evaluation

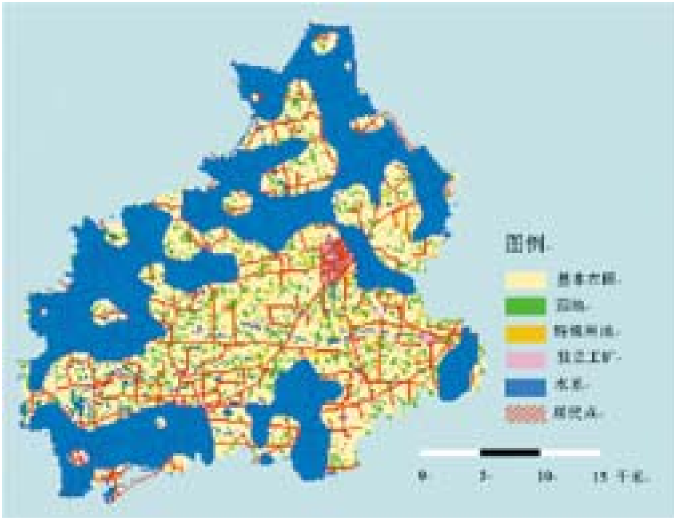
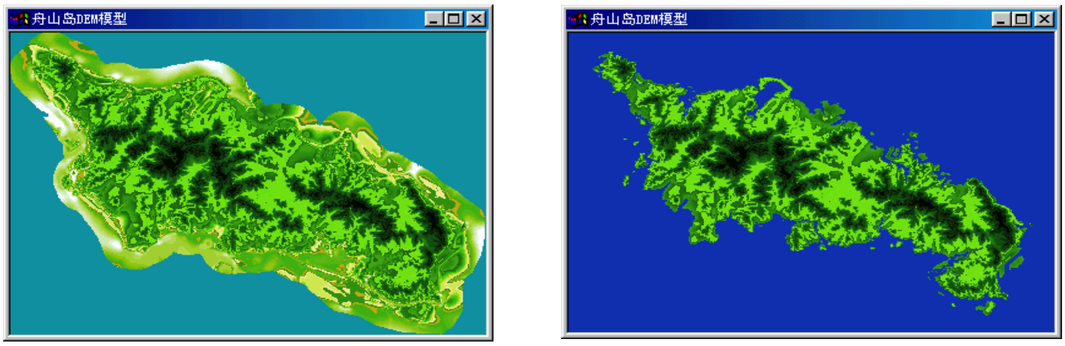


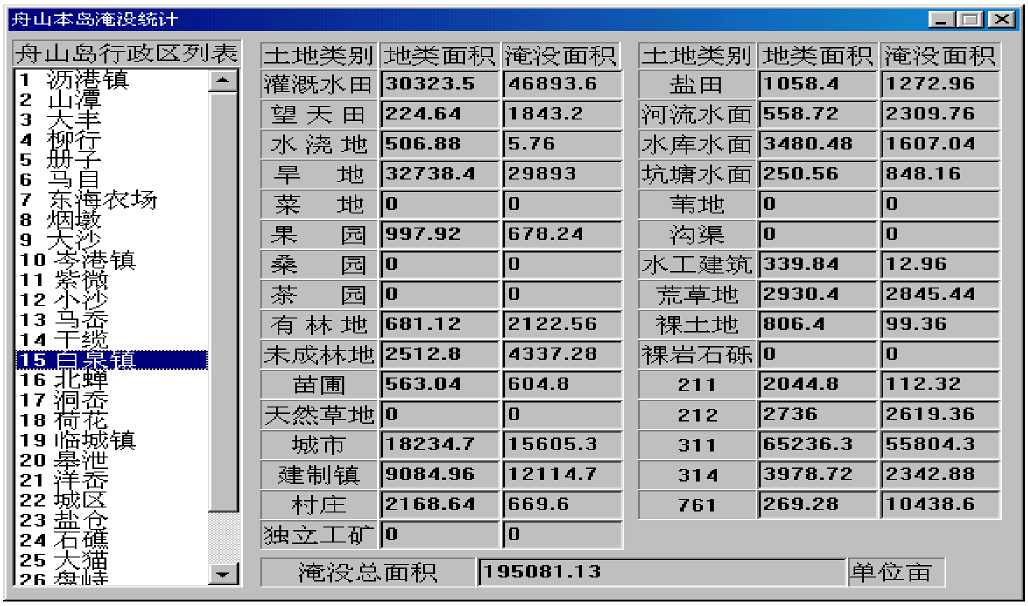
Fig.3 A sample of non-source flood



(a) Situation before source flood

(b) Situation after source flood

Fig.4 A sample of source flood



舟山本岛淹没统计

舟山岛行政区列表

1 沥港镇
2 山潭
3 大丰
4 柳行
5 册子
6 马目
7 东海农场
8 烟墩
9 大沙
10 岑港镇
11 紫微
12 小沙
13 马岙
14 干缆
15 白泉镇
16 北蝉
17 洞岙
18 荷花
19 临城镇
20 皋泄
21 洋岙
22 城区
23 盐仓
24 石礁
25 大猫
26 盘峙

土地类别	地类面积	淹没面积	土地类别	地类面积	淹没面积
灌溉水田	30323.5	46893.6	盐田	1058.4	1272.96
望天田	224.64	1843.2	河流水面	558.72	2309.76
水浇地	506.88	5.76	水库水面	3480.48	1607.04
旱地	32738.4	29893	坑塘水面	250.56	848.16
菜地	0	0	苇地	0	0
果园	997.92	678.24	沟渠	0	0
桑园	0	0	水工建筑	339.84	12.96
茶园	0	0	荒草地	2930.4	2845.44
有林地	681.12	2122.56	裸土地	806.4	99.36
未成林地	2512.8	4337.28	裸岩石砾	0	0
苗圃	563.04	604.8	211	2044.8	112.32
天然草地	0	0	212	2736	2619.36
城市	18234.7	15605.3	311	65236.3	55804.3
建制镇	9084.96	12114.7	314	3978.72	2342.88
村庄	2168.64	669.6	761	269.28	10438.6
独立工矿	0	0			

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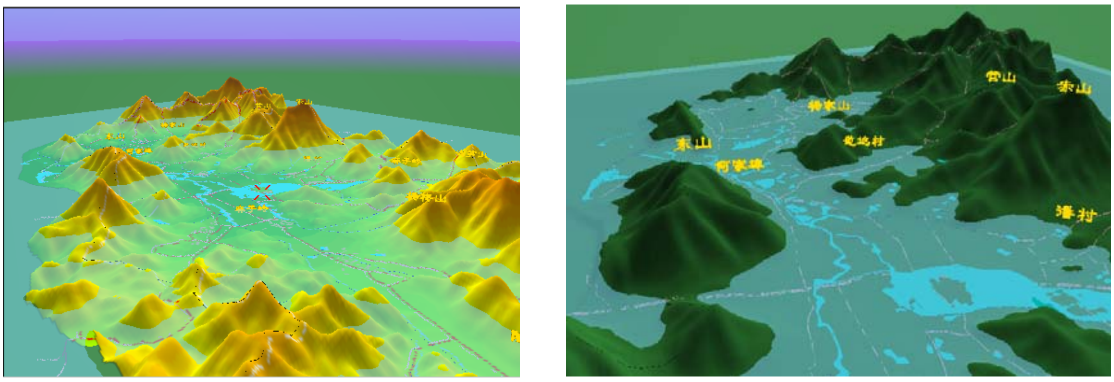
Fig.5 flood statistics



(a) (b)

Fig.6 3D virtual reality dynamic display of flood area