Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 17 No. 3 pp. 739-746 2018

Original Research Paper Open Access

Assessment of Eco-environmental Quality on Land Use and Land Cover Changes Using Remote Sensing and GIS: A Case Study of Miyun County

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 04-11-2017
Accepted: 19-12-2017

Key Words:
Miyun reservoir
LULC changes
Eco-environment quality
Remote sensing
GIS

ABSTRACT

The eco-environment in Miyun Reservoir in Beijing city has received more attention as the main surface source of the drinking water natural ecological zone for the capital of China. Meanwhile, the changes in land use and land cover (LULC) are a major cause of eco-environmental changes and represent an important part of the global change affecting the environmental quality. Therefore, in this paper, taking the Miyun county as the evaluation unit, supported by RS (remote sensing) and GIS (geographical information system), the spatio-temporal changes of land use from 2003 to 2013 were analyzed with the Landsat TM (OLI) images, and then several synthetic evaluation indices were set up including, natural condition, environmental pollution, geologic hazard and local social economy factors. Combining AHP methods with GIS, the regional environmental evaluation model was established and eco-environmental quality was evaluated. The results showed that the areas of cropland, forestland and water body increased, with the annual change rate of 3.2%, 2.27% and 0.89% respectively. While the annual change rate of grassland, unused land, and built-up land decreased by (-) 5.35%, (-) 3.96% and (-) 1.04%, respectively. In 2003, the medium level area occupied the most, followed by the light level area, which was 899.90 and 823.73km^2, respectively. However, in 2013, light level dominated the position of the study region, the potential level occupied the subordinate position, with the area ratio of 48.57% and 28.59%, respectively. The sum area of potential and the light level area increased from 46.64% in 2003 to 76.52% in 2013, which indicated that the study region maintained a better grade of the eco-environmental quality. During the past decade, the regional eco-environmental quality has been transferred from worse status to better status, especially in hilly region, due to the implementation of eco-environmental protection measures, such as the Grain for Green and Natural Forest Protection since 1998.

INTRODUCTION

Land use generally refers to how people use the land in terms of social-economic functions, and can be defined as changes in land resources related to biophysical factors such as biodiversity, soil and ecological processes (Weng 2001), whereas land cover defines the physical pattern of land surfaces (Li et al. 2014), which is one of the many biophysical attributes of the land that affect how ecosystems function (Turner et al. 1995). In fact, land use influences the environment mainly by landcover (Wang et al. 2010a), then monitoring land use change (LUC) is important because of the global environmental threats that they are often associated with (Townshend et al. 2012). Moreover, land use and land cover (LULC) is regarded as important factors for environmental assessment and have close relationships to population migration and economic conditions (DeFries 2012), and clearly reflects the dimensions of anthropogenic activities on the environment (Lopez et al. 2001), and is perhaps the most relevant form of global environmental change phenomenon occurring at varying spatial and temporal scales (Misra et al. 2015).

Meanwhile, the changes in LULC represent an important part of the global change affecting the environment (Vorovencii 2014), which inevitably affect the structure and function of ecosystems and influence the regional and global climate, hydrology, vegetation, biogeochemical cycles and biodiversity (Broadbent et al. 2012, Collier et al. 2013). Herein, environmental problems refer to any human-induced damage to the physical environment resulting from LULC (Gusso et al. 2015). In recent years, the space technologies, such as remote sensing (RS), geographic information systems (GIS), and numerical modelling techniques have been developed as the powerful and cost-effective tools for establishing spatio-temporal databases of the changes in LULC and evaluating the ecological environment. Furthermore, the LULC is widely devoted to ecological environment changes and driving mechanisms closely related to human activities (Thielen et al. 2008, Theodoropoulos et al. 2012, Petrosillo et al. 2013, Bae & Ryu 2015). Therefore, the researches on the spatio-temporal characteristics of LULC are useful for understanding the various impacts on the overall ecological condition of the eco-environment, which is not only the direct reflection of human activities on the basis of the nature, but also is the important instruction indicator of ecological and environmental changes in the reservoir area (Chen et al. 2011).

Miyun county, situated in the northeastern of Beijing, is very important surface source of drinking water and natural ecological zone. While in recent years, with the joint influence of natural factors (e.g., concentrated rainfall, steep topography, loose soil, and low vegetation coverage) and social factors (e.g., large population intensity, reclamation on steep slopes, indiscriminate felling, and overgrazing) (Li et al. 2013), the wide spread problem not only caused great changes in LULC of Miyun county, but also already has become one of the most serious environmental issues for Miyun Reservoir, that is the safety of water supply for Beijing. Furthermore, it threatened the sustainability of agricultural productivity in Miyun watershed where economically important diverse crops are produced (Chen et al. 2011). Therefore, it is very necessary to master the current situation of LULC and implement the protective measures for regional eco-environment by understanding LULC as a consequence of eco-environment assessment. The specific objectives of this study are as follows: To elucidate and evaluate the LULC spatio-temporal change process between 2003 and 2013; to develop an eco-environmental numerical evaluation model supported by RS and GIS; to reveal spatial distribution and temporal changes for past decade of eco-environmental quality.

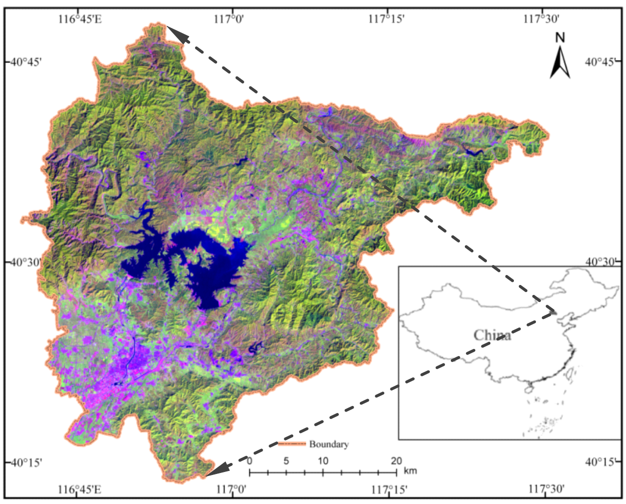

Fig.1: Location of the study area in China.

MATERIALS AND METHODS

Study area: Miyun county is located in the north area of Beijing (Fig. 1) and lies between 40°14'-40°48' N and 116°41'-117°30' E with an area of 2226.1km^2. The northwest part of the study area is gently mountainous, while the southeast part is mainly hilly and partially plain (Chen et al. 2011), and the altitude varies from 150 to 1800m above sea-level with an average elevation of 962m. The climate of the region is warm and semi-humid continental monsoon with a range of annual rainfall between 407mm in the northwest zones to 797mm in the southeast (Li et al. 2013). About 80% of the rainfall occurs between June and September. Distribution of precipitation is generally decrease from southeast to northwest. Annual average temperatures in upper and lower watershed are 9°C and 25°C respectively (Chen et al. 2011). Meanwhile, the soil layer of this study region is thin, and this region suffers severe soil erosion and is considered a priority area for soil conservation project in China (Chinese River Sediment Bulletin 2006) (Chinese River Sediment Bulletin 2006).

Satellite data processing: In order to explore some of the eco-environmental problems that result from LULCC. Availability of RS images were firstly taken into account in choosing the study area. Landsat data (7 ETM + and 8 OIL) dated September 20th, 2003 and October 23rd, 2013 were acquired and used to evaluate the LULC changes and ecoenvironment quality for this study, respectively. The standard false colour composites were generated displaying bands 6, 5, 4 for Landsat 8 OIL data as red, green and blue, respectively, supported by the ENVI 5.1 remote sensing software, the image was geo-rectified by Transverse Mercator (TM) projection using ground control points (GCPs) from 1:50,000 scale to pographic maps, at least 50 ground control points (GCPs) were used to register the images, which were dispersed throughout the scene and yielded a root mean square errors (RMSE) of less than 0.5 pixels. Using the corrected image of Landsat 8 OIL as geo-referenced, the image-to-image method was carried out for Landast 7 and achieved the RMSE of 0.38.RS images masked by study region boundary, which were analyzed for land cover by creating a land-cover map. The classes of land cover in the study region included croplands (paddy and dry farming land), forestlands (forest, shrub and others), grasslands (natural grasslands and pastures), water bodies (rivers and reservoirs), built-up areas (urban areas, rural settlements and others) and unused lands (wetland, bare rock and so on), then land cover maps were obtained by following a supervised classification approach consisting more than 30 sampling signatures for each land-uses. Meanwhile, selecting 50 random points verified the classification accuracy, and additionally the classification process was repeated until the recorded image had an accuracy level of more than 90% for all the classes (Giraldo et al. 2012). The classification accuracy of LULC types by Kappa coefficients for 2003 and 2013 were greater than 0.80.

Other data extraction: In addition to land use cover, there are many factors that affect the eco-environmental quality (Wang et al. 2008), therefore, in order to synthetically analyse eco-environmental vulnerability in the study region, the other data used for eco-environment quality in this study were mainly collected and included: (1) average rainfall and accumulated temperature over 0 and 10°C from the local meteorological department; (2) soil erosion data came from the database of "the second and the fourth national soil erosion RS investigation" based on the Landsat TM; (3) soil types and environmental pollution and some geologic hazard data came from the land and resource department of Miyun county; (4) vegetation cover data obtained from the Landsat images product; (5) DEM data obtained from 1:50,000 scale topographic maps; (6) the other data, including social economy, population density, per capita arable land and per capita GDP were provided by Miyun Statistic Bureau. Finally, all the gathered data were processed and then converted to spatial data in ArcGIS software with Transverse Mercator (TM) projection in grid format.

ECOLOGICAL EVALUATION MODEL

Establishment of the evaluation index system: The establishment of a proper evaluation index system was basic for the scientific analysis of eco-environment (Wang et al. 2008), while the ecological environment is a dynamic (Hou et al. 2015), and constantly affected by changing energy and material cycles. Therefore, according to the regional eco-environment features, the eco-environmental quality evaluation index system of the study region was established by four big groups including, natural conditions, environmental pollution, geologic hazard and local social economy, total of 18 factors after consulting some experts for advice of eco-environment and the assessing standard of ecological demonstration area of the study region (Fig. 2). Generally, local factors used for eco-environment quality assessment should be taken into account as natural environmental variables and the impacts of human activities.

Dimensionless evaluation factors: Due to the above evaluation factors being quantified using different units, they could not be compared directly (Wang et al. 2010b). Meanwhile, these factors, both had negative and positive interrelation to eco-environmental evaluation. Positive interrelation for those factors was highly advantageous to eco-environmental quality, and negative interrelation for those factors was disadvantageous to eco-environmental quality (Xiong et al. 2007). Therefore, the negative and positive assessment factors must be dimensionless. In the research, Formula 1 and Formula 2 were used to evaluate the eco-environmental status for positive factors and negative interrelation factors. The positive factors were C1, C2, C3, C4, C5, C6, C7, C11, C15, C17, C18, C23, C24, C25, while negative factors were C7, C8, C9, C10, C11, C12, C13, C14 and C16. All the factors were processed by these methods (Liu et al. 2003):

$$x_i = \frac{x_i - x_{i\min}}{x_{i\max} - x_{i\min}} \times 10 \quad ...(1)$$

$$x_i^{'} = \frac{x_{i\max} - x_i}{x_{i\max} - x_{i\min}} \times 10 \quad ...(2)$$

Where, i represents evaluation unit, X_i is the original value for the factors of grid i, varying from 0 to 10 and X_{imax} and X_{imin} represent the maximum and the minimum value of gird i, respectively.

Weight of evaluation factors: The analytic hierarchy process (AHP) is a simple systematic engineering method to quantitatively analyse non-quantitative objects (Li et al. 2007), which could decompose the complex problem to some layers and some factors and could compare and calculate as a result of weight (Xu 2002). In this research, according to the Delphi expert advice system, the experts with ecological backgrounds were invited to give the relative importance of each factor, respectively. The AHP method was applied to determine the weight of each factor (Dorey 2000).

Integrated assessment of eco-environmental quality: As a complex system with multi-subject and multi-level of eco-environmental quality, the synthetic evaluation index of environmental quality was adopted to make levels more confident and accurate (Li et al. 2006, Liu et al. 2002, Wang 2001), which means that values of all the indexes were over laid in each evaluation unit and the synthetic value was used to determine the environmental quality. Therefore, using the GIS software, the local regional eco-environment quality was carried out with the method of the multi-level weighted sum after standardization and quantization of the thematic data with grid format. Meanwhile, the integrated assessment value of each grid was the sum of corresponding weighted values of all the related factors, the equation was used as follows:

$$EEQ = \sum_{i=1}^{n} C_i \times w_i \;\; EEQ = \sum_{i=1}^{n} C_i \times w_i \quad ...(3)$$

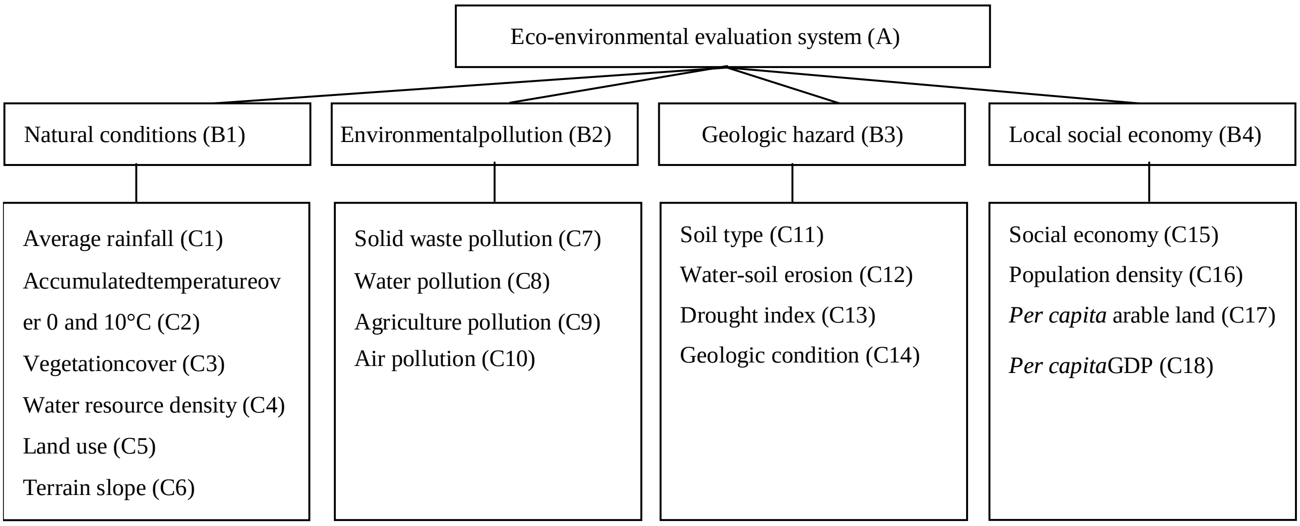

Fig. 2: Index system for integrated assessment of eco-environment.

Where, EEQ is the integrated assessment value of eco-environment quality, C_i is the value of each factor, *w* is the weight for the factor of grid *i*, *n* is the total number of evaluation factors.

RESULTS AND ANALYSIS

Land use change analysis: In Table 1, it shows that more than 69% of the total land area was dominated by forest land, cropland and grassland, and it is obviously indicated that the land use structural characteristics of the Miyun county were major on forestry, agricultural and animal husbandry production, while 48.24% and 59.18% of forest land was the major land use type in 2003 and 2013, respectively, which nearly distributed in the whole study region (Fig. 3), especially in northern mountain region. The areas of cropland, forestland and water body increased, with the annual change rate of 3.2%, 2.27% and 0.89% respectively. While the grassland, built-up land and unused land decreased by 138.16km^2, 18.44km^2 and 161.88km^2 respectively, the unused land area reduced relatively higher over the different types, followed by the annual change rate of (-) 5.35%, (-) 1.04% and (-) 3.96%, respectively. The reduced unused land was occupied by forestland in some local regions, which shows the rational land use pattern due to the implementation of natural forest protection project. However, the grassland area decreased at the cost of increased cropland by the certain economical profits driving, especially near the Miyun Reservoir, therefore, it reflected the bad environmental conditions, which have affected the water resources by wastewaters and chemical pollution.

Supported by Spatial Analysis Module of Arc GIS 10.3, the integrated assessment eco-environmental value was calculated by Eq. (3) for each factor of grid, then the assessment results were aggregated and reclassified to obtain eco-environmental quality classification, which were classified into five levels (potential, light, medium, heavy, very heavy) by using Natural Breaks (Jenks) methods, respectively. The final results are shown in Fig. 4 and Table 2. On this basis, the integrated assessment from 2003 to 2013 was overlayed and obtained the transition probabilities, which were helpful for presenting the spatial distribution speciality and exploring the spatial transfer status from the different levels of eco-environment quality (Table 3).

The general assessment results analysis: The assessment results showed that the sum area proportion including, potential, light and medium levels was 87.07% in 2003 and 90.1% in 2013 of the total area, respectively, which represented the good natural environment situation of the study region. While the light level occupied the most area of the total land in 2013, which accounted for 1081.29 km^2, the medium level in 2003 accounted for 40.40% of the study region and dominated the position. The potential and light levels were located in the mountain region with the steep slopes, where there were lots of forestland with a thick vegetation cover and good forestry resources, these regions belonged to the prime natural forestland and less human activities. On one hand, the natural terrain conditions restricted the intensity and scope of human activity, on the other hand, due to the implementation of the Grain-for-Green Program (GGP) in 1998a by China Government, more and more forestland were protected and the regional eco-environmental quality made a great improvement. The sum area of heavy and very heavy level was 9.05% and 4.53% of the

Table 1: Change in area of different land use types from 2003 to 2013.

Land use types	2003 Area/km^2	2003 Proportion, %	2013 Area/km^2	2013 Proportion, %	Area changes /km^2	Annual area change rate, %
Cropland	206.56	9.28	272.59	12.25	66.03	3.20
Forestland	1073.93	48.24	1317.37	59.18	243.44	2.27
Grassland	258.35	11.61	120.19	5.4	-138.16	-5.35
Waterbod	100.98	4.54	109.99	4.94	9.01	0.89
Built-upland	176.99	7.94	158.55	7.12	-18.44	-1.04
Unused land	409.27	18.39	247.39	11.11	-161.88	-3.96

Table 2: Area and proportion of each EEQ level in the research area.

Eco-environmental Quality Level	2003 Area/km^2	2003 Percentage, %	2013 Area/km^2	2013 Percentage, %
Water body	86.03	3.86	96.95	4.36
Potential	214.70	9.64	622.26	27.95
Light	823.73	37.00	1081.29	48.57
Medium	899.90	40.43	324.57	14.58
Heavy	162.05	7.28	72.46	3.25
Very Heavy	39.68	1.78	28.57	1.28

Table 3: The transition probabilities each EEQ level from 2003 to 2013.

Transition probabilities	Water body	Very heavy	Heavy	Medium	Light	Potential
Water body	0.9680	0.0087	0.0147	0.0077	0.0007	0.0002
Very Heavy	0.0067	0.4166	0.1844	0.2009	0.1196	0.0718
Heavy	0.0288	0.0357	0.2516	0.3172	0.2608	0.1060
Medium	0.0055	0.0052	0.0206	0.2390	0.5876	0.1421
Light	0.0035	0.0009	0.0042	0.0542	0.5515	0.3857
Potential	0.0041	0.0001	0.0053	0.0224	0.2383	0.7297

study region in different periods, respectively, the regions were focused on low and flat areas, especially the regions with low slope and elevation, where it was easy for both residential purposes and agricultural activities for humans. To a certain extent, it was the human activities that accelerated the local environmental degradation, which made the regional eco-environmental quality to become worse and worse. In a word, the area of potential and light level increased, 407.56 km^2 of the increasing area of the light level was the largest, while the area of medium, heavy and very heavy level decreased, and the medium with the most decreasing area accounted for 575.33 km^2.

Analysis of potential eco-environmental quality: Areas with the potential level accounted for 9.64% in 2003 and 27.95% in 2013, respectively. These regions situated in the mountainous areas of the northern region, where the natural forests occupied the dominant position and had more ecological sensitivity. Due to the natural environmental conditions restriction, especially in the steep slopes, the intensity of human activities was restricted, more and more forestlands with high vegetation were protected and showed the reasonable spatial distribution, which kept the good eco-environment quality and performed the good ecosystem services. However, our field surveying showed that the soil erosion in some regions was very serious because of the less forest protection and human activities, especially on the steep slopes and at elevations between 600 and 800m. It is clear that the spatial distribution of potential level has certain correlation to the regional topography and geomorphology. Therefore, we should reduce the human disturbing activities and take more ecological measures to protect the forest resources.

Analysis of the light eco-environmental quality: The area proportion of light level is 37.00% in 2003 and 48.57% in 2013, respectively, which occupied a subordinate and main position and mainly located in the hilly region of the study area. The medium and high level was its major conversion resources, and the transferring probability was 58.76% and 26.08% (Table 3), respectively. Due to the terrain condition control and the implementation of Natural Forest Protec-

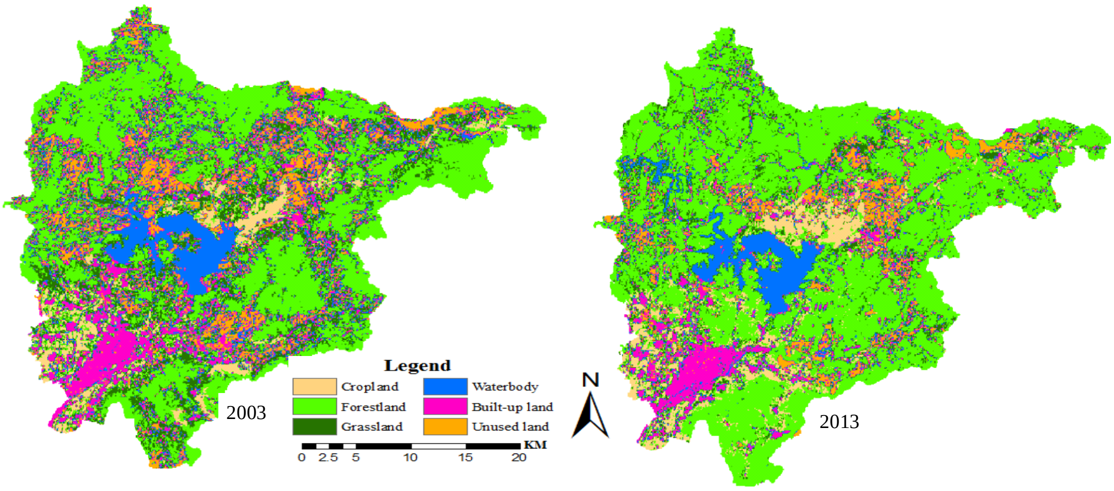

Fig. 3: Land use patterns from 2003 to 2013.

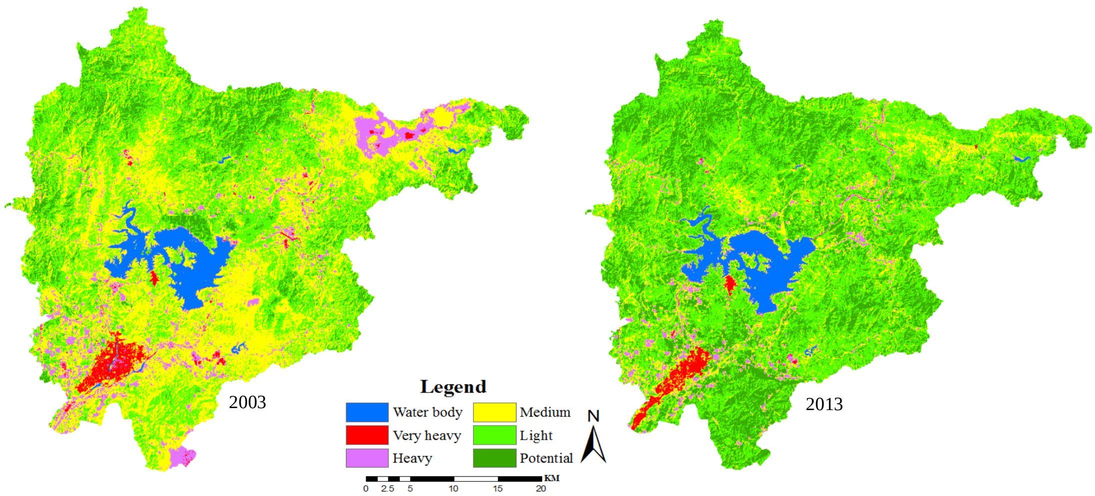

Fig. 4: Distribution of eco-environmental quality of the study area in 2003 and 2013.

tion Program (NFPP) (Gong et al. 2017), these regions with light level were occupied by natural forest, the second natural forest, along with some grassland and little cropland, where there were few human activities. Meanwhile, the conversion from cropland to forestland and grassland played the key roles, more and more forestland and grassland were transferred and protected by local government, which indicated that the local land use became rational and the regional eco-environment quality gradually improved. However, the transferring probability from potential to light level was 22.83%, which showed that in some regions eco-environmental quality was deteriorated, in fact, the phenomenon for damaging forests to reclaim land still existed. Therefore, in future, we should conscientiously implement NFPP and perform the regional ecological restoration measures.

Analysis of medium eco-environmental quality: 40.43% in 2003 and 14.58% in 2013 of the medium level were occupied by the abandoned land, degraded grassland, shrub, paddy fields and forestland. These regions were greatly affected by human activities, especially in the gently sloping and low elevation, the phenomenon of slope farming was more serious, and the conversion between paddy land and forestland was frequent, which not only destroyed the regional vegetation structure, but even exacerbated the extent of soil and water loss and the regional ecological environment vulnerability. Therefore, in this level region, under the more and more human activities, the conversion from medium to heavy level easily occurred, which was prone to more ecological problems, even deteriorated the local ecological environment quality. Therefore, more protection measures should be strengthened, including the prohibition of overgrazing, the implementation of NFPP and GGP. Meanwhile, 58.76% of the medium level was transferred to another level, the heavy level was its major transferring-into resource, accounting for 31.72%.

Analysis of heavy eco-environmental quality: The heavy level was occupied by wasteland, including the shrub fallow, abandoned forestland, abandoned land and individual mining waste land, which were strongly disturbed by human activities. The resources of local land and plants were destroyed and accelerated the regional soil erosion, and then severely deteriorated to the local eco-environment quality. Although with the implementation of ecological protection and ecological restoration measures, the eco-environment quality gradually improved, 18.44% of the very heavy level was transferred to this level, the phenomenon for land degradation and desertification was still quite serious, meanwhile, 31.72% and 26.08% of heavy level was converted to medium and potential light level.

Analysis of very heavy eco-environmental quality: 1.78% in 2003 and 1.28% in 2013 of very heavy level situated at the region on gently sloping lands (<5°) and at low elevations (<200m), were almost occupied by urban or suburban. These regions were suitable for humans to habitat and work on the agricultural production. Therefore, more and more human activities intensity existed and most areas had the very heavy eco-environmental quality. While in the recent decade, with the acceleration development of urbanization, more and more arable land was transformed into built-up land, which not only changed the land surface and land use structure, but also destroyed the regional vegetation cover, and made the air and water polluted. Moreover, the more artificial landscape was occupied and dominated the position. Deforestation and land reclamation driven by economic profits and social development is a general phenomenon in this region. Fortunately, the area of the very heavy level has decreased due to the more people's awareness on the protection of the ecological environment.

DISCUSSION AND CONCLUSION

Under the support of RS and GIS, the AHP method was used to determine the variables and their weights, a mathematical evaluation model was developed to analyse the eco-environmental problem in mountainous region in the northeastern of Beijing, the capital of China, and the evaluation results were analysed. We have drawn the following conclusions:

1. The areas of cropland, forestland and waterbody increased, with the annual change rate of 3.2%, 2.27% and 0.89% respectively. On the contrary the grassland, unused land and built-up land decreased. The decreasing area of unused land was greater than that of grassland and built-up land, which was 161.88 km^2. Meanwhile, the annual change rate of grassland, unused land and built-up land was (-) 5.35%, (-) 3.96% and (-) 1.04%, respectively.
2. In 2003, the medium level dominated the situation, followed by the light level, with the area ratio of 40.43% and 37.00, respectively. While in 2013, the light level occupied the largest area, followed by the potential level, which accounted for 48.57% and 28.59%, respectively. Due to the implementation of the environmental protection and ecological construction for frail eco-environmental regions, such as the implementation of Grain for Green and Natural Forest Protection since 1998, it indicated that the eco-environmental quality of Miyun county gradually improved from bad status to good status during the past decade.
3. Our surveys show that the transformation from good to bad eco-environmental quality still existed in some local regions, and the phenomenon of the deforestation, indiscriminate felling, overgrazing and land reclamation driven by human activities is a general phenomenon, especially on some steep regions and at the medium elevation, which can accelerate the regional soil erosion and make the local eco-environmental quality worse and worse. Therefore, we should adjust the measures to local conditions, strengthen and preform the environmental protection and ecological construction and measures for regional eco-environmental status, such as Grain for Green and Natural Forest Protection, Miyun Reservoir Ecological Protection and so on.

ACKNOWLEDGMENT

This research was supported by Foundation of Bureau of Sanjiang Engineering Management and Construction (SGZL/KY-10), Natural Scientific Foundation of Heilongjiang Province (Grant No. QC2017036, D201410), Natural Science Foundation of Heilongjiang Province Department Education Commission (Grant No. 12531513). We appreciate the staff of the Ecological Research Central in 3S laboratory of Heilongjiang University. We also want to express our respect and thanks to the anonymous reviewers and the editors for their helpful comments in improving the quality of this paper.

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