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Use of Intensity Analysis to Measure Land Use Changes from 1932 to 2005 in Zhenlai County, Northeast China

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Abstract: Analyzing spatiotemporal dynamics of land use and land cover over time is widely recognized as important to better understand and provide solutions for social, economic, and environmental problems, especially in ecologically fragile region. In this paper, a case study was taken in Zhenlai County, which is a part of farming-pastoral ecotone of Northeast China. This study seeks to use multi-temporal satellite images and other data from various sources to analyze spatiotemporal changes from 1932 to 2005, and applied a quantitative methodology named intensity analysis in the time scale of decades at three levels: time interval, category, and transition. The findings of the case study are as follows: 1) the interval level of intensity analysis revealed that the annual rate of overall change was relatively fast in 1932–1954 and 1954–1976 time intervals. 2) The category level showed that arable land experienced less intensively gains and losses if the overall change was to have been distributed uniformly across the landscape while the gains and losses of forest land, grassland, water, settlement, wetland and other unused land were not consistent and stationary across the four time intervals. 3) The transition level illustrated that arable land expanded at the expense of grassland before 2000 while it gained intensively from wetland from 2000 to 2005. Settlement targets arable land and avoids grassland, water, wetland and other unused land. Besides, the loss of grassland was intensively targeted by arable land, forest land and wetland in the study period while the loss of wetland was targeted by water except for the time interval of 1976–2000. 4) During the early reclamation period, land use change of the study area was mainly affected by the policy, institutional and political factors, followed by the natural disasters.
Keywords: intensity analysis; land use and land cover change; pattern; driving forces; Northeast China

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1 Introduction

Historical land use and land cover (LULC) change has been generally considered as an essential driver of global environmental change (Lambin, 1997; Foster *et al.*, 2003; Foley *et al.*, 2005; Gragson and Bolstad, 2006; Fischer and Lindenmayer, 2007; Turner *et al.*, 2007; Frondoni *et al.*, 2011), significantly affecting key aspects of earth system functioning (Lambin, 1997). Current ecological and environmental issues such as water pollution (Bolstad and Swank, 1997; Wear and Bolstad, 1998), hydrological alteration (Foley *et al.*, 2005), soil sealing and compaction (Dupouey *et al.*, 2002; Bakker *et al.*, 2005), habitat loss and fragmentation (Sinclair *et al.*, 1995; Pearson *et al.*, 1999), biodiversity reduction (Sala *et al.*, 2000; Huston, 2005), climate change (DeFries *et al.*, 1997) and, especially, global carbon balance (Houghton, 2003), have been closely

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linked to land use and land cover change (LUCC). Analyzing and mapping the changes in LULC over time, especially in the eco-fragile region, is recognized as important to better understand and provide solutions for social, economic, and environmental problems (Lu *et al.*, 2004; Pelorosso *et al.*, 2009; EI-Kawy *et al.*, 2011).

The edges of grassland areas that are invaded by farmland will generally form farming-pastoral ecotone (Zhao, 1953; Lu and Jia, 2013), which is a transitional belt and also the natural barrier for ecological security (Liu *et al.*, 2011) characterized by ecological vulnerability, poverty and multi-ethnic groups. The farming-pastoral ecotone of Northern China is located in the transitional zone between the semi-humid agriculture area and the arid/semiarid pastoral area (Zhou and Zhang, 1982). It is a sensitive region of terrestrial ecosystems which is more vulnerable to global change and human disturbance. In the past century, high-intensity human activities, such as excessive reclamation, grazing, excavation and abandonment, have produced enormous negative environmental impacts in the region. The natural grassland has suffered profound land use transformation during the last century (Liu *et al.*, 2011), which has been mainly converted into cropland due to climate warming, increased population and food demand, *etc*. This destruction of natural vegetation, especially the degradation of grassland, has constantly drained the service functions of the local ecosystem service (Costanza *et al.*, 1997; Chen *et al.*, 2008) as well as the regional climate (Angell and McClaran, 2001). In this context, studying spatiotemporal dynamics over the past century in the ecologically vulnerable area are becoming significant topics.

Because of the importance of LUCC phenomenon, scientists have developed various techniques for detecting the changes, heavily relying on advances in remote sensing (RS) and geographical information system (GIS) (Lu *et al.*, 2004; Berberoglu and Akin, 2009). Previous studies of land use changes mainly focused on analyzing the categorical changes of land use and land cover with the accumulation of remotely sensed images to compute the transition matrix based on a two-epoch timescale. However, previous analysis of the change matrix is not sufficient to provide systematic and quantitative information of LUCC. Some efforts have been made to throw light on the underlying causes and processes of the fundamental transformations based on analysis of the transition matrix (Huang *et al.*, 2012). Aldwaik and Pontius (2012) developed the method further into an approach named intensity analysis, which examines changes among land categories at three levels: time interval, category and transition. Intensity analysis quantifies at each level the deviation between observed change intensity and hypothesized uniform change intensity. Some researchers (Braimoh, 2006; Versace *et al.*, 2008; Romero-Ruiz *et al.*, 2011; Shoyama and Braimoh, 2011; Huang *et al.*, 2012; Zhou *et al.*, 2014) have used the concepts introduced by Pontius and Malizia (2004). But intensity analysis has been only applied in the last four decades at most, following the advent of the first land satellite, Landsat-1, launched in 1972. Understanding long-term human-environment interactions is essential to understanding changes in terrestrial ecosystems (Ramankutty and Foley, 1999; Petit and Lambin, 2002). Thus, it is necessary to study longer-term spatiotemporal land use changes.

Considering the richness of regional LUCC data over the past century, we take Zhenlai County which is a part of the farming-pastoral ecotone of Northeast China, located in northwestern Jilin Province, as an example. This study seeks to use multi-temporal satellite images and other data from various sources to analyze spatiotemporal changes in Zhenlai County from 1932 to 2005 and apply intensity analysis method in the time scale of decades. Our main objectives are: 1) to detect and evaluate spatiotemporal changes in land use and land cover from 1932 to 2005 in the study area using the method of intensity analysis; 2) to analyze the driving forces of the land use and land cover change during the past century in Zhenlai County, Northeast China.

2 Materials and Methods

2.1 Study area

Zhenlai County (45°28′N–46°18′N, 122°47′E–124°04′E) (Fig. 1), as a typical farming-pastoral ecotone, is located in the Baicheng City of northwestern Jilin Province in Northeast China, occupying the northernmost part of the province and bordering Heilongjiang to the east and Inner Mongolia to the west. After the enactment of 'lifting a ban on reclaiming' policy in the late Qing Dynasty (1902), the study area has experienced a relatively complete and dramatic LUCC during the past century. The county has a variety of geomorphologic types and features a terrain that is high in the northwest and low in the southeast. Its northwest is adjacent to the Da Hinggan Mountains, its central area is mostly rolling hilly land, and its east and south surround the Nenjiang River and the Taoer River, respectively, forming a fertile flood plain on the banks of both rivers. The major soil types are chernozem, alluvium soil, alkali soil and meadow soil. Climatically, the region is subject to a temperate continental monsoon climate with distinct seasons, as it is located in inland areas of mid-latitude. The mean annual precipitation is 402.4 mm, unevenly distributed over time, while the mean annual evaporation is 1755.9 mm, about four times as much as the mean annual precipitation. Thus, the low amount of precipitation and the high amount of evaporation mainly result in a drought-prone climate in the study area, especially in spring. The mean annual temperature is around 4.9℃.

2.2 Data

Based on our former study about the LUCC rate and the available data in the study area, monitoring land use and land cover changes in the study area was done at 5 years: 1932, 1954, 1976, 2000, and 2005. One Landsat Multispectral Scanner (MSS) and two Landsat Thematic Mapper (TM) images were selected pertaining to the years 1976, 2000, and 2005. And then the land use data were interpreted from the above remote sensing images which were downloaded from the United States Geological Survey (USGS) (http://glovis.usgs.gov/). Meanwhile, our research team reconstructed the spatiotemporal distribution of land use and land cover in 1932 and 1954, respectively, using topographic maps and physical environmental background maps including of terrain, climate, geology, soil, vegetation, hydrology, and socio-economic statistical data (Bai *et al.*, 2004; 2005; 2007; Lyu *et al.*, 2010; 2012; 2015; Yang *et al.*, 2014; 2015; 2017; Yang, 2015). The digital reconstruction model of land use was built based on the cellular automata (CA) model and Geomod model, respectively (Bai *et al.*, 2007; Lyu *et al.*, 2015; Yang *et al.*, 2015b). The basic idea is firstly to analyze changes in land use and land cover using remote sensing data and then classify the various land use change forms; secondly, to determine the driving factors influencing changes in land use; thirdly, to undertake spatial overlay analysis between the various natural driving factors' maps and land use change maps, respectively, and to calculate the probability of

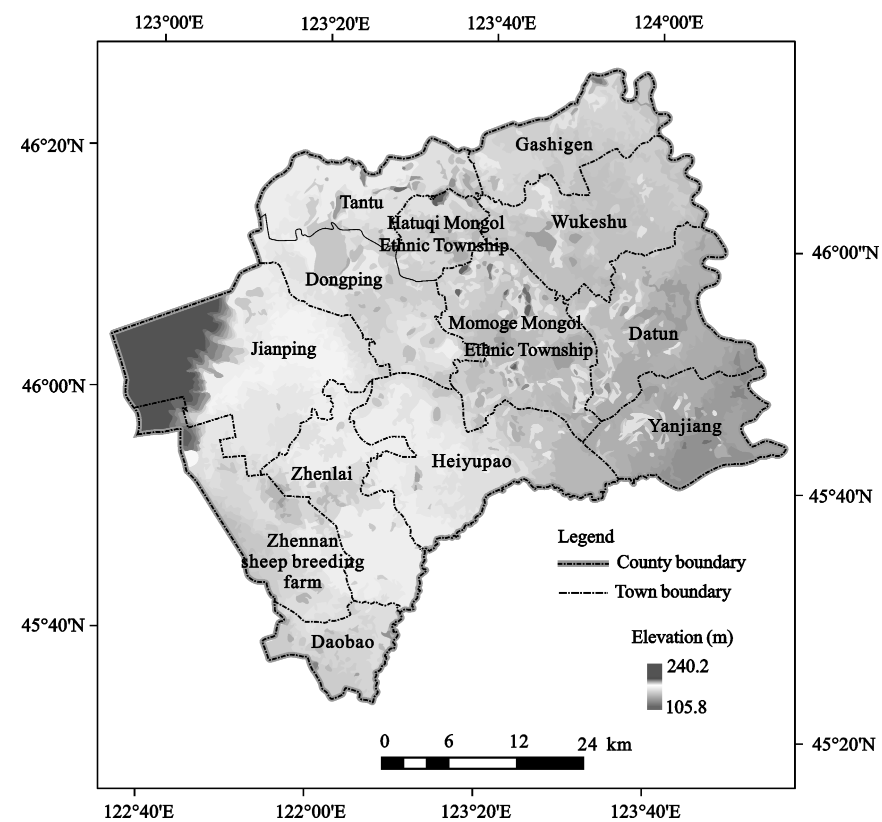


Fig. 1 Elevation map of Zhenlai County in Jilin Province, China

each land use in each grid; fourthly, to distribute the total area of each land use into the spatial grids based on the probability in each grid according to spatial allocation principles or approaches; finally, to calibrate the model results compared with base data, such as the topography maps.

2.3 Classification system

To be able to make comparisons over time, the maps had to be thematically generalized. Taking into account both the local characteristics and the land use classification system in China, seven suitable land categories were aggregated for this study: arable land (including paddy field and dry land); forest land (including deciduous forest, coniferous forest, low pinewood, orchards, *etc.*); grassland (including natural grassland and pasture); water bodies (including river, lake and pond); settlement (urban and rural construction); wetland and other unused land (including sand, saline-alkali land and bare land) (Fig. 2).

2.4 Intensity analysis method

Intensity analysis is based on the cross-tabulation matrix for each time interval accounting for the intensity of land transitions at interval, category, and transition levels in order to extract three types of information (Aldwaik and Pontius, 2012; Huang *et al.*, 2012; Zhou *et al.*, 2014). The interval level answers the question that in which time intervals is the annual rate of overall change relatively slow versus fast. For any particular time interval, the category level examines that which land categories are relatively dormant versus active. Based on the above analysis of the two levels, the transition level answer the question that which transitions are intensively avoided versus targeted by a given land category in a given time interval. For intensity analysis across time intervals, stationarity means that the pattern at one time interval is the same as the pattern at the other time intervals, where the pattern is defined with respect to uniform intensities. Equations (1)–(8) present the notation and equations for the intensity analysis (Aldwaik and Pontius, 2012).

At the interval level, we analyze the total change in each time interval to examine how the size and annual rate of change vary across time intervals, and then we compare the observed rates to a uniform rate that would exist if the annual changes were distributed uniformly across the entire time extent. Equation (1) defines each

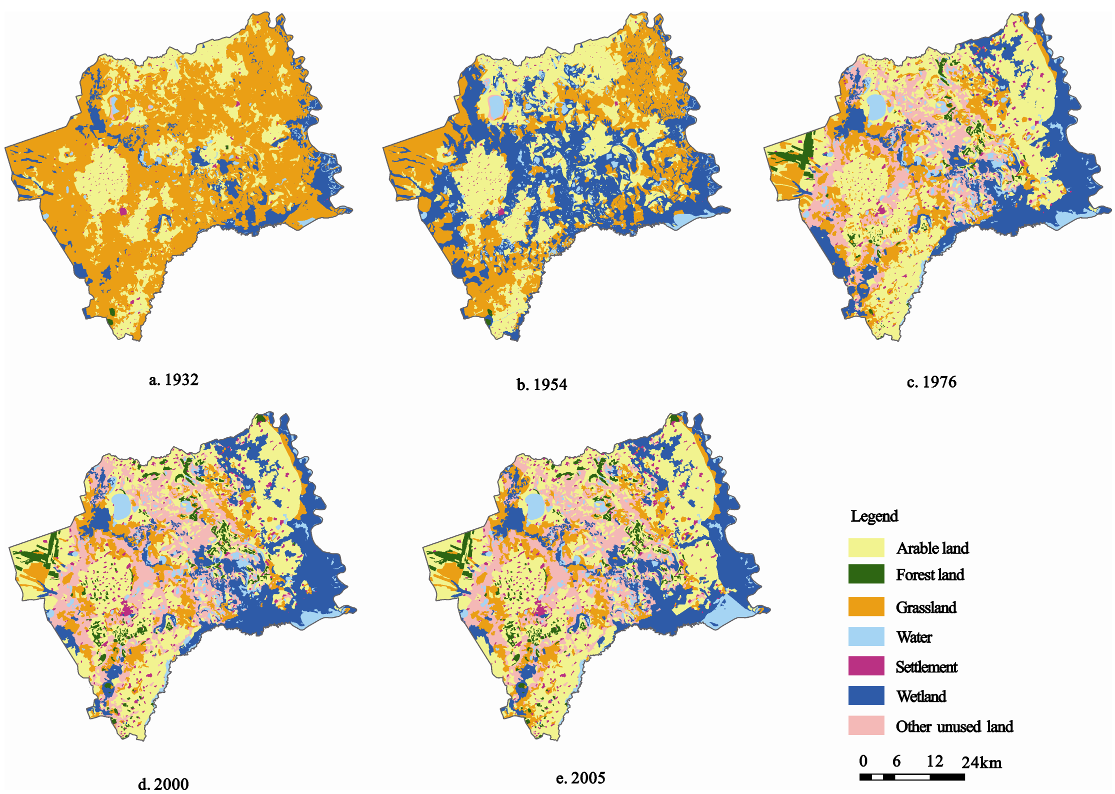


Fig. 2 Land use and land cover maps for five years of Zhenlai County in Jilin Province, China

interval's annual rate of overall change while Equation (2) defines the uniform annual rate for the entire temporal extent of the study, which would exist if the pattern of change were perfect stationary in terms of rate of overall change. In other words, if values of S_t were equal for all t, then those values of S_t would equal U.

The category level of intensity analysis examines which categories are relatively dormant versus active in a given time interval. This analysis computes the intensity of annual gross gains (Equation (3)) and annual gross losses (Equation (4)) for each category and then compares them with a uniform intensity of change (Equation (1)) that would exist if the overall change were distributed uniformly across the landscape. Thus, Equation (1) links the interval level analysis with the category level analysis. This assessment is performed for each time interval.

The transition level of intensity analysis addresses the question that which transitions are particularly intensive in a given time interval. It is helpful to consider the transition from a particular category m to a different category n. we first examine the pattern of gain of category n. If category n exists at a particular place at the initial time, then category n cannot gain at that place. When category n gains, it must gain from places that are initially not category n. Category n might intensively avoid gaining from some particular categories and might intensively target gaining from some other categories. Alternatively, if category n gains uniformly across the landscape, then category n will gain from other categories in proportion to the initial sizes of those other categories. Equation (5) and Equation (6) identify which other categories are intensively avoided versus targeted for gaining by category n in a given time interval.

The transition level of the losing category explains the sizes of the transitions from the losing categories. Equation (7) and Equation (8) analyze the loss of category m in a manner analogous to how Equation (5) and Equation (6) analyze the gain of n. *Given* the empirical gross loss of category m, Equation (7) and Equation (8) identify which other categories intensively avoid versus target category m for takeover in a given time interval. Equation (7) and Equation (8) account for the fact that if category m exists at a particular place at the end of a time interval, then category m cannot have lost at the place during the interval. This uniform intensity portrays a situation in which category m loses to other categories, where all non-m categories gain from category m in proportion to the relative sizes of the non-m categories at the later time. If category m were to lose to all other categories in a uniform manner, then $Q_{tmj} = V_{tm}$ for all j. We check for stationarity of a transition from m to n by investigating the intensity among all time intervals. If the loss of category m is either avoided by category n for all time intervals or targeted by category n for all time intervals, then we define the transition from m to n as stationary, given the loss of m. For each time interval, the transition intensity level of analysis produces two sets of outputs. One set analyzes transitions for gains of category n, and the other set analyzes transitions for losses of category m.

$$S_t = \frac{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tij}\right] \Big/ \sum_{j=1}^{J}\sum_{i=1}^{J} C_{tij}}{Y_{t+1} - Y_t} \times 100\% \tag{1}$$

$$U = \frac{\sum_{t=1}^{T-1}\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tij}\right] \Big/ \sum_{j=1}^{J}\sum_{i=1}^{J} C_{tij}}{Y_T - Y_1} \times 100\% \tag{2}$$

$$G_{tj} = \frac{\left(\sum_{i=1}^{J} C_{tij} - C_{tij}\right) \Big/ \left(Y_{t+1} - Y_t\right)}{\sum_{i=1}^{J} C_{tij}} \times 100\% \tag{3}$$

$$L_{ti} = \frac{\left(\sum_{j=1}^{J} C_{tij} - C_{tij}\right) \Big/ \left(Y_{t+1} - Y_t\right)}{\sum_{j=1}^{J} C_{tij}} \times 100\% \tag{4}$$

$$R_{tin} = \frac{C_{tin} \Big/ \left(Y_{t+1} - Y_t\right)}{\sum_{j=1}^{J} C_{tij}} \times 100\% \tag{5}$$

$$W_{tn} = \frac{\left(\sum_{i=1}^{J} C_{tin} - C_{tin}\right) \Big/ \left(Y_{t+1} - Y_t\right)}{\sum_{j=1}^{J}\left(\sum_{i=1}^{J} C_{tij} - C_{tnj}\right)} \times 100\% \tag{6}$$

$$Q_{tmj} = \frac{C_{tmj} \Big/ \left(Y_{t+1} - Y_t\right)}{\sum_{j=1}^{J} C_{tij}} \times 100\% \tag{7}$$

$$V_{tm} = \frac{\left(\sum_{j=1}^{J} C_{tmj} - C_{tmm}\right) \Big/ \left(Y_{t+1} - Y_t\right)}{\sum_{i=1}^{J}\left(\sum_{j=1}^{J} C_{tij} - C_{tim}\right)} \times 100\% \tag{8}$$

where S_t represents annual intensity of change for time interval $[Y_t, Y_{t+1}]$; Y_t represents year at time point t, and t ranges from 1 to T–1; C_{tij} represents number of pixels that transition from category i at time Y_t to category j at time Y_{t+1}; J represents number of categories; i represents index for a category at an initial time; j represents index for a category at an initial time; U represents value of uniform line for time intensity analysis; T represents number of time points; G_{tj} represents annual intensity of gross gain of category j for time interval $[Y_t, Y_{t+1}]$; L_{ti} represents annual intensity of gross loss of category i for time interval $[Y_t, Y_{t+1}]$; R_{tin} is annual intensity of transition from category i to category n during time interval $[Y_t, Y_{t+1}]$, where $i \neq n$; n represents index for the gaining category in the transition of interest; W_{tn} represents value of uniform intensity of transition to category n from all non-n categories at time Y_t during time interval $[Y_t, Y_{t+1}]$; Q_{tmj} represents annual intensity of transition from category m to category j during time interval $[Y_t, Y_{t+1}]$, where $j \neq m$, m represents index for the losing category in the transition of interest; V_{tm} represents value of uniform intensity of transition from category m to all non-m categories at time Y_{t+1} during time interval $[Y_t, Y_{t+1}]$.

3 Results

3.1 Interval level of intensity analysis

The annual change areas are 1.672%, 2.699%, 0.398% and 0.887% of total area, respectively, for the four time intervals of 1932–1954, 1954–1976, 1976–2000 and 2000–2005. And the uniform intensity at the interval level in the study area is 1.509%. The interval level of intensity analysis produces Fig. 3. In the right side of Fig. 3, if an interval bar ends to the left of the uniform line, then the change is relatively slow for that time interval. If an intensity bar extends to the right of the uniform line, then the change is relatively fast for that time interval. The left side of Fig. 3 shows that the size of the change during the first time interval and second time interval are large, especially for the second time interval. And the size of the change during the time intervals of 1976–2000 and 2000–2005 are small. This could be explained by the various time intervals and different land conversion speeds. The four time intervals are 22, 22, 24 and 5, respectively, and thus, it is evident that the interval change area during 2000–2005 is the least. Besides, the right side of Fig. 3 shows that the annual rate of change in the second time interval 1954–1976 was the fastest during the whole study period accordingly. Especially, it should be noticed that the size of the change during the third time interval is larger than the size during the fourth time interval, while the right side of Fig. 3 indicates the reason, which is that the duration of the third time interval is longer than the duration of the fourth time interval. The right side of Fig. 3 suggests that the annual rate of change was actually faster in the fourth time interval compared to the third time interval. The rate of change is not perfectly stationary at this interval level of analysis because the bars on the right do not equal to the uniform line.

3.2 Category level of intensity analysis

The category level of intensity analysis produces one graphic per time interval, as Figs. 4a to 4d shows. If a bar ends below the uniform line, then the change is relatively dormant for that category. If a bar extends above the uniform line, then the change is relatively active for that category. Fig. 4 shows that the annual change intensity of arable land during each time interval is dormant as the bars end below the value of uniform line. This indicates that arable land is consistent and stationary across the four time intervals for the transition level of intensity analysis, revealing that arable land experiences less intensively gains and losses if the overall change was to have been distributed uniformly across the landscape. The bar for gain of forest land extends above the uniform line during the time interval of 1954–1976, while the gain of forest land is dormant during the other three time intervals as the corresponding bars end below the uniform line, indicating that forest land during 1954–1976 experiences change more intensively than if the overall change would have been distributed uniformly across the landscape. Similarly, the loss of forest

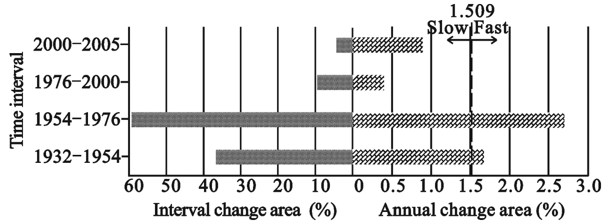


Fig. 3 Time intensity analysis for four time intervals. Bars that extend to the left of zero show area of overall changes in each interval while bars that extend to the right of zero show intensity of annual area of change within each time interval

land is active during 1954–1976 and 1976–2000 while it is dormant during 1932–1954 and 2000–2005, respectively. Fig. 4 shows that the gains of grassland and water are dormant during 2000–2005, whereas they are active during the other three time intervals. The loss of grassland is dormant during 1932–1954 and 1976–2000 while it is relatively active during the other time intervals. The bar for loss of water extends above the uniform line during 1932–1954 and 2000–2005 while it ends below the uniform line during 1954–1976 and 1976–2000, respectively. In addition, settlement experiences gain more intensively than the landscape in general during 1934–1956 while it is dormant during the other three time intervals. Similarly, settlement experienced losses more intensively than the landscape in general except for the time interval of 2000–2005. The bars for gain of wetland extend above the uniform line during the time intervals of 1932–1954 and 2000–2005 while the bar for loss of wetland ends below extend above the uniform line only at the first time interval. The gains of other unused land are dormant during 1932–1954 and 1976–2000, whereas the losses of other unused land are active except for the time interval of 2000–2005.

3.3 Transition level of intensity analysis

Zhenlai County, as a part of the farming-pastoral ecotone of northern China, was not allowed to reclaim until the enactment of 'lifting a ban' policy in the late Qing Dynasty (1902). In the past century, the region has experienced a large-scale population migration and land reclamation process, revealing dramatic LUCC. Thus, considering the essential influence of human activities on land use and land cover change, we will investigate and focus the transition from other land categories to arable land and settlement here. Meanwhile, we will also emphasis on the analysis of transition among grassland, wetland and other unused land considering the impact of climate on the natural categories. Fig. 5 shows the intensities for gain of grassland, settlement, grassland, wetland, other unused land, and the intensities for loss of arable land, grassland, wetland and other unused land in the four time intervals, respectively.

The transition level examines how the size and intensity of a category's transition vary across the other categories that are available for that transition. In the following five rows of graphs (A–E) of Fig. 5, the horizontal dash line represents the uniform line. If an intensity bar ends below the uniform line, then the transition systematically avoids that category. If an intensity bar extends above the uniform line, then the transition systematically targets that category. Fig. 5A shows arable land gains mainly from grassland in terms of the size of the annual transition during the time intervals of 1932–

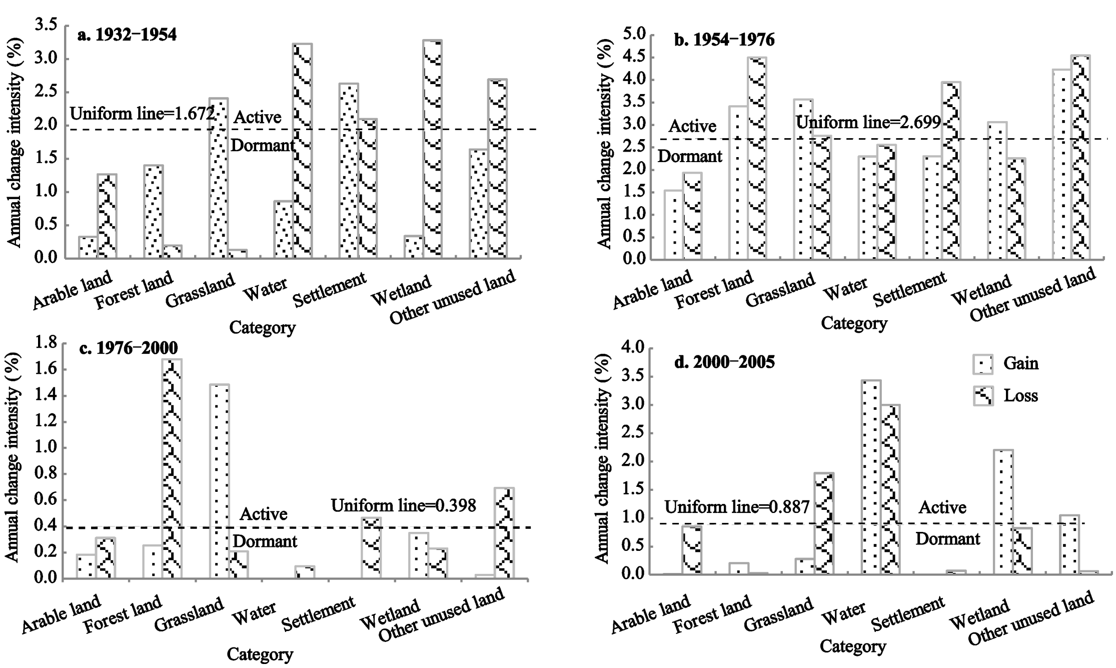
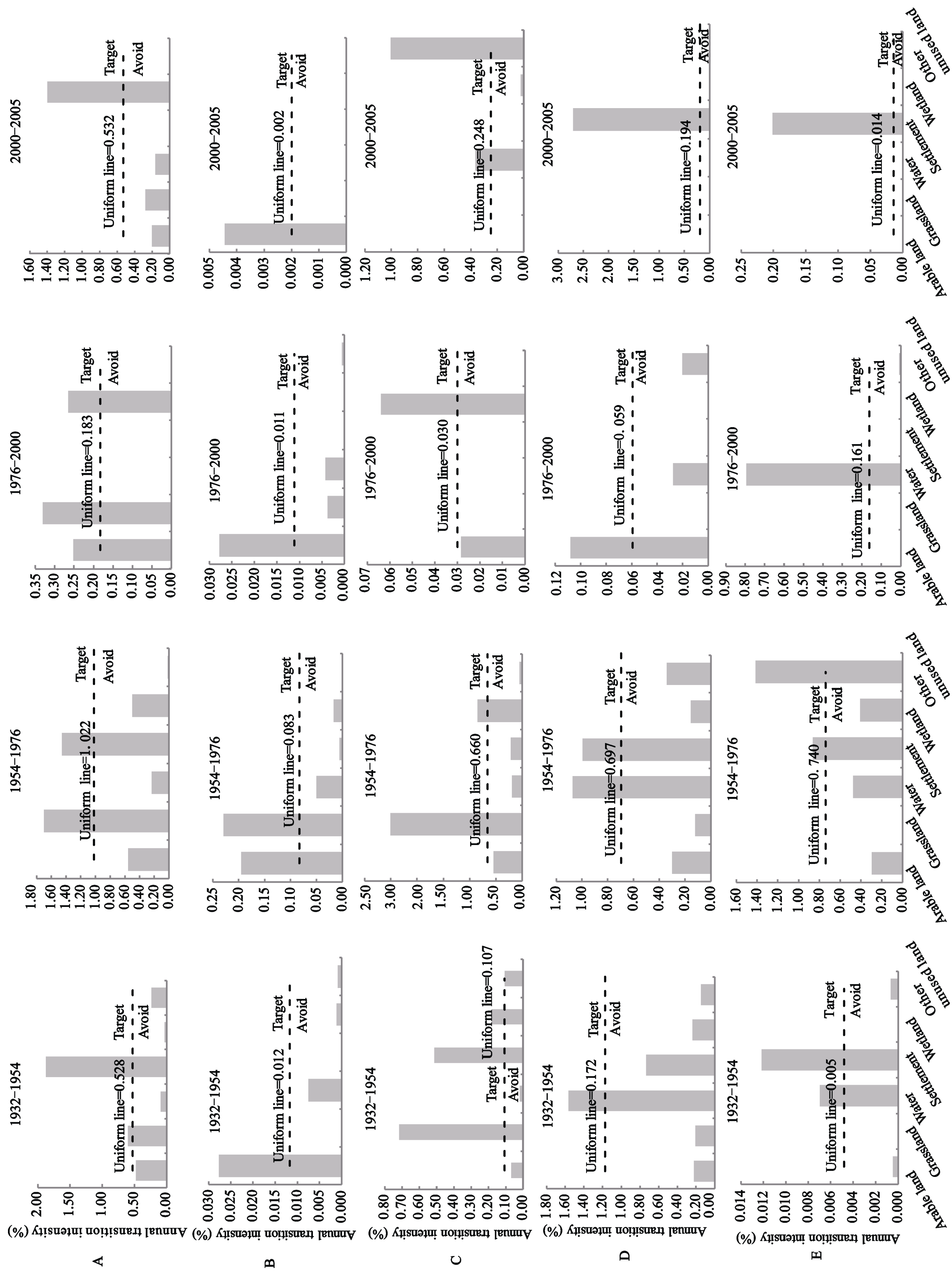


Fig. 4 Category intensity for four time intervals of study area


A
B
C
D
E
Annual transition intensity (%)
1932–1954
1954–1976
1976–2000
2000–2005
Uniform line=0.528
Uniform line=1.022
Uniform line=0.183
Uniform line=0.532
Uniform line=0.012
Uniform line=0.083
Uniform line=0.011
Uniform line=0.002
Uniform line=0.107
Uniform line=0.660
Uniform line=0.030
Uniform line=0.248
Uniform line=0.172
Uniform line=0.697
Uniform line=0.059
Uniform line=0.194
Uniform line=0.005
Uniform line=0.740
Uniform line=0.161
Uniform line=0.014
Target
Avoid
Arable land
Grassland
Water
Settlement
Wetland
Other unused land
Category

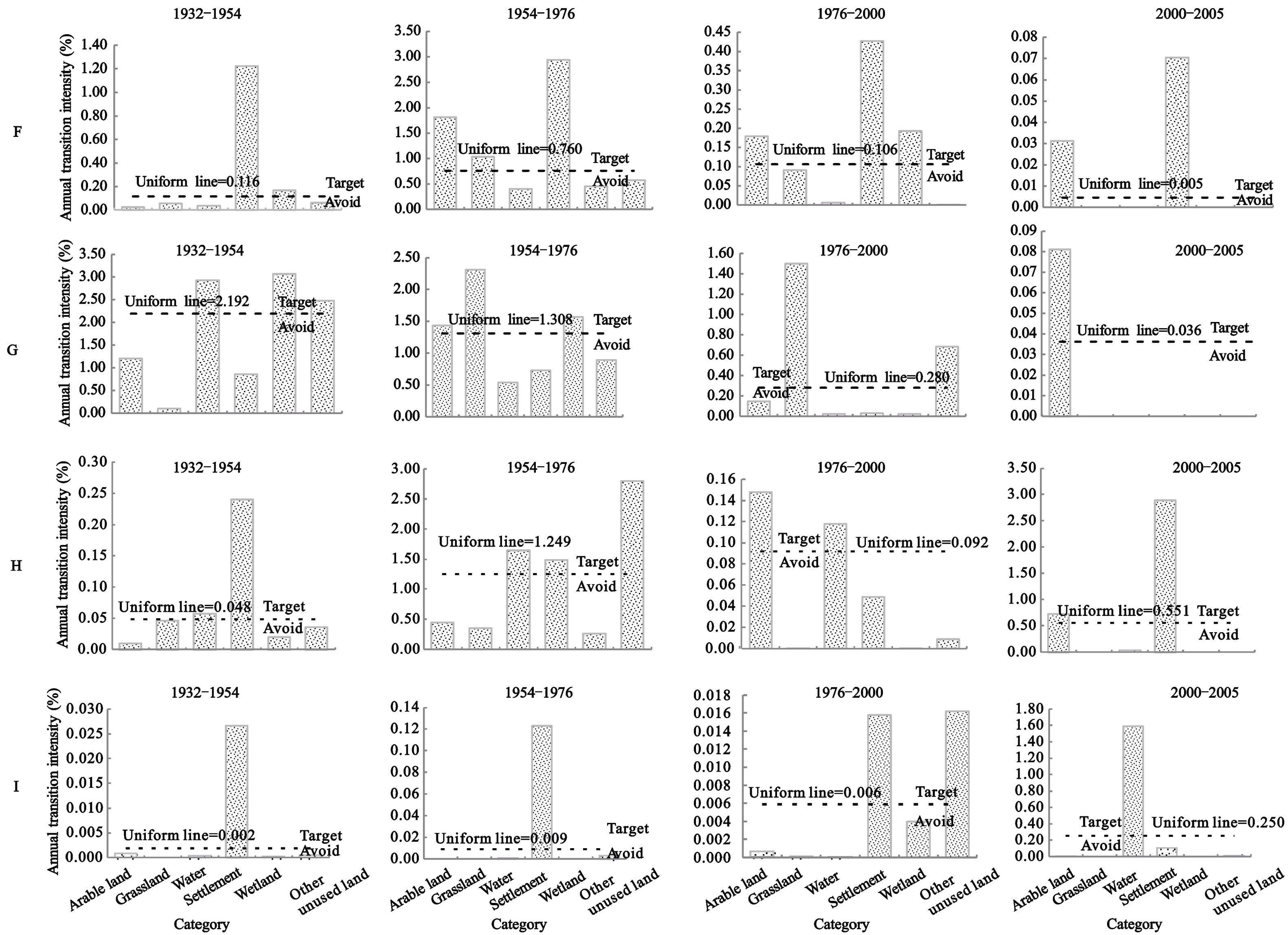


Fig. 5 Transition intensities of land categories gain/loss, where columns represent the four time intervals (1932–1954, 1954–1976,1976–2000, 2000–2005), rows represent gaining categories. (A-Arable land, B-Settlement, C-Grassland, D-Wetland, E-Other unused land) and the losing categories (F-Arable land, G-Grassland, H-Wetland,I-Other unused land), respectively

1954, 1954–1976, 1976–2000, and then mainly from wetland from 2000 to 2005. Meanwhile, the gain of arable land both avoids water and other unused land for all the four time intervals and the transition from water or other unused land to arable land is stationary, given the gain of arable land. Fig. 5B shows the results for the transition from other land categories to settlement. The results indicate that settlement targets arable land and avoids grassland, water, wetland and other unused land for all time intervals, reflecting that the transition from arable land, grassland, water, wetland and other unused land to settlement is stationary. Fig. 5C and Fig. 5D suggest the transitions from arable land to grassland and from forest land, settlement and other unused land to wetland are stationary for the four time intervals. Grassland avoids arable land while it targets forest land during the time intervals of 1932–1954 and 1954–1976 and targets wetland and other used land from 1976 to 2000 and from 2000 to 2005, respectively. Given the observed gross gain of wetland, it intensively avoids gaining from forest land, settlement and other unused land, while it targets gaining from grassland during the first and second time intervals, from arable land during 1976–2000 and from water during 2000–2005. Fig. 5E reveals other unused land tends to be intensively targeted gaining from water during 1932–1954, 1954–1976, and 2000–2005 which indicates obvious climate change during the three time intervals, and it targets gaining from grassland from 1976 to 2000 which suggests serious deterioration of the eco-environment. Meanwhile, other unused land avoids arable land, forest land and settlement.

As for the transition intensity of land categories loss (Figs. 5F to 5I), the vertical axis represents the annual transition intensity as a percent of the gaining category while a horizontal line shows the gaining categories for the entire study area. And the horizontal dash line represents the uniform line. If an intensity bar ends below the uniform line, then the loss of that category is avoided. Otherwise, the loss of that category for that time interval is targeted. Fig. 5F shows the results for the loss of arable land, which is targeted intensively by settlement for the four time intervals. This indicates that the transition from arable land to other land categories is stationary, given the loss of arable land. It should be also noticed that the loss of arable land is avoided intensively by water and other unused land. Besides, arable land tends to be targeted more intensively by forest land during 1954–1976, 1976–2000 and 2000–2005, mainly caused by the construction of the Three-north Forest Protection Project and subsequent afforestation. Fig. 5G reveals that loss of grassland is intensively targeted by water, wetland, and other unused land during the time interval of 1932–1954, which is consistent with the fact that 1936–1959 was pluvial period in the past century in Northeast China (Gao *et al.*, 2010). Grassland tend to be targeted by arable land, forest land and wetland during 1954–1976, and by forest land and other unused land during 1976–2000, and by arable land during 2000–2005, respectively. Fig. 5H shows that the loss of wetland is intensively targeted by water except for the time interval of 1976–2000. The last graph shows the fact that other unused land is intensively targeted by water during the first, second and third time interval while it is targeted by grassland during 2000–2005. Besides, it should be also noticed that the loss of other unused land is targeted by wetland.

4 Discussion

4.1 Patterns and processes in LUCC

Above research adopted by intensity analysis showed that the study area experienced a complicated process in land use and land cover change during the past century. The interval level of intensity analysis revealed that both the annual change area and annual change intensity during 1954–1976 are the largest for the four time intervals. Meanwhile, the transition level of intensity analysis strikingly illustrated that arable land expanded at the expense of grassland during 1932–1954, 1954–1976 and 1976–2000 while it gained intensively from wetland from 2000 to 2005. This could be driven by the national macro-policy actively encouraging people to reclaim and farm to develop local agriculture so that people reclaimed and cultivated land intensely especially during 1954–1976 which created the dominant effect on land use. The adjustment of production relations mobilized people's enthusiasm to reclaim land since 1950s (Liu and Huang, 2002; Song *et al.*, 2008). The category level of intensity analysis and the transition level of intensity analysis showed that the patterns during the four time intervals were quite different and not all the processes of LUCC in this study area are stationary. The frequent transitions among grassland, wetland, and other unused land are mainly caused by the following two reasons: 1) wetland had a clear relationship with precipitation and would be changed into grassland in the years with less precipitation; 2) there were plenty of lakes and ponds inside and surrounding the Nenjiang River and the Tao'er River to the east and south of the study area, respectively, which made the nearby wetland, grassland, and other unused land convert frequently. Settlement targets arable land and avoids grassland, water, wetland and other unused land which should attract people's attention to attaching importance to the food security.

4.2 Driving forces of LUCC

4.2.1 Natural factors

(1) Climate factors

Because there will not be much change for the factors such as geology, landscape, vegetation and soil in a short time, thus, the climate condition becomes the main factor affecting the land use and land cover change in the study area (Wang *et al.*, 2013). In the last century, Zhenlai County had obvious climate warming trend which constituted an environment background for land use and land cover change. The increasing annual average temperature and decreasing annual precipitation in Zhenlai County over the past century (Fig. 6) resulted in high evaporation and frequent droughts which had caused serious damage to the natural ecosystems such as grassland and wetland. Wetland degenerates to dry meadow due to severe water shortages and land degradation resulted from grassland desertification, salinization and alkalinization, is increasingly common. It was calculated that 33.35% of wetland was changed to other unused land during 1954–1976, reflecting the natural process affected by climate change (Yang *et al.*, 2014). Water bodies were mainly influenced by natural factors, especially affected by climate change in the absence of irrigation facilities such as reservoirs.

(2) Natural disaster

Nature disaster often impacts on land use/cover change in the form of abrupt change. From 1908 to 1939, there were totally 10 different-scale flood disasters and 2 droughts. Droughts had important impact on agricultural production of the year while they had little effect on LUCC. However, floods could result in relevant LUCC, such as wetland, grassland and water.

4.2.2 Demographic factor

Population is the most important factor for human's social and economic development and also one of the crucial driving forces of the LUCC. The population development in Zhenlai County experienced a long process of evolution. There were few inhabitants around the study area before the late Qing Dynasty until the ban on the prohibition policy was lifted. The population was 20 300 in 1914. During the period of the northeastern occupation by Japan, migration population increased to 44 568 in 1934. According to the record of *Hundred years in Zhenlai* (*1910–2010*), the total numbers of households in the study area increased from 22 775 in 1949 to 116 666 in 2009, while the total population increased from 121 060 to 295 440 during this period (Fig. 7). Demographic change, resulted from changes in policies and population growth, generally leads to major land reclamation process and expansion of agricultural area to meet the food requirements for local people, which is

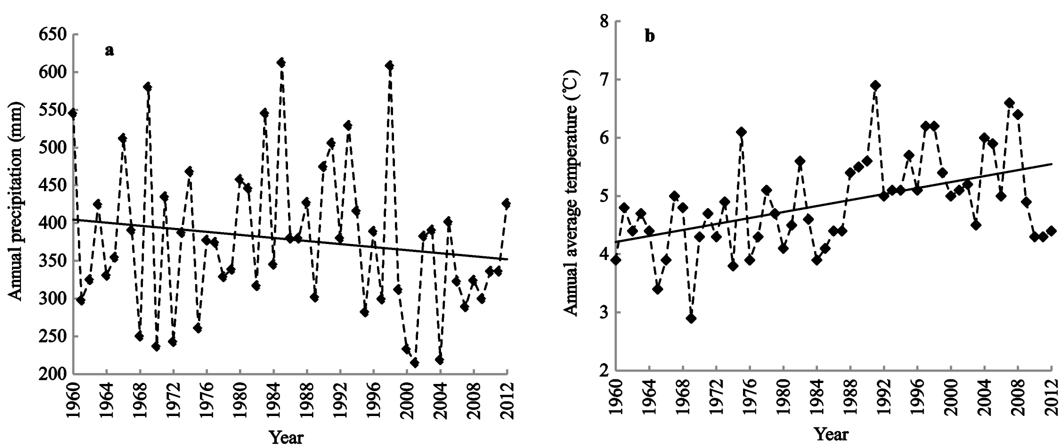


Fig. 6　Change of climate factor from 1960 to 2012 in study area

the main driver causing pressure on historical grassland and wetland. Besides, the rapid growth of population also increase the intensity of the existing cultivated land, resulting in excessive reclamation and land-use type change. Meanwhile, it was difficult to find local jobs for a large number of agricultural population at that time and then the local people had to bring more land under cultivation to increase their income. Our previous researches show that arable land expanded at the expense of grassland and wetland over the past century due to land reclamation. It was calculated that grassland had the largest sum of transition probability between the period 1954 and 2005, especially that people intensely reclaimed and cultivated land during 1954–1976. Meanwhile, the growth of population also resulted in the increase of settlements to meet residents' demands (Yang *et al.*, 2014).

4.2.3 Political factor

Wars: Wars often occurred before the founding of new China in 1949. When Russo-Japanese War broke out in 1904, most of local people had to leave their home to take refuge, and only half of them came back when the war was finished (Local Record of Zhenlai County, 1995; Lyu *et al.*, 2010). A civil war broke out as some dukes rebelled against Emperor, occupied county town of Zhenlai and then declared 'independence' in 1912. After the fall of northeastern part of China in 1931, Japanese invaders forced the local people reclaim the land and on the other hand, the immigrant from Japan set reclamation point at Erlongshan, Heidimiao, Taobao village *et al.*. By the end of 1943, the total arable land reached 31 520 ha (Local Record of Zhenlai County, 1995). Generally, wars influence human activities and the population size and then indirectly affect the local land use and land cover change.

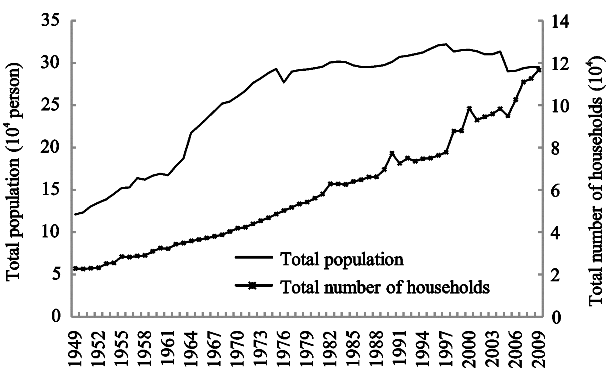


Fig. 7 Population change in the study area

Policy system: It mainly contained land ownership, policy, land reform and major political events, *etc*. The rulers of the Qing Dynasty regarded the northeastern China as their birthplace and then they began to implement the ban policy lasting for more than 200 years from 1668. During the period, population growth was quite slow and most of the land maintained the natural state without development. And in 1904, the late Qing government lifted the ban of the northeast China and then large people moved into resulting in rapidly growing population and dramatically increasing arable land (Gazetteer of Baicheng area, 1984; Zhenlai County Annals, 1985; Local Record of Zhenlai County, 1995). After the foundation of new China in 1949, the county put the development of forestry in an important position. Especially, after 1978, forest area increased fast due to the implementation of a series of instructions of the Communist Party of China (CPC) Central Committee and the State Council on strengthening the construction of the Three North Shelterbelt. Cumulative area for afforestation had reached to 52 469.5 ha by 1985, which was 29.8 times as much as that of 1949 year (Local Record of Zhenlai County, 1995). Meanwhile, the national polices such as private land possession system (1949–1952), agricultural co-operation (1953–1978) and household contract responsibility system (1978–present) had dramatic and direct effects on land utilization.

4.2.4 Socioeconomic development factors

Zhenlai County experienced rapid socioeconomic development over the last century. Due to the available of available data, we collected industrial output value data in the study area from 1987 to 2012. Fig. 8 reveals that the total value of the first industry, the second industry and the third industry increased rapidly. At the same time, farmer's per capita and Gross Domestic Product (GDP) per capita kept increasing during the past decades. The rapid economic development has promoted the infrastructure construction and also increased the area of urban land. Although the second and tertiary industries had rapid developments in the past few years in this county, agriculture and animal husbandry is still the important source of income for local rural residents. When economic growth boosts the rapid development of agriculture and animal husbandry, it also causes the loss of grassland and wetland. In addition, although the 'Three North Protection Forest' has constructed since the 1990s, the poor direct economic returns due to the single

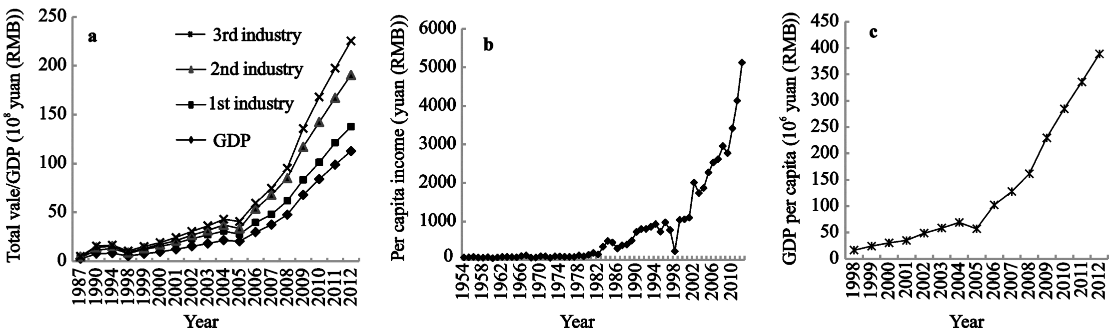


Fig. 8 Socioeconomic development factors. a. Change of industry output value; b. Farmer's per capita income; c. GDP per capita

timber forest resulted in farmers' low enthusiasm about the afforestation and returning farmland to forest, and deforestation occurred frequently to increase the income of local people. Forest area reduced a lot as the area of deforestation was larger than the one of new forest.

5 Conclusions

Analyzing and mapping the changes in LULC over time, especially in the eco-fragile region, is recognized as important to better understand and provide solutions for social, economic, and environmental problems. This study used published land use and land cover data, based on topographic and environmental background maps and also remotely sensed images including Landsat MSS and TM, to examine patterns with processes of land transitions among various land categories by adopting a quantitative methodology named intensity analysis during time intervals between 1932, 1954, 1976, 2000, and 2005 in Zhenlai County of Jilin Province, a part of farming-pastoral ecotone of northern China. Intensity analysis was used to analyze the land use change on the time scale almost one century. The findings of the case study can be summarized as follows.

(1) The interval level of intensity analysis revealed that the annual rate of overall change was relatively fast in 1932–1954 and 1954–1976 time intervals while it was relatively slow during the 1976–2000 and 2000–2005 time intervals.

(2) The category level of intensity analysis showed that arable land experienced less intensively gains and losses if the overall change would have been distributed uniformly across the landscape while the gains and losses of forest land, grassland, water, settlement, wetland and other unused land were not consistent and stationary across the four time intervals.

(3) The transition level of intensity analysis strikingly illustrated that arable land expanded at the expense of grassland during 1932–1954, 1954–1976 and 1976–2000 while it gained intensively from wetland from 2000 to 2005. And the gain of arable land both avoids water and other unused land for all the four time intervals. Settlement targets arable land and avoids grassland, water, wetland and other unused land. Besides, the loss of grassland was intensively targeted by arable land, forest land and wetland in the study period while the loss of wetland was targeted by water except for the time interval of 1976–2000.

(4) With the enactment of 'lifting a ban on reclaiming' policy from the government of the Qing Dynasty, a large number of people came here and brought their agricultural generation to the region, accelerating the development of land. During the early reclamation period, the land use change of the study area is mainly affected by the policy, institutional and political factors, followed by the impact of natural disasters.

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