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Evaluating Agricultural Drought Hazard Risk Based on GIS-MCE

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Abstract

Multi-Criteria Evaluation (MCE)is one of applications of multiple criteria decision making（MCDM）. GIS is an information system that is designed to work with data referenced by spatial or geographic coordinates. GIS combined with MCE can achieve measurable evaluation of drought risk. Technologies of evaluating agriculture meteorological drought risk with GIS-MCE are introduced, Taking precipitation anomaly as main drought evaluation index, the paper calculated the spatial distribution of meteorological factors to the whole region by the interpolation method of IDW. In addition, use multiple regression analysis method to study the correlation of meteorological factors, geography factors and social economic factors. The study fully reflects the important role of population density and regional economic development for drought division, making the drought spatial distribution model more accurate and comprehensive. Ultimately, In considering each factor effects, calculate the multi-factor comprehensive division map by GIS-MCE method, which including establishing evaluation criteria and weight by Delphi method, obtaining the spatial distribution of factors of the meteorological drought risk by diffusing spatial attribute value and implementing evaluation by spatial overlay calculation. The results indicated that technology of GIS-MCE can combine multiple source information associating with agriculture meteorological drought risk and achieve measurable result.

Keywords: *Agricultural drought; Hazard; GIS; Division*

1. Introduction

Agro-meteorological disasters generally refer to adverse weather or climate anomalies which led to crop production significantly decrease in the process of agricultural production [1]. With climate change becoming more evident, agro-meteorological disasters keep an increasing degree on frequency, increasing and damage, which form a serious threaten to national food security and agricultural sustainable development. Risk assessment and hazard division of natural disaster are the basic work to make mitigation strategies, land use planning, socio-economic development and the insurance industry [2]. Accurately and timely assessing the production losses and economic losses after crops suffered the agro-meteorological disasters is urgent problems of agricultural production.

A geographic information system (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. A GIS is both a database system with specific capabilities for spatially-referenced data, as well a set of operations for working with the data. There are five essential elements that a GIS contains: data acquisition, preprocessing, data management, manipulation and analysis, and product generation. Data acquisition is the process of identifying and gathering the data required for application. Preprocessing involves manipulating the data in several ways so that it may be entered it into the GIS. Data-management functions govern the creation of, and accession, the database itself. These functions provide consistent methods for data entry, update, deletion, and retrieval. Manipulation and analysis are often the focus of attention

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for user of the system. In this portion of the system are the analytic operators that work with the database contents to derive new information. Product generation is the phase where final outputs from the GIS are created. These output products might include statistical reports, maps, and graphics of various kinds. Geographic information systems are used in a wide variety of settings.

Multi-Criteria Evaluation (MCE) is one of applications of multiple criteria decision making（MCDM, including multi-object evaluation and multi- attribute evaluation. As an application of multi- attribute evaluation, agriculture meteorological drought risk evaluation is the analyzing process based on multiple attributes associated with evaluation region.

GIS technology is an effective means to carry on agro-climatic resources division. There are a large number of researchers engaged in related research, and made a series of new research achievement. Zhaoxia Guo[3] established the grid model of climatic elements based on GIS. According to of crop climatological division index and different weighted standard of each division factor, multiple spatial elements were analyzed. Then, vector chart of climatic resources and crop agro-climatic division was shown on. Jianyuan Wang[4] finds out the limited factor of chestnut growth and division standard in Taian City. He established the DEM model of meteorological factor and space data, and adopted the method of space analysis in GIS. By way of agro-meteorology division in Taian City, study determined the suitable, light suitable and unsuitable region. Li Qiao[5] selects 10 factors influencing Shan Xi Province's ecological agriculture drought. Use K-Means Cluster Analysis and Hierarchical Cluster Analysis to study ecological zoning of agricultural drought in Shan Xi Province. On the base of analysis and past studied results, the paper divided Shan Xi Province into 8 areas according to their corresponding ecological agriculture drought. Ronghua Liu[6] took production rate and precipitation anomaly of North China Plain winter wheat in growing season as index. By analyzing these indexes, distribution and frequencies of drought in different degree were determined.

Recently, the frequency of meteorological disasters have notable upward trend in Lianyungang City, which have a huge impact on people's livelihood and national development. With climate change and anomaly, although Lianyungang is located in the transition zone of the warm temperate and subtropical region, the occurrence of drought has increased frequently year by year. In the past 50 years, Lianyungang City, in 1967, 1978, 1988, 2002 and 2010, the precipitation is seriously less than normal annual value. Especially the end of 2010 to the spring of next year, the condition is that the rainfall was only 10% comparing with the same period for many years, which had upgraded to serious drought and faced the most severe drought in past 60 years. The paper taking the precipitation anomaly percentage as drought index, fully think about the impact of terrain on drought disaster. What's more, consider socio-economic factors as drought evaluation factor. Finally, accurately and comprehensively obtain the spatial distribution of drought.

2. Study Area and Data Sources

Lianyungang is located northeast of Jiangsu Province, about 7446 square kilometers between latitudes 34° and 35°07′ N, longitudes 118°24′ and 119°48′ E. It is located in the transition zone of the warm temperate and subtropical, and it is one of the most frequented by natural disasters cities in China (see Figure 1). Cultivated land accounts for about 51% of the total land areas, which contains a great potential of reserve land resource. In various disasters, drought and floods are relatively frequent and involve a larger sphere, which retain an important impact on local economy, especially the development of agriculture.

Figure 1. Study Area

With the development and flourish of geographic information technology, GIS has provided a service platform for meteorological disaster monitor and evaluation analysis. It not only improved the temporality of data collection, but also can accurately calculate the disaster area, damage extent, risk degree, buffer analysis and so on. The paper take full consideration to meteorological factors, terrain and socio-economic factors, and using technology of GIS to deal with meteorological drought assessment and analysis that enhance the accuracy, timeliness and objectivity of disaster analysis.

Meteorological data come from the Lianyungang meteorology bureau, including 30 years of precipitation data (1985-2005) and 2009 rainfall data of 6 major meteorological stations(see Table.1). Terrain data come from SRTM3(see Figure 1 and Figure 2). The Shuttle Radar Topography Mission (SRTM) is a NASA mission conducted in 2000 to obtain elevation data for most of the world. It is the current dataset of choice for digital elevation model data (DEM) since it has a fairly high resolution (1 arc-second, or around 25 meters, for the United States, and 3 arc-second, or around 90 meters at the equator, for the rest of the world), has near-global coverage (from 56°S to 60°N), and is in the public domain and population[7].Areas and GDP in each county come from Jiangsu Province statistics yearbook 2009(see Table.2).

Table 1. The Average Monthly Rainfall for Nearly 30 Years

	1	2	3	4	5	6	7	8	9	10	11	12
Ganyu	180	209	324	472	684	1039	2373	2049	791	482	323	133
Liandao	213	252	352	440	619	974	2072	1875	950	477	392	136
Urban	170	212	339	462	625	1118	2353	1940	709	433	352	122
Donghai	199	222	358	492	713	1048	2292	1703	783	467	314	135
Guanyun	217	252	395	502	647	1121	2210	1766	797	466	348	140
Guannan	221	277	412	532	695	1239	2246	1724	899	455	369	154

Table 2. Statistics of Lianyungang in 2009

	Totalpopulation (million)	GDP (billion)	Area (square kilometers)
Ganyu	110.8	182.44	1427
Donghai	113.16	162.69	2037
Guanyun	101.52	119.36	1853
Guannan	76.47	107.1	1027
Urban	88.69	146.1	1156
Liandao	20.42	48.22	535

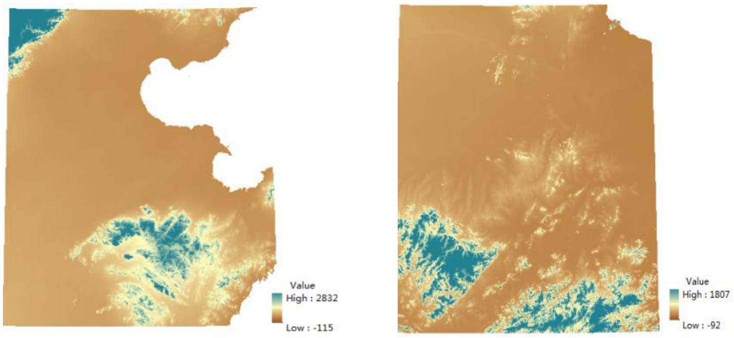

Figure 2. Original SRTM

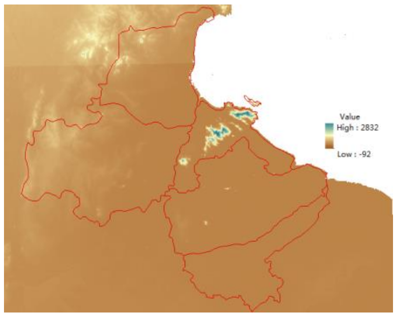

Figure 3. Stitching and Cutting SRTM

3. Research Methods

Firstly, regarding precipitation anomaly as the drought evaluation index and using inverse distance weighted (IDW) method to conduct spatial interpolation. Based on the GIS platform, the spatial distribution of index value in the spring of 2009 has been shown. Secondly, establish triangular irregular network (TIN) and extract the DEM information from the elevation information of SRTM3 image. Thirdly, taking counties as the administrative units, put the per capita GDP and population density to raster that obtain grid information. Finally, standardize the three indexes of precipitation anomaly, geographical factor, and social economic factor to gain each index weight based on Delphi method. Using the method of mathematical statistics and the GIS spatial analysis, got the spatial distribution of drought disaster division in Lianyungang, which depend on the superposition of geographical factors, social economic factors and drought index value. Index processing is shown as Figure 4.

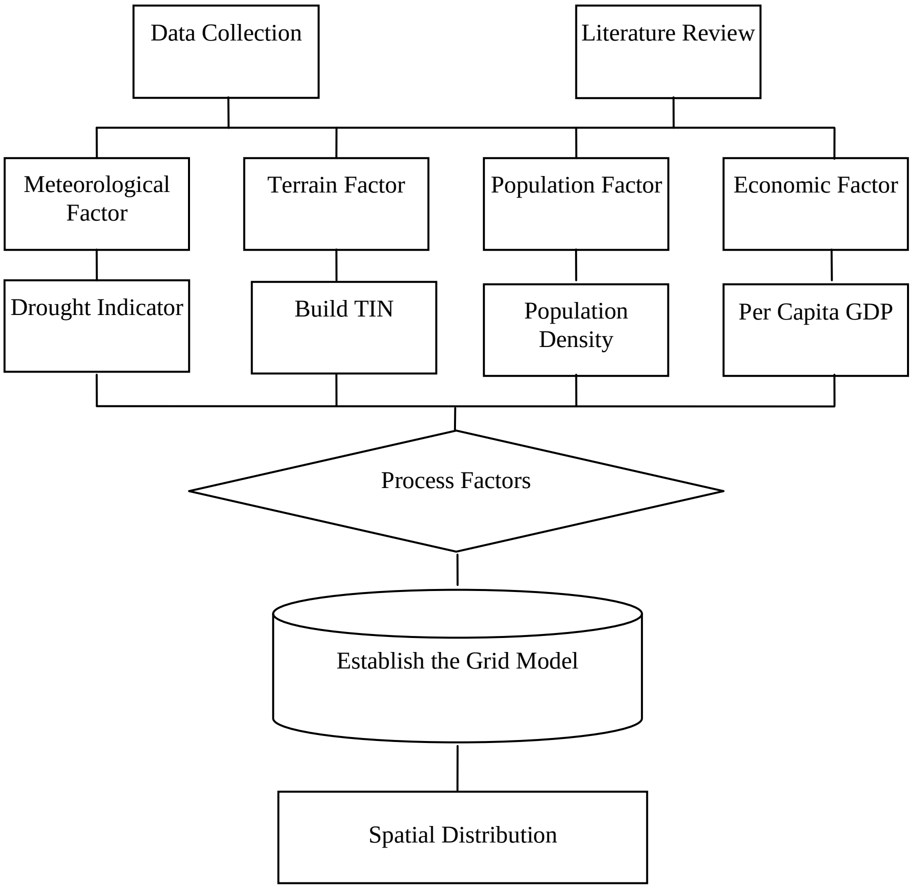

Figure 4. Index Process

3.1. Precipitation Anomaly

Drought can be defined as a kind of disaster phenomena, which lead to water serious imbalance, crops wither, river flow reduction, groundwater and soil water depletion, drinking water shortage *etc*., because of no rain or little rain, soil lacking water, and air drying[8]. The essence of drought is water shortage. Precipitation is the main source of agricultural water, and it is also a major affect factor to drought. Generally study methods include precipitation anomaly percentage rate[9], Penman formula, days without rain and so on. The index is proposed by Rooy in 1965. Precipitation anomaly percentage rate [10] is one of the indicators which shows a period precipitation characteristic exceed normal or less than normal precipitation value, and directly reflect the precipitation caused by drought.

According to the habits and characteristics of agricultural production, divide the drought into spring drought, summer drought and autumn drought. Spring drought mainly occurred in China's Huang-Huai River basin, that the temperature rose quickly, air keep relatively low humidity, soil moisture loss fast [11]. However, Lianyungang is a typical district of the Huang-Huai River region. According to statistics data of the rainfall in the spring of 2009 and the climate value nearly 30 years in Lianyungang, calculate the precipitation anomaly results that shown in Table 3.

Table 3. Rainfall in the Spring of 2009 and the Climate Value Nearly 30 Years

	Mean rainfall in spring of 2009	Mean climate value in the spring of nearly 30 years	Precipitation anomaly percentage in the spring of 2009
Ganyu	28.63	38.620	-0.25859
Liandao	38.03	41.787	-0.08982
Urban	35.83	39.687	-0.09709
Donghai	31.43	40.353	-0.22105
Guanyun	29.20	42.307	-0.3098
Guannan	29.53	43.293	-0.31783

The inverse distance weighted interpolation is a common geometrical model for interpolation based on groups of three nearest control points, Weighting the contribution of each control point by the square of the inverse of the distance from the control point to the interpolated point. This model works as follows. To determine the estimated value at any point on the surface, find the nearest three control points. Determine the plane that goes through the three points, and then calculate the value of the desired point from the value on the plane that corresponds to the desired x-y position.

Using inverse distance weighted interpolation method obtained the city's precipitation anomaly percentage (Figure 5), and adopting hierarchical classification visually represent drought distribution with addition from one to nine grade. As can be seen from photograph, drought intensity in different regions show significant diversity, especially in southern Guanyun and Guannan keep a severe drought degree, however, central plains and eastern coastal areas keep relatively less drought.

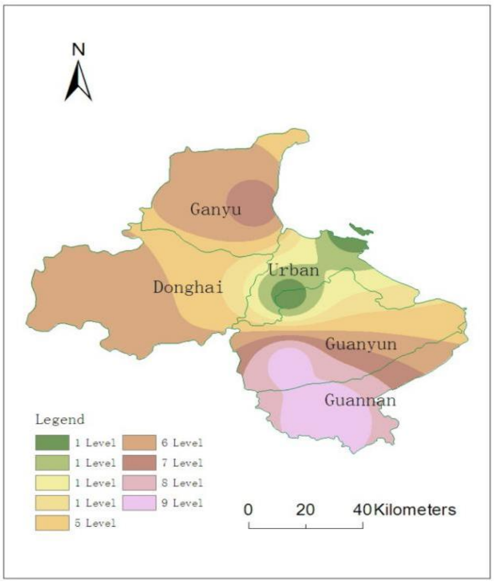

Figure 5. Precipitation Anomaly Percentage Distribution in 2009 Spring

3.2. Deal with Terrain Factor

A triangulated irregular network (TIN) is a digital data structure used in a geographic information system (GIS) for the representation of a surface. A TIN is a vector-based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three-dimensional coordinates (x, y, and z) that are arranged in a network of non-overlapping triangles. TINs are often derived from the elevation data of a rasterized digital elevation model (DEM). An advantage of using a TIN over a raster DEM in mapping and analysis is that the points of a TIN are distributed variably based on an algorithm that determines which points are most necessary to an accurate representation of the terrain. Data input is therefore flexible and fewer points need to be stored than in a raster DEM, with regularly distributed points. The TIN model represents a surface as a set of contiguous, non-overlapping triangles. Within each triangle the surface is represented by a plane. The triangles are made from a set of points called mass points.

An advantage of using a TIN rather than a raster DEM in mapping and analysis is that TIN can determine the density and location of sampling points based on the complicated terrain, which greatly reduce data redundancy in flat region.

Based on elevation information SRTM3 in Lianyungang, established TIN within eliminating redundant data in flat area (Figure 6), and convert to the DEM raster image which can locate a specific point (Figure 7).

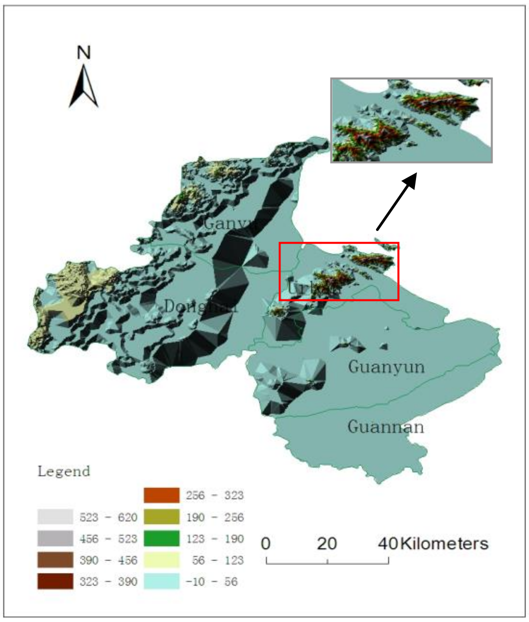

Figure 6. TIN Model in Lianyungang City Spring of 2009

3.3. Deal with Social Economic Factors

According to the population and GDP in Lianyungang 2009 (Table 4), regarding each county as basic division unit, the paper gain the picture of the population density (Figure 8) and per capita GDP (Figure 9).

Table 4. Population and GDP in Lianyungang 2009

Division unit	Population [ten thousand]	GDP [billion]	Area [km^2]	Population density [per person/km^2]	GDP [yuan/per person]
Guanyun	101.52	119.36	1853	548	11757.29
Ganyu	110.8	182.44	1427	776	16465.70
Donghai	113.16	162.69	2037	556	14376.99
Urban	88.69	146.10	1156	767	16473.11
Guannan	76.47	107.10	1027	745	14005.49

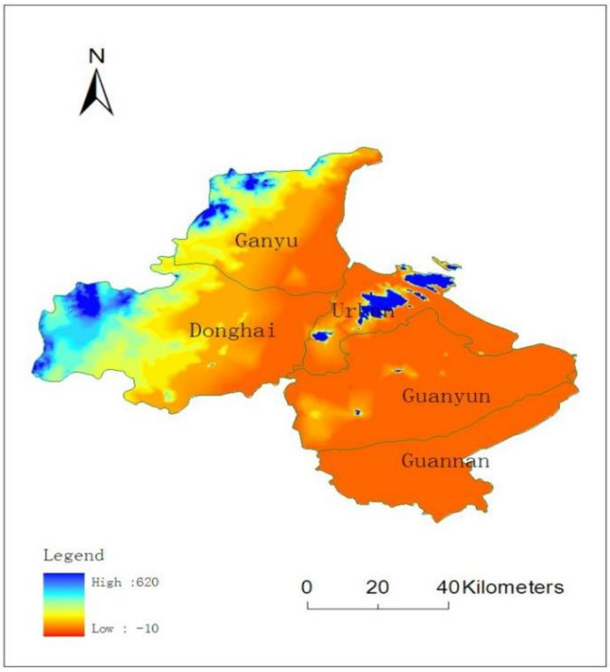

Figure 7. DEM Raster Images in Lianyungang City

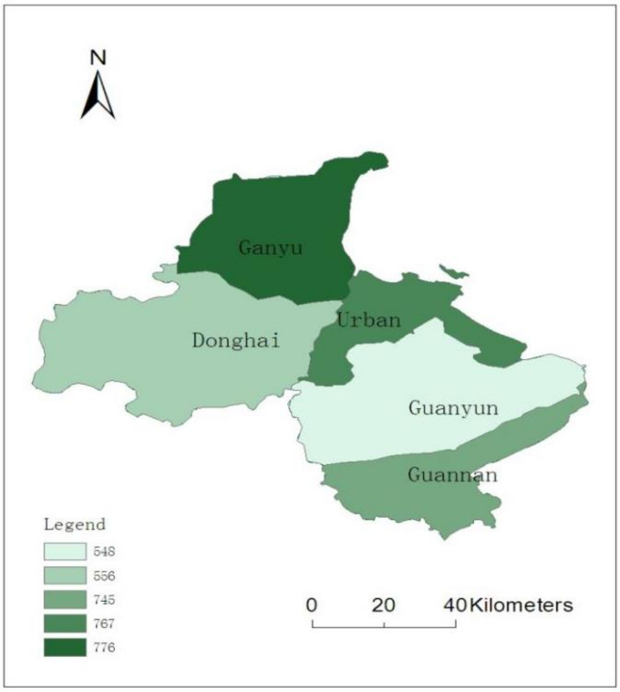

Figure 8. Population Density in Lianyungang 2009

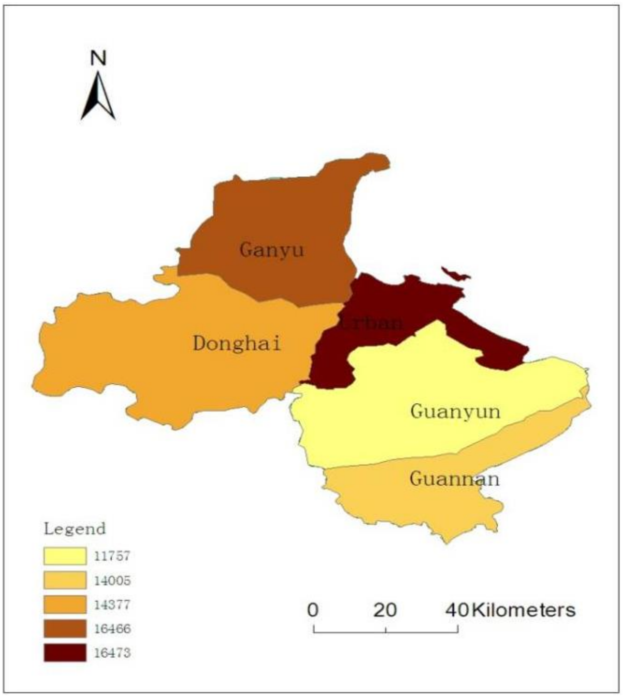

Figure 9. Per capita GDP in Lianyungang 2009

3.4. Drought Risk Division.

Multi-factor statistical analysis is widely used in division research and comprehensive evaluation. Comprehensive evaluation process generally considering three steps as follows [15]:

3.4.1. The Selection of Evaluation Factors: Drought hazard division model can't wonderfully build without meteorological factors and terrain factors. This thesis established the climate resource grid by correlation analysis of the two factors, and use socio-economy as cofactor of drought disaster division evaluation, which largely increased the credibility of drought division. Meteorological factors, terrain factors and socio-economic factors show the spatial data information in the form of small grid, and obtain the final result that is the spatial distribution of drought division by analysis characteristic of the mathematical statistics and GIS.

Considering the drought index, the terrain factors and socio-economic factors, in order to deal with data convenient and quick, the factors will be standardized. Data is mapped to 0 ~ 1 scope to process. It takes the dimensionless standardization method, that is Yi=(Xi-Xmin)/(Xmax-Xmin). Among them, Xi is the value before standardization and Yi is the after one. Xmin is minimum data, and Xmax is opposite.

3.4.2. Comprehensively Scoring Multi-Factor: Overlay analysis is basal function of GIS, including arithmetical overlay, logic Overlay, fuzzy Overlay and so on. There is some limitation in general overlay analysis, such as not comparatively considering weightiness of layers, no way to confirm threshold value of consecutively distributing variable and not be able to evaluate all of spatial elements roundly, for example, not be able to order results of evaluation.

Because of limitations above, general overlay analysis can not meet for the requestment of evaluating land quality based on GIS and MCE.

Numeric overlay calculation of spatial data refers to that taking attribute value of spatial object as consecutive variable, and transforming them to some new value which falling into some special numeric zone, after these, factors' new value is weighting and linearly combined. All of these are based on spatial cell plotting and spatial attribute value diffusing. Spatial cell plotting divides consecutive space into equal spatial cells and spatial attribute value diffusing transforms consecutive attribute value to discrete dot value which belongs to different spatial cells. After depositing data above in date table, numeric overlay calculation can be carried on as follows:

$$S = \sum_{i}^{n} D_i \times P_i \quad (2)$$

where S is value of evaluation, D_i is measurable value of factor, P_i is weight of factor.

Weight determine commonly use Delphi method, Arithmetic method, regression coefficient method, fuzzy comprehensive evaluation approach and so on [14]. Delphi method extensively consulted expert opinions to predict a project or a program for the future development, also known as expert investigation method. This paper using Delphi method, analyzing which ones are important, which ones are not so important, so as to determine the weight index size. In GIS platform, the author using the weight based on Delphi method to assign precipitation anomaly, social economic factors and terrain factors. According to overlay analysis of factors attributes, multi-factors comprehensive evaluation are shown, which work out space distribution of drought disaster in the spring of Lianyungang 2009 (Figure 10).

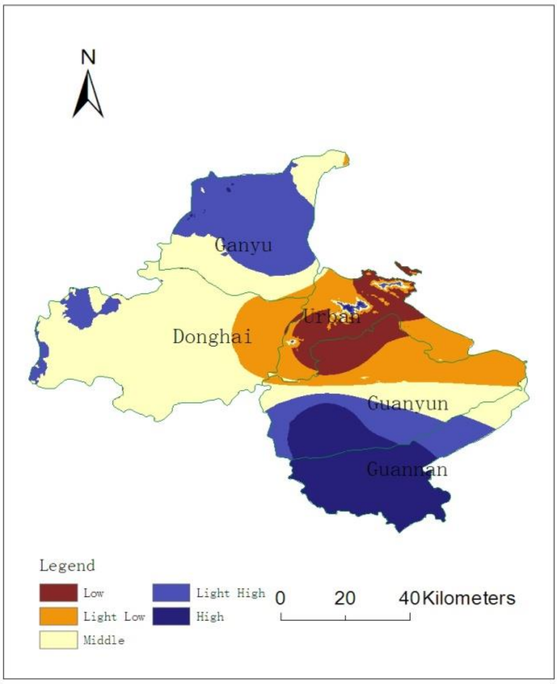

Figure 10. Space Distribution of Drought Disaster Risk in the Spring of Lianyungang 2009

From the space distribution features of drought degree, northwestern hilly land and southern areas in Lianyungang City keep high degree drought impact. The central plains region contains eastern Donghai County, northern Guanyun and coastal areas are followed. Because the social economic factor is blended to, make drought risk division distribution not single. The loss caused by drought has certain relevance to economic level and population density of the administrative units. Good economic development and population density areas, facing great degree of drought, will certainly bring more social and economic loss than other regions.

4. Conclusions

The establishment of climate resources grid closely related to climate distribution and topography. The distribution of climate resources has obvious geographical features. However, the limited climate stations can't accurately reflect the geographical space of climatic conditions, so spatial interpolation is necessary needed. Taking precipitation anomaly as main drought evaluation index, the paper calculated the spatial distribution of meteorological factors to the whole region by the interpolation method of IDW. In addition, use multiple regression analysis method to study the correlation of meteorological factors, geography factors and social economic factors. The study fully reflects the important role of population density and regional economic development for drought division, making the drought spatial distribution model more accurate and comprehensive. Ultimately, In considering each factor effects, calculate the multi-factor comprehensive division map by grid projection method.

Currently, in time scale, the drought disaster division mainly concentrate on using the exist model to conduct regional research for a period of time. However, ignore two points: First, crop have different needs for water in each growth stages, which lead to various degrees of drought. The second do not integrate major crop production areas. For the above two points, the article will focus on crop growing areas and time scale of crop in the next step. It will greatly improve the assessment accuracy of drought economic losses, reduce the loss of relief funds, and promote sustainable economic development in Lianyungang.

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