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Historical trends of wetland areas in the agriculture and pasture interlaced zone: A case study of the Huangqihai Lake Basin in northern China

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ABSTRACT

Wetland degradation has become a serious global environmental issue. The agriculture and pasture interlaced zone (APIZ) in China is often close to the transition zone between arid and semi-arid regions, and it is extremely ecologically sensitive and vulnerable to global change. However, reports on changes in wetland areas in such zones are rarely available. Here, we analyzed remote sensing images to quantify the historical change in the wetland area of the Huangqihai Lake Basin located in the APIZ in China. The comparison indicated an excellent agreement between the results from remote sensing images and historical records for the lake area. Our results showed that 73% of wetland area had disappeared during 1976–2010. About 86% of the lost wetland area was converted to grassland, forest, and bare fields, while 14% was converted to cropland and built-up land use types. The largest lake in this basin, the Huangqihai Lake, was in a state of contraction during this period, and it has been completely dry since 2008. A large share (54%) of the lost area of the lake has become marshes, while about 97% of the original marsh area within the basin disappeared during 1976–2010. Without substantial efforts in wetland management and protection, this trend in natural wetland degradation is likely to continue. Mapping wetland areas with remote sensing images is an effective approach to providing wetland area information in a spatially and temporarily explicit way in regions where monitoring programs are not available. Such information is useful for understanding wetland degradation processes, and is helpful for investigating the driving forces of wetland degradation.

1. Introduction

According to the Ramsar Convention on Wetlands, wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres". Known as "the Earth's kidney", wetlands are one of the three largest ecosystems in the world (Ausseil et al., 2007), and provide various important ecosystem services, such as maintaining biodiversity, preventing drought and flood, regulating climate, conserving soil, and purifying water (Millennium Ecosystem Assessment, 2005; Liu et al., 2008a). Wetland also plays an extremely important role in the carbon balance (Houghton et al., 1996; Prigent et al., 2001). With an extremely high soil carbon density, wetlands store about 30% of the global soil carbon, although they cover only 6% of the Earth's surface (Post et al., 1982). Releasing this carbon will cause rising greenhouse gas concentrations (Heimann, 2010). Hence, wetland conservation is a key to sustaining the ecosystem services that human rely upon and to prevent further intensification of global warming.

Wetland degradation has become a serious environmental issue, causing many sustainability concerns. On a global scale, appropriately 50% of the wetland area has been lost in the last century (Zedler and Kercher, 2005). Although policies and activities have been initiated for wetland conservation, it is still an ongoing challenge to stop significant degradation and losses (Grings et al., 2009; Prigent et al., 2001). Such a challenge is even bigger in arid and semi-arid regions. Arid regions have suffered serious wetland degradation, such as the shrinking of the Aral Sea in Central Asia (Micklin, 2007), the Dead Sea in the Middle East (Enzel et al., 2003), Lake Chad in the Sahel (Sarch and Birkett, 2005), and the disappearance of Lop Nor in western China (Wang, 2010). In semi-arid regions, many saline or sub-saline wetland areas in Central Spain, known as important areas for the migration and

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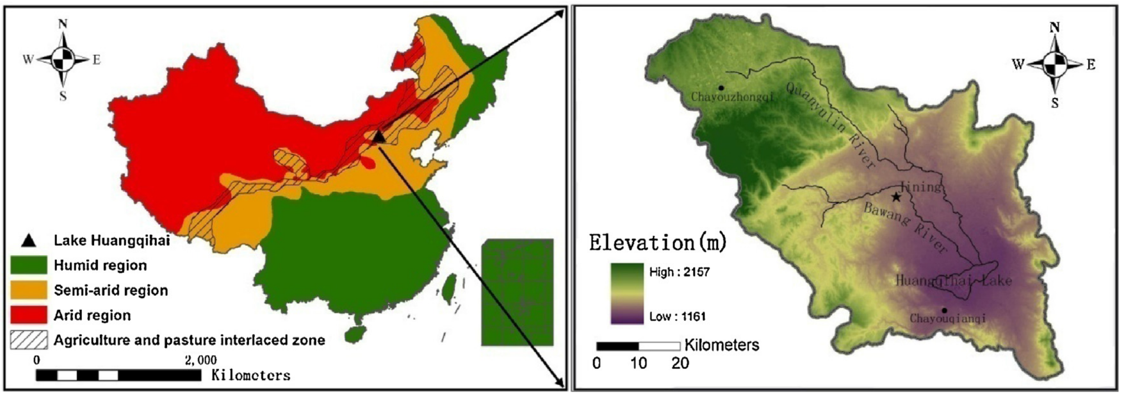

Fig. 1. The location and main characteristics of the Huangqihai Lake basin (right).
Data source: Regional delineation of arid, semi-arid and humid regions from Yang et al. (2005).

wintering of waterfowl in Europe, are subject to changes induced by natural and human factors (Schmid et al., 2004). The Loboi Swamp located in East Africa was reduced dramatically by about 60% from 1969 to 2002 (Ashley et al., 2004). As an important component of the country's wetlands resources, northwest China has many types of wetland, such as river source regions, oases, beaches and inland lakes (Li et al., 2003; Lu, 1990; Wang et al., 2012). These wetlands are also suffering from heavy losses, resulting in the shrinking of rivers and lakes, desertification, salinization and degradation (Wu and Ci, 2002; Wang et al., 2006; Yang et al., 2010; Li et al., 2012).

To understand the process of wetland degradation, it is important to investigate the reasons behind it and to implement appropriate wetland conservation policies. However, changes in wetlands are not well recorded, and relevant documents are often inconsistent, specifically in developing countries (Finlayson et al., 1999; Gong et al., 2010). In addition, in many instances, the process and mechanism of wetland degradation are poorly understood in arid and semi-arid regions (Han et al., 2012). Long-term and interdisciplinary wetland research is often concentrated in regions with tropical and temperate climates, e.g. the Florida Everglades, the Middle Parana River, and the Czech Biosphere Reserve, but literature is rare in arid and semi-arid environments (Sánchez-Carrillo and Angeler, 2010).

In this paper, we analyze remote sensing images to quantify the historical trend of wetland areas in the Huangqihai Lake Basin (Fig. 1) located in the agriculture and pasture interlaced zone (APIZ) (Fig. 1). The APIZ in China is often close to the transition zone between arid and semi-arid regions, and is very ecologically sensitive and vulnerable to global change (Thornes and Brandt, 1994; Lavee et al., 1998; Peters et al., 2006; IPCC, 2007; Shoshany, 2012). However, reports on changes of wetland area in the APIZ are rarely available. Mapping wetland areas in a spatially and temporarily explicit way will provide insights into the degradation process of wetlands in the APIZ and the transition zone between arid and semi-arid regions. Satellite remote sensing has many advantages for inventorying and monitoring wetlands in part due to its repeat coverage and relative low costs (Ozesmi and Bauer, 2002). By interpreting pixel information from remote sensing images, the changing processes of wetland area can be modeled and presented.

2. Materials and methods

2.1. Study area

The Huangqihai Lake is a closed inland lake lying in the central part of the Inner Mongolia Autonomous Region in China, with a latitude of 40°47′–40°55′N and longitude 113°10′–113°23′E. The lake water is mainly supplied by the Quanyulin and Bawang Rivers (Fig. 1), as well as precipitation and groundwater. The Huangqihai Lake basin has an area of 4560 km^2, and it mainly consists of one city (Jining City) and two counties (Chayouqianqi and Chayouzhongqi). The annual average temperature is 4.6 °C with a frost-free period of 99–113 days per annum. The average annual precipitation is 379 mm year^{-1}, with 60% concentrated in the months of July and August. The average annual evaporation is 2267 mm year^{-1}, which is 6 times the amount of precipitation (Liu et al., 2008a,b).

2.2. Remote sensing images and processing

Multi-temporal Landsat images (Landsat MSS/TM/ETM+) were used to quantify historical change of wetland area in the Huangqihai Lake basin, covering a period of 34 years. We also demonstrate the area fluctuations of the Huangqihai Lake with a time series of Landsat images including 14 scenes in this period. All the images were acquired from the International Scientific Data Service Platform (ISDSP) (http://datamirror.csdb.cn/index.jsp) and the United States Geological Survey (USGS) (http://glovis.usgs.gov/). Except for the image in 1976, all other images have a spatial resolution of 30 m. A detailed description of these images is provided in Tables 1 and 2.

The area of wetland and other land use/land cover (LULC) were derived from the remote sensing images using the ENVI 4.7 software package (the Environment for Visualizing Images) and ESRI ARCGIS 9.3 in 3 steps. First, the remote sensing images were downloaded and processed. We only used images during July and September because this is the rainy season in the Huangqihai Lake basin when the wetland area is the largest in a given year. The Huangqihai Lake is small enough to be covered by one scene; hence, only one image on one specific day was used. However, the Huangqihai Lake basin is larger than the area of one scene and hence we used 3 scenes on days close to each other in a month. For this

Table 1
Detailed description of the images used to derive area of wetland and other land use in the Huangqihai Lake basin.

Acquired time	Satellite	Sensor type	Spatial resolution	Source
1976-7	Landsat-2	Landsat MSS	57 m	USGS
1987-9	Landsat-5	Landsat TM	30 m	USGS
1993-9	Landsat-5	Landsat TM	30 m	ISDSP
1999-9	Landsat-7	Landsat ETM+	30 m	ISDSP
2006-9	Landsat-5	Landsat TM	30 m	ISDSP
2010-7	Landsat-5	Landsat TM	30 m	USGS

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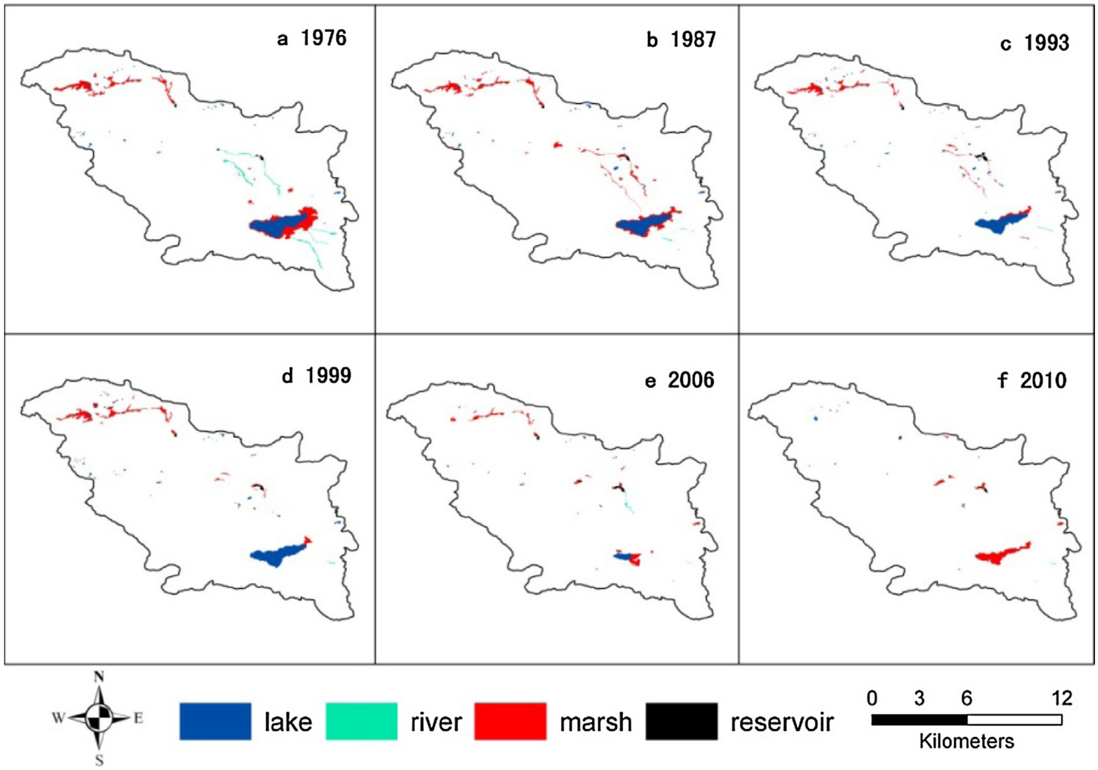

Fig. 2. Spatial distributions of different wetland types.

reason we have only indicated the months in Table 1 to which the images correspond. Second, the original images were processed in ENVI 4.7 using the following steps in sequence: atmospheric correction; image mosaicking; geometric correction; enhancement; and image subsetting. Images acquired in all years were co-registered to the 2006 master image with a root mean squared error smaller than 0.5 pixels. All the images were re-sampled to the same spatial resolution of 30 m. This means that the MSS images in 1976 were resampled to 30 m to match other TM/ETM+ image resolutions. Third, visual interpretation of the processed images was carried out in ESRI ARCGIS 9.3 based on the object's spectral reflectance, texture, structure, tone, and other features. The classification of LULC is illustrated in Table 3. During the interpretation, a topographic map, field survey data, a Digital Elevation Model (DEM) (from: http://datamirror.csdb.cn/index.jsp), and high-resolution Google Earth imagery were used as auxiliary information to improve the accuracy.

Table 2
Detailed description of the images used to derive the area of the Huangqihai Lake.

Acquired time	Sensor type	Spatial resolution	Source
1976-07-08	Landsat MSS	57 m	USGS
1987-09-08	Landsat TM	30 m	USGS
1989-09-29	Landsat TM	30 m	USGS
1993-09-24	Landsat TM	30 m	ISDSP
1999-07-31	Landsat ETM+	30 m	ISDSP
2000-07-01	Landsat ETM+	30 m	ISDSP
2001-08-21	Landsat ETM+	30 m	ISDSP
2002-09-09	Landsat ETM+	30 m	ISDSP
2004-07-28	Landsat TM	30 m	ISDSP
2006-09-12	Landsat TM	30 m	ISDSP
2007-09-15	Landsat TM	30 m	USGS
2008-09-01	Landsat TM	30 m	USGS
2009-09-27	Landsat TM	30 m	USGS
2010-07-05	Landsat TM	30 m	USGS

3. Results

3.1. Historical trend of wetland area

The spatial and temporal distribution of wetlands in the Huangqihai Lake basin is exhibited in Figs. 2 and 3. Spatially, wetlands were mainly distributed along rivers and lakes, and also in the mountainous area in the north. From these figures it is obvious that wetland area had declined in all regions. Wetlands in northern and central parts of the lake basin have almost disappeared, while wetlands in the southern part have shrunk sharply from 1976 to 2010 (Fig. 2). Temporarily, wetlands decreased from 193.5 km^2 in 1976 to 52.9 km^2 in 2010. As a result, the percentage of wetland area in the lake basin decreased from 4.2% in 1976 to 1.2% in 2010. This means that 73% of the wetland area had disappeared during this period with an average annual rate of decrease of 4 km^2 $year^{-1}$. Sharp decreases can be found during 1976–1993 and 1999–2006. With rivers drying up and marshes degenerating from 1976 to 1987, the wetland area decreased sharply to 151.7 km^2 (Fig. 2b).

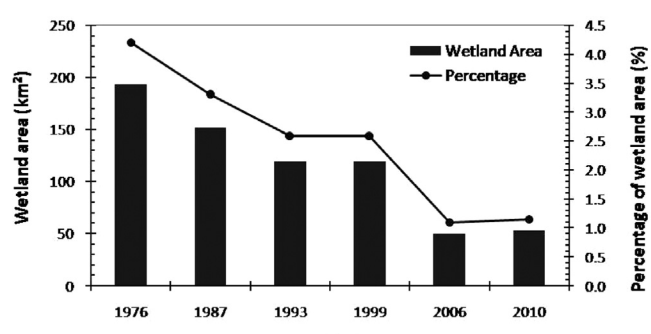

Fig. 3. Temporal changes of wetland area in the Huangqihai Lake basin.

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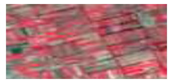
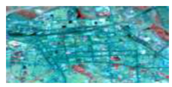
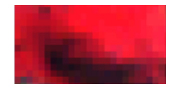
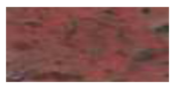
Table 3
Land use/land cover classification system and interpretation characteristics for LULC types.

Level 1	Obvious characteristics	Image example	Level 1	Level 2	Obvious characteristics	Image example
Cropland	Regular magenta patches		Wetland	Lake	A blue-black broad plane	
Forest	Dark red tone			River	A blue-black long and narrow plane	
Built-up	Many steel-gray grids			Marsh	A reddish black irregular plane	
Grassland	Light red tone			Reservoir	Similar to lake, but with a dam	
Bare fields	High spectral reflectance					

The change process of wetlands from 1987 to 1993 was similar to the previous period and the wetland area decreased further to 119.3 km^2 (Fig. 2c). During 1993–1999, wetlands experienced a relatively stable phase, with an area that was almost unchanged (Fig. 2d). Unfortunately, the wetland area declined sharply again after 1999, mainly because of the distinctive shrinking of Huangqihai Lake (Fig. 2e). Since 2006, the percentage of wetland area has remained at about 1%. In 2010, with the Huangqihai Lake drying up, wetland resources have become very scarce in the Huangqihai Lake basin (Fig. 2f).

There are four main wetland types in the Huangqihai Lake basin: marshes, lakes, rivers, and reservoirs. Marshes were once the single largest wetland type with an area of 96.8 km^2, accounting for 50% of the total wetland area in 1976 (Fig. 4). The marsh area decreased sharply during 1976–1993, and it has remained at a level of around 40 km^2 since then. The marsh area increased in 2010 with the edges of the Huangqihai Lake converting to marsh land (Figs. 2f and 4). Lakes used to be the second largest wetland type with an area of 75.9 km^2 in 1976, accounting for 39% of the total wetland area. Before the 21st century, lakes maintained a relatively high proportion. However, the area of lakes declined at unprecedented rates after 1999 with a decrease in area of 82% during 1999–2006. In 2010, most of the lakes had dried up in the study area, leaving an area of only 1.8 km^2, and accounting for 0.04% of the total land area in the basin. Although rivers only occupy a small area, they are one important recharging source to the Huangqihai Lake. There was a sharp decreasing trend in the area of the river from 18.0 km^2 to 1.4 km^2 during 1976–1987. Since 1987, rivers in the catchment have almost dried up, leading to a sharp decline in the discharge of the river to the Huangqihai Lake. In contrast to the sharp decline in the natural wetland area, the reservoir area fluctuated during the entire study period with a peak area of 5.9 km^2 in 1993.

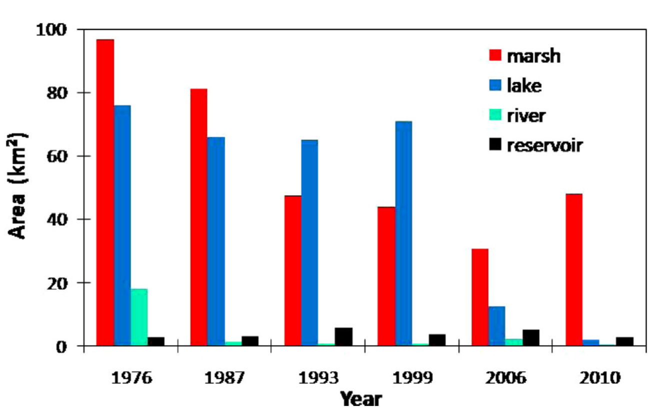


Fig. 4. Area change of different wetland types from 1976 to 2010.

3.2. Conversion between wetland and other LULC

The spatial distribution of LULC of the Huangqihai Lake basin from 1976 to 2010 is demonstrated in Fig. 5 and the overall changes are summarized in Table 4. There is a general trend of losing natural ecosystems in the Huangqihai Lake basin. As the dominant land use type, grassland had a decreasing coverage from 68% in 1976 to 54% in 2010. In contrast, cropland area had increased from 20% to 36%, and built-up area increased from 0.3% to 2.1% during 1976–2010. The sharp increase in cropland was mainly at the early stage of the reforms and openness in the 1980s, and this area increased by 13% during 1976–1987.

Wetlands were primarily transformed to grassland, cropland and bare fields in 1976–2010 (Fig. 6a). A total of 134 km^2 of wetlands were converted into grassland, while about 35 km^2 of wetlands were converted into cropland during this period. There were 34 km^2 of wetlands converted into bare fields during the period of 1999–2006. Since then, other LULC types have also been transferred into wetlands (Fig. 6b) partly due to greater variations in the climate (e.g. with more precipitation in a wet year). In total, there were 86 km^2 of other LULC converted into wetland, mainly as grassland and cropland before 2006, but also as bare fields during 2006–2010.

3.3. Fluctuations of the water area of the Huangqihai Lake

The Huangqihai Lake used to be the biggest lake in this basin, covering approximately 35% of the total wetland area in 1976, and 89% of the lake area in the basin. Fig. 7 demonstrates the dynamic processes that have resulted in changes to the water area of the Huangqihai Lake. During the past 34 years, substantial changes have taken place in the water area of the lake. In 1976, the area of the lake was as large as 67.6 km^2. Eleven years later in 1987, the area had dropped to 59.3 km^2 and continued to decrease to 33.5 km^2 in 1989. Although it rose to 51 km^2 and 59.8 km^2 in 1993 and 1999, respectively, the water area has continued to fall in the 21st century. In 2006, the area covered only 16.2 km^2, approximately 24% of that in 1976. The surface water area of the

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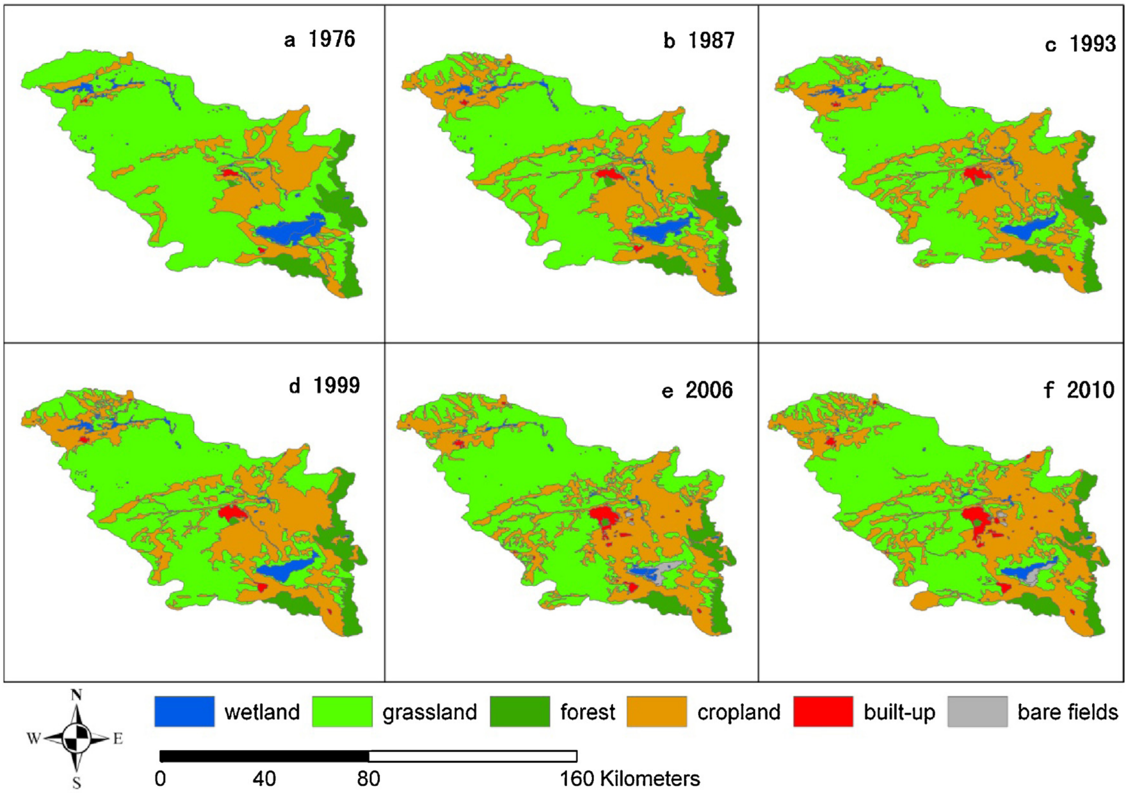

Fig. 5. Land use/land cover (LULC) maps of the Huangqihai Lake basin in 1976 (a), 1987 (b), 1993 (c), 1999 (d), 2006 (e), and 2010 (f), respectively.

Table 4
Area (km^2) and percentage (%) of different types of land use/land cover in the Huangqihai Lake basin from 1976 to 2010.

Year	Wetland		Grassland		Forest		Cropland		Built-up		Bare fields	
	Area	Percentage	Area	Percentage	Area	Percentage	Area	Percentage	Area	Percentage	Area	Percentage
1976	193.5	4.21	3128.5	68.03	338.2	7.35	923.5	20.08	15.2	0.33	0.0	0.00
1987	151.7	3.30	2579.2	56.08	311.8	6.78	1524.0	33.14	32.2	0.70	0.0	0.00
1993	119.3	2.59	2554.6	55.55	302.6	6.58	1588.4	34.54	33.5	0.73	0.0	0.00
1999	119.4	2.60	2583.2	56.17	331.5	7.21	1517.5	33.00	46.5	1.01	0.8	0.02
2006	50.4	1.10	2582.9	56.16	275.1	5.98	1566.9	34.07	78.9	1.72	44.6	0.97
2010	52.9	1.15	2477.8	53.88	284.5	6.19	1654.5	35.97	98.6	2.14	30.7	0.67

Huangqihai Lake has now completely disappeared since 2008. A large share (54%) of the lost lake has been converted to marshes, 25% to bare fields and 21% to grasslands (Fig. 5f).

4. Discussion

4.1. Comparison with other studies

Our study has indicated that the Huangqihai Lake has been in a state of contraction over the past 34 years. This finding coincides very well with the results from Li and Wang (1993). Using historical records and maps, Li and Wang (1993) showed the fluctuations of the Huangqihai Lake during 1800–1990. Here we compare our results with those of Li and Wang (1993) to reveal conformity. As shown in Fig. 8, the changes in the trends during 1976–1990 agree very well across the two studies. This provides us with confidence regarding the accuracy of the results obtained from the remote sensing images, although ground truth data are lacking for the area of the Huangqihai Lake during historical periods.

The Huangqihai Lake is one of many examples of shrinking lakes in the world in recent decades. Besides those listed in the introduction of this paper, there are many records regarding lake contraction. For example, the area of the thermokarst lake on the Tuktoyaktuk Peninsula in northwestern Canada decreased by 11% during 1992–2001 (Plug et al., 2008). Lakes in the northern part of Poland have shown a tendency toward both a decrease in area and number, with the total area shrinking from 0.32 million ha to 0.28 million ha, and the number of lakes decreasing from 9296 to 7081 during 1954–2006 (Choinski et al., 2011). In Africa, Lake Chad has split into different individual seasonal or perennial lake pools partly influenced by spectacular droughts during 1973–2011 (Lemoalle et al., 2012). In arid region of Central Asia, Bai et al. (2011) detected that more than half of the inland lakes have atrophied sharply in the past 30 years and 50% of the total area has disappeared. Many inland lakes in China have also suffered from shrinkage and salinization, and some have even dried up completely, such as Lop Nur Lake in the Tarim Basin (Hu et al., 2005, 2007). In semi-arid regions, the Baiyangdian Lake area in the North China Plain decreased by 42% from 81 km^2 in 1974 to 47 km^2 in 2000 (Zhuang et al., 2011).

At the APIZ, the lakes have been subject to frequent fluctuations and have shown a clear tendency toward shrinkage over the last century (Liu and Wu, 1996). The Daihai Lake, an inland lake 64 km southwest of the Huangqihai Lake, has experienced frequent expansion and contraction and once had the largest area of 760 km^2, but the water level has continued to fall with a faster pace

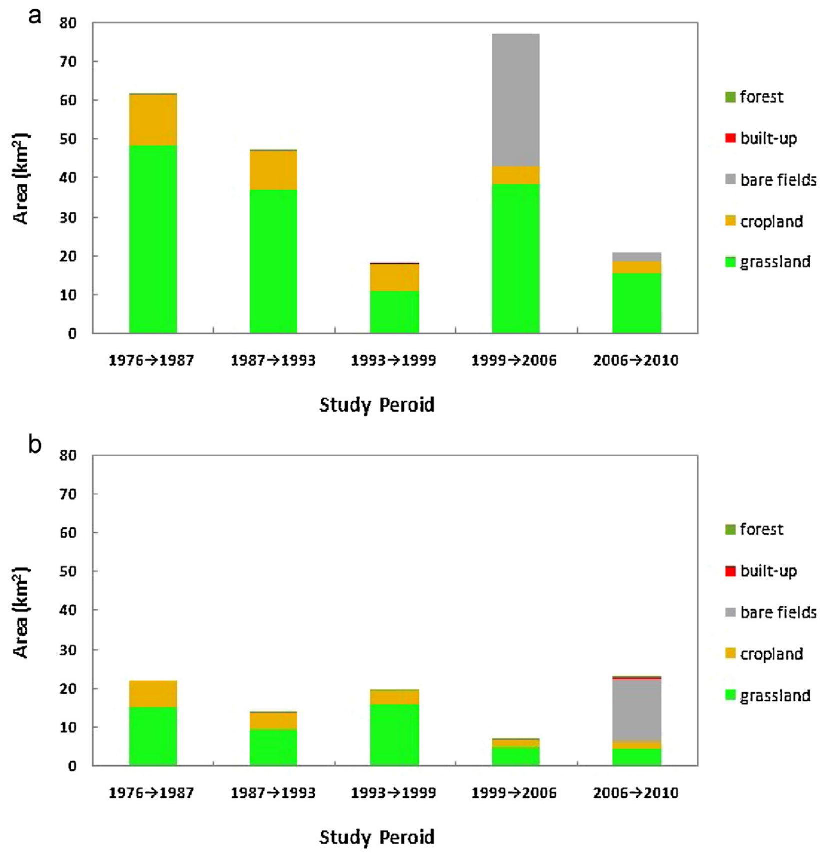

Fig. 6. Wetland area changes from 1976 to 2010 in the Huangqihai Lake basin. (a) Wetlands convert to other LULC and (b) other LULC converts to wetlands.

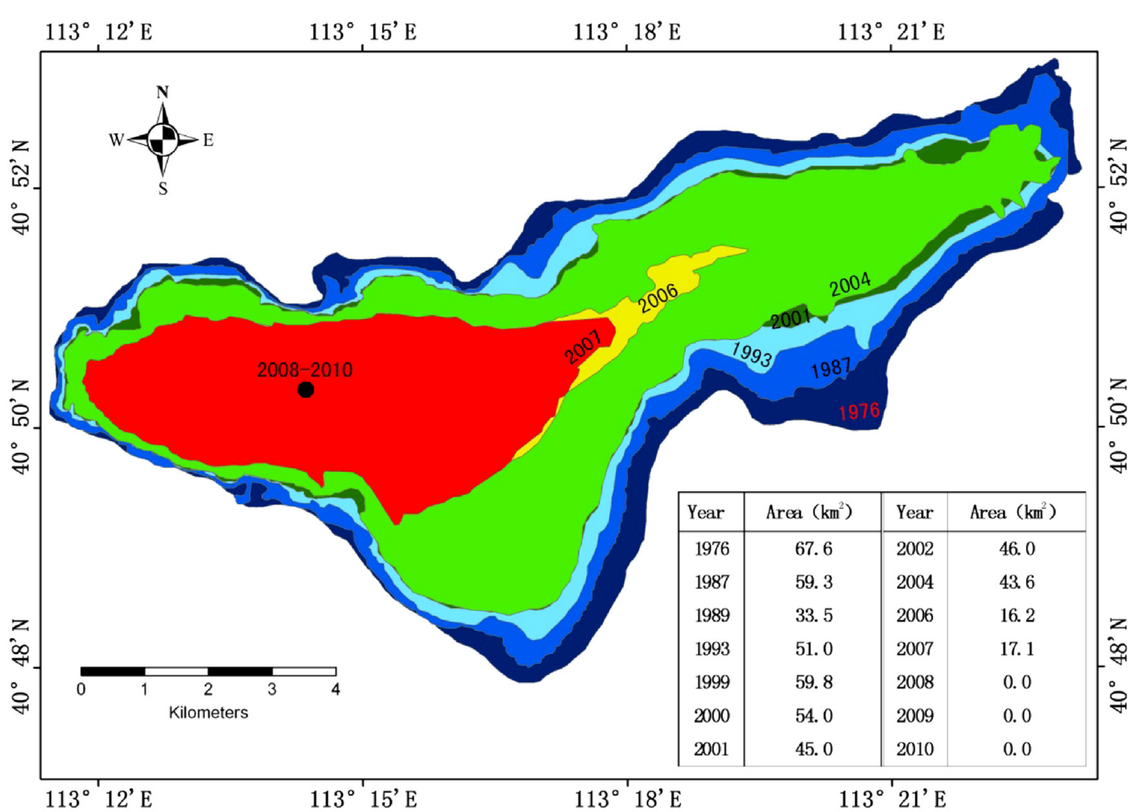

Fig. 7. Lake shoreline retreat in the past 34 years.

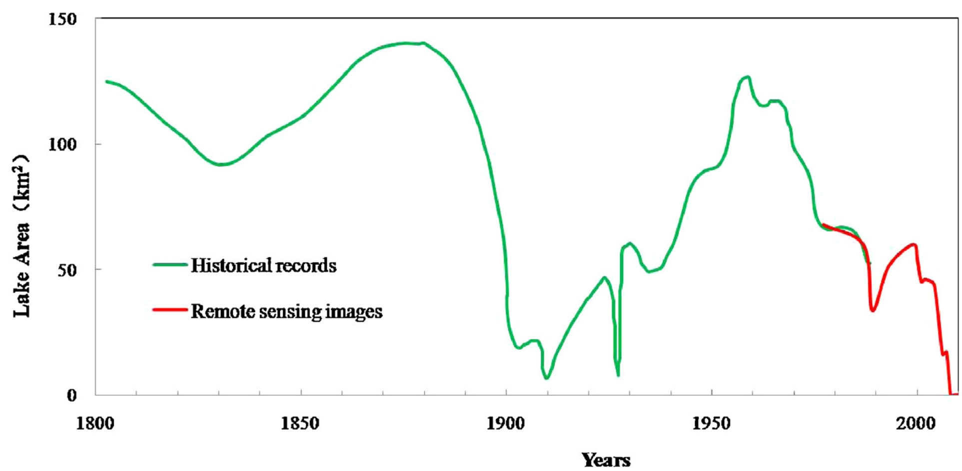

Fig. 8. Fluctuation of the area of the Huangqihai Lake.
Data sources: historical records from Li and Wang (1993), and the results from remote sensing images from this study.

of decline since the 1970s, causing a decline in the area of the water from 160 km^2 in 1970 to 88 km^2 in 2002 (Zhou and Jiang, 2009). Li et al. (1992) stated that the evolution of the Huangqihai Lake and Lake Daihai have shown similarly consistent patterns.

The contraction trend of the Huangqihai Lake is similar to many other lakes. However, for the Huangqihai Lake, the speed of shrinkage is fast and the severity is high. The lake has effectively disappeared in about one decade by the 21st century.

4.2. Wetland degradation in the Huangqihai Lake basin

Wetland degradation can be caused by natural and anthropogenic driving forces. The results are often distinct: human activities often change wetlands to direct human land uses (e.g. cropland, built-up), while under natural forces, wetlands often convert to other types of natural ecosystems (e.g. grassland). There are many cases for direct human uses of wetland. For example, in the Sanjiang Plain, the biggest and typical marsh wetland in China, agricultural expansion in the original marsh land, as a result of the "food first" agricultural policy, largely drove the decrease in marsh area of 77% from 35,270 km^2 to 8100 km^2 between 1954 and 2005 (Wang et al., 2011). Another example is to convert coastal wetlands to enclose tideland for cultivation and urban area. In India alone, land use changes with increasing areas of built-up land and cropland had caused a loss of over 40% of mangrove areas on the western coast (Upadhyay et al., 2002).

For the Huangqihai Lake basin, our results show that wetlands were converted to both human direct use and other natural ecosystems. From 1976 to 2010, a total of 120 km^2 of wetlands were converted into grassland, forest, and bare fields, while about 20 km^2 of wetlands were converted into cropland and built-up areas (Fig. 9). Hence, for the lost wetlands, 86% were converted into other ecosystems, while 14% were converted to human direct land use. Daily precipitation records show that the APIZ in northern Chinais generally experiencing a climatic trend toward lower precipitation and runoff (Gong et al., 2004), resulting in a conversion from wetlands to dry grassland. Meanwhile, salinization in the arid and semi-arid regions has transformed some wetlands into bare fields (mainly saline and alkaline land) (Williams, 1999). In addition, forests in the Huangqihai Lake basin have expanded as a response to the ecological policy of returning farmland to forests adopted by the Chinese Government (Wang et al., 2008). On the other hand, this region has experienced improving socioeconomic development and population growth with a rapid expansion of both cropland and built-up areas in the Huangqihai River basin, as well as in other regions of China (Xie et al., 2005; Gao et al., 2007; Wang et al., 2009; Zhang et al., 2010; Song et al., 2012).

The sharp decrease in wetland area implies that the governmental institutions and decision makers need to take urgent action to preserve, conserve and even restore the degraded wetland ecosystems in the Huangqihai Lake basin. More research and conservation activities are required in this region with joint efforts of central and local governments, the non-govenmental organizations, researchers and the stakeholders.

4.3. The future fate of wetland areas

Our findings show that the Huangqihai Lake has completely converted to marsh land in recent years (Fig. 2). However, we also observed a sharp decline in marshes as a result of conversion to grassland and cropland in the basin area, particularly in the northern part (Fig. 7). During 1976–2010, about 97% of the original marshes (i.e. a total area of 94 km^2) had diappeared, with 19 km^2 being converted into cropland and built-up areas, and 75 km^2 into grassland. If such trends continue, the remaining wetlands (mainly in the previous Huangqihai Lake area, see Fig. 2) are likely to be further developed for human use, leading to substantial losses of wetland ecosystem services. Hence, there is an urgent need for effective conservation policies and measures to protect and manage the wetland resources in the Huangqihai Lake basin. Ecological restoration programs should also be established. For example, in 2012, the People's Government of Chayouqianqi proposed a Comprehensive Treatment Project on Wetland Conservation and Restoration in the Huangqihai Nature Reserve in the Inner Mongolia Autonomous Region. This program has five goals: (1) protecting and restoring natural wetland ecosystems and maintaining the species and genetic diversity; (2) protecting wildlife and their habitats, and preventing humans from destroying the ecological environment; (3) maintaining the region's ecological balance, and guaranteeing local development; (4) sustaining wetland ecosystems through scientific management; and (5) improving people's awareness of environmental protection through publicity and education. However, such a program has not yet received final approval by the government.

4.4. Decade-scale change vs. century-scale change

The Huangqihai Lake is a closed lake and its change is under the control of climate (Li and Wang, 1993). From the Holocene onwards, due to regional climate variability, the lake level has been

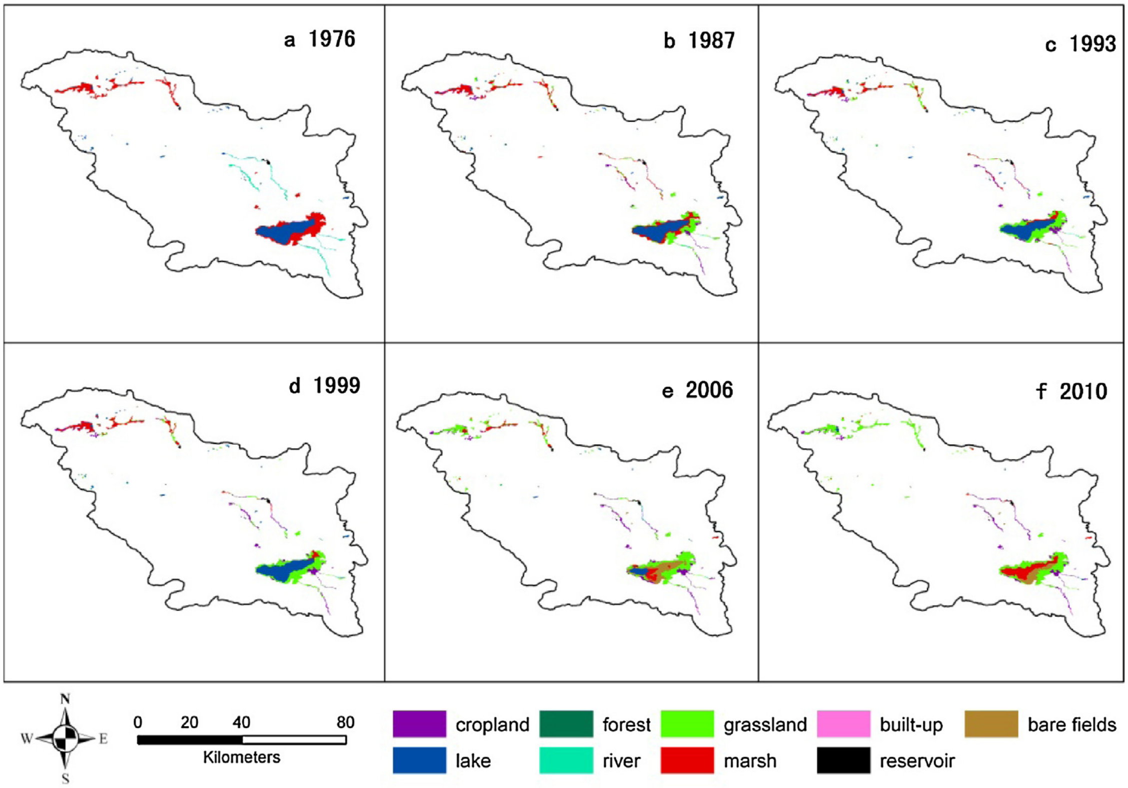

Fig. 9. Evolution of wetland from 1976 to 2010 in the Huangqihai Lake basin.

fluctuating (Li and Wang, 1993; Liu et al., 2008b). Although we observed a state of contraction for the Huangqihai Lake during 1976–2010, historical records also show that the lake was nearly dried up in 1910 and in 1929, while it returned to a large area of around 120 km^2 in the 1960s (Fig. 8) (Li and Wang, 1993). There are reasons to question whether the dried up lake will recover again in the future. To answer this question, the reasons behind the degradation must be investigated by jointly considering natural and anthropogenic factors. This will be the next step in our research. From Fig. 8, it seems that the lake area fluctuates on a cycle of about 100 years. It is also interesting to understand the driving forces for this cycle and how human activities influence such cycles.

4.5. Shortcomings

There are a few shortcomings in the present study. First, there is no ground truth data on wetland area in the Huangqihai Lake basin to validate the results derived from the remote sensing images. With the development of surveying and mapping technologies, images with high spatial resolution can be a reliable data source for the regions lacking in situ data. Nevertheless, there is the need for a monitoring program to track the ecological change of wetlands in the basin. Second, the advantages of using satellite remote sensing for monitoring wetland resources have been widely acknowledged. However, this approach also has limitations, for example, it is difficult to identify small or long, narrow wetlands (Ozesmi and Bauer, 2002). Hence, the quality of area of rivers is expected to be lower than that of lakes and marshes in the present study. Third, a driving force analysis was not performed. According to a preliminary and qualitative investigation, the combined impacts of climate change and human activities resulted in the degradation of the wetlands (Zhao et al., 2002). However, an in-depth and quantitative analysis is needed to study the extent of the impacts on wetland area change from both natural and anthropogenic driving factors. It is interesting to understand to what extent the variations in the lake level are dependent on climate change in different historical periods. Further work is required to reveal the driving mechanism of wetland degradation at the APIZ in order to better understand the evolutionary pattern of wetlands under pressure of climatic change and human activities.

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