Proceedings of the International Symposium on Conservation and Eco-friendly Utilization of Wetland in the Three Gorges Reservoir

Research on Net Primary Productivity and Its Spatio-temporal Characteristics in the Three Gorges Reservoir Area (Chongqing Section) During 1998 to 2007*

LI Yue-chen[1,2,3], JIAN Tai-min[1], HE Zhi-ming[1], HU Xiao-ming[1]
(1. College of Geography and Tourism, Key Laboratory of GIS Application, Chongqing Normal University, Chongqing 400047;
2. Chongqing Institute of Meteorological Science, Chongqing 401147; 3. School of Civil Engineering
Architecture and Construction, Chongqing Jiaotong University, Chongqing 400074, China)

Abstract: Based on the CASA model, we report a remote sensing estimation of net primary productivity (*NPP*) during 1998 to 2007, using SPOT/VGT NDVI data, vegetation-type coverage, as well as meteorological and other data, and we analyze its spatio-temporal characteristics. Results show that: 1) the volatility of *NPP* during 1998 to 2007 drops on the whole. 2) Seasonal variation of *NPP* during 1998 to 2007 shows the following regularity: summer (675.705 gC · m^{-2}) > spring (368.2 gC · m^{-2}) > autumn (207.944 gC · m^{-2}) > winter (49.495 gC · m^{-2}). In summer, the maximum value of *NPP* (1 022.173 gC · m^{-2}) occurred in 2000; the minimum value of *NPP* (318.321 gC · m^{-2}) occurred in 2006. 3) *NPP* values in the research region varied between 184.8 and 515.548 gC · m^{-2} during 1998 to 2007. High values were mainly distributed in northeast Chongqing, such as Wuxi, Wushan, Fengjie, and in south east Chongqing, such as Shizhu, Wulong and others. Low values were distributed in Zhongxian, Fuling and most of the main urban areas. 4) The highest productivity per unit area was found in regions of broad-leaved forests. Productivity was progressively lower in the following vegetation classifications: bush fallow and irrigated grass vegetation, coniferous forest vegetation, grassy marshland, aquatic vegetation, and water area.

Key words: Three Gorges Reservoir area (Chongqing section); *NPP*; spatio-temporal characteristics
Chinese Library Classification: X171.1 **Documet Code**: A **Artide ID**: 1672-6693(2012)03-0156-07

Earth's biosphere and ecological system is the material basis of human survival and development. Vegetation is an important constituent of land ecological systems, and plays an important role in regional climate change and the global carbon cycle[1-3]. Vegetative net primary productivity (NPP) refers to the accumulation of plant organic matter per unit area and unit time; "net" refers to the deduction of autotrophic respiration from total photosynthesis in obtaining this measure[4-5]. *NPP* is an important component of the carbon cycle of Earth's surface. It not only directly reflects the productive capacity of vegetative communities in natural environmental conditions and thereby characterizes the quality of the terrestrial ecological system, but it also acts as the main factor that adjusts the carbon sink of the ecological system and regulates ecological processes[6]. Describing the patterns of spatial variation of *NPP* is therefore of vital significance for the evaluation of terrestrial ecological systems, understanding the regulation of ecological processes, and estimating carbon sinks on land. As a result, many domestic and foreign scholars have conducted research on *NPP*[7-9].

The Three Gorges Reservoir Area (TGRA) is lo-

---

* **Received**: 03-27-2012
Foundation: Open Foundation of Chongqing Meteorological Administration(No. kfji-201103); the Foundation of Chongqing Colleges and Universitiea InnovationTeamsin Resouree Environment and Ecological Construction: the Foundation of Chongqing Geography Key Discipline.
First author biograghy: LI Yue-chen, male, professor, doctor, he mainly focuses on natural resources environmental remote sensing and GIS.

cated on the Yangtze River and is the throat of an ecological barrier in the Yangtze River watershed. Complex natural conditions together with complex social and economic characteristics determine its ecological and geographic importance. In terms of functional ecology, the region is a special area in China because it is an ecological barrier of national significance with respect to the environmental safety of the Yangtze River basin. It is clear that research on this region has vital theoretical and practical significance. However, research in this field to the present time has mainly examined static conditions, and has rarely focused on dynamic spatial and temporal changes in *NPP*. So in order to illustrate the response of the TGRA vegetation to local and global change, we used the CASA model to estimate *NPP* within the TGRA during 1998—2007 and to analyze its dynamic space-time characteristics.

1 Study Area

The TGRA of Chongqing is located in the upper reaches of the Yangtze River (105°49′ ~ 110°12′E; 8°31′ ~ 31°44′N). The southeast and northeast parts of the study area are at the junction of Chongqing with Hubei, the southwest is bound by Sichuan and Guizhou, and the northwest is adjacent to Sichuan and Shanxi. The area studied includes 22 districts and counties (including autonomous counties) of Chongqing and covers 46 158.53 km^2 with a total population of 19 235 000 (of whom 12 432 400 are agricultural) at the end of 2009[10].

The area is characterized by a humid subtropical monsoon climate. Spring comes early and the autumn late; winter is warm and the summer hot. The annual average temperature is 15 ~ 18° C, with high annual and daily range of air temperature. Average annual precipitation is 1 150.26 mm, unevenly distributed spatially. The TGRA of Chongqing crosses three major tectonic units: the Dabashan fold belt, east Sichuan fold belt, and the uplift fold belts of Sichuan, Hebei, Hunan and Guizhou. The landform consists of mountains and hills. The main types of soil are purple, yellow, yellow brown, brown, lime, alluvial, paddy, and others[11]. The zonal vegetation is subtropical evergreen broadleaved together with warm coniferous forest. The TGRA is a special area functionally from an ecological economic perspective in China and the world. The Chongqing part of the TGRA accounts for 80% of the total, illustrating Chongqing's eco-economic significance.

2 Data

The information used in this analysis came from three main sources: meteorological data, remote sensing data, and vegetation cover classification. Meteorological data were mainly derived from temperature and rainfall records at 35 Chongqing meteorological sites, together with ground radiation data at a central site and its four surrounding sites. The data included monthly total precipitation, monthly mean temperature, monthly total radiation, monthly net radiation, along with elevation and geodetic coordinates. Remote sensing data came from Western China Environment and Ecological Science Data Center (http://westdc.westgis.ac.cn) of the National Natural Science Foundation Commission, SPOT/VEGETATION S10 ten-day East Asia vegetation normalized index products which have spatial resolution of 1 km, and dates from 1998 to 2007. Chongqing vegetation cover classification figure data were obtained by scanning the vegetation type map of the Chongqing atlas, followed by geometric correction and rectification, vectorization, and then combining its 36 fine classes into 8 classes.

3 Methods

In this research, the CASA model is a model of an ecological process. *NPP* is mainly determined by two variables: light and effective radiation which is absorbed by plants (*APAR*) and the light energy utilization ratio (ε).

$$NPP(x,t) = APAR(x,t) \times \varepsilon(x,t) \qquad (1)$$

where, t is time, x is spatial location, $APAR(x,t)$ is the photosynthetically active radiation which is absorbed by pixel x during t month. $\varepsilon(x,t)$ is the actual light energy utilization rate of pixel x during t month.

3.1 Estimation of *APAR*

The photosynthetic absorption of available radiation (*APAR*) depends on the sun's total radiation and the proportion of radiation that is absorbed by vegetation (*FPAR*). FPAR can be determined by the normalized difference vegetation index (*NDVI*) and vegetation type.

$$APAR(x,t)=SOL(x,t)\times FPAR\times 0.5 \qquad (2)$$

where, $SOL(x,t)$ is the total amount of solar radiation at pixel x during t month; $FPAR(x,t)$ is the proportion of available radiation that is absorbed by the vegetation layer; the constant 0.5 is the proportion of the sun's effective radiation that can be used by vegetation (wavelengths between 0.38 and 0.71 μm). In a certain range, there is linear relationship between *FPAR* and *NDVI* (Ruimy and Saugier, 1994). The linear relationship can be determined by the maximum and minimum value of a certain vegetation type and the maximum and minimum value of *FPAR*.

$$FPAR(\mathrm{x,t})=\frac{\mathrm{NDVI(x,t)}-\mathrm{NDVI}_{min}}{\mathrm{NDVI}_{max}-\mathrm{NDVI}_{min}}\times (FPAR_{\max}-FPAR_{\min})+FPAR_{\min} \qquad (3)$$

Where, $NDVI_{\min}$ and $NDVI_{\max}$ correspond to *NDVI* maximum and minimum values of vegetation type i. This can be calculated by band calculation, using ENVI software. The values of $FPAR_{\min}$ and $FPAR_{\max}$ are 0.001 and 0.95, and have no relationship with vegetation type[13].

3.2 Estimation of the light energy utilization efficiency

The accurate estimation of light energy utilization efficiency (ε) is a key factor to simulate productivity in the CASA model. The authors have confirmed that the maximum light energy utilization efficiency of vegetation ($\varepsilon_{\max}$) exists under ideal conditions, but different vegetation has its own light energy utilization efficiency[14], which is related to temperature, water, soil, individual plant growth and some other factors. Therefore, it is unscientific to regard ε as a worldwide constant. We therefore obtained simulative results by applying the eco-physiological process model BIOME-BGG of Running et al.[15] to 10 types of vegetation (Tab. 1). The global monthly average maximal light energy utilization rate of aquatic vegetation, water and other ecological systems is 0.389 gC · MJ^{-1} which is calculated by the CASA model.

Tab. 1 Vegetation types and corresponding parameters of maximum light energy utilization gC · MJ^{-1}

vegetation form	highest light energy utilization rate ($\varepsilon_{\max}$)
evergreen coniferous forest	1.008
broad-leaved evergreen forests	1.259
deciduous conifers	1.103
broadleaved deciduous forest	1.044
mixed forest	1.116
fallen leaves, hedges and savannas	0.768
sparse shrubs	0.774
Elfin forest thickets	0.888
grasslands	0.608
Farm vegetation	0.604

Under actual conditions, ε can be affected by temperature and water. It can be expressed as follows:

$$\varepsilon(x,t)=T_{\varepsilon 1}(x,t)\times T_{\varepsilon 2}(x,t)\times W_{\varepsilon}(x,t)\times\varepsilon_{\max} \qquad (4)$$

Where, $T_{\varepsilon 1}(x,t)$ and $T_{\varepsilon 2}(x,t)$ are the coercive effects of low and high temperature on light energy utilization. These can be calculated by Potter's method [16] using optimum temperature and monthly average temperature. $W_{\varepsilon}(x,t)$ is the water coercion impact factor, which reflects the influence of moisture conditions on the light energy utilization rate of vegetation. $W_{\varepsilon}(x,t)$ gradually increases along with the increase of effective moisture in the environment. Its value range is 0.5 (under extreme drought conditions) to 1 (under extraordinarily wet conditions). More complex parameters were needed when using the CASA model to calculate the water stress factor. So in this work we used the real evapo-transpiration and potential transpiration model that has been put forward by Chinese scholars to simulate the water stress factor, according to the actual situation in China. The computational formula is[17]:

$$\omega_{\varepsilon}(x,t)=0.5+0.5\times EET(x,t)\div PET(x,t) \qquad (5)$$

Where $EET(x,t)$ is the actual evapo-transpiration value. Most of these can be calculated by the regional actual evapo-transpiration model of Guangsheng Zhou, using monthly total rainfall data and a net radiation factor. *PET* (*x*, *t*) is the potential evapo-transpiration quantity, which can be calculated by the Thornthwaite method [18-19], using monthly average sunshine duration and average rainfall data.

4 Analysis of Results

4.1 Annual features of *NPP*

From 1998 to 2007, the variation in annual average *NPP* per unit area of vegetation showed a downward trend (Fig. 1). High values appeared in the years 2000, 2003 and 2005. In these years, the average *NPP* was 356.083 gC · m^{-2}, 357.163 gC · m^{-2} and 445.234 gC · m^{-2}, respectively. Among these three years, the peak *NPP* value occurred in 2005. Relatively low values appeared in years 1999, 2004 and 2006. The average *NPP* per unit area of these three years were 323.957 gC · m^{-2}, 261.506 gC · m^{-2} and 243.242 gC · m^{-2}, respectively, among which the lowest was in 2006. High values appeared in the years 2000, 2003 and 2005 because there were no big meteorological disasters in those years, and plants grew well because light, heat, and precipitation were relatively well-distributed. The lower values can be related to a disastrous flood in 1999; while in 2004 the study area experienced the heaviest rainstorm since 1982, which resulted in poorer light, heat and water conditions. In 2006, the study area experienced unusually high temperatures, which were associated with reduced precipitation and enhanced evapo-transpiration, which therefore reduced *NPP*.

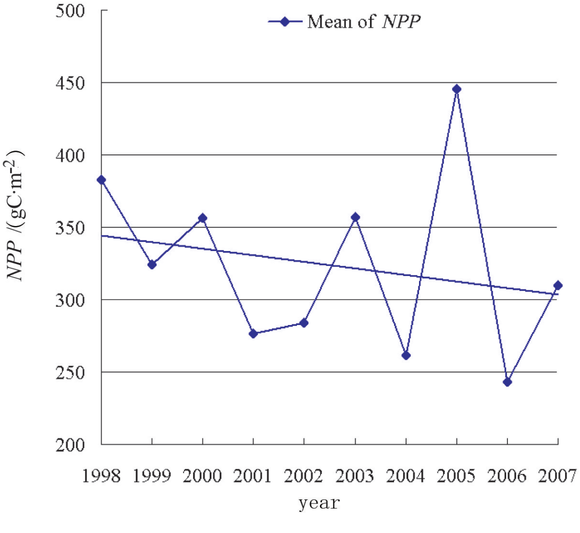

Fig. 1 *NPP* annual variability

4.2 Seasonal features of *NPP*

Calculations of the seasonal variation of the vegetative *NPP* in the study area from 1998 to 2007, as shown in Fig. 2, reveal that the average productivity per unit area in summer (from June to August), 675.705 gC · m^{-2} > the productivity in spring (from March to May), 368.2 gC · m^{-2} > the productivity in fall (from September to November), 207.944 gC · m^{-2} > the productivity in winter (December, January and February), 49.495 gC · m^{-2}. The climatic factors which are used to estimate the *NPP* (rainfall, radiation, temperature and illumination) are all highest in summer and lowest in winter, and this leads to the seasonal variation of *NPP*. Notable seasonal features of *NPP* in the studied ten years were as follows. 1) In summer, the maximum value (1 022.173 gC · m^{-2}) appeared in 2000, and the second highest value (985.491 gC · m^{-2}) appeared in 2005. The minimum value (3 18.321 gC · m^{-2}) appeared in 2006, which was due to the uneven distribution of light, heat, and available water caused by the high temperatures in that year in Chongqing. 2) In Spring, the fluctuation pattern was similar to that of summer, but the wave is less pronounced and annual differences less clear. The maximum value (516.306 gC · m^{-2}) appeared in 2005, which contributed to 2005 having the highest total *NPP* in the ten year span studied. The minimum value (221.827 gC · m^{-2}) appeared in 2006. 3) In fall, the fluctuation pattern was also somewhat similar to those in summer and spring, although with relatively small differences among years. The maximum value (374.585 gC · m^{-2}) appeared in 2000. 4) In winter, there were no big differences among years. The maximum value (140 gC · m^{-2}) appeared in 2006. In the winter of 2006, the high temperature and drought of that year were over, and precipitation promoted the growth of vegetation. Relatively suitable light, heat and water meant that winter growth contributed more than usual to annual *NPP*.

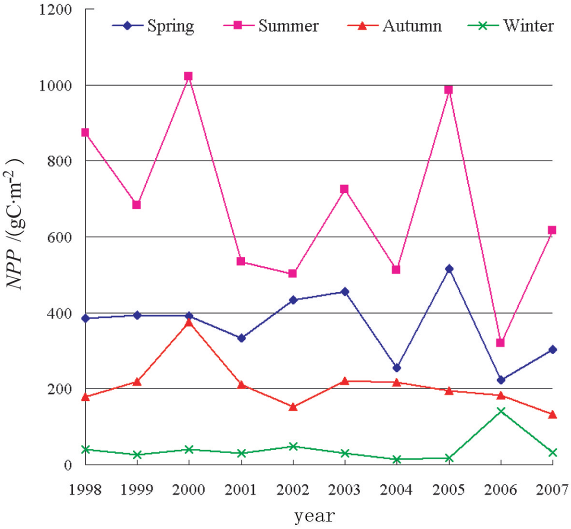

Fig. 2 *NPP* seasonal variability

4.3 Spatial features of *NPP*

Based on the statistics of annual *NPP* from 1998 to 2007, the authors have prepared three maps: annual average *NPP* distribution, ten-year average *NPP* distribution, and ten-year seasonal variation (shown in Fig. 3,4). The average annual *NPP* from 1998 to 2007 in the studied area ranges from 184.8 gC m^{-2} to 515.548 gC · m^{-2}. The maximum value appeared in Wuxi, Wushan and Fengjie counties in the northeast of Chongqing, and Shizhu and Wulong counties in the southeast. Mountainous vegetation cover type and high degree of vegetation cover in these areas are key reasons for the appearance of these maximum values. Minimum values appeared in Zhong county, Fuling county and the main urban areas. In these places, large areas of cultivated lands and city construction land reduce the utilization of light energy, which is important in the estimation of *NPP*. From 1998 to 2000, regions with high *NPP* values were located in Wuxi county, Wushan county and Fengjie county; while regions with low values were mainly located in Zhong county and Changshou county. From 2001 to 2003, regions with high *NPP* values declined relative to 1998–2000 in Wuxi and Wushan counties, but increased in the counties of Fengjie, Yunyang, Shizhu, Wulong, and Wanzhou district. Obvious areas with low *NPP* appeared on both sides of the Yangzi River. From 2004 to 2007, the high-value *NPP* regions in Wuxi, Wushan and Fengjie counties were relatively reduced, but increased gradually in Wulong and Shizhu counties. Low *NPP* regions became fewer in Fuling District, Zhong county and Wulong county.

4.4 Differentiating characteristics of *NPP* according to vegetation types

NPP values of different vegetation cover types within the study area are shown in Tab. 2. The productivity per unit area of broad-leaved forest vegetation is the highest each year, followed by thickets and irrigated grass, coniferous forest vegetation, meadows, and aquatic vegetation. The productivity per unit area of open water areas is the lowest. Because of the larger leaf area, the absorptive capacity of evergreen broad-leaved forest vegetation is strong, so its *NPP* per unit area is the highest. Due to their dense spread, thickets and irrigated grass vegetation have somewhat better absorptive capacity for illumination and moisture. Because of relatively sparse branches and leaves, and low leaf area index, the *NPP* of coniferous forest vegetation is lower than that of thickets and irrigated grass, although it benefits from well developed root systems. Aquatic areas are less affected by temperature, precipitation, and illumination than other ecosystem types, and have the lowest *NPP* values. The productivity per unit area of cultivated land and economic forests are low relative to the potential capacity of these lands, which is mainly due to the combined actions of harvesting of crops, cultivation of land, and damage to root systems, leaf area, limbs, and other factors. Nevertheless, because it covers the largest total area, cultivated land has the greatest contribution to total *NPP* in the study area. All eight of these types of vegetative cover reached their maximum values in the year 2005. This shows that the collaborative conditions of optimum light, heat and water corresponded with the highest *NPP* in all kinds of vegetative cover. Similarly, the eight types of cover all reached their minimum values in 2006 due to high temperatures and drought, which led to synergy of minimal conditions of light, heat, water. The annual changes in all kinds of vegetation cover follow a similar pattern over the years, except for 2007 when the *NPP* of open water areas was a little higher than that of aquatic vegetation.

Tab. 2 Average productivity of vegetation classes in the Chongqing TGRA, 1998 – 2007

Vegetation classes	Water area /(gC · m^{-2})	coniferous forest /(gC · m^{-2})	broad-leaved forest /(gC · m–2)	thickets and irrigated grass /(gC · m–2)	meadow /(gC · m^{-2})	aquatic vegetation /(gC · m^{-2})	cultivated land /(gC · m^{-2})	economic forest /(gC · m^{-2})
Area/km^2	728	9 897	4 923	1 448	1 622	42	26 911	590
1998 年	261.47	387.48	520.50	428.06	351.73	294.36	336.44	329.72
1999 年	219.95	331.87	445.12	355.02	311.06	249.93	283.30	273.05
2000 年	231.47	369.85	494.34	409.74	361.84	272.09	303.92	292.19
2001 年	194.50	295.25	393.27	317.17	277.33	210.20	248.74	249.16
2002 年	198.62	303.76	409.39	331.77	273.37	212.62	254.47	251.19
2003 年	234.22	385.17	509.34	423.70	370.89	289.10	318.67	319.11
2004 年	178.29	261.69	334.26	298.06	246.05	187.06	229.89	243.33
2005 年	294.48	463.86	594.01	474.64	444.41	322.95	387.81	380.19
2006 年	155.88	254.17	342.72	281.10	246.11	180.76	206.77	198.92
2007 年	213.58	323.53	455.98	343.11	284.16	202.17	267.15	261.25

5 Discussion and Conclusions

The TGRA (Chongqing section) has an important eco-geographic position. The condition of the natural environment of this area relates directly to the safety of the Three Gorges project, the ecological security of the whole Yangzi River watershed, and the sustainable socio-economic development of the region. In this study we have examined the eco-geographic significance of the study area and the limitations of previous research. On the basis of the CASA model, using remote sensing and weather data, we have estimated the *NPP* of vegetation from 1998 to 2007. The quantitative outputs reveal the spatial and temporal features and characteristics of the vegetative *NPP*. The results show the following. 1) The change of annual vegetative *NPP* from 1998 to 2007 shows a downward trend in the study area. 2) The seasonal variation of averaged *NPP* shows that summer (675.705 gC · m^{-2}) > spring (368.2 gC · m^{-2}) > fall (207.944 gC · m^{-2}) > winter (49.495 gC · m^{-2}). In summer, the peak value (1 022.173 gC · m^{-2}) appeared in 2000, and the lowest value (318.321 gC · m^{-2}) appeared in 2006. 3) Annual *NPP* was distributed between 184.8 gC · m^{-2} and 515.548 gC · m^{-2}. Peak values appeared in relatively forested areas such as Wuxi county, Wushan county and Fengjie county of the northeast Chongqing, and Shizhu county and Wulong county of southeast Chongqing. Lowest values appeared in the areas like Zhong county, Fuling county and major urban areas. 4) Variation in annual productivity per unit area of vegetation is in the order, highest to lowest: broad-leaved forest > thickets and irrigated grass > coniferous forest > meadows and aquatic vegetation.

The estimation of some parameters reported in this paper may have errors due to inevitable limitations imposed by using the present CASA model, the complexity of the terrain and climate conditions of the study area, and that the period studied is only ten years. Nevertheless, despite the probable errors, the findings reported in this paper can reflect the geographical spatial pattern as well as the annual and seasonal features of the *NPP* of the study area. Future study will focus on improving the precision of estimation of the CASA model parameters, extending the time sequence, simulating and forecasting the trends in vegetative productivity of the TGRA, helping to establish an effective ecological-environment protection mechanism, and laying the foundation for improving the quality of the natural environment of the TGRA.

References:

[1] Braswell B H, Schimel D S, Linder E, et al. The response of global terrestrial ecosystems to inter-annual temperature variability[J]. Science, 1997, 278: 870-872.

[2] Cao M K, Li K R. Perspective on terrestrial ecosystem-climate interaction [J]. Advances in Earth Sciences, 2000, 15(4): 446-452.

[3] Hou Y Y, Liu Q H, Yan H, et al. Variation trends of China terrestrial vegetation net primary productivity and its responses to climate factors in 1982-2000[J]. Chinese Journal of Applied Ecology, 2007, 18(7): 1546-1553.

[4] Walker B, Steffen W L. The terrestrial biosphere and global change: Implications for natural and managed ecosystems: A synthesis of GCTE and related research [R]. Stockholm, Sweeden: IGBP Book, 1997.

[5] Zheng L Y, Zhang J H. Research advances in the evaluation and estimation of grassland Net Primary Production [J]. Transactions of the Chinese Society of Agricultural Engineering, 2007, 23(1): 278-285.

[6] Field C B, Behrenfeld M J, Randerson J T, et al. Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components[J]. Science, 1998, 281: 237-240.

[7] Cao M K, PrinceS D, Small J, et al. Remotely sensed interannual variations and trends in terrestrial net primary productivity 1981-2000[J]. Ecosystems, 2004, 7: 233-242.

[8] Ricotta C, Avena G, De Palma A. Mapping and monitoring net primary productivity with AVHRR NDVI time-series: statistical equivalence of cumulative vegetation indices[J]. International Society for Photogrammetry and Remote Sensing (ISPRS) Journal of Photogram, Remote Sensing, 1999, 54(5/6): 325-331.

[9] Gao Z Q, Liu J Y. Simulation study of China' s net primary production[J]. Chinese Science Bulletin, 2008, 53(3): 317-326.

[10] Chongqing Municipal Bureau of Statistics. Chongqing statistical yearbook 2008. Beijing: China Statistics Press, 2010.

[11] Liu C X, Li Y C, Yang H, et al. RS and GIS-based assessment for eco-environmental sensitivity of the Three Gorge Reservoir area of Chongqing[J]. Acta Geographica Sinica, 2011, 66(5): 631-642.

[12] Zhu W Q, Pan Y Z, Zhang J S. Estimation of net primary productivity of Chinese terrestrial vegetation based on remote sensing [J]. Chinese Journal of Plant Ecology, 2007, 31(3): 413-424.

[13] Dong D, Ni J. Modeling changes of net primary productivity of karst vegetation in southwestern China using the CASA model[J]. Acta Ecologica Sinica, 2011, 31(7): 1855-1866.

[14] Zhu W Q, Chen Y H, Pan Y Z et al. Estimation of Light Utilization Efficiency of Vegetation in China Based on GIS and RS[J]. Geomatics and Information Science of Wuhan University, 2004, 29(8): 694-698.

[15] Running S W, Thornton P E, Nemani R, el al. Global Terrestrial Gross and Net Primary Productivity from the Earth Observing System[J]. Sala O, Jackson R, Mooney H. Methods in Ecosystem Science. NewYork: Springer Verlag, 2000, 44-57.

[16] Potter C S, Randerson J T, Field C B, et al. Trrrestrial ecosystem production: A process model based on global satellite and surface data[J]. Global Biogeochemical Cycles, 1993, 7: 811-841.

[17] Piao S L, Fang J Y, Guo Q H. Application of CASA model to the estimation of Chinese terrestrial net primary productivity[J]. Chinese Journal of Plant Ecology, 2001, 25(5): 603-608.

[18] Zhang X S. The potential evapotranspiration (PE) index for vegetation and vegetation-climatic classification (2) - an introduction and PEP program[J]. Acta Phytoecologica Sinica, 1989, 13(3): 197-207.

[19] Liu X Y, Li Y Z, Wang Q S. Evaluation on several temperature-based methods for estimating reference crop evapotranspiration[J]. Transactions of the Chinese Society of Agricultural Engineering, 2006, 22(6): 12-18.

(Editors: Martin WILLISON, OU Hong-ye)
(English Translator: LI Yue-chen)