APPLICATION OF LANDSAT SATELLITE DATA FOR THE QUANTIFICATION OF THE LAKE CHANGES IN THE DARKHAD DEPRESSION, NORTHERN MONGOLIA

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Abstract:

We quantified the lake changes in the Darkhad depression based on the Landsat satellite imagery. The Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (TM and ETM+) imagery were acquired from summer months (1986/07/23, 1995/06/30, and 2007/07/17). The lake areas on the imagery were delineated by the normalized difference water index (NDWI). Lakes in raster format were converted to vector-based shape-files using by ArcGIS software. We found 1038 lakes in the Darkhad depression during the study period. These lakes were arbitrarily sub-divided by size into four categories: small lakes, medium lakes, large lakes, and very large lakes. Small lakes occupy an area ranging between 1 to 10 ha and constitute about 73% of the 403 lakes in considered in the study, but only 6.6% of the total lake area of all lakes combined in 1986. Approximately 3.4% of the lakes sampled exceeds 100 ha in area (large and very large lakes), accounting for 76% of the total lake area sampled. Only 3 lakes have an area greater than 1000 ha, and the maximum size is 5233.8 ha. The 28 new lakes have appeared by 61 ha in 1986-1995, whereas 15 new lakes formed by 32.1 ha in the Darkhad depression between 1995 and 2007. There was a significant increasing trend in mean annual air temperature since the 1979s for the Darkhad depression. Besides, there was no significant trend in summer precipitation during the same period.

Key words: lake, changes, Darkhad, northern Mongolia, and Landsat

1. Introduction

The Darkhad depression is located in northern Mongolia, close to the Mongolia-Russia border, is one of the most interesting examples of vast lakes, and thermokarst lakes. Thermokarst lakes are common features of northern high-latitude regions where ice-rich permafrost exists. Thermokarst lakes are formed due to thawing permafrost and melting of massive ground ice (1). Therefore, occurrence of active thermokarst lakes often indicated that permafrost is unstable and warming (5).

The Darkhad depression is characterized by ice-rich continuous permafrost. The surface of the permafrost experienced strong thermal erosion, which resulted in the formation of thermokarst lakes on the depression floor (3). The permafrost is probably thawed under the largest lake, the Dood Tsagaan, which occupies the lowest part of the Darkhad depression. During the last decades, efforts of many scientists have been focused on the study of geocryology, geology, geomorphology, and environmental changes in the Darkhad depression (2, and 3).

The purpose of this study is to quantify of the lake changes in the Darkhad depression. For this Landsat satellite imageries from the past 21 years were used. The application of remote sensing data for the monitoring of these largely remote and extensive landscapes is often the most cost-effective tool, and is therefore a fast growing research area. By using remote sensing, it is possible to observe such environments frequently and at large scales, observe changes, and deliver basic data for the depression.

2. Topography and environmental settings

The Darhad depression is an area which is located in northwestern part of Mongolia, and consists of the natural special situation (Figure 1). The depression is surrounded by high-mountain ranges ~ 3200 m above sea level, which is approximately 100 km long from north to south and 20-40 km wide. The depression floor is at 1540 m above sea level and is covered by numerous thermokarst lakes, which of Dood and Deed Tsagaan Nuur, Targan Nuur are the largest. Many medium to large rivers feed the Darkhad depression. The depression drained by the Shishigt river, a head of the Yenisei River (3).

The Darkhad depression is characterized by several types of landscapes formed in different geomorphologic and moisture conditions. There are three zonal types of landscapes which are taiga, forest steppe, and steppe. Most of the depression floor is forest-free. The vegetation assemblages are dominated by boreal species, which can survive in servere climate conditions (2). The depression is characterized by ice-rich continuous permafrost. This area contains widespread mountain permafrost, and comprises the southern fringe of the Siberian continuous permafrost zone. Mean annual permafrost temperature is -1°C to -2°C in the depression. Active-layer thickness is shallow ~0.5 to 1.0 m (4). On the depression, permafrost related landforms such as pingo, ice-wedge polygon, hummock, and thermokarst are extensively distributed (6).

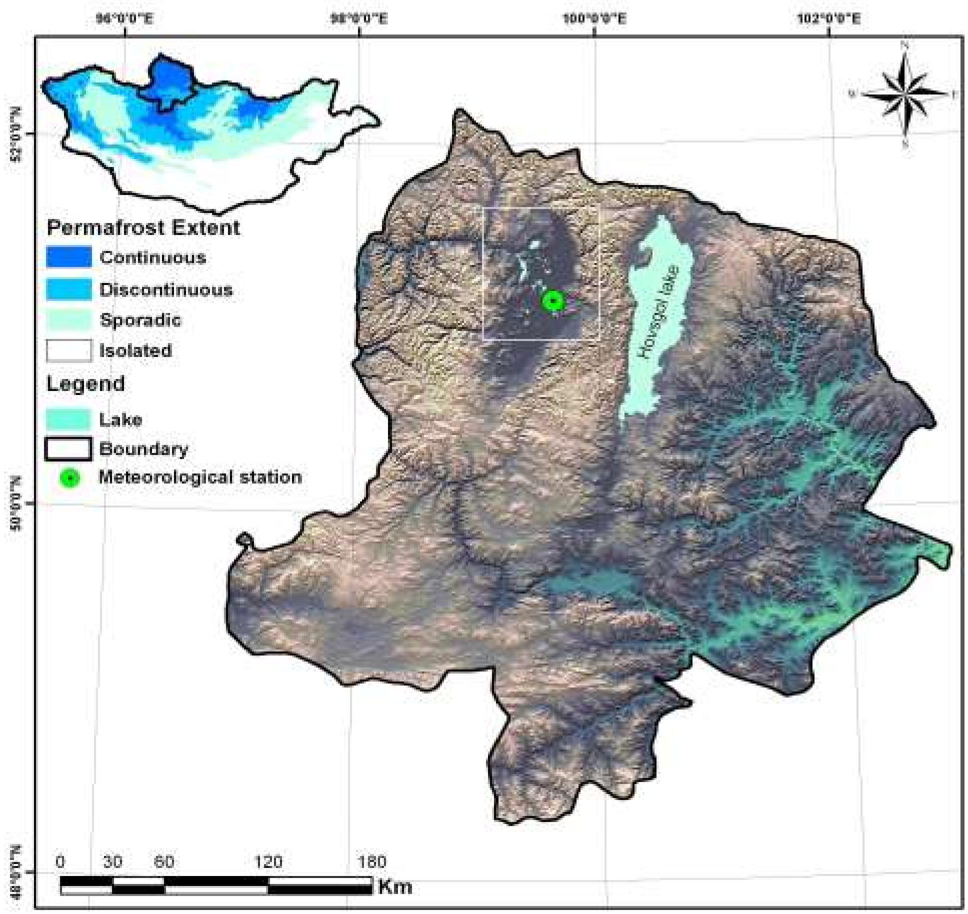

Fig. 1. Darkhad depression in the Hovsgol province and permafrost distribution map of Mongolia.

3. Data and Methods

In this study, we used the Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (TM and ETM+) satellite imagery (1986/07/23, 1995/06/30, and 2007/07/17) to quantify the lake changes in the Darkhad depression. The imagery obtained from the United States Geological Survey (USGS). Smoke from wildfires and clouds were a major limitation in acquiring useful the satellite imagery from the summer months. All imagery re-projected to UTM zone 48N, and all bands were mosaicked to cover the Darkhad depression.

Lake areas on the images were delineated by the normalized difference water index (NDWI). Lakes in raster format were converted to vector-based shape-files using by ArcGIS 10 software. In this analysis, a minimum lake size of 1 ha (10 pixels) was chosen as the cut-off for the lake change analysis. Besides, we calculated the normalized difference vegetation index (NDVI) at each image. In addition, we shortly described the methods of NDWI and NDVI .

NDWI and NDVI were computed for each pixel using the following equations (1 and 2).

Where:

$$NDWI = \frac{(band\,4 - band\,5)}{(band\,4 + band\,5)} \qquad NDVI = \frac{(band\,4 - band\,3)}{(band\,4 + band\,3)}$$

We used meteorological data to evaluate the correlation between lake and hydro-climatology parameters. The meteorological data from 1979 to 2007 were obtained from the Lkhumberenchin station which is located in the Darkhad depression. Using the monthly mean air temperatures, and precipitation data, we estimate the mean annual air temperature (MAAT), total summer precipitation (P) for June, July, August, and September (JJAS).

4. Results

We identified 1038 lakes on the Darkhad depression in 1986, 1995, and 2007. These lakes were arbitrarily sub-divided by size into four categories: small lakes, medium lakes, large lakes, and very large lakes (Table 1). The lake behaviors on the Darkhad depression are summarized in Table 1. Small lakes occupy an area ranging between 1 to 10 ha and constitute about 73% of the 403 lakes in considered in the study, but only 6.6% of the total lake area of all lakes combined in 1986. Approximately 3.4% of the lakes sampled exceeds 100 ha in area (large and very large lakes), accounting for 76% of the total lake area sampled. Only 3 lakes have an area greater than 1000 ha, and the maximum size is 5233.8 ha.

Figure 2 shows the difference of the lakes on the Darkhad depression between 1986 and 2007. Over the entire 1986-2007 study period, the majority (more than 76%) of the lakes surveyed decreased in the lake area. The 28 new lakes have appeared by 61 ha in 1986-1995, whereas 15 new lakes formed by 32.1 ha between 1995 and 2007.

Table 1. Total lake area estimated in the Darkhad depression in 1986, 1995, and 2007.

Type of lakes	Size (ha)	1986		1995		2007	
		Number	Area (ha)	Number	Area (ha)	Number	Area (ha)
Small lakes	1 to 10	298	997.8	226	708.4	202	591.0
Medium lakes	10 to 100	91	2527.2	91	2078.9	90	1828.5
Large lakes	100 to 1000	11	2992.9	10	1845.7	10	1622.8
Very large lakes	1000 up	3	8387.0	3	7434.3	3	7381.5
Total		403	14904.9	330	12067.3	305	11423.8

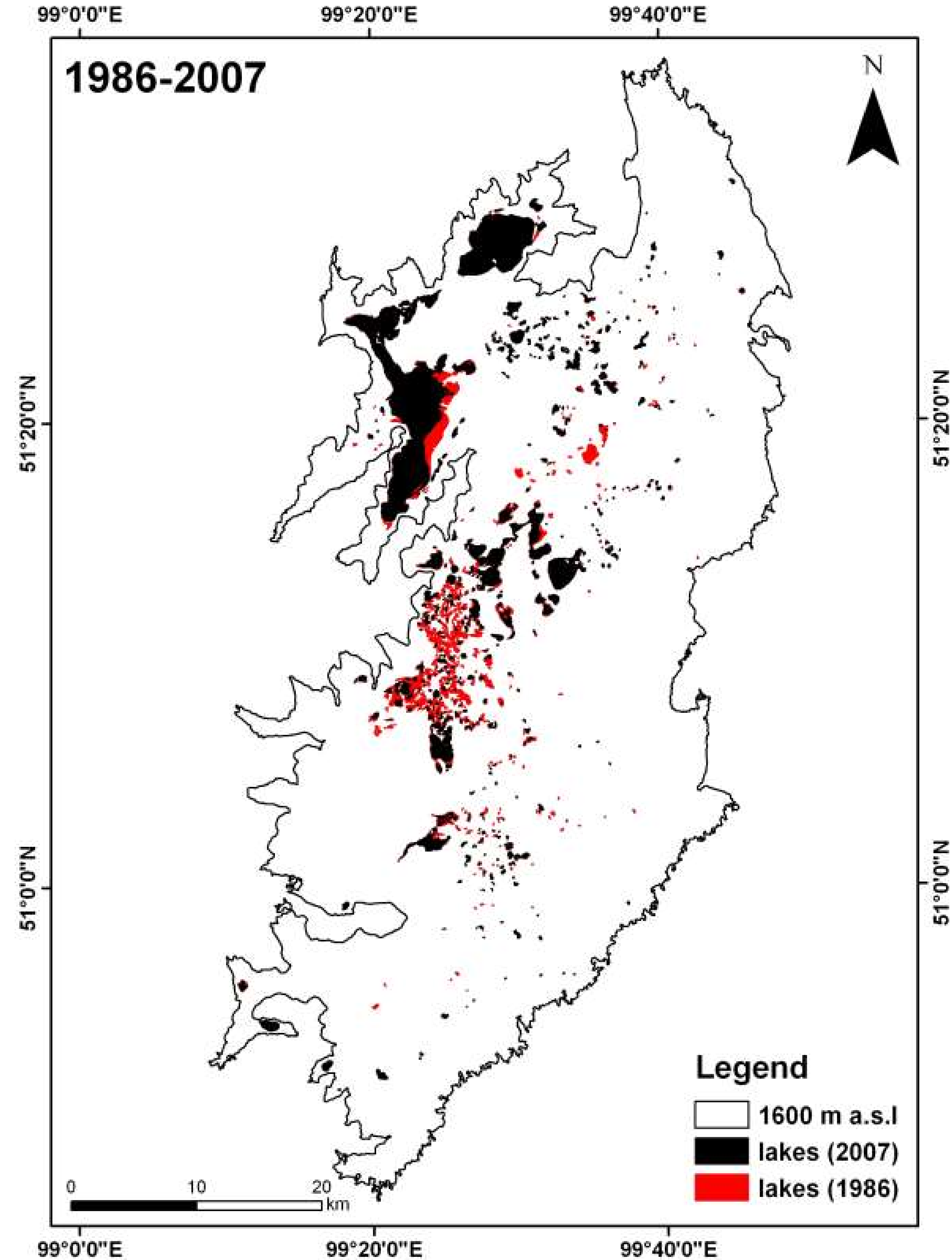

Fig. 2. Difference of thermokarst lakes on the Darkhad depression between 1986-2007.

All lake categories showed a reduction in the lake area from 1986 to 2007 (Table 1), which consistent with the analyzed hydro-climatology data at the Darkhad depression (Figure 3). As shown in the Figure 3, trend of MAAT was significantly increased by 2.4°C for the depression as demonstrated in disappearing and decreasing of lakes. During the study period, some new lakes were formed in 1995 and 2007, which correlated the melting of ice-rich permafrost due to the significant increasing trend of MAAT. Whereas, summer precipitation has 320 mm in 1986, 147 mm in 1995, and 167 mm in 2007, respectively, its trend has almost constant.

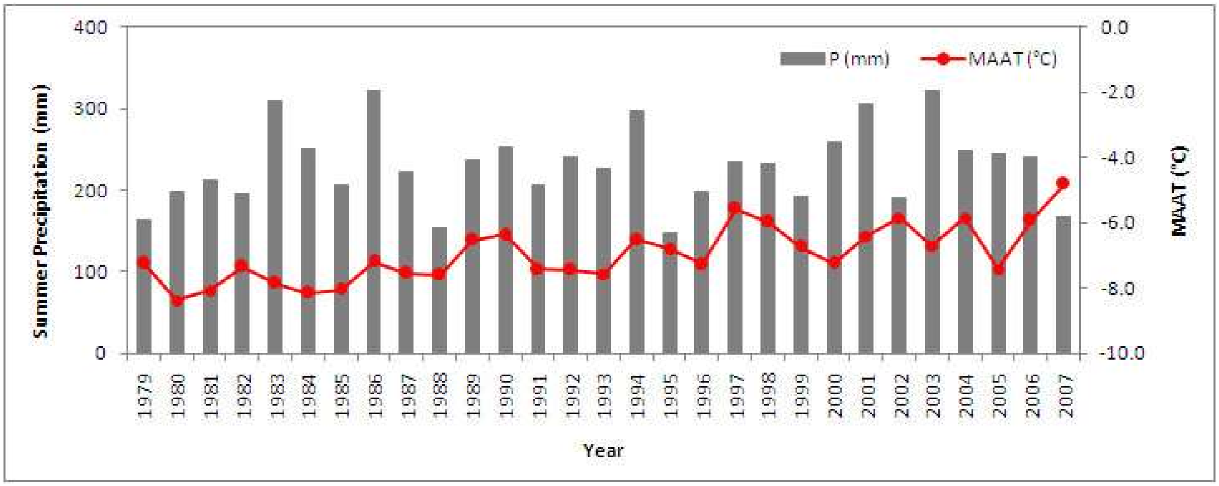

Fig. 3. Trends of the total summer precipitation (P/mm), and mean annual air temperature (MAAT/°C) at the Darkhad depression (1986-2007).

Figure 4 showed the normalized difference vegetation index (NDVI) at the Darkhad depression in 1986, 1995, and 2007, respectively. The NDVI was correlated with the summer precipitation for each year.

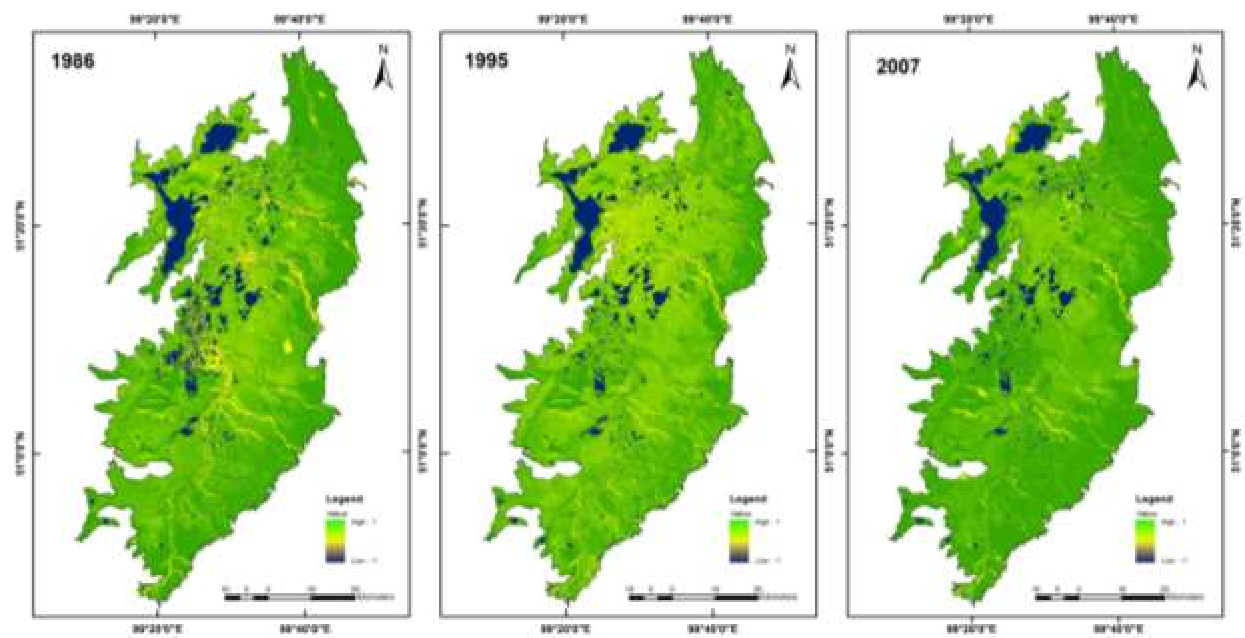

Fig. 4. NDVI at the Darkhad depression between 1986-2007 based on Landsat imagery.

5. Conclusion

We quantified lake changes at the Darkhad depression in the northern Mongolia using the Landsat satellite imagery over the past 21 year period. That medium resolution Landsat satellite imagery was useful to investigate lake changes in the larger scale areas. The results indicated that thermokarst lakes decreased by 23% in total area, and the number of lakes (24%) over the Darkhad depression in the continuous permafrost zone. We suggest that future research on lakes and thermokarst lake changes in the Darkhad derpression should describe active erosion processes and quantify erosion rates, in small , medium, and large lakes respectively.

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