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Analysis of Vulnerability to Flood Hazard Based on Land Use and Population Distribution in the Huaihe River Basin, China

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Synopsis

Information on spatial distribution of potential flood extent, land use and land cover as well as population is significant to analyze vulnerability to flood hazard. Taking the typical flood event of the year 2003 occurred in the Huaihe River basin, China, this paper analyses the spatial extent and temporal pattern of flood inundation with the application of time-series Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) composite data products with the spatial resolution of 250m. Meanwhile land use classification generated by multi-temporal MODIS NDVI 16-day composite data is presented. Based on the resultant MODIS-derived flood inundation mapping, a method to identify the people at risk vulnerable to flooding is proposed, and the distribution of population affected by flooding is derived. Finally the flood hazard vulnerability is analyzed by a spatial analysis method, which is helpful to assess flood hazard vulnerability in the further study.

Keywords: vulnerability, flood hazard, MODIS, NDVI, spatial analysis

1. Introduction

Floods are known as frequent and most devastating events worldwide. Asia continent is much affected by floods and the counties like China, India, and Bangladesh are extremely vulnerable (WWAP, 2006). The impacts of hazardous events are often exacerbated by the interactions with other hazards or by occurring in areas with a high density population and/or social vulnerability. Thus the need for a spatially oriented vulnerability assessment is highlighted. For example, Birkmann (2006) stressed the need for a paradigm shift from the quantification and analysis of the hazard to the identification, assessment and ranking of vulnerability. In this regard, vulnerability has emerged as the most critical research field in disaster studies. Although vulnerability is a multidimensional and multivariate concept associated with high uncertainty in measurement and classification, land use and population are the key components of exposure for flood hazard vulnerability analysis. Large scale flooding due to heavy rainfall and drainage congestion has been regularly experiencing in the floodplain area of the Huaihe River basin, China. The summer dominant rainfall and special topographic conditions make the region highly vulnerable to flooding. In this research, taking the Huaihe River basin as case study, the main objective is to study the vulnerability based on land use and land cover as well as demographic data.

Geo-referenced land use and land cover (LULC) data sets are primary inputs for environmental modeling and monitoring, natural resource management, and policy development. A variety of LULC data sets are needed to support the growing and diverse demands of the global environmental change research community. Over the past decade, the science of large-area LULC mapping has made considerable strides as remotely sensed data and computing resources have improved and advanced classification techniques have emerged (DeFries and Belward, 2000).

Furthermore the identification of potential hazard is essential in describing biophysical vulnerability. Thus a typical historical flood event is taken to supply the prerequisite information. For detecting large flooded areas, satellite remote sensing provides powerful techniques. Many studies have been undertaken in these research fields with the application of a range of satellite data sources, such as Landsat, IKONOS, SPOT, NOAA-AVHRR and RADARSAT SAR data. However large-area mapping using for example Landsat data has been limited by the considerable costs of acquiring and processing the large data volumes that are required. For a severe flood occurring in a large area, Moderate Resolution Imaging Spectroradiometer data products (Huete et al., 1999) offer a great opportunity to acquire the expected information.

In the paper, three primary research questions are addressed regarding MODIS data processing, flood information extraction and vulnerability analysis. Firstly it is to deal with time-series MODIS NDVI composite imagery for regional scale flood identification and land use mapping in the Huaihe River Basin, China. The second is to estimate the distribution of people at flood risk based on flood event analysis; and the last is to analyze the flood hazard vulnerability.

2. Descriptions of study area

The Huaihe River basin (HRB) is situated in eastern China, which is one of the seven major river basins in China (Fig. 1). Geographically, it locates between the latitude 31°N-36°N and longitude 112°E -121°E, covering an area of 270,000km^2. HRB is composed of two water systems, one is the Huaihe River to the south of the old Yellow River and the other is the Yishusi River to the north. The catchment area of the Huaihe River water system is 190,000 km^2, accounting for about 70% of the total area of the basin. The Huaihe River originates from the Tongbo Mountain, and flows into the Yangtze River with the length of approximately 1000 km. The elevation usually is from 100 m to 200 m across the hills in the western HRB, from 50 m to 100 m in the southern HRB and about 100 m in the northeastern HRB. The elevation ranges from 15 m to 50 m in the plain area in the north of the Huaihe River, and from 2 m to 10 m in the area in the lower reaches of the HRB (Fujiyoshi and Yihui, 2006).

Climatologically, it lies in the warm semi-humid monsoon region. Precipitation mainly occurs in the period from mid-May to mid-October. Because of anomalies of the Meiyu front during the rainy season, which is influenced by the South Asian monsoon and the unique topography, the basin has been known for its frequent disasters.

Moreover, this region is populous with the population density of 623 capita per km^2 in 2003, at the same the total population reached 168.0116 million, accounting for 13% of the nation’s population. And there is 17% of the country’s cultivated land (Anhui Statistical Yearbook, 2004). Therefore it is of great socio-economic importance.

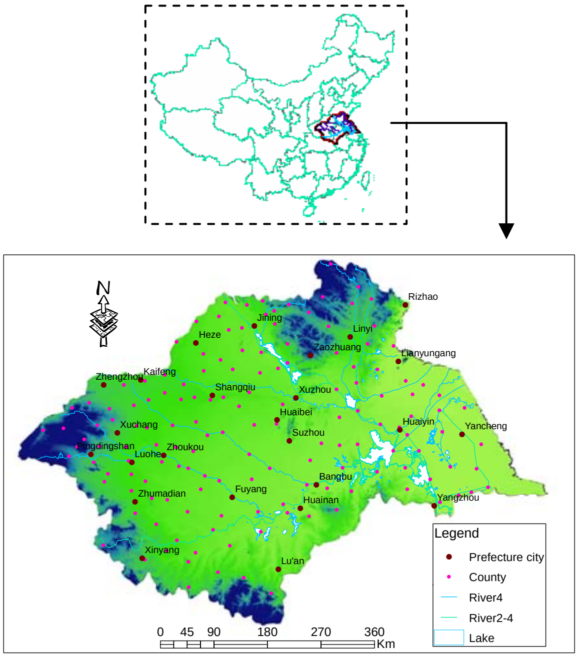


Fig. 1 The location of the Huaihe River basin (The upper figure shows its location in China.)

3. Methodology

3.1 MODIS image data

Among a suite of standard MODIS data products available to the users, the “MOD13Q1 V004” MODIS satellite products are utilized, which are the 16-day composite 250-m Vegetation index (VI) data downloaded from NASA’s Earth Observing System (EOS) website (http:// modis.gsfc.nasa.gov/data). The MODIS VIs provide a consistent spatial and temporal coverage of vegetation conditions and complement each other for vegetation studies (Huete et al., 2002). The time series consist of 23 images, each of which has a file size of 500 megabytes and covers an area of 1200 km by 1200 km. Two tiles (h27v05, h28v05) of the MODIS data are required for the study area. The NDVI and EVI MODIS products were geometrically, atmospherically and bidirectional reflectance distribution fraction (BRDF) corrected, validated and quality assured through the EOS program (Huete et al. 2002). For each composite data, the VI data are extracted by tile, mosaiched, and reprojected from the Sinusoidal (SIN) to Albers Equal Area Conic projection according to a nearest neighbour resampling routine, and then inputed into a multilayer image stack with 250 m×250 m grid cell resolution. This results in a continuous sequence of NDVI temporal values for each pixel.

Because of lack of field observations, Google Earth images across the study area are used to supply ground truth points. Time-series VI data are sampled and analyzed from the sites of specific land use classifications in the study area.

3.2 Multi-temporal NDVI profiles

The VI profiles represent the temporal plant canopy responses to soil, plant and water regime combinations within the study area for each period. The multi-temporal VI profile of a specific land use and land cover type is applied to analyze and compare to each other in order to determine the classification. In additions, regional variations in each kind of land use type are also considered.

Thus, in this study the index such as NDVI, EVI and derived NDWI sampled dispersedly from composite imagery data have been shown in figure 2, where six kinds of land use and land cover have been considered according to the research requirement and biophysical conditions. Each general land use has unique multi-temporal NDVI and EVI profiles.

This study mainly relies on the NDVI profiles to detect the land use and land cover classification because both NDVI and EVI show the similar characteristic for each land use as demonstrated in Fig. 2.

3.3 Data pre-processing for NDVI time series

Many analysis methods have been developed to detect land use classification with the application of NDVI time-series data. After NASA launched the MODIS, researchers can get a variety of time-series data. However, these time-series data inevitably contain disturbances caused by cloud presence, atmospheric variability and snow. Noise degrades data and has bad effect on the analysis. A couple of automated methods for de-noising have been proposed to reconstruct high quality NDVI time-series data, such as the best index slope extraction (BISE) algorithm (Viovy et al., 1992; Kozan et al., 2004), the Savitzky-Golay filter approach (Savitzky et al., 1964), wavelet method and some other interpolation methods.

In this research, an adaptive Savitzky–Golay filter has been tested, which is one way of smoothing data and suppressing disturbances. The filtering equation is shown as below (William et al., 1992).

$$g_i = \sum_{n=-n_L}^{n_R} c_n f_{i+n} \tag{1}$$

Here n_L is the number of points used “to the left” of a data point i, i.e., earlier than it, while n_R is the number used to the right, i.e., later. f_i is the time series. c_n is the filter coefficient. g_i is the result.

After sampling VI data from some positions, the quality analysis of multi-temporal MODIS composite imagery has been performed, and some noise in the data at the period of 33 and 353 has been found. With the application of the Savitzky–Golay filtering method, the filtered time profiles of NDVI, EVI and some other derived data are obtained from MOD13 16-day composite time-series data with 250-m spatial resolution. The smoothed results show that the method is effective,

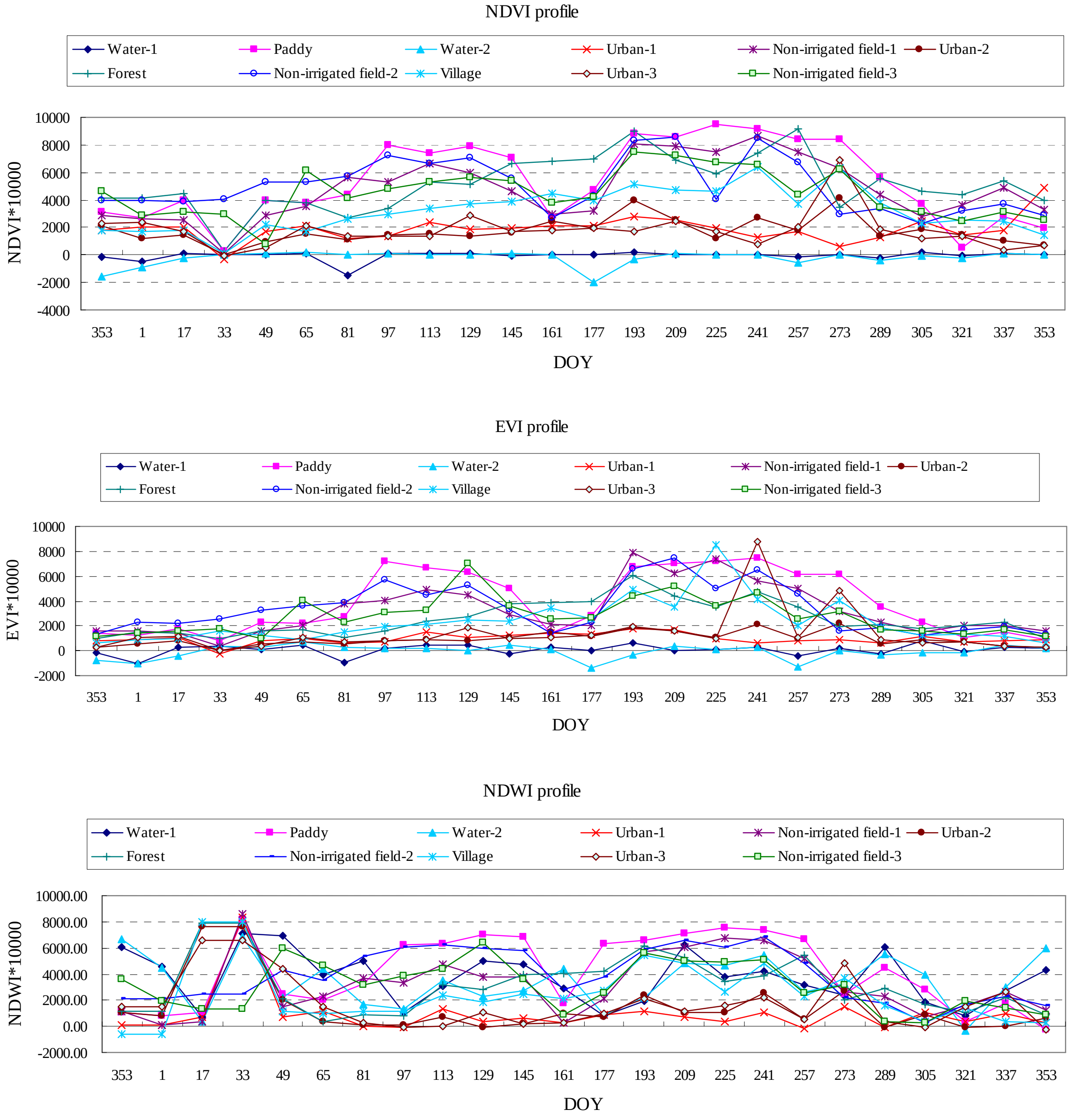


Fig. 2 Multi-temporal NDVI, EVI and NDWI profiles of the major land use types

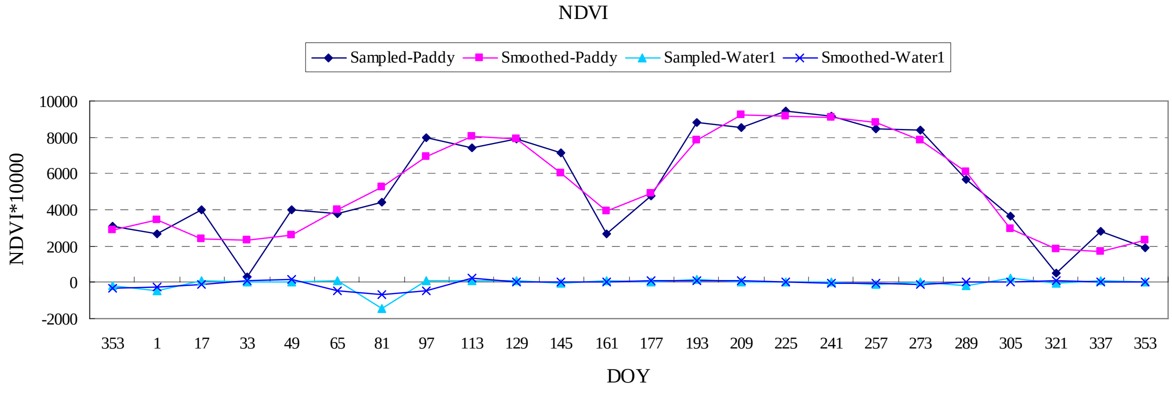


Fig. 3 The comparison of smoothed NDVI data and sampled NDVI data

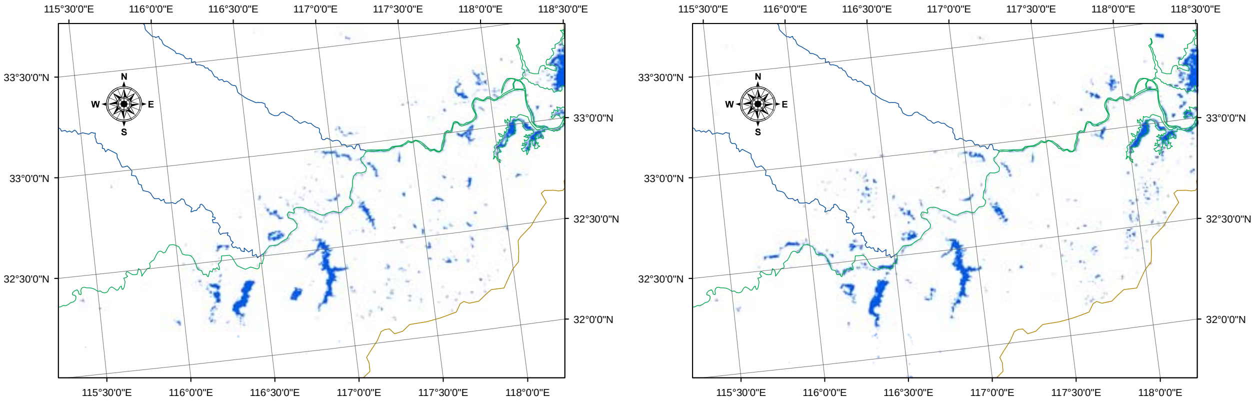
especially it can keep the peak value of NDVI in growing season (Fig. 3). It also is helpful to select reasonable threshold for classifying land use.

3.4 The identification of flooded area

Flooding is equivalent to an increase in water-covered area through time. As such, it can be detected as a change in the water covered area. To study the extent of flood inundation, the extraction of spatial information based on the multi-temporal images is conducted by the Decision Tree classifier, which is defined as a classification procedure that recursively partitions a data set into more uniform subdivisions based on tests defined at each node in the tree (Chandra and Clinton, 2005). It is obvious that the change of index value sampled from water area is very gentle and the value is the lowest compared with that sampled from other kind of land use (Fig. 2). Therefore to extract the water area, the key is to determine the dynamic threshold. Because it is hard to distinguish between water areas and urban, the background data of lake and reservoirs have been taken as auxiliary data. According to multi-temporal data analysis, the water distribution in the Huaihe River basin is identified in terms of the flood event in the year 2003. The flood occurred from the end of June to the beginning of August, around that time the temporal change of water information is demonstrated, where the blue color area stands for water area (Fig. 4). With the application of spatial analysis, the water covered area is synthesized. After the elimination of background water body, the flooded area marked by red color is mapped (Fig. 5). The total area affected is 2575.75 km^2, which mainly spreads around flood detention areas.

3.5 Land use classification

Due to the occurrence of great land use and land cover change in developing country, the MODIS composite data are adopted to classify land use, which have higher spatial resolution than AVHRR.



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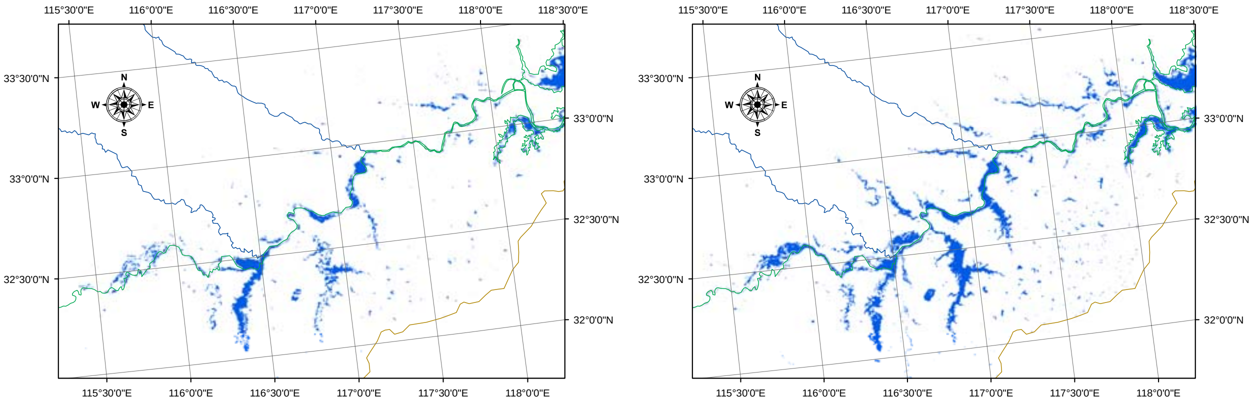

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Fig. 4 The temporal change of flood inundation area

To implement the extraction of land use and land cover in larger area is challenging, as many factors could have effects on the dynamics of VI data. However each general land use has clear multi-temporal NDVI and EVI profiles, the Decision Tree method is still applied to classify the land use. Firstly with the application of quality control flags for cloud, some masks for cloud cover have been generated to eliminate the area affected by cloud. Then based on the features of land use, the dynamic thresholds to determine the land use classification are specified elaborately. The distribution of different land use is shown in figure 6.

3.6 The distribution of population at flood risk

The population distribution is the key factor to make mitigation plan as well as hazard analysis. To obtain the potential people at flood risk, the census (2002) is applied. In GIS platform, the affected population distribution is mapped (Fig. 7). Accordingly the populations at flood risk in the whole basin can be estimated, the result is vital to analyze the vulnerability to flood hazard.

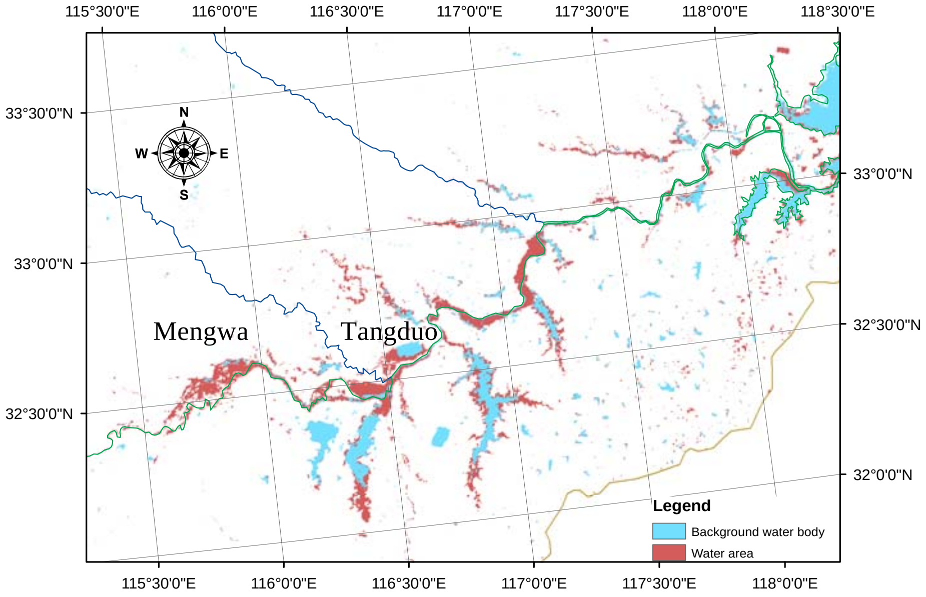

Fig. 5 The identification of flood distribution along the Huaihe River

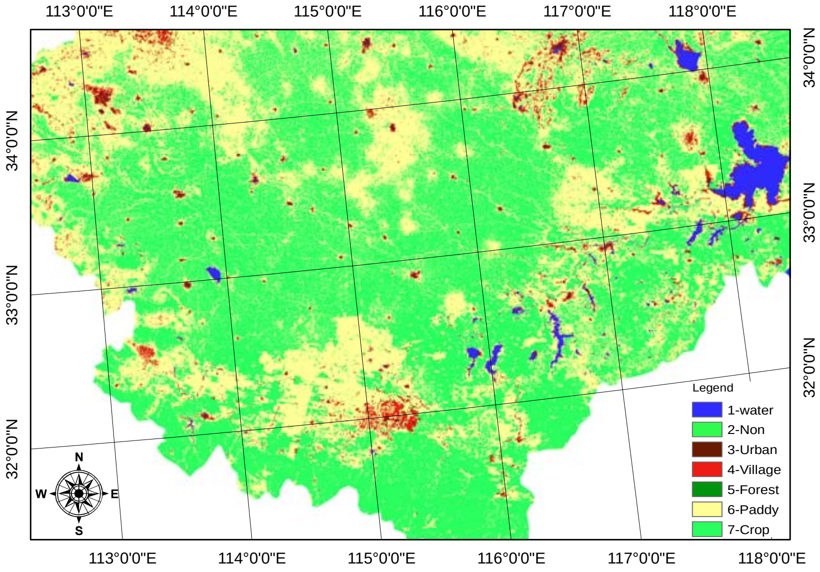

Fig. 6 The extraction of land use and land cover in the year 2003

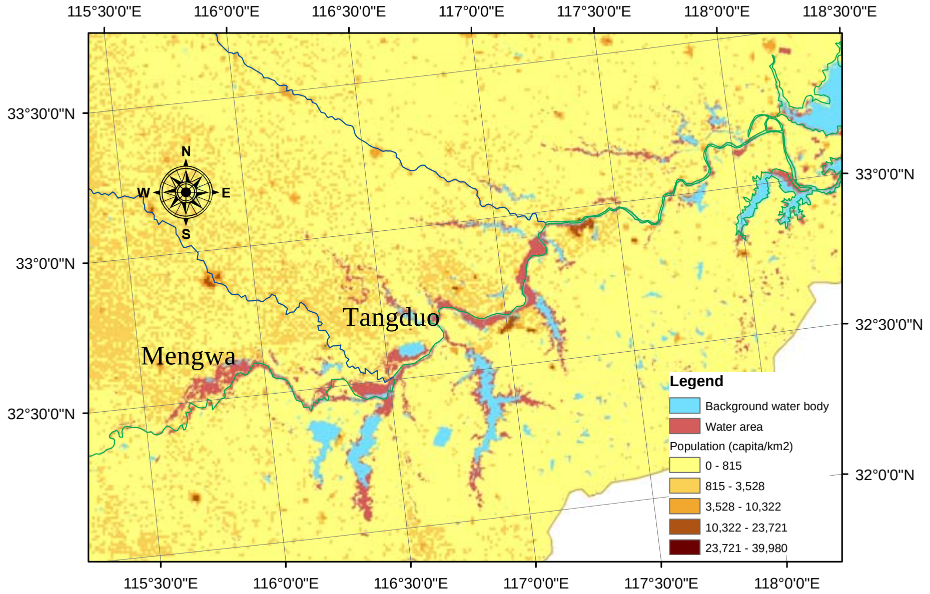

Fig. 7 The location of population affected by flood

4. Vulnerability Analysis

The conceptual ''hazards-of-place'' model of vulnerability was presented by Cutter (1996), which combines biophysical and social determinants. The social and biophysical elements interpenetrate and shape the overall vulnerability of the place. Simply place vulnerability can be viewed as biophysical vulnerability and social vulnerability, in which biophysical vulnerability relies on hydro-geological characteristics. As a result, the biophysical vulnerability can be shown by the vulnerable area (Fig. 5). Moreover social vulnerability relies on the exposure, the susceptibility of social groups to the impacts of hazards as well as their resilience.

In a general sense, social vulnerability is determined by the presence of a human population at risk to a particular hazard. At present, in this research the key factors of exposure, such as land use and population are taken into consideration. Combining with demographic data, spatial distribution of people at risk to flood hazard is derived based on overlay analysis and buffer analysis (Fig. 7). The result indicates that the people at flood detention areas such as Mengwa, Lake Tangduo, etc. are much more vulnerable to flood. For example, at Mengwa community, there are 152,598 people estimated to have been affected and 377.9 km^2 land vulnerable to flooding (except water area) (Table 1). Because it locates at the floodplain and is populous, it is relative vulnerable to flood hazard. The analysis result shows the methodology is effective and applicable to identify the flood vulnerable area. Accordingly in the whole basin, the amount of farmland and population vulnerable to waterlogging can be estimated.

Table 1 The area of land vulnerable to flood

Land use	Crop	Paddy	Village
Area (km^2)	298.2	76.8	2.3
Land use	Forest	Urban	Water
Area (km^2)	0.3	0.3	14.2

5. Conclusions and Remarks

This study attempts to analyze the flood hazard vulnerability in the Huaihe River basin, China. The proposed methodology is applied to produce time-series inundation maps for the analysis of typical flood event in the year 2003. Meanwhile integrated with demographic data, spatial analysis of vulnerability to flood hazard at a regional scale is put forth. In this study, it pays more attention on the method to estimate the flooded area, which is applicable to large area flood with long duration. In addition it is important to assess the result quality.

However, the degree to which populations are vulnerable to flood hazard is not solely dependent upon proximity to the flood threat or the exposure determinants, social factors also play a significant role in vulnerability measurement. In the further study the holistic vulnerability can be assessed in detail.

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土地利用図と人口分布を基にした中国淮河流域における洪水災害に対する脆弱性に関する解析

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要　旨

潜在的な浸水域や土地利用・土地被覆，ならびに人口等の空間的な分布情報は，洪水被害に対する脆弱性の解析に重要な意味を持つ。本論文では，中国淮河流域で発生した代表的な洪水イベントである2003年の事例を対象として，MODIS画像から作成した空間解像度250mのNDVI時系列を用いて，洪水浸水域の空間的広がりおよび時間的パターンを解析した。一方，MODIS/NDVIの16日間合成画像から作成した土地利用分類が，利用可能である。MODISから作成した浸水域マップを元に，洪水が住民に与えるリスクを特定する手法を提案し，また洪水被害を受けた人口の分布を作成する。さらには空間的な解析手法を適用することで，洪水被害の脆弱性を解析する。今後の研究においても，洪水被害の脆弱性を評価するために本手法は有益である。

キーワード: 脆弱性，洪水被害，MODIS，NDVI，空間的解析