An integrated GIS-based analysis system for land-use management of lake areas in urban fringe

Yong Liu a, Xiaojian Lv a, Xiaosheng Qin b, Huaicheng Guo a,∗, Yajuan Yu a, Jinfeng Wang a, Guozhu Mao a

a College of Environmental Sciences, Peking University, Beijing 100871, China
b Faculty of Engineering, University of Regina, Regina, Sask., Canada S4S 0A2

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Abstract

Lake areas in Chinese urban fringes are under increasing pressure of urbanization. Consequently, the conflict between rapid urban sprawl and the maintenance of water bodies in such areas urgently needs to be addressed. An integrated GIS-based analysis system (IGAS) for supporting land-use management of lake areas in urban fringes was developed in this paper. The IGAS consists of modules of land-use suitability assessment and change/demand analysis, and land evaluation and allocation. Multicriteria analysis and system dynamics techniques are used to assess land-use suitability and forecast potential land-use variation, respectively. Cost approximation and hypothetical development methods are used to evaluate land resource and market values, respectively. A case study implementing the system was performed on the Hanyang Lake area in the urban fringe of Wuhan City, central China, which is under significant urbanization pressure. Five categories of suitability were investigated by analyzing 11 criteria and related GIS data. Two scenarios for potential land-use changes from 2006 to 2020 were predicted, based on a systematic analysis and system dynamics modeling, and a hierarchical land-use structure was designed for the conservation of aquatic ecosystems. The IGAS may help local authorities better understand and address the complex land-use system, and develop improved land-use management strategies that better balance urban expansion and ecological conservation.

Keywords: Land-use suitability assessment; Land-use allocation; GIS; Multicriteria analysis; Lake area

1. Introduction

Chinese cities have experienced rapid population growth and continuous expansion in recent years, resulting in considerable and sustained demand for land resources. The urban lake areas of China, often located in urban fringes, are ideal locations for recreational activities and the maintenance of ecological diversity. Lake area is often defined as the area with several lakes and the water systems among the lakes. However, rapid urbanization has imposed significant pressure on the land-use structure, and terrestrial and aquatic ecosystems, of these areas. Meanwhile, there is still a lack of integrated land-use planning for such areas, leading to many serious socio-economic and eco-environmental consequences, such as disorganized urban development and allocation of land-use types, over-consumption of land and/or water resources, and incomplete civil and environmental infrastructures. In coming years, rapid urbanization in China is expected to place an increased burden on urban land use, especially on fringe areas. Therefore, comprehensive studies should be advanced to support land-use management of the lake areas in urban fringes.

Over the past years, studies of land-use management were mainly conducted within watershed and regional contexts (Ren, 1997; Wang et al., 2004), focusing on urban area (Rossi-Hansberg, 2004; Svoray et al., 2005), agricultural area (Lopez et al., 1994; Carsjens and van der Knaap, 2002; Klocking et al., 2003), forest land (Ells et al., 1997; Sharawi, 2006) and land-use allocation of farming and forestry land (Riveiro et al., 2005). A number of innovative approaches were applied in land-use management, covering land-use suitability assessment, land-use change forecasting, land evaluation and land-use allocation. In the field of land-use suitability assessment, GIS techniques are acknowledged to be a powerful tool as implied by recent stud-
ies (Pereira and Duckstein, 1993; Bojorquez-Tapia et al., 2001; Collins et al., 2001; Joerin et al., 2001; Phua and Minowa, 2005). Collins et al. (2001) reviewed the application of GIS-based methods in land-use suitability analysis in the United States, and grouped them into computer-assisted overlay mapping, multicriteria analysis method (MCA) and artificial intelligence method. Alshuwaikhat and Nassef (1996) introduced a spatial decision support system for urban land-use management of City Beish in Saudi Arabia; the system included a potentiality model for urban development as well as a land-use suitability model and an assignment model for land-use allocation; the study verified the successful application of GIS techniques and indicated that a comprehensive approach was necessary for land-use management.

In the field of land-use change/demand forecasting, a number of methods were used, including system-dynamics modeling, scenario analysis, input–output design, land-transformation simulation and neural networks prediction (Fischer and Sun, 2001; Pijanowski et al., 2002; Yu et al., 2003; He et al., 2005; Tang et al., 2005). Pijanowski et al. (2002) proposed a land transformation model for forecasting land use changes in Michigan’s Grand Traverse Bay Watershed, coupling with GIS and artificial neural networks; the results indicated that a variety of social, political and environmental factors was necessary for forecasting land-use change. He et al. (2005) developed an integrating system dynamic (SD) and cellular automata model for forecasting land-use scenario changes of northern China in the next 20 years, and suggested that the SD model was suitable for analyzing the complex behavior of land-use systems at different scales. In the field of land evaluation, more and more researchers have viewed integrated land evaluation as an aid to land-use management, where economic value as well as direct and indirect land values was addressed (Sui, 1992; Johnson et al., 1994; Rossiter, 1996; Lopez et al., 1994; Ells et al., 1997; Mcdonald, 2001). In the field of land-use allocation, Klocking et al. (2003) developed a GIS-based model for spatial allocation of crop schemes in the Thuringian Basin of Germany. Wang et al. (2004) proposed a GIS-based inexact-fuzzy multi-objective programming for land allocation in Lake Erhai Basin, China and confirmed the efficiency of applying GIS in land-use management. Many other approaches were also employed in previous studies for dealing with the allocation problems in land-use management, such as fuzzy allocation of forest land in British Columbia (Ells et al., 1997), cost-benefit investigation on decision making for local land-use allocations (Mcdonald, 2001) and integer linear programming for multi-site land-use allocations (Aerts et al., 2003).

In spite of above achievements, there is still a lack of studies on integrated land-use management systems of lake areas under rapid urbanization. The special features of lake areas at urban fringes, such as the discord between rapid urban expansion and maintenance of natural water bodies and ecological services, make the management of these areas unique. In addition, successful land-use management strategies aim to examine complex land-use systems and provide decision makers with important information on land-use suitability assessment, potential change forecasting and corresponding allocation results (Alshuwaikhat and Nassef, 1996). Any single method will not be effective for land-use management of lake areas. A comprehensive method and analysis system is essential for tackling the problems of land-use management.

In this respect, an integrated GIS-based analysis system (IGAS) will be developed in this study for supporting land-use management of lake areas in urban fringes. The IGAS covers land-use suitability assessment, land-use change and demand analysis, and land evaluation and allocation. GIS and multicriteria analysis (MCA) were integrated for suitability assessment, and system dynamics models are used for forecasting possible land-use changes. A cost approximation method (CAM) and hypothetical development method (HDM) are used to evaluate land resource value and territorial market value, respectively. A three-step procedure is proposed for land-use allocation, which includes excluding restricted areas, allocating the remaining land and testing the allocation results. The Hanyang Lake area of Wuhan City in central China was selected for a case study.

2. Methodology

Land-use management of lake areas is a multi-component and multidisciplinary process that requires more than a single method for successful results. Thus, an integrated GIS-based analysis system (IGAS) was developed in this study for a more efficient and scientific management of such areas from a holistic point of view. IGAS consists of land-use suitability assessments, system analysis of potential land-use change and demand, and land evaluation and corresponding allocation for lake areas under urbanization (Joerin et al., 2001; Carsjens and van der Knaap, 2002; Phua and Minowa, 2005; Svoray et al., 2005). The detailed framework is shown in Fig. 1. The proposed IGAS may better reflect the complex, dynamic and integrated characteristics of land-use management systems, and thus make management more practical.

2.1. MCA and the GIS-based land-use suitability assessment

The suitability assessment is a fundamental step in regional land-use management (Mcdonald and Brown, 1984). It can be defined as the identification of the most appropriate spatial pattern for future land use according to specified requirements, preferences or predictions of certain activities (Stoms et al., 2002; Malczewski, 2004). Land-use suitability assessment has developed from hand-drawn and sieve mapping to expert knowledge replication under a variety of situations (Collins et al., 2001). In land-use suitability assessment, human use information and physical data are essential basic sources (Roberts et al., 1979). Many data sources were employed, including spatial satellite images, land-use maps, administrative zoning information, vegetation distribution and socio-economic statistical information. The Arc/Info system was applied for spatial data management.

In addition, because the suitability of any assessment unit depends on the demands on the specific type of land use, the goals for the land-use suitability assessment can be obtained.
through stakeholder interviews and policy analysis. Thus, land-use suitability assessment is a multicriteria decision-making problem, and we used an MCA method for classifying and weighting criteria. The MCA method is particularly useful when there are large numbers of criteria (Carsjens and van der Knaap, 2002). Since the 1990s, the combination of MCA and GIS has been promoted for use in solving spatial problems in urban planning, forest conservation and site determination (Phua and Minowa, 2005). In land-use suitability assessment, alternative options and preferences for land use can be determined using MCA, through the identification of desirable objectives, related attributes and criteria, such as social, economic, environmental and ecological factors. Quantitative analysis is necessary for MCA, including scoring, ranking and weighting. A single conclusion is produced after the quantitative analysis. The main steps in MCA for land-use suitability assessments include defining the objectives and the corresponding judgment criteria, analyzing the criteria, assessing the standards, quantitatively analyzing the criteria for the assessment units and aggregating the judgments (Malczewski, 2004, 2006).

There are several steps in a land-use suitability assessment (Fig. 2) (Svoray et al., 2005). In this study, spatial satellite images, land-use maps and administrative zoning information were first digitally input into the GIS, then overlaid with each other. The minimum assessment unit was confirmed based on the above information, and saved in the GIS spatial database. The grids near lakes were 100 m × 100 m and, in other areas, were 200 m × 200 m. The MCA was then introduced. The assessment criteria and the corresponding transforming standards were listed following the literature reviews and discussions with researchers and local experts. An MCA technique, analytical hierarchy process (AHP), was applied to formulate the assessment system (Saaty, 1980; Zeleny, 1982). MAC can combine both geographical data and stakeholders’ preferences into unidimensional values for alternative decisions (Malczewski, 2004). Local experts on land resources, water resources, environmental
protection, aquatic ecology, commerce, urban planning, geology and social development were invited to fulfill the pair-wise comparisons for developing the weighting matrix. The weight \( W_i \) of each criterion was calculated by the AHP model. Finally, the total score of land-use suitability for one assessment unit \( S_i \) was calculated using the following equation:

\[
S_i = \sum_{i=1}^{n} W_i P_i
\]

where \( P_i \) represents the transformed value of each criterion based on the corresponding standards, and \( n \) represents the number of criteria. The values of \( P \) for each unit were input into the GIS attribute database and could be displayed or output from the database.

2.2. System analysis of potential land-use changes

Land-use management in lake areas must consider a wide variety of factors, such as population increases, economic development and demand for land resources, as well as geological characteristics, surface landforms and water levels. All of these factors are dynamic, and thus land-use management models must not only consider these factors simultaneously, but forecast any potential changes in these factors.

The lake area was divided into four logical subsystems for analysis in this study: the population, economic, current land use and environmental subsystems. The relationships among these subsystems are complex. The increasing population and urbanization will undoubtedly result in more demand for residential areas, living space, leisure and landscape. The expansion of industry and the adjustment of economic structure will also lead to increases in demand for industrial and commercial land, civil engineering, financial services and sports. Agricultural land will be reduced to make way for urban sprawl. All of these changes will lead to more pollution being discharged into aquatic systems. The demand for ecological conservation of aquatic and terrestrial ecosystems is the main reason that grasslands are increasing.

The following steps were used to predict the potential land-use changes in the lake area: system analysis; subsystem partitioning; identifying potential land-use changes, such as population increases, governmental policies affecting urbanization and urban planning; and changes in economic structure and magnitude and the corresponding demands for various land types; model construction based on the previous step; model verification, validation and sensitivity analysis; and drafting and investigating scenarios (Guo et al., 2001). A system dynamics (SD) model for land-use management of lake areas was constructed based on the above system analysis. The fourth-order Runge–Kutta method was applied to this model for the purpose of integration.

(1) Social subsystem

\[
RP(t) = RP(t - dt) + (GR_\text{RP} \cdot AGR_{\text{RP}} - UR_{\text{RP}}) \cdot dt
\]

Urban population:

\[
UP(t) = UP(t - dt) + (UP \cdot NGR_{UP} + AMP \cdot f_{\text{AMP}} + UR_{\text{RP}}) \cdot dt
\]

(2) Economic subsystem

\[
GDP = GDP_1 + GDP_A + GDP_{SI}
\]

Agricultural GDP:

\[
GDP_A(t) = GDP_A(t - dt) + GDP_A \cdot GR_A \cdot dt
\]

Industrial GDP:

\[
GDP_I(t) = \sum_{i=1}^{m} GDP_{I_i}(t)
\]

\[
= \sum_{i=1}^{m} (GDP_{I_i}(t - dt) + GDP_{I_i} \cdot GR_{I_i} \cdot dt)
\]

Service industrial GDP:

\[
GDP_{SI}(t) = \sum_{j=1}^{n} GDP_{SI_j}(t)
\]

\[
= \sum_{i=1}^{m} (GDP_{SI_j}(t - dt) + GDP_{SI_j} \cdot GR_{SI_j} \cdot dt)
\]

where \( GDP_A(t) \) represents the agricultural GDP at time \( t \) (million US$), \( GDP_I(t) \) the industrial GDP at time \( t \) (million US$), \( GDP_{SI}(t) \) the service industrial GDP at time \( t \) (million US$), \( GDP_{I_i}(t) \) the \( i \)th industrial GDP at time \( t \) (million US$), including food, textile, chemical, refinery, medical and other industry types according to the statistical classes in China, \( GDP_{SI_j}(t) \) represents the \( j \)th service industrial GDP at time \( t \) (million US$), including commerce, communication, educational service, finical service, architectural service, tourism and transportation service, \( GR_A \) the annual net increasing rate of GDP \( A \) (%), is a function of intrinsic increasing rate and the decreasing rate of farmland.
area, GR_{it}, the annual net increasing rate of GDPI_{it} (%) and GR_{Si}, the annual net increasing rate of GDPSi_{it} (%).

(3) Land-use subsystem

Total land-use demands:

\[ TLD(t) = \sum_{i=1}^{k} LA_i(t) \]  

(9)

Industrial land area:

\[ LA_i(t) = \sum_{i=1}^{m} LA_{il}(t) = \sum_{i=1}^{m} (LA_U(t - dt) + \Delta GDP_{Si} f_{ILSi}) \]  

(10)

Residential land area:

\[ LAR(t) = LAR(t - dt) + \Delta UP f_{LR} - LARR \]  

(11)

Grassland area:

\[ LA_G(t) = LA_G(t - dt) + LA_G f_G \]  

(12)

Service industrial land area:

\[ LA_Si(t) = LA_W(t) + LA_C(t) + LA_T(t) + LA_U(t) + LA_D(t) \]  

\[ = \sum_{j=1}^{n} LA_{Si}(t) \]  

\[ = \sum_{j=1}^{n} (LA_{Si}(t - dt) + \Delta GDP_{Si} f_{ILSi}) \]  

(13)

where TLD(t) is the total land-use demands for urban expansion at time t (ha), LA_{it}(t) means the area of the {i}th land-use type at time t (ha), LA_{it}(t) the industrial land-use area at time t (ha), LA_{il}(t) the {i}th industrial land-use area at time t (ha), \Delta GDP_{Si} the increasing amount of {i}th industrial GDP from time t - dt to t (million U$), f_{ILSi} the factor between {i}th industrial GDP and land-use demand (ha 10^{-6} U$), f_{LR} the increasing rate (%) which is decided by the objective grassland ratio in the total urban area, LA_{it}(t) the area of public facilities land, storage land, transportation land, municipal utilities and specific-purpose land (ha), LA_{St}(t) the service industrial land-use area at time t (ha), LA_{St}(t) the {j}th service industrial land-use area at time t (ha), \Delta GDP_{Si} the increasing amount of {i}th service industrial GDP from time t - dt to t (million U$), f_{ILSi} the factor between {i}th service industrial GDP and land-use demand (ha 10^{-6} U$), LA_{it}, LA_{jt}, LA_{Ut} and LA_{Dt} are also affected by industrial development and population increasing.

(4) Environmental subsystem

Domestic wastewater:

\[ DS = UP AD_{UP} 365 \times 10^{-6} + VP AD_{VP} \times 10^{-6} \]  

(14)

Non-point sources:

\[ NPS = \sum_{k=1}^{t} LA_k C_{LA_k} \]  

(15)

Atmospheric deposit:

\[ PAD = PPS + PSS = RC_A W \times 10^{-5} \times SC_S A_W \times 10^{-9} \]  

(16)

where DS means the domestic pollutants discharging into the water systems in the lake area (tonnes year^{-1}) and the pollutants often refer to chemical oxygen demand (COD), total phosphorus (TP) and total nitrogen (TN); DS means the industrial pollutants discharging into the water systems in the lake area (tonnes year^{-1}); AD_{UP} is the average pollutants discharge for one urban population 1 day (g day^{-1}); VP is the visiting population (person); AD_{VP} is the average pollutants discharge for one urban population 1 day (g day^{-1}); NPS is the pollutants from the different land-use types in the lake area (tonnes year^{-1}); LA_{it} is the area of {i}th industrial land-use type in Eqs. (8)–(12); C_{LA_{it}} is the pollutants losing amounts of {i}th industrial land-use type (tonnes year^{-1} ha^{-1}); PAD is the pollutants from atmospheric deposition (tonnes year^{-1}); PPS is the pollutants in the precipitation (tonnes year^{-1}); PSS is the pollutants in the dust sinking (tonnes year^{-1}); R is the rainfall in the area (mm a^{-1}); C_{i} is the average pollutant concentration in the rain (g m^{-3}); A_{W} is the water area (ha); S is the atmospheric dust settling directly from the lake surface (kg ha^{-1} year^{-1}); C_{i} is the average pollutant concentration in the atmospheric sinking (mg kg^{-1}); F_{ID} is the pollutants discharging for one unit GDP_{i} (tonnes 10^{-6} U$).

2.3. Land evaluation procedure

Land values will affect land-use management, especially for areas under urbanization. Land values provide a reasonable way to compare the various use potentials of land and land uses. Some methods that can be used for land evaluation (FAO, 1976; Sui, 1992; Johnson et al., 1994; Lopez et al., 1994; Rossiter, 1996; Ells et al., 1997; AQSIQ, 2001b; Mcdonald, 2001; Wu, 2003) include capitalization of earnings, the market data approach, the hypothetical development method, the cost approximation method and the base land price valuing method. The land evaluation process for a lake area can be divided into several steps, including identifying the stakeholders and objectives, defining the evaluation units; collecting and integrating the basic data, build evaluation methods and models for land evaluation, and computing the evaluation and calibrating the results (FAO, 1976).
Before land-use allocation analysis, land evaluation was conducted, the cost approximation method (CAM) and hypothetical development method (HDM) were used to evaluate land resource value and land market value, respectively (AQSIQ, 2001b). The land resource value often includes the cost of land acquisition, transfer/construction of civil facilities and profit (Wu, 2003), and may be formulated as follows:

$$V_{LR} = C_{LR} + C_{TC} + C_{TI} + P$$  \hspace{1cm} (18)

where $V_{LR}$ is land resource value, $C_{LR}$ the cost of land acquisition, $C_{TC} + C_{TI}$ is the cost of transfer and construction of civil facilities and $P$ is the profit.

Market values can be calculated using the following equation:

$$V_{LM} = V_T - C_T - P$$  \hspace{1cm} (19)

where $V_{LM}$ is market value, $V_T$ the total value and $C_T$ is the total development cost (AQSIQ, 2001b). $V_T$ for undeveloped areas was ascertained based on analogies with the value of developed areas with the same land-use suitability as the undeveloped areas.

2.4. GIS-based land-use allocation

Land-use allocation is an important part for land-use management. The allocation results in spatial and temporal scales can be useful for local decision making on future lands arrangements, optimal management and ecological protection of the lake riparian area. The procedures of conducting a GIS-based land-use allocation based on land-use sustainability assessment and land evaluation are described as follows: (a) excluding the restricted areas in the GIS system, such as those protected by legal requirements, natural conservation zones, important habitats and riparian areas (Carsjens and van der Knaap, 2002). The restricted areas will be protected strictly and should not be allocated for any other land-use types other than grassland, forests or ecological land. (b) Allocating the remaining land according to the results of sustainability assessment, potential land-use changes and evaluation. Then a balance of land-use demand and supply will be calculated. The land-use demands are from the SD model mentioned above. The potential amounts of the land area for supply result from the land-use sustainability assessment. The stakeholders and the administrative offices on land-use management will then be invited for the primary land-use allocation after the discussion on the above results. A quantitative allocation will be decided on spatial layout in the GIS system. (c) Testing and validating the allocation results. A quantitative comparison among the land-use demand and supply will be conducted for checking sustainability. The results will be used for validation. A feedback mechanism will be established for the land-use allocation based

![Fig. 3. The Hanyang lake area.](image-url)
on the above analysis. Any inappropriate allocations will be adjusted.

3. Case study

3.1. Description of the study area

The city of Wuhan, and its sub-district Hanyang, located in the central part of China, have sufficient water resources. The Hanyang lake area is located between 113°40’E and 114°16’E and 29°58’N and 30°33’N, with a total area of 122.6 km² (Fig. 3), and comprises six lakes and several rivers. The population density, urbanization level and economic growth in the area are much lower than those in other parts of Wuhan City. Urban land occupies 45.74% of the total area of Hanyang (Tables 1 and 2), and there is plenty of room to accommodate for more urban sprawl. The areas of the six lakes (from H1 to H6) are 0.0755, 0.66, 1.53, 3.16, 2.77 and 5.09 km², respectively. The corresponding volumes are 0.076 × 10⁶, 0.792 × 10⁶, 2.14 × 10⁶, 4.74 × 10⁶, 3.60 × 10⁶ and 7.64 × 10⁶ m³. The average depths of the six lakes are 1.0, 1.2, 1.4, 1.5, 1.3 and 1.5 m.

According to the Wuhan Urban Planning (1996–2020), authorized by the China central government in 1997, Hanyang will become a new focus for urbanization over the next several years. Currently, the lake area is suffering from disorganized land-use, reduced water quality and water area, and degraded aquatic ecosystems. In recent years, the land-use structure in this area has changed rapidly, with most of the riparian areas being exploited without taking appropriate conservation precautions. Pollution levels have reached an estimated 292,000 tonnes day⁻¹, from mainly domestic, industrial and agricultural non-point sources. The current average Secchi disk reading is 0.25 m. The average total nitrogen (TN) concentrations of the six lakes (from H1 to H6) in 2005 are 4.16, 3.71, 12.58, 17.90, 8.13 and 56.42 mg/L. The governmental requirement of the TN concentration in the six lakes is 1.5 mg/L. Therefore, a comprehensive land-use management study is desired for the period 2006–2020. The aim of the study was to assess future land-use suitability, analyze and forecast potential land-use demands, and evaluate land-use values. The results, including some suggestions on land allocation and management in the upcoming years, may help the local government better understand and manage land-use.

3.2. GIS-based land-use suitability assessment

Several factors may affect land-use suitability in Hanyang. The dense distribution of water systems in the area has resulted in a high subsurface water table and high possibility of flooding. The groundsill is also affected. Urban water systems play important roles in providing ecological habitats and supporting recreational activities, thus it is critical for the ecological and landscape effects be accounted for in the process of land-use suitability assessment. Also, location is important for urban land assessment. After literature reviews and discussions with researchers and local experts in 2004, the criteria for land-use suitability assessment in the Hanyang lake area were selected from a long list that included natural and ecological attributes, socio-economic conditions and location factors (Wu, 2003). The AHP method was used to calculate the weights of criteria, including pair-wise comparisons and weighting matrix establishment (Fig. 4). The 11 criteria (L1–L11) used are shown in Fig. 4 as below: L1 as bearing capacity of foundation soil (kg cm⁻²), L2 as geographical disaster, L3 as groundwater depth (m), L4 as flood-submerged conditions (difference of surface-water and flood level), L5 as ecological sensitivity, L6 as distance from water (m), L7 as population density (person km⁻²), L8 as land-use degree, L9 as environmental quality, L10 as business services impact degree and L11 as transportation accessibility. The relative importance of the criteria through pair-wise comparisons was obtained by consulting and surveying the opinions of experts (Ramanathan, 2001). Twenty local experts were invited to fill in the pair-wise comparisons to gen-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The areas of different developed urban land-use types in Hanyang lake area in 2005</th>
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</thead>
<tbody>
<tr>
<td>Land-use type</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>Residential land (R)</td>
<td>1080.33</td>
</tr>
<tr>
<td>Public facilities land (C)</td>
<td>618.14</td>
</tr>
<tr>
<td>Public grass (G)</td>
<td>270.67</td>
</tr>
<tr>
<td>Industrial land (M)</td>
<td>2550.07</td>
</tr>
<tr>
<td>Storage land (W)</td>
<td>196.56</td>
</tr>
<tr>
<td>Transportation land (T)</td>
<td>18.1</td>
</tr>
<tr>
<td>Municipal utilities (U)</td>
<td>71.58</td>
</tr>
<tr>
<td>Ecological land (E)</td>
<td>772.22</td>
</tr>
<tr>
<td>Specific-purpose land (D)</td>
<td>26.53</td>
</tr>
<tr>
<td>Total</td>
<td>5604.2</td>
</tr>
</tbody>
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<tr>
<th>Table 2</th>
<th>The different land-use types of the regions near the six lakes in 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land-use</td>
<td>Lake Yue</td>
</tr>
<tr>
<td>Residential land (R)</td>
<td>15.74</td>
</tr>
<tr>
<td>Public facilities land (C)</td>
<td>17.94</td>
</tr>
<tr>
<td>Public grass (G)</td>
<td>7.96</td>
</tr>
<tr>
<td>Specific-purpose land (D)</td>
<td>18.14</td>
</tr>
<tr>
<td>Industrial land (M)</td>
<td>4.06</td>
</tr>
<tr>
<td>Storage land (W)</td>
<td>2.15</td>
</tr>
<tr>
<td>Transportation land (T)</td>
<td>12.38</td>
</tr>
<tr>
<td>Municipal utilities (U)</td>
<td>4.73</td>
</tr>
<tr>
<td>Ecological land (E)</td>
<td>7.79</td>
</tr>
</tbody>
</table>
erate the weighting matrix in October 2004, which is shown in Table 3.

The measured values of criteria were transformed into values \( (P_i) \) ranging from 0 to 100. The standards for transformation of criteria L1–L9 are shown in Table 4 (SEPA and AQSIQ, 1995; AQSIQ, 2001a; Wu, 2003), and those for L10 and L11 were decided from two sources, namely, The commercial development planning 1999–2020 and The planning for commercial distribution in Wuhan, issued by Wuhan municipal government in 1998.

The total score of the land-use suitability assessment for each assessment unit were obtained via Eq. (1). The results were inputted into the GIS, and five categories of land-use suitability in the Hanyang lake area were obtained (Fig. 5). As shown in Fig. 5, category I is suitable for residential land, financial services and some service industries with high value added \( (S \geq 74) \). Category II is suitable for other service industries and residential land with \( S_f \in [53,74) \). Category III is suitable for residential or storage land with \( S_f \in [45,53) \). Category IV is suitable for industrial land with \( S_f \in [30,45) \) and category V is suitable for grassland or ecological land with \( S < 30 \) (Wu, 2003).

Land near water areas is often a priority for urban expansion, as it has a relatively high utility value added in addition to its desirability of an enhanced visual landscape. As shown in Fig. 5, among the six lakes in the study area, Lake Lianhua and Lake Yue are located near the downtown area of Wuhan City, resulting in high suitability for land-use development for commercial purposes. The northeast and northwest areas near Lake Moshiu have good location and landscape, increasing their suitability for urban expansion. The conditions amenable to transportation in the north and southeast near Lake Moshiu make these areas suitable for residential housing and related commerce. The south part of Lake Moshiu is unsuitable for urban expansion in the short term due to poor conditions of local transportation, civil facilities and water quality. Of the total land area near Lake Longyang, 10.74% can be used for immediate urban expansion, due to good location and transportation conditions (Table 5). However, the land to the west and south of Lake Longyang are not suitable for urban development, due to their high subsurface water table and the weak bearing capacity of foundation soil. Currently, agriculture is the main land-use type in Lake Sanjiao and South Lake Taizi, as these areas are comparatively far from downtown, and have poor transportation, a high subsurface water table, and weak ground capacity. This indicates that they are not suitable for urban development in the next few years.

### 3.3. Scenarios for potential land-use changes

A SD model was constructed for the study area, containing 185 parameters and formulations. Two scenarios were predicted for the period 2006–2020 based on the system dynamics model, described above. Scenario I predicts land-use changes under...
Table 4
The transforming standards for the criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Standards for transforming values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–20</td>
</tr>
<tr>
<td>L1</td>
<td>0–0.9</td>
</tr>
<tr>
<td>L2</td>
<td>Deep sullage</td>
</tr>
<tr>
<td>L3</td>
<td>0–0.5</td>
</tr>
<tr>
<td>L4</td>
<td>&lt;−6 m</td>
</tr>
<tr>
<td>L5</td>
<td>Highly susceptible</td>
</tr>
<tr>
<td>L6</td>
<td>800–1000</td>
</tr>
<tr>
<td>L7</td>
<td>0–1000</td>
</tr>
<tr>
<td>L8</td>
<td>Hard to use</td>
</tr>
<tr>
<td>L9</td>
<td>Seriously polluted</td>
</tr>
</tbody>
</table>

Fig. 5. Result of land-use suitability assessment for Hanyang lake area.

the present developmental mode, while scenario II considers impacts of local policies on urbanization, and modification of economic structure.

Under scenario I, the population increases at its current rate of 0.72%. Tourism, trade and commerce, and vehicle manufacture become the main economically important industries. The expansion of the urban area in scenario I will result in a rapid increase in land used for industry, grassland residents and public facilities (Table 6; Fig. 6). By 2020, the total area of urban expansion will increase to 100.31 km², of which industrial land will be 54.05% of the total, followed by residential land (20.33%). The percentage of land used for public facilities will be only

Table 5
The areas of different land-use suitability near the six lakes

<table>
<thead>
<tr>
<th></th>
<th>I (ha)</th>
<th>II (ha)</th>
<th>III (ha)</th>
<th>IV (ha)</th>
<th>V (ha)</th>
<th>Water area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Lianhua</td>
<td>11.11</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>9.97</td>
</tr>
<tr>
<td>Lake Yue</td>
<td>–</td>
<td>80.90</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>64.70</td>
</tr>
<tr>
<td>Lake Moshui</td>
<td>–</td>
<td>125.38</td>
<td>380.31</td>
<td>115.46</td>
<td>–</td>
<td>306.19</td>
</tr>
<tr>
<td>Lake Sanjiao</td>
<td>–</td>
<td>–</td>
<td>247.03</td>
<td>101.08</td>
<td>248.57</td>
<td></td>
</tr>
<tr>
<td>Lake Longyang</td>
<td>–</td>
<td>76.63</td>
<td>296.32</td>
<td>218.15</td>
<td>–</td>
<td>122.56</td>
</tr>
<tr>
<td>South Lake Taizi</td>
<td>–</td>
<td>–</td>
<td>131.54</td>
<td>434.68</td>
<td>121.90</td>
<td>495.45</td>
</tr>
</tbody>
</table>

Note: ‘−’ means there is no such land-use suitability near the targeted lake.
Table 6
The model outputs for the Hanyang lake area (2005–2020)

<table>
<thead>
<tr>
<th>Variable</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario I</td>
<td>Scenario II</td>
<td>Scenario I</td>
<td>Scenario II</td>
</tr>
<tr>
<td>GDP (10^4$)</td>
<td>302,601</td>
<td>789,775</td>
<td>864,649</td>
<td>1,263,058</td>
</tr>
<tr>
<td>GDP_A (10^4$)</td>
<td>2,345</td>
<td>2,823</td>
<td>3,169</td>
<td>3,279</td>
</tr>
<tr>
<td>GDP_I (10^4$)</td>
<td>254,845</td>
<td>713,038</td>
<td>739,089</td>
<td>1,140,413</td>
</tr>
<tr>
<td>GDP_SI (10^4$)</td>
<td>45,412</td>
<td>73,915</td>
<td>122,391</td>
<td>119,429</td>
</tr>
<tr>
<td>TPA</td>
<td>893,804</td>
<td>923,879</td>
<td>939,397</td>
<td>957,621</td>
</tr>
<tr>
<td>COD (tonnes year(^{-1}))</td>
<td>24759.6</td>
<td>39711.05</td>
<td>18300.3</td>
<td>42562.47</td>
</tr>
<tr>
<td>TP (tonnes year(^{-1}))</td>
<td>138.91</td>
<td>224.03</td>
<td>93.09</td>
<td>239.17</td>
</tr>
</tbody>
</table>

11.68%. The high percentage of industrial land will lead to low economic efficiency. The dense distribution of industry in the Hanyang Lake area will also pose significant pressures on local transportation, public facility construction and housing. In scenario I, there will be 9.71 km\(^2\) of grassland, which is 9.78% of the total urban area, and which does not meet the target goal of 15% set by the Ministry of Construction, China.

Table 6 shows that the urbanization level in scenario II is higher than that in scenario I. The population increases at a rate of 1.0%. High value-added agriculture, tourism, trading and commerce, and high-tech industry will be encouraged in the area. The corresponding land-use changes and urban expansion are different from those in scenario I (Table 6; Fig. 6). By 2020, the total area of urban expansion will have increased to 110.16 km\(^2\), of which industrial land will be 30.77% of the total. The percentage of residential land will be 26.38%. The percentage of grassland will be 20.84%, meeting the target goal. In scenario II, the increased area of grassland could contribute to the important principles of ecological restoration. The aquatic system is the core natural ecosystem in the study area. Buffer belts and the riparian ecosystems that feed lakes and rivers are essential for the ecological improvement and maintenance of ecosystem services in the Hanyang Lake area. Under scenario II, the annual increase in industrial land will be restricted to an area of 100 ha, which is lower than in scenario I. In scenario II, the increase in industrial land will also be lower than that of the industrial production value. Economic efficiency is higher than that achieved in scenario I. More residential land is necessary for accommodating the increased population.

A comprehensive assessment of the two scenarios was conducted based on the criteria of GDP, population, land-use structure, ecological effects and the stakeholders’ opinions. The results showed that scenario II was much better than scenario I (Table 6). All the land values and the GDP in this study are all valued in US$ for better understanding. They were converted from the Chinese monetary unit according to the exchange rate of 1–7.90. The GDP in Table 6 are all present values. The conclusion is consistent with that of researchers and local governmental officials. Because it is the better alternative, the land-use allocation analysis discussed in the next section is based on scenario II only.

The above results demonstrated that there will be sustained population increases in both scenarios, as a direct result of urbanization of the local area. The urbanization of the Hanyang Lake area over the next 15 years will impose significant pressures on land use. The GDP in scenario II is US$ 362,997 \(\times 10^4\) more than that in scenario I (Table 6). The discrepancy comes from the adjustment of economic structures, which will also lead to various land-use demands in both scenarios. Less industrial land and more grassland were predicted in scenario II, but the industrial GDP in scenario II was also higher than that in scenario I. The results imply that, for Chinese cities with a great population burden, the main task for local decision makers is to adjust economic structures for minimum land-use consumption to gain...
higher economic benefits. The results also demonstrated that both the pursuit of economic development and the suitable allocation of land resources are critical to the land-use management of the Hanyang Lake area.

### 3.4. Land evaluation

The method of CAM and HDM were applied to evaluate land resource value and land market value of the study area. According to Eq. (18) and the investigation of the study area, the average land resource value is between US$ 65,600 and 97,500 ha⁻¹. According to Eq. (19), the land market values for the five land-use suitability categories, in the order of I–V, were 2.15, 1.64, 1.17, 0.76 and US$ 0.43 million ha⁻¹, respectively.

### 3.5. Land-use allocation results

In the Hanyang Lake area, the lakes and rivers were first excluded, then a hierarchical land-use structure was designed for the remainder of the area. The water area was at the core, and there was a riparian conservation belt with a width of approximately 50–100 m (Osborne and Kovacic, 1993). The total riparian area was 434.5 ha. Restoration of natural wetlands is the main technique for maintaining riparian areas, especially in the estuaries. A buffer belt 30 m wide is constructed around the riparian area, with synchronous landscape designed for residential leisure. The area outside the buffer can be used for residential housing, with a minimum requirement of 30% of the area remaining as grassland.

The land in the study area is allocated on both spatial and temporal scales. According to the suitability assessment, the spatial layout for the land near the six lakes is established based on group discussions between experts and officials (Fig. 7a). Lake Yue and Lake Lanhua have good locations and are suitable for commerce, financial services and tourism based on the ecological conservation of water systems. Industrial development is not allowed in this area. The land to the south and north of Lake Moshui can be used for residential development, while the northeast part can be used for hypo-commercial development. The east part of the land near Lake Longyang is planned for hypo-commercial and low-pollution industrial development. Urban development is prohibited in the hills near Lake Longyang. The land southwest of Lake Longyang will be protected as grassland for its fragile aquatic ecosystem and serious pollution. The lands near Lake Sanjiao are suitable for residential development and for a university campus. The south part of the land near South Lake Tazi is suitable for industrial construction, in consideration of the industrial development planned by the local government. The northeast part of the land near South Lake Tazi is used for leisure services and physical training.

There will also be a numeric allocation of land-use types based on the forecasting of potential land-use changes, suitability assessment and spatial layout. Sixteen sub-regions are allocated based on the above analyses, to better understand the above assessment of land-use suitability (Fig. 7b). From the above analysis and Fig. 6, it can be seen that there will be considerable changes to the structure, spatial layout and area covered by residential land, industrial land and grassland in the study area. The allocation results for the three land-use types are shown in Table 7. Based on a comparison of Table 7 with scenario II, the allocation of grassland, industrial and residential land use can meet land-use demands, regardless of its spatial distribution and numeric magnitude. From Table 7, industrial land will be mainly allocated in zones A, M and O during 2006–2010 and zones L, P and Q during 2011–2020 (Fig. 7b). With the population increasing, the increased demand for residential land will be fulfilled by zones J and M during 2006–2010 and zones J, P and Q during 2011–2020. The ecological objectives of the Hanyang Lake area will be guaranteed by the increase in grassland, mainly in zones J, A, M and O during 2006–2010 and zones J, L, P and Q during 2011–2020. The exploitation of grassland will also be helpful in the maintenance of water systems. The above allocation results provide local decision makers with references for land-use management, both in numerical assignments and in spatial and temporal scales during 2006–2020. The above results demonstrated that the IGAS application can help determine balanced development schemes for ensuring both urban expansion and ecological conservation.

### 3.6. Discussion

In most previous studies, only land-use suitability assessment or land-use allocation were tackled in the land-use management process, which cannot reflect long-term changes in land-use types or the effects of land evaluation on land-use management. The developed IGAS model addresses this problem by integrating land-use suitability assessment, the forecasting of potential land-use change, land evaluation and land-use allocation into a general framework. Integrated, systematic complex, and dynamic characteristics are involved in the proposed IGAS model. In addition, previous studies of land-use management focused mainly on urban areas at a watershed scale, and there are no such studies on lake areas at urban fringes. The dual goals of urban expansion and ecological conservation need to be satisfied in the land-use management process for lake areas, especially for Chinese cities experiencing rapid urbanization. The IGAS model, which focuses on lake areas at urban fringes, involves both the intrinsic processes and the external driving forces of land-use management systems, by considering the special characteristics of lake areas as well as external economic, social and ecological factors.

Criteria selection is essential for land-use suitability assessment. Compared with the criteria used for urban land-use management, including topography, ground conditions, groundwater and geological hazards (Dai et al., 2001), those of lake areas at urban fringes are clearly different. The 11 criteria in this study are associated with the special goals of land-use management for socio-economic and eco-environmental requirements.

The systematic and complex characteristics of land-use systems make system analysis an essential tool for supporting land-use management. According to the two scenarios outlined by the IGAS model in this study, there will be rapid development in the study area. Land-use structure and utilization efficiency...
can be used as important indicators for scenario comparison. The magnitude of industrial land-use is effectively controlled under scenario II, with a reduction of 2000 ha in 2020 compared to scenario I, while at the same time, scenario II has a higher GDP*. In China, under great pressure from population growth and rapid urbanization, it is inevitable for decision makers to try to harmonize the conflicts between economic development and resource utilization. Thus, it is essential to seek more effective methods of land-use management. The total magnitude of land-use for urban sprawl must be limited to a maximum size based on system analysis, forecasting, evaluation and optimal allocation.

Fig. 7. Land-use allocation for Hanyang lake area from 2006 to 2020.
As indicated above, the ecological restoration and protection of water systems in the coming years is an important part of land-use management in the Hanyang Lake area. Thus, a hierarchical land-use structure is proposed in this study for better maintenance of aquatic and riparian ecosystems. The restricted area should be protected, and land with high suitability should be prioritized for development. Suitable land-use development under the premise of conservation could be a win-win strategy for lake areas, and is a strategy, which has been partly approved by the land evaluation in the study area.

In addition, market mechanisms can be applied to land-use management based on land evaluation and suitability assessment (Rossiter, 1996). For Chinese cities experiencing rapid urbanization, more effective polices are necessary, which may lead to sustainable land use and optimal allocation on both spatial and temporal scales. The results of the study were presented to the local stakeholders in late 2005 and received many responses. Scenario II was identified to be the ideal scenario based on interviews with local government and stakeholders. An optimal allocation of the lands in temporal and spatial scales is now under consideration according to the stakeholders’ suggestions.

4. Concluding remarks

This study offers a scientific basis for land-use management in the Hanyang Lake area in China. The proposed IGAS consists of GIS-based land-use suitability assessment, system analysis of potential land-use change and demand, land evaluation and land-use allocation. Interpretation of the allocation results could be useful in the policy making process in coming years. The land-use suitability assessment is a practical tool for making decisions on land-use development. The forecasting of land-use change is more useful for land-use management and allocation in the future. GIS is a useful tool for integrating information, and assisting in decision-making.

Land-use management is a complex problem in which different goals, stakeholders and criteria must be considered. In the suitability assessment process, multicriteria analysis can integrate the various criteria, such as subsurface water table levels, flooding risk, ecological and landscape effects, and location. Because lake areas are different from urban or agricultural areas, the criteria are distinct. Ecological conservation of water systems and riparian areas is a significant task for land-use management and should be prioritized in the land-use allocation process. Landscape effects should also be considered. The joint application of AHP and GIS is the main method for studying land-use suitability assessment, and this method was successfully applied in the case study.

Land-use management of lake areas at urban fringes is a dynamic, rather than a static, process. Land-use is affected by many factors, such as population, economic structure, policy and ecological conservation goals. Therefore, system analysis and dynamic modeling of land-use change is essential for future land-use allocation. Four subsystems were considered in this study, and potential land-use changes were modeled from 2006 to 2020. According to the results, the total urban area will expand to 110.16 km², and the percentages of industrial and residential areas and grasslands will be 30.77%, 26.38% and 20.84%, respectively. Local ecological conditions can be improved by increasing the amount of grassland. Land-use economic efficiency will also be improved. In the Hanyang Lake area, a total riparian area of 434.5 ha will be protected before 2020. A hierarchical land-use structure was also designed for the conservation of aquatic ecosystems. The remaining land is allocated on spatial and temporal scales. The allocation results will be useful for policy decision making on local urban sprawl and ecological conservation.

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References


