Geological risk assessment for the rapid development area of the Erhai Basin

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ABSTRACT

For low-slope hilly land development to have more new land space in a watershed, it is particularly important that to coordinate the sharply increasing conflicts between mountainous and urban land utilization in the city. However, development of low-slope hilly land easily induce potential risks of geologic hazards such as landslide and landslip. It may lead to further environmental losses in a watershed. Hence, it is necessary to study potential risks of geo-hazards in low-slope hilly land development in urban area. Based on GIS spatial analysis technique, we select a study area, Dali City in the Erhai Basin located in watershed belt of Jinsha River, Lancang River and Red River in Yunnan Province of China. Through studying some relevant key indexes and parameters for monitoring potential risks of geo-hazards, we establish a composite index model for zoning the area with potential risks of geo-hazards in development of low-slope hilly land in the study area. Our research findings indicate that the potential risks of geo-hazards in eastern Dali City is relatively low while of that on slow hills with gentle slopes in the western area are relatively high. By using a zoning research method, generated maps show geological information of potential risks of geo-hazards on low-slope hilly land which provide important messages for guarding against natural geo-hazards and potential environmental losses in a watershed.

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1. Introduction

Affected by the global climate change and rapid urbanization, the demand for the land used for the urban and rural construction has been continuously increasing and the farmland resources has been continuously reduced, as a result, the conflict between the development and utilization of land and the farmland protection has been increasingly sharp [Deng et al., 2015; Jin et al., 2015a, b; Shi et al., 2014]. Under the strict control over the land use and the farmland protection system in China, with regard to the conflict between the development and utilization and the protection of the land resources, so many prefectures implement the development strategy of low-slope hilly land [Lin and Ho, 2003; Deng et al., 2008; Hao et al.,

2012; Jin et al., 2015a, b]. Low-slope hilly land refers to the land with gentle slope lower than 25° that is distributed in mass in a centralized manner in the vast hilly country with low hills, mainly including unused land, waste garden plot and poor efficiency woodland. In combination with the actuality of the land utilization in China, little land resource per capita, high intensity of land development and insufficient standby land resource have become the confinement factor of the regional economic and social development [Gong et al., 2012; Li et al., 2013]. Therefore, it is an important approach to develop and utilize the unused land such as low-slope hilly land so as to relieve the pressure in vast population and limited farmland, tense supply of land for construction and land protection [Liu and Li, 2014; Jin et al., 2013]. Yunnan Province is a key region in development of low-slope hilly land by the state, the central government and local governments have clearly pointed out that the construction and development of the urbanization and industrialization in Yunnan Province should make full use of low-slope hilly land and probe into the new land use mode in the development process of the

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Table 1
Summary of various index screening methods.

Class	Typical screening method	Advantage	Disadvantage	Analysis mode
Stationary index screening method	Theoretical analysis method	Only theoretical analysis and research contrast required, without any requirement on the research index.	Rough screening degree and insufficient precision of the results.	Qualitative analysis
	Delphi method	In virtue of the expertise, the results are authoritative.	Great difficulty in selection by the experts and great subjective differences in the experts	Qualitative analysis
Quantitative index screening method	Principal component analysis method	Screening the indexes with the related algorithms, the quantization results can has high analyzable degree.	Data and information required and great demand for the samples	Quantitative analysis
	Grey correlation analysis method	The association degree matrix obtained reflects the correlativity among the indexes and it can easily eliminate the equivalent indexes.	It is relatively difficult to determine the critical value and it lacks the consistency	Quantitative analysis
Composite index screening method	Analytic hierarchy process	Combination of qualitative analysis and quantitative analysis, with remarkable hierarchy	It is relatively difficult to determine the weight number of the index	Qualitative + quantitative
	Neural network method	Relatively weak influences from the human factors, which are suitable for the requirements on the changes of the index influence degree.	It is necessary to establish the neural network model, the calculation is complicated and the specialized software is required.	Qualitative + quantitative

Table 2
Monitoring indicator system of landslide induced by low-slope hilly land in Dali.

Class	Factor	Sub-factor	Index	Index property	Correlativity
Basic factor	Geology	Tectonic movement	Fractured zone	Quantitative	Positive correlation
			Geological age	Quantitative	Positive correlation
	Topography	DEM	Soil type	Quantitative	Positive correlation
			Slope	Quantitative	Positive correlation
			DEM	Quantitative	Positive correlation
			Relief type	Quantitative	Positive correlation
Inducing factor	Vegetation	Vegetational coverage	Vegetational coverage	Quantitative	Negative correlation
	Climate and hydrology	Rainfall	Rainfall	Quantitative	Positive correlation

Table 3
Class and value of the assessment factors for assessing geological hazard risk.

Basic factor						Inducing factor	Value
Elevation	Slope	Vegetational coverage	Relief type	Geological age	Soil type	Rainfall	
>2800, <1500	0–8	1–0.8	Dip plain	Jurassic(J), Triassic(T), Permian(P)	Light clay	1136–1137	1
2500–2800	2–15	0.8–0.6	Rolling plains	Carboniferous(C), Cretaceous(K)	Heavy loam	1137–1190	2
2200–2500	15–25	0.6–0.4	Small rolling upland	Ordovician(O), Devonian(D)	Medium loam	1190–1240	3
1500–1700	25–35	0.4–0.2	Mediate rolling upland	Neogene(N), Paleogene(E)	Light loam	1240–1280	4
1700–2200	35–90	0.2–0	Large rolling upland	Quaternary(Q), Cambrian(G)	Sandy loam	1280–1330	5

urbanization and industrialization. Up to now, Yunnan Province has accumulated a great lot of findings and information in the development of low-slope hilly land, which have provided the reference to the development and utilization of low-slope hilly land in different regions. Foreign scholars predicted the vulnerable hazardous zones in different mountainous terrains by using varieties of methods [Anbalagan, 1992; Gupta and Joshi, 1990; Gupta et al., 1999; González et al., 2012] and the Chinese researchers studies on low-slope hilly

land made by the predecessors mainly focuses on the development and utilization as well as the countermeasure analysis at the economic, social and ecological level [Jin et al., 2015a, b; Chen et al., 2010; Zhang et al., 2011, 2012; Deng et al., 2013], however, few studies on the geo-hazard in the process of development and utilization of low-slope hilly land have been made. This paper, with Dali City, Yunnan Province as a typical research area, selects the influencing factors contributable to the geo-hazard in the development and utilization of low-slope

Table 4
Weight of the influencing factor of the geo-hazard.

Class	Weight	Factor	Weight	Composite weight
Basic factor	0.64	Geological age	0.26	0.1664
		Landform and topography	0.19	0.1216
		Elevation	0.12	0.0768
		Slope	0.18	0.1152
		Coverage	0.1	0.064
		Soil type	0.15	0.096
Inducing factor	0.36	Rainfall	0.36	0.36

Fig. 1. Elevation.

hilly land, establishes the risk assessment system of the geo-hazard arising from the development of low-slope hilly land with the composite index model, makes the spatial simulation and statistic analysis of the evaluation system and evaluation results based on GIS technique, contrasts the land use zones in low-slope hilly land in Dali City so as to provide the scientific guidance to the development and utilization of low-slope hilly land in Dali City, reduce the probability of the geo-hazard in the development of low-slope hilly land and realize the harmonious and sustainable development between the population and the land in Dali City.

2. Study area

Dali City is located at the west of Yunnan Plateau ($99^{\circ}58' \sim 100^{\circ}27'E$, $25^{\circ}25' \sim 25^{\circ}28'N$), with the total land area of 1425 km^2 , which is belong to part of Erhai Basin. It is situated at the

watershed belt of Jinsha River, Lancang River and Red River and belongs to Lancang River water system. The topographic form and the trend of the mountain chain are obviously controlled by the structural line and the fault, the topography is high in the west and low in the east and it heightens step by step from the Erhai Basin as the center to its surrounding. The relief types in this area are mainly the mountainous area, plateau, hill, lake and small basin and so on, among which the mountains and rivers are mountains and rivers, high mountains, lakes, basins and hills are alternately distributed and the area of the dam area of the basin, the mountains and the lakes accounts for 15.9%, 69% and 15.1% of the total area respectively. Dali City is located at the belt with low latitude and high altitude, the climate and the plants are vertically distributed and they belong to the climate of northern subtropical zone, warm-temperate zone and cool temperate zone respectively, where the sunlight is sufficient, the heat quantity is abundant, the annual year

Fig. 2. Slope.

temperature difference is small and the daily temperature difference is large, the dry season is distinct from the rainy season while the four seasons are not so distinctive. The annual mean temperature is 15 °C, the mean temperature in the coldest month (January) is 8.7 °C and the one in the hottest month (July) is 20.1 °C. The solar radiation is relatively strong, the sunlight is sufficient and the annual mean sunlight is 2474 h. The rainfall is plentiful and the annual average rainfall is 1100 mm. The soil types in Dali City are various, the soil of the farmland is fertile and suitable for the growth of the plants [Duan et al., 2015; Zomer et al., 2015].

In recent years, the economic strength in Dali City has been continuously enhanced, the scale of the land for construction has been rapidly expanded, the conflict between the population and the land has been extremely prominent and the basic drive for development and utilization of the low-slope hilly land has been formed. Relative to the plain region, the low-slope hilly land is

lower in the ecological bearing capacity and higher in ecological sensitivity. In case of no correct understanding and objective evaluation of the low-slope hilly land, the development will result in the destruction of the natural environment, even the geo-hazard and ecological disaster [Mugagga et al., 2012; La et al., 2011]. The previous studies mostly focused on the discussion of the methods of the development and utilization of the low-slope hilly land or the existing problems, but they did not go enough deep into the comprehensive development and utilization mode and intensity as well as the routing under the risk constraint of the geo-hazard. Therefore, this paper, in combination with the characteristics of topography, landform, climate and soil in Dali City and the geo-hazards such as landslide and mud rock flow in this area, selects Dali City, Yunnan Province as a research sample and predicts the geo-hazard of the low-slope hilly land in Dali City so as to provide the reference to the development and utilization of the land and the

Fig. 3. Vegetational coverage.

sustainable economic development in this area and the one to the structural adjustment of the land utilization of the low-slope hilly land with the geo-hazard risks and the stipulation of the land management policy.

3. Data and processing

3.1. Data

The main data for the risk assessment of the geo-hazard from the development of the low-slope hilly land in Dali City mainly cover the following contents: data about topography and landform, data about soil property, data about the vegetational cover, data about geological age, data about fractured zone and data about climate, among which the data about topography and landform are gathered from the data of the Digital Elevation Model (DEM) of Dali

City and the data about the slope of the research area are prepared based on the data of the Digital Elevation Model (DEM); [Deng et al., 2010; Liu et al., 2003, 2014] the data about the soil property mainly include the loam soil ratio, the content of soil organic matter, ratio of sand grain/dust particle/clay in the soil; the data about the vegetational cover are derived based on Landsat remote sensing data of Dali, Yunnan Province; the data about the climate are provided by China Meteorological Administration.

3.2. Data processing

Under the platform of ArcGIS10.2, the topographic map of the research area is generated into the digital elevation model (DEM) and the slope map; the 2nd survey data and the remote sensing images are used to determine the data about the relief types and the geological age; the ratio of the sand grain/dust particle/clay in

Fig. 4. Relief type.

the soil is used to calculate and determine the soil types; the data about the rainfall are used to calculate the average annual rainfall from 1961 to 2013; based on the principle of dimidiate pixel model, the formula for the vegetational coverage is used to calculate the vegetational coverage. Each processed index is translated into the form of a grid, in combination with the area and shape of the min. Image spot of the assessment object, the pixel with the sampling spacing of $100\text{ m} \times 100\text{ m}$ is determined as the assessment unit.

4. Model and methodology

4.1. Indicators

Scientific indicator system is a precondition of the comprehensive assessment. Aiming at the screening of the indicators, the scholars at home and abroad have put forward various methods [Yu et al., 2011; Kang et al., 2013; Alvarez et al., 2015], now so many

scholars among them have classified these methods and formed so many literature overviews, which are divided into stationary index screening method, quantitative index screening method and composite index screening method, among which the stationary index screening method mainly includes theoretical analysis method and Delphi method and so on; the typical quantitative index screening method includes principal component analysis method and grey correlation analysis method and so on; the composite index screening method includes analytic hierarchy process and neural network method and so on. The characteristics of each method are analyzed in the following table:

Due to the various factors and token factors affecting the risks of the geo-hazard, if all indexes are included into the assessment index system without any selection, the index set will be vast and multifarious, resulting in the increase in the workload of the risk assessment of geo-hazard in the low-slope hilly land and the inaccuracy of the assessment results. In order to avoid the

Fig. 5. Soil type.

circumstance above mentioned, it is necessary to take some measures for simplifying the function evaluation indexes of the underground water. Based on the reference to so many successful assessment cases of the geo-hazards, the indexes for the geo-hazard in the low-slope hilly land will be selected in accordance with the dominating principle, measurability principle, operability principle and comprehensibility principle. Among the various geo-hazards, the abrupt geo-hazards such as landslide and mud rock flow are featured in short-term breakout period, remarkable threat and destructiveness and complicated genesis, therefore, the present research on and application of the geo-hazard monitoring mostly centers on the abrupt geo-hazard. The genesis factors of the geo-hazard in Dali City are not independent from each other and sometimes they interact. Some factors remarkably react and play a role in control while some factors interact with other factors and impose the remarkable effects. Therefore, the risk assessment index

will be selected based on the detailed research on the conditions in Dali City in combination with the findings of the predecessors [Michoud et al., 2012; Sajinkumar et al., 2014; Liu et al., 2015], the national standards and the relevant literature indexes [Raghuvanshi et al., 2014; Uromeihy and Mahdaviyar, 2000; Aleotti and Chowdhury, 1999]. In combination with the characteristics of the research area and the currently available data and information, two kinds of factors including the basic factors and the inducing factors are selected [Caine, 1980]. For basic factors, slope is one of the main factors of geological disasters, is the source of the formation of various geological disasters, and DEM has a strong correlation with regional rainfall, and has different vegetation types and vegetation coverage in different elevation ranges. So this paper choose DEM and slope at the same time; For inducing factors, this paper selects rainfall, rainfall not only increases the load of rock and soil on the slope, but also the weak structural surface, reduces the

Fig. 6. Geological age.

cohesive force of the rock and soil, and destroys the original mechanical equilibrium of the rock and soil, thus inducing the occurrence of geological disasters such as landslides, collapse, debris flow and so on.

4.2. Index normalization

The sources, numeric areas and measurement units of the indexes of the geo-hazard differ from each other, as a result, it is difficult to make the comprehensive summary measurement and compare them. Therefore, after the value of a single index is calculated, it is necessary to normalize the assessment indexes, i.e., make them dimensionless so as to eliminate the effects of the dimensions on the assessment results. Among so many dimensionless processing method, the valuation method is adopted. The

larger the factor classification value, the higher the probability of inducing the geo-hazard. Specifically speaking, the influencing factors of the geo-hazard in Dali City are classified in ArcGIS10.2. Then, based on the degree of influence of the assessment indexes on the geo-hazard [Caine, 1980; Chien-Yuan et al., 2005; Cardinali et al., 2006], the influencing factors are classified and evaluated with GIS spatial analysis tool, with the value of 1–5 from high to low respectively (Figs. 1–7).

4.3. Assessment model

As to the influencing indicator system of the geo-hazard of the low-slope hilly land in Dali City, including elevation, slope, vegetational coverage, geological age, relief type, soil type and rainfall, in combination with the basic geological conditions of the research

Fig. 7. Rainfall.

area, the potential risk model of the geo-hazard of Dali City in the research area, namely the composite index model is established.

The composite index model makes dimensionless the dimensions with different properties and transforms them into the normalized form and these transformed real numbers become the composite indexes. The composite index model is strongly sensitive to the changes in the indexes, so it is helpful to review the assessment objects in an all-round way. The expression of the composite index model is:

$$Z_i = \sum_{j=1}^n P_j \times W_j \quad (1)$$

where, Z_i is the composite risk index of the geo-hazard, $i = 1, 2, \dots, n$, assessment unit; P_j is the value of the i th assessment factor, $j = 1,$

$2, \dots, m$, assessment factor; W_j is the weight of the j th assessment factor in i th assessment unit.

The composite index model is a kind of knowledge-driven assessment model and the weight of the factor will be determined in the assessment process. According to the actual conditions of Dali City, theoretical analysis is made. The methods searched and summarized from the literature are adopted to valuate the weight of the factors and then the related mathematical operation of the weight coefficient is carried out so as to obtain the quantitative data of the potential pre-warning distribution of the geo-hazard (Table 4) [Hou et al., 2006; Cong et al., 2008; Hasekiogullari and Ercanoglu, 2012; Mao and Hei-Yan, 2011] (Tables 1–3).

The design of the potential pre-warning model of the geo-hazard makes full use of the related algorithm of GIS technique and map algebra. The calculation steps for the potential geo-hazard

Fig. 8. Grade map of potential risk indexes of geo-hazard.

distribution in Dali City mainly include: (1) analyzing the basic factor and the inducing factor inducing the geo-hazard; (2) making these factors dimensionless with ArcGIS10.2 spatial analysis tool based on their characteristics, namely valuation; (3) calculating the weight indexes of the factors affecting and inducing the geo-hazard in Dali City; (4) Superposing the layers of the influencing factors after calculation to carry out the potential risk pre-warning of the geo-hazard.

5. Results

Based on the weight of the assessment indexes, through ArcGIS10.2 operating platform, in combination with the assessment factors including elevation, slope, vegetational cover, geological age, relief type, soil type and rainfall, the composite index of the

potential pre-warning risk of the geo-hazard can be derived from [Formula \(1\)](#). In order to more visually express the distribution of the potential risk of the geo-hazard in the research area and represent the differences in the risk of the regional geo-hazard, the inflection-point method of broken line graph is adopted to reclassify the potential risk of the geo-hazard and the results indicate there are five grades, including low, medium-low, medium, medium-high and high ([Fig. 8](#)).

The high risk area is relatively small, and the area is $6.61 \times 10^7 \text{ m}^2$, take up only 4.4% of the total area of Dali City. It is mainly distributed near the southwestern corner of Dali City and in other areas in a scattered manner. It is featured in the frequent geo-hazard, bad stability, high risk, bad geo-environmental conditions formed by the geo-hazard and low soil and water conservation capacity. The medium-high risk area is $3.06 \times 10^8 \text{ m}^2$, is 20.3% of

the total area, adjacent to the high risk area. It is mainly distributed in the western area of Dali City. The medium risk area is featured in relatively low risk level, relatively small threat to the affected objects, however, it belongs to the inducing area of the geo-hazard, so attention will be paid to the prevention of the geo-hazard, account for around 22.8% of its area. The medium-low risk area is the largest, with an area of $5.18 \times 10^8 \text{ m}^2$, 34.5% of it. The risk is relatively small, the threat to the lives and properties of the residents and the engineering facilities is relatively small, as a result, attention will be paid to the prevention of the geo-hazard. The grade one stability area in the low risk area is centered in the northern area of Dali City, with an area of $2.71 \times 10^8 \text{ m}^2$, it make up 18% of its total and the southeastern area in a scattered manner, where the stratum of Permian System, Triassic System and Jurassic Period is mainly distributed and relatively old and stable. It can withstand the interference of a certain inducing factor. However, in the case of interaction of many kinds of inducing factors, the stability will fall down greatly, so this area will not be ignored.

6. Conclusions and discussion

This paper assesses the potential risk of the geo-hazard from the development of the low-slope hilly land in Dali City, Yunnan Province and the results indicate: (1) the risk of geo-hazard in the east of Dali City is relatively small and it is advantageous for the development and construction of the low-slope hilly land and the degree of suitability is relatively high; (2) the development conditions of the low-slope hilly land in the west of Dali City are relatively bad, as a result, the probability of the geo-hazard is obviously higher than the one in the east and it is not applicable to the development and utilization; (3) as to the areas with relatively bad development conditions, the present conditions can be improved to a certain extent so as to make it possible to develop and utilize it in the coming future.

Through the superposition analysis of the influencing factors of the geo-hazard and GIS spatial analysis technique, this paper establishes the risk assessment system of the geo-hazard in the low-slope hilly land in Dali City and this research makes up the previous social and economic research on the low-slope hilly land to a certain extent. However, it only takes into account the basic factor and the inducing factor instead of other factors affecting the geo-hazard in establishing the geo-hazard indicator system. In addition, the findings only zone the potential geo-hazard in Dali City and it is necessary to improve the scientific and technical application in the monitoring, pre-warning and management of the development of the low-slope hilly land in Dali City in combination with the threshold value of the inducing factor of the geo-hazard and the geo-hazard pre-warning model so as to better provide the reference to the pre-warning management of the geo-hazard from the development of the low-slope hilly land.

It is noteworthy that the zoning of the potential risk of the geo-hazard will be continuously updated, increase the accuracy of the potential risk zoning and provide a large quantity of historical data for supplementation. In addition, the potential risk zoning of the geo-hazard will combine the pre-warning model of the geo-hazard and the science and technology for the monitoring of the development of the low-slope hilly land and improve the scientific level of the pre-warning management of the geo-hazard from the development of the low-slope hilly land in China.

Conflicts of interest

The authors declare no conflict of interest.

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References

- Aleotti, P., Chowdhury, R., 1999. Landslide hazard assessment: summary review and new perspectives. *Bull. Eng. Geol. Environ.* 58, 21–44.
- Alvarez Etcheberria, I., Garayar, A., Calvo Sánchez, J.A., 2015. Development of sustainability reports for farming operations in the Basque Country using the Delphi method. *Rev. Contab.* 18, 44–54.
- Anbalagan, R., 1992. Landslide hazard evaluation and zonation mapping in mountainous terrain. *Eng. Geol.* 32, 269–277.
- Cardinali, M., Galli, M., Guzzetti, F., Ardizzone, F., Reichenbach, P., Bartoccini, P., 2006. Rainfall induced landslides in December 2004 in south-western Umbria, central Italy: types, extent, damage and risk assessment. *Nat. Hazards Earth Syst. Sci.* 6, 237–260.
- Caine, N., 1980. The rainfall intensity: duration control of shallow landslides and debris flows. *Geogr. Ann.* 62, 23–27.
- Chen, Y., Yu, J., Khan, S., 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environ. Model. Softw.* 25, 1582–1591.
- Chien-Yuan, C., Tien-Chien, C., Fan-Chieh, Y., Sheng-Chi, L., 2005. Analysis of time-varying rainfall infiltration induced landslide. *Environ. Geol.* 48, 466–479.
- Cong, W., Tiefeng, L.I., Pan, M., 2008. Research on dynamic predictive model of regional rainfall-triggered geologic Hazard based on unsaturated flow theory. *Acta Sci. Nat. Univ. Pekin.* 44, 212–216.
- Deng, X., Huang, J., Rozelle, S., Zhang, J., Li, Z., 2015. Impact of urbanization on cultivated land changes in China. *Land Use Policy* 45, 1–7.
- Deng, X., Huang, J., Rozelle, S., Uchida, E., 2010. Economic growth and the expansion of urban land in China. *Urban Stud.* 47, 813–843.
- Deng, X., Huang, J., Rozelle, S., Uchida, E., 2008. Growth, population and industrialization, and urban land expansion of China. *J. Urban Econ.* 63, 96–115.
- Deng, X., Zhao, C., Yuan, Y., 2013. Analysis of the drought risk in Yunnan Province based on the WRF model. *China Popul. Resour. Environ.* 23, 95–101.
- Duan, X., Rong, L., Zhang, G., Hu, J., Fang, H., 2015. Soil productivity in the Yunnan province: spatial distribution and sustainable utilization. *Soil Tillage Res.* 147, 10–19.
- Gong, J., Liu, Y., Chen, W., 2012. Land suitability evaluation for development using a matter-element model: a case study in Zengcheng, Guangzhou, China. *Land Use Policy* 29, 464–472.
- González, A.O.O., Navarro, A.R., Salgado, R.M., Nicienza, C.G., Fernández, M.I., 2012. Urban development and human activity as factors in terrain instability in Tijuana. *Eng. Fail. Anal.* 19, 51–62.
- Gupta, R.P., Joshi, B.C., 1990. Landslide hazard zoning using the GIS approach—a case study from the Ramganga catchment, Himalayas. *Eng. Geol.* 28, 119–131.
- Gupta, R.P., Saha, A.K., Arora, M.K., Kumar, A., Gupta, R.P., Arora, M.K., Kumar, A., 1999. Landslide Hazard zonation in a part of the Bhagirathi Valley, Garhwal Himalayas, using integrated remote sensing – GIS. *Himal. Geol.* 20, 71–85.
- Hao, P., Geertman, S.C.M., Hooimeijer, P., Sliuzas, R., 2012. The land use diversity of urban villages in Shenzhen. *Environ. Plan. A* 44, 2742.
- Hasekiogullari, G.D., Ercanoglu, M., 2012. A new approach to use AHP in landslide susceptibility mapping: a case study at Yenice (Karabuk, NW Turkey). *Nat. Hazards* 63, 1157–1179.
- Hou, M., Jia, S.H., Guo, Z.C., 2006. Using RS, GIS and AHP technologies for landslide Hazard Assessment: Taking Tiantai landslide in Xuanhan County, Sichuan province as an example. *Geoscience* 20, 668–672.
- Jin, G., Li, Z., Wang, Z., Chu, X., Li, Z., 2015a. Impact of land-use induced changes on agricultural productivity in the Huang-Huai-Hai river Basin. *Phys. Chem. Earth* 79, 86–92.
- Jin, G., Li, Z., Lin, Q., Shi, C., Liu, B., Yao, L., 2015b. Land use suitability assessment in low-slope hilly regions under the impact of urbanization in Yunnan, China. *Adv. Meteorol.* 2015 (2015) [Article ID 848795], 1–10.
- Jin, S.J., Moruno, L.G., Blanco, J.H., 2013. A site planning approach for rural buildings into a landscape using a spatial multi-criteria decision analysis methodology. *Land Use Policy* 1, 108–118.
- Kang, S., Post, W., Wang, D., Nichols, J., Bandaru, V., West, T., 2013. Hierarchical marginal land assessment for land use planning. *Land Use Policy* 30, 106–113.
- La, G.P., La, R.D., Martinico, F., 2011. Agricultural and green infrastructures: the role of non-urbanised areas for eco-sustainable planning in a metropolitan region. *Environ. Pollut.* 159, 2193–2202.
- Li, J., Deng, X., Seto, K.C., 2013. The impact of urban expansion on agricultural land use intensity in China. *Land Use Policy Int. J. Cover. All Asp. Land Use* 35, 33–39.
- Lin, G.C.S., Ho, S.P.S., 2003. China's land resources and land-use change: insights from the 1996 land survey. *Land Use Policy* 20, 87–107.
- Liu, J., Kuang, W., Zhang, Z., Xinliang, X.U., Qin, Y., Ning, J., Zhou, W., Zhang, S., Rendong, L.I., Yan, C., 2014. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *J. Geogr. Sci.* 24, 195–210.
- Liu, J., Liu, M., Zhuang, D., Zhang, Z., Deng, X.Z., 2003. Study on spatial pattern of land-use change in China during 1995–2000. *Sci. China* 46, 373–384.

- Liu, M., He, Y., Wang, J., Lee, H.P., Liang, Y., 2015. Hybrid intelligent algorithm and its application in geological hazard risk assessment. *Neurocomputing* 149, 847–853.
- Liu, Y., Li, Y., 2014. Environment: China's land creation project stands firm. *Nature* 511, 410–410.
- Mao, W., Hei-Yan, R.U., 2011. Hazard evaluation for Jinpingzi landslide based on GIS and AHP method. *Earth Environ.* 39, 399–404.
- Michoud, C., Derron, M.H., Horton, P., Jaboyedoff, M., Baillifard, F.J., Loye, A., Nicolet, P., Pedrazzini, A., Queyrel, A., 2012. Rockfall hazard and risk assessments along roads at a regional scale: example in Swiss Alps. *Nat. Hazards Earth Syst. Sci.* 12, 615–629.
- Mugagga, F., Kakembo, V., Buyinza, M., 2012. Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. *Catena* 90, 39–46.
- Raghuvanshi, T.K., Ibrahim, J., Ayalew, D., 2014. Slope stability susceptibility evaluation parameter (SSEP) rating scheme – an approach for landslide hazard zonation. *J. Afr. Earth Sci. Vol. 24th Colloq. Afr. Geol.* 99, 595–612.
- Sajinkumar, K.S., Anbazhagan, S., Rani, V.R., Muraleedharan, C., 2014. A paradigm quantitative approach for a regional risk assessment and management in a few landslide prone hamlets along the windward slope of Western Ghats, India. *Int. J. Disaster Risk Reduct.* 7, 142–153.
- Shi, Q., Chen, S., Shi, C., Wang, Z., Deng, X., 2014. The impact of industrial transformation on water use efficiency in northwest region of China. *Sustainability* 7, 56–74.
- Uromeihy, A., MahdaviFar, M.R., 2000. Landslide hazard zonation of the Khorshrostan area, Iran. *Bull. Eng. Geol. Environ.* 58, 207–213.
- Yu, J., Chen, Y., Wu, J., 2011. Modeling and implementation of classification rule discovery by ant colony optimisation for spatial land-use suitability assessment. *Comput. Environ. Urban Syst.* 35, 308–319.
- Zhang, H., Li, H., Chen, Z., 2011. Analysis of land use dynamic change and its impact on the water environment in yunnan plateau Lake area — a case study of the Dianchi Lake Drainage area. *Proced. Environ. Sci.* 10, 2709–2717.
- Zhang, M.G., Zhou, Z.K., Chen, W.Y., Slik, J.W.F., Cannon, C.H., Raes, N., 2012. Using species distribution modeling to improve conservation and land use planning of Yunnan, China. *Biol. Conserv.* 153, 257–264.
- Zomer, R.J., Xu, J., Wang, M., Trabucco, A., Li, Z., 2015. Projected impact of climate change on the effectiveness of the existing protected area network for biodiversity conservation within Yunnan Province, China. *Biol. Conserv.* 184, 335–345.