

Evaluation of Suitability Areas for Maize in China Based on GIS and Its Variation Trend on the Future Climate Condition

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Abstract Climate change is one of the most significant factors for the migration of the suitable planted areas of maize. The hyper-resolution data of daily mean precipitation, temperature, soil, and topography that supported by Institute of Soil Science and National Climate Center were collected to assess the effect of climate change on migration of the suitable planted maize areas, and it provides a foundation for macro-management decisions of agriculture. Climate data mentioned above was simulated by regional climate model, which showed the experiments of the twentieth century and the forecast tests of twenty-first century. Based on the factors above, relevant criteria, suitability levels, and their weights for each factor were defined. And the database of climate and soil was established. In this article, we use the multi-criteria evaluation (MCE) approach based on GIS to identify the suitable planting areas for maize in China. The results demonstrated that the most suitable degrees of active accumulated temperature, maximum and minimum temperature in growth period moving north dramatically, and the precipitation moving slightly in the future, which will lead to the planting areas of maize moving northward, and the areas were increased by $4.61 \times 10^5 \text{ km}^2$.

Keywords Maize · Geographic information system (GIS) · Climate change · Multi-criteria evaluation · Kriging interpolation · Analytical hierarchy process

1 Introduction

Any change in climate will have implications for climate-sensitive systems such as agriculture, forestry, and some other natural resources. With respect to agriculture, change in temperature and precipitation will produce change in scheduling of field

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operations, crop yield, cropping systems, and so on [1]. To research and develop agriculture on condition of climate change, the accurate identification and the characterization of current production areas and potential areas in future are necessary [2]. Multi-criteria evaluation (MCE) approach was used to determine relevant criteria (factors) as the biophysical restraints and to define the suitability levels for each factor. MCE was defined as “an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter” [3] could be understood as a world of concepts, approaches, models, and methods that aid an evaluation (expressed by weights, values, or intensities of preference) according to several criteria [4]. MCE has been one of the most widely applied models in management and planning because (1) it was the formal approach, (2) the presence of multiple criteria, and (3) the evaluation are made either by individuals or by groups [5]. Geographic information system (GIS) has a powerful function in spatial analyses such as predicting the distribution of the wild relatives of bean by analyzing climate conditions that favor bean’s growth [6] and for planning potential conservation areas by using relationships between environmental factors and the distribution of birds [7]. However, the utility or GIS functionality in the management of the above areas has been limited by the restrictions inherent in overlaying of digital information maps. Some of these restrictions are as follows: (1) overlays are difficult to use when there are many underlying variables (more than 4), (2) the overlay procedure does not enable one to take into account that the underlying variables are not of equal importance [8]. From the 1990s, integration of the MCE approach with GIS for solving spatial planning problems has received considerable attentions among urban planners. The ability of GIS to integrate with the MCE approach has been shown in studies related to site determination for a nuclear waste facility [9] and for a noxious waste facility [10]. And the GIS-based MCE has also extended to solving planning problems that involve conflicting multi-objectives such as land use allocation problems [8, 11, 12]. MCE seems to be applicable to GIS-based land suitability analysis [13] and help us to carry out the delineation of suitable areas for crops [10, 14, 15]. The maize is one of the most important grain crops in China, playing a crucial role in protect food security [16]. The main goal of this research is to study the change of the suitable areas for the maize with the GIS-based MCE in current climate condition and the future climate condition, using the climate data from National Climate Center and the soil data from Institute of soil Science in Nanjing.

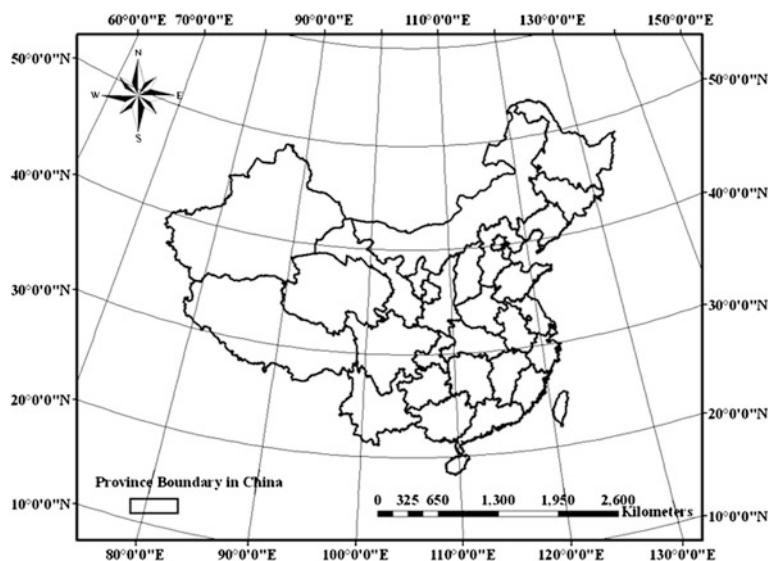


Fig. 1 Study area

2 Methods

2.1 Study Area

The study area throughout the land of China, include mainland of China, Hong Kong Special Administrative Region, the Macao Special Administrative Region, and Taiwan Province. It is located between latitude $3^{\circ}52'N$ and $53^{\circ}33'N$ and longitude $73^{\circ}40'E$ and $135^{\circ}2'30'E$. The total area is approximately $9,600,000 \text{ km}^2$ [17] (Fig. 1).

2.1.1 Procedures

The distribution and growth of crops are decided by water, temperature, light, and soil, according to the leading dominant (the main factor affecting the growth of maize), incompatibility (the factor affecting the maize independence), diversity (selected factors were significantly different and can express the threshold), and marketability (factors which be chosen have a corresponding data) [18]. In light of expert opinions, as well as literatures, eight factors, which are closely connected with the growth of maize, were selected to establish the relevant criteria of MCE. They were as follows: accumulated temperature, average temperature in April which was regarded as the minimum temperature, the average temperature in July

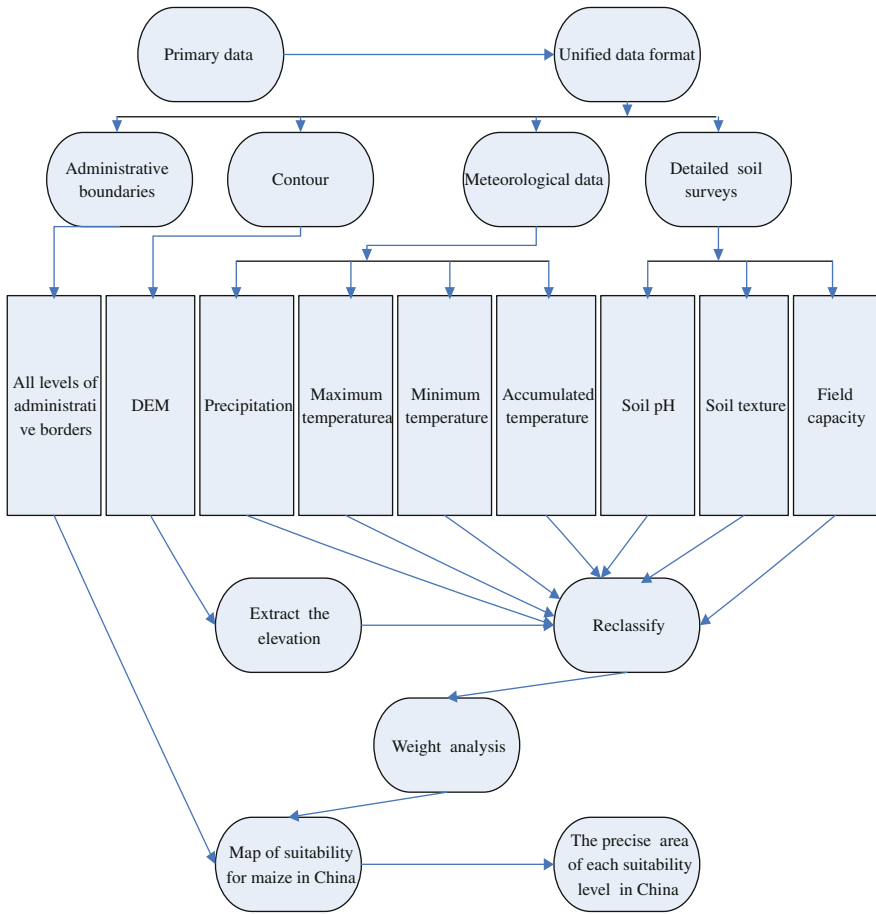


Fig. 2 Flow chart shows the main procedures applied in this study

was the maximum temperature, the annual precipitation, soil texture, soil pH, elevation, and field water-holding capacity. Then, the database was established (Fig. 2).

2.1.2 Establish of Spatial Databases

Climate Database

Climate data from the simulation with regional climate model by National Climate Center, including the control experiments data of the twentieth century (1961–1990) and the forecast tests data of twenty-first century (2071–2100). The format of the original data was text, calculated with the R software; the daily

Table 1 Mean relative errors (MRE) results of four interpolation methods

	IDW	OK	SP	TR
Accumulated temperature	0.142731	0.101632	0.175351	0.147622
Minimum temperature	0.162719	0.151387	0.189255	0.157697
Maximum temperature	0.085669	0.069609	0.098144	0.102951
Precipitation	0.077262	0.449331	0.477557	0.3924253

average data of 30 years were obtained. Based on these data, annual accumulated temperature ($\geq 10\text{ }^{\circ}\text{C}$), the minimum temperature, the maximum temperature, and the annual precipitation were extracted and calculated separately. Convert the data to grid in ArcGIS9.2, extract by point, and then interpolate the temperature data and the precipitation data with the kriging and the IDW method. Before interpolation for the spatial data, compare the accuracy of various interpolation is necessary. 90 % percent of the points were used as the training points while the others were test points, and use mean relative error (MRE) between the measured (Z_{oi}) and the value after interpolation to test the results of the inverse distance weighting (IDW), ordinary kriging (OK), spline (SP), and trend surface (TR). The formula is as follows (Table 1):

$$\text{MRE} = \frac{1}{n} \sum_{i=1}^n \left| \frac{Z_{oi} - Z_{ei}}{Z_{oi}} \right| \tag{1}$$

The results showed that OK was the best interpolation for the temperature and the IDW for the precipitation in this study.

Soil Database

Soil characteristics data were taken from digital Soil Type Maps (from ISSCAS) using a scale of 1:1,000,000. Sampling points was created, and the total number of points was 99,034. The information of soil texture and soil pH was obtained from soil type. Then, the soil texture point data and the soil pH point data were interpolated into grid maps within ArcGIS.

Relief Database

The altitude data were obtained from the digital elevation model (DEM). DEM has characteristics of space location and attribute of terrain, and it is an indispensability part when establishing resource and environment information in different levels [19]. National digital contour map at the scale of 1:250,000 was obtained from the State Bureau of Surveying and Mapping. These contour data were used to create DEM within ArcGIS, and the process was contours \rightarrow TIN \rightarrow lattice \rightarrow DEM.

Unification of the Data Format

All the data were converted to the same format, the spatial resolution was 5,000 m per pixel, the Krasovsky_1940_Albers coordinate system was used as the projected coordinate system, and GCS_Krasovsky_1940 was the geographic

coordinate system. The spheroid of the maps was the Krasovsky_1940, and the datum was D_Krasovsky_1940.

2.1.3 MCE Process for Suitable Areas of Maize in Current and Future Climatic Conditions

Define Specific Suitability Level of the Factors

By means of expert opinion and literatures [20], a specific suitability level per factor for maize was defined (Table 2). These levels were used as a base to construct the criteria maps. The levels were as follows: most suitable, moderate suitable, medium, moderate unsuitable, and unsuitable. Then, factor maps were constructed in the ArcGIS environment.

Weighting for the Factors

A variety of techniques exist for the development of weights, but the promising technique is the pairwise comparison developed by Saaty (1977) in the context of a decision-making process known as the analytical hierarchy process [11]. It has characterized of systematization, flexibility, and practicality. Relative importance of each factor was compared, according to regression between them and final yield of maize, the score of each factor were given, and amend the score with the relationship between them. The comparison of first pairwise matrixes was made. Ratings were provided on a nine-point continuous scale, which ranges from 9 to 1/9. A 9 indicates that relative to the column variable, the row variable is significantly more important. A 1/9 indicates that relative to the column variable, the row variable is significantly less important. Statistics the number of each factor appeared in the literature which described the yield and the distribution of maize, establish another pairwise comparison matrixes. Test two matrix use the CRJ (Matrix Consistency ratio), if the $CRJ < 0.10$ matrix was available; if the $CRJ > 0.10$, we must amend the matrix on the opinion of experts who research the maize. Weight was calculated in the MATLAB software using the pairwise comparison matrixes above (Table 3).

3 Results

Once the factors and constraints maps have been obtained, and the weights of each factor were calculated, the next step was to overlay each factor map by its weight to construct the suitability map for maize in China. These works were conducted with the weighted overlay module in the ArcGIS environment.

Table 2 Suitability level per factor for the maize

	Accumulated temperature (°C)	Precipitation (mm)	Max temperature (°C)	Min temperature (°C)	Soil texture	Soil pH	Elevation (m)	Field capacity
Most suitable	2,500–3,300	500–800	20–25	10–17	Loam	6.5–7.0	<1,200	0.30–0.46
Moderate suitable	3,300–5,000	300–500 or 800–1,500	15–20 or 25–30	17–20	Sand	5.0–6.5	1,200–1,500	0.25–0.30
Medium	5,000–7,000	1,500–2,000	5–15	0–10	Sand clay or loam	7.0–8.0	1,500–3,000	0.23–0.25 or 0.46–0.50
Moderate unsuitable	1,000–2,500	2,000–2,500	>25	>20	Other	<5.0	3,000–3,600	0.18–0.23
Unsuitable	<1,000 or 7,000	0–300	<0	<–5	Clay	>8.0	>3,600	<–0.18 or >0.53

Table 3 Weight of various factors

Factor	Accumulated temperature	Precipitation	Minimum temperature	Maximum temperature	Field capacity	Soil texture	Soil pH	Elevation	Total weight
Weight	0.20948	0.19134	0.141142	0.163879	0.11368	0.075808	0.059333	0.04547	1

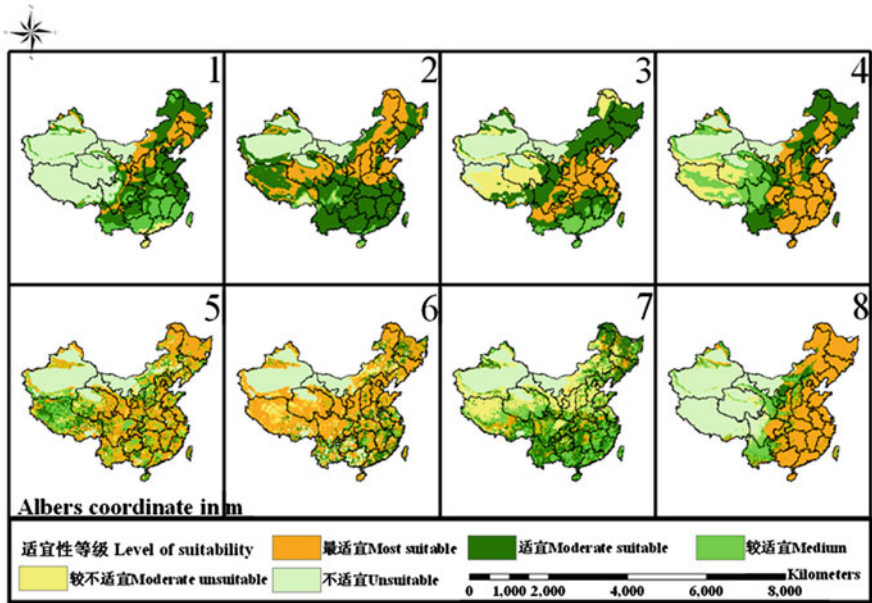


Fig. 3 Factor maps for the maize in current climate condition in China

The maps include suitability levels for each factor. Keys are as follows: (1) accumulated temperature, (2) precipitation, (3) minimum temperature, (4) maximum temperature, (5) field water-holding capacity, (6) soil texture, (7) soil pH, and (8) elevation.

We assume that the terrain and soil conditions remain unchanged. The result (Figs. 3, 4) indicates that under the same classification, (1) the most suitable levels of the accumulated temperature, minimum temperature, and the maximum temperature shift to northward significantly, and the precipitation has inconspicuous deviation to northward, and (2) compared with the accumulated temperature of the current climate condition and the accumulated temperature of the future, all of the China have the trend of becoming warmer in future, but more obvious change appeared in the north.

The results (Figs. 5, 6) identified the most suitability level for maize in current climate condition in China located in the Northeast China Plain, North China Plain, some areas of Ningxia, Gansu, Shanxi, and so on. Statistics show that the areas were approximately $7.82 \times 10^5 \text{ km}^2$. The moderate suitability areas main appeared in the south of ecotone, and it is about $4.53 \times 10^6 \text{ km}^2$. Results of the “Map of suitability for maize in future climate condition in China” indicated that the most suitability level mainly distributed around the Da Hinggan Mountains and the Xiao Hinggan Mountains, and the total area was $8.03 \times 10^5 \text{ km}^2$, showed increasing trend.

The ecotone was the boundary to the influence of climate change (Fig. 7), and decreased suitability levels appeared in the south of ecotone, including Northeast

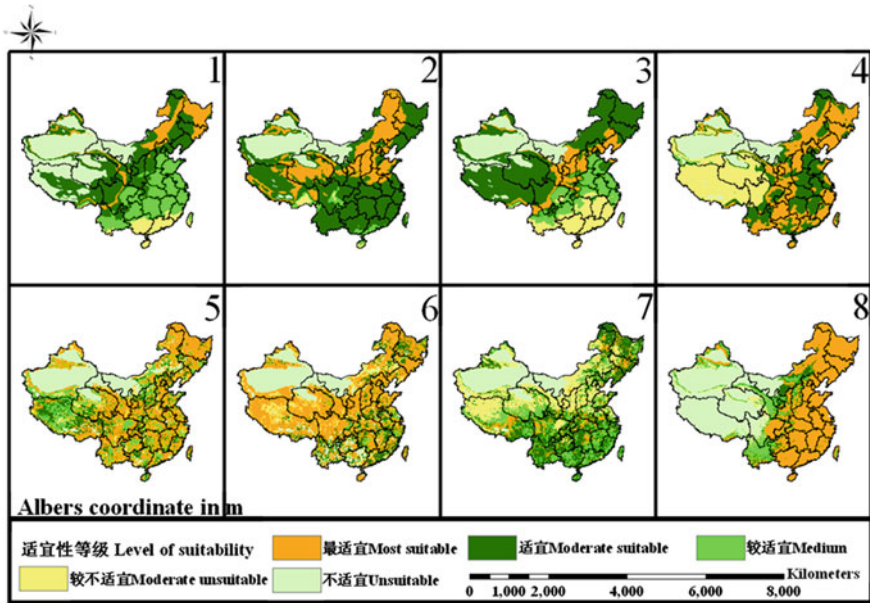


Fig. 4 Factor maps for the maize in future climate condition in China

China Plain, North China Plain, and so on. The increased levels were located in the Qinghai–Tibet Plateau, the Da Hinggan Mountains, the Xiao Hinggan Mountains, the piedmont of Tianshan, and so on. These places will be more appropriate for growth of maize in future. The most suitability level and the moderate suitability level were regarded as the areas of the potential high yield. Table 4 shows change in the areas of the potential high yield in every province from current to future. “+” refers to the increase in areas, “–” the decrease, and “0” means that there was no change in that province. We can find that the areas of the potential high yield were increased for $4.61 \times 10^5 \text{ km}^2$.

4 Discussion

Production and distribution of maize were the result of multifactor effect [21], and the eight factors that have been chosen in this research were the restrictive factor in various stage of maize growth in the natural conditions. Based on the report of Ceballos-Silva et al., the spatial data input, extraction, analysis, and visualization functions of GIS were used to establish the national spatial database of climate, topography, and soil. MCE procedure in this research was useful to evaluate the suitable areas for certain crops. As the first phase of MCE, the factors were selected based on agronomic knowledge of local experts and reviews of existing literature. And then the comparison pairwise matrixes in the context of analytical

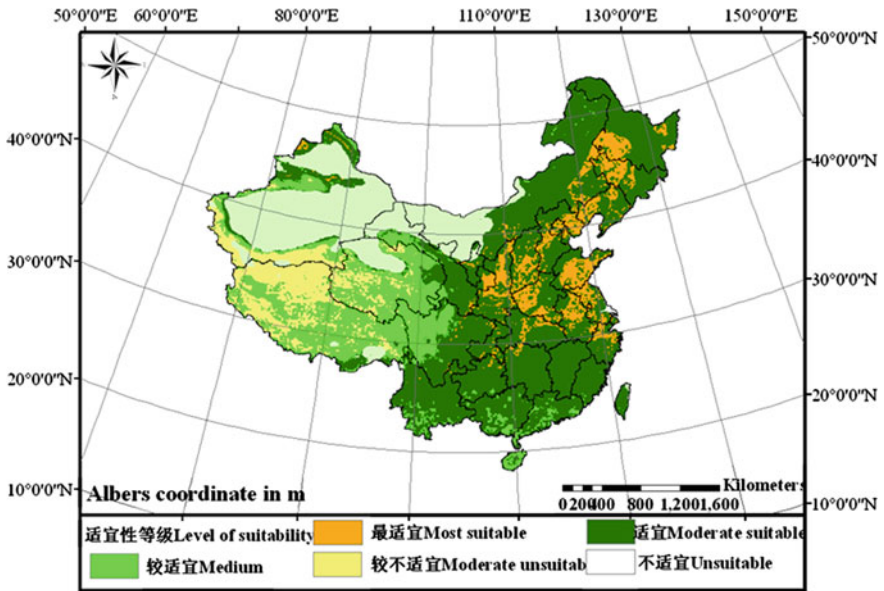


Fig. 5 Map of suitability for maize in current climate condition in China

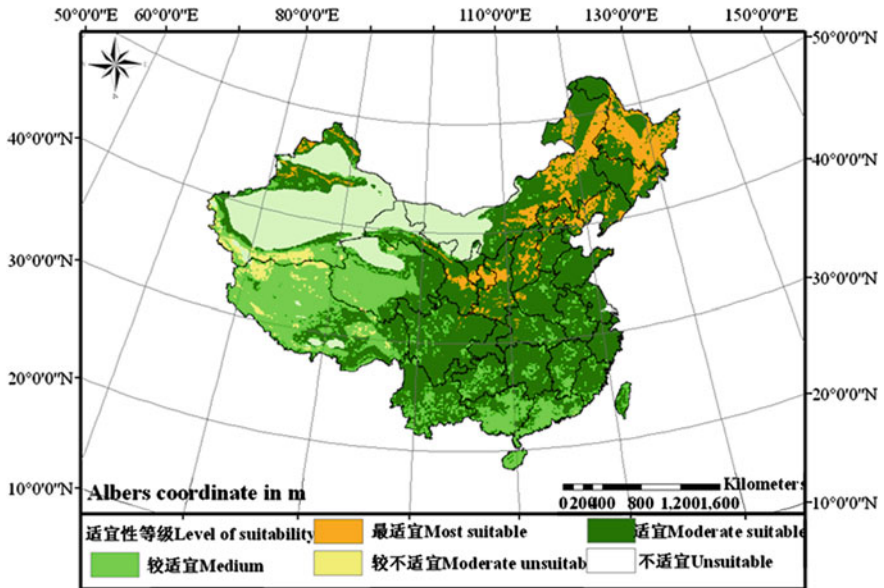


Fig. 6 Map of suitability for maize in future climate condition in China

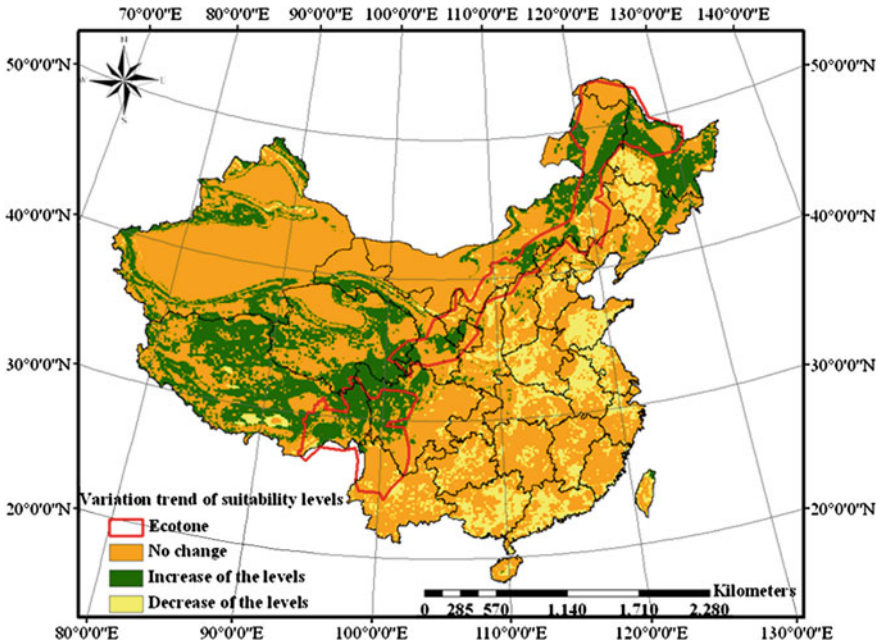


Fig. 7 Map of suitability area change trend for maize in China

hierarchy process was made to obtain the weights and confirmed to be a useful approach. Finally, five suitability levels of maize were divided using the method of GIS-based MCE. The result showed the areas of the potential high yield consistent with the actual distribution of high-yield area, which demonstrated that this method was credible and practical in dividing the suitability levels of the future.

However, the former techniques are merely tools, which provide means to reach a specific objective. Without the knowledge about the study object (crops in this case) and without appropriate databases, such tools would be useless. Climate data in this research were provided by National Climate Center and were simulated by regional climate model (RegCM3) to the control experiments of the twentieth century and the forecast tests of twenty-first century. RegCM3 was improved from RegCM2 by the Abdus Salam International Center for Theoretical Physics in the year of 2003–2004. This model has a higher resolution, could simulate the distribution of temperature and precipitation very well, and provide a higher quality data for the study.

The study based on the application of GIS and MCE method can be compatible with a nice bit of space data such as weather, soil, and geography and analyzed them to distribute the importance of influence on corn growth, kept in the research process from the unilateral of considering a factor or all factor function effect equal in value. In China, the suitability for maize moves toward the north, so the distributing of forest is in the current climate condition replace by grow maize in

Table 4 Analysis the areas of the potential high yield in 32 provinces

Province	The areas of the potential high yield in current climate ($\times 10^5 \text{ km}^2$)	The areas of the potential high yield in future climate ($\times 10^5 \text{ km}^2$)	The areas of the potential high yield changes ($\times 10^5 \text{ km}^2$)
Xizang	0.44	3.17	+2.73
Qinghai	0.49	2.44	+1.95
Xinjiang	2.14	3.80	+1.67
Sichuan	2.81	4.37	+1.57
Gansu	2.00	2.67	+0.66
Neimenggu	8.20	8.36	+0.16
Heilongjiang	4.48	4.48	0.00
Shanghai	0.05	0.05	0.00
Liaoning	1.44	1.44	0.00
Jilin	1.90	1.90	0.00
Beijing	0.16	0.16	0.00
Shanxi	1.57	1.57	0.00
Tianjin	0.12	0.11	-0.01
Shananxi	2.05	2.04	-0.01
Chongqing	0.82	0.81	-0.01
Zhejiang	0.98	0.97	-0.02
Hebei	1.87	1.85	-0.02
Ningxia	0.43	0.40	-0.03
Shandong	1.52	1.48	-0.04
Jiangsu	0.93	0.89	-0.05
Hainan	0.07	0.02	-0.05
Henan	1.65	1.54	-0.11
Taiwan	0.32	0.19	-0.13
Anhui	1.40	1.25	-0.15
Hubei	1.86	1.69	-0.17
Fujian	1.17	0.98	-0.19
Hunan	2.12	1.93	-0.19
Jiangxi	1.67	1.33	-0.34
Guizhou	1.72	1.35	-0.37
Yunnan	3.38	2.90	-0.48
Guangdong	1.36	0.64	-0.72
Guangxi	2.01	0.95	-1.06
Total	53.12	57.73	4.61

the future climate condition, the area increased $4.61 \times 10^5 \text{ km}^2$. Reflected that climate variety lead forest to degeneration or distribute area deviation.

The agriculture manages measure, socioeconomic income, and soil tiny environment, etc. to have the function that cannot underrate to the maize's planting, and collected the data of this date in the further research and carried on an evaluation to the planting of small dimensions scope area first. Later expand a whole country further again

This study was the earlier stage of ecosystem-agriculture valuation management (EAM) information platform technique cooperation work, also be placed in the processing analysis to the static state data up, when environment data of database occurrence variety the whole system need to re-tidy up, its inconvenience links at the Internet, data and handing over of the user's with each other, so at after expect and work in, would emphasized looking for the dynamic state model, finally build up the dynamic valuation management system.

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References

1. Southworth, J., Randolph, J.C., Habeck, M., Doering, O.C., Pfeifer, R.A., Rao, D.G., Johnston, J.J.: Consequences of future climate change and changing climate variability on maize yields in the midwestern United States. *Agric. Ecosyst. Environ.* **82**(1–3), 139–158 (2000)
2. Corbett, J.H.: GIS and environmental modeling: progress research issues. In: Goodchild, M.F., Steyaert, T.L., Parks, O.B. (eds.) pp. 117–122. USA (1996)
3. Belton, V., Stewart, T.J.: *Multiple Criteria Decision Analysis: An Integrated Approach*. Kluwer Academic Publishers, Boston (2002)
4. Barredo, C.J.I.: *Systems Information Geographical Evaluation Multi-Criteria laordenacio n del territorio*. Editorial RA-MA Editorial, Madrid, EsPana (1996)
5. Mendoza, G.A., Martins, H.: Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *For. Ecol. Manage.* **230**(1–3), 1–22 (2006)
6. Jones, P.G., Beebe, S.E., Tohme, J., Galwey, N.W.: The use of geographic information systems in biodiversity exploration and conservation. *Biodivers. Conserv.* **6**, 947–958 (1997)
7. Mariuki, J.N., De Klerk, H.M., Williams, P.H., Bennun, L.A., Crowe, T.M., Berge, E.V.: Using patterns of distribution and diversity of Kenyan birds to select and prioritize areas for conservation. *Biodivers. Conserv.* **6**, 191–210 (1997)
8. Janssen, R., Rietved, P.: *Geographical Information Systems for Urban and Regional Planning*, pp. 129–138. Kluwer press, Dordrecht (1990)
9. Carver, S.J.: Integrating multi-criteria evaluation with geographical information systems. *Int. J. Geogr. Inf. Syst.* **5**(3), 321–339 (1991)
10. Malczewski, J.A.: GIS-based approach to multiple criteria group decision-making. *Int. J. Geogr. Inf. Sci.* **10**(8), 321–339 (1996)
11. Eastman, J.R., Jin, w., Kyem, A.K., Toledano, J.: Raster procedures for multi-criteria/multi-objective decisions. *Photogram. Eng. Sens.* **61**(5), 539–547 (1995)
12. Yeh, W.H., Li, L., Mansuripur, M.: Vector diffraction and polarization effects in an optical disk system. *Appl. Opt.* **37**(29), 6983–6988 (1998)
13. Pereira, J.M.C., Duckstein, L.: A multiple criteria decision-making approach to GIS-based land suitability evaluation. *Int. J. Geogr. Inf. Sci.* **7**(5), 407–424 (1993)
14. Aguilera, H.N.: *Panorama Agriculture Mexicana*, pp. 58–69. De geografía, Mexico (1986)
15. Heywood, I., Oliver, J., Tomlinson, S.: *Innovations of GIS*, pp. 127–136. Taylor and Francis, UK (1995)
16. Huang, H.Q.: The Influence of global food shortage on Chinese economy. *Contemp. Econ.* **7**, 6–7 (2008)

17. Ceballos-silva, A., Lo'pez-blanco, J.: Delineation of suitable areas for crops using a multicriteria evaluation approach and land use/cover mapping: a case study in central Mexico. *Agric. Syst.* **77**(2), 117–136 (2003)
18. Shi, B.S., Wen, Z.P.: The weighted method for the score that experts give. *China Acad. J. Electron. Publishing House* (5), 57–58 (1996)
19. Guo, R., Chen, Y., Wan, F., Li, F., Liu, J., Sun, G.: Delineation of suitable areas for potato in China using a multi-criteria evaluation approach and geographic information system. *Sens. Lett.* **8**(1), 167–172 (2010)
20. Ceballos-Silva, A., Lopez-Blanco, J.: Delineation of suitable areas for crops using a multi-criteria evaluation approach and land use/cover mapping: a case study in Central Mexico. *Agric. Syst.* **95**, 117–136 (2003)
21. Li, Y.Z., Dong, X.W., Liu, G.L., Tao, F.: Effects of light and temperature factors on yield and its components in maize. *Chin. J. Eco-Agri.* **10**(2), 86–89 (2002)