Morphological classification and origin of lake depressions in Mongolia

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Abstract: An improved classification of the origin of lake depressions due to geological, geomorphological factors and climate change is a requirement of the day in Mongolia. We present a new holistic classification using comparative analysis method. This study suggests a two-tier classification in terms of origin and morphological feature of the lakes, which replaces the previous one-tier classification. Mongolia has identified 11 main and 26 subtypes of origin, and 8 main types of morphology, based on the features of 32 lake depressions. The result of the study shows that the lakes of Mongolia developed in 3 stages, first, affected by tectonic movement, followed by glacial and finally, owing to other exogenic factors. This morphological classification study will create the basic conditions for preserving and using these lakes more efficiently and ecologically in the future by making the classification of the origin of lake depression.

Keywords: Mongolia; Lake Depression; Comparative analysis; Morphological classification; Central Asia;

INTRODUCTION

Lakes are defined as relatively large bodies of slowly moving or standing water surrounded by land [1]. A lake depression is a form of land surface that contains water under the influence of endogenic and exogenic factors [2-4]. The study of the origin and morphological classification of the lake depression started more than 130 years ago [2-10].

The history of defining and determining the origin of Mongolia’s lake depressions is relatively young, only about 50 years [11].
Examining the relationship between the origin and depression morphology of lakes is one of the important components of maintaining the balance of nature [4-8; 12].

Mongolia geographical location is unique with a comparatively high topography in the heart of Central Asia, which extends along the entire latitude [13-14]. Mongolian topography is the result of gradual transition conditions from the southern Siberian mountains to the steppes and Gobi Desert of Central Asia and from the northern cold humid climate to the southern arid climate [15]. Lakes and lake depressions of Mongolia in their formation [11] have many unique features. For instance, large depressions between mountainous and hilly regions are largely located northwest to the southeast [11; 13-14]. Mongolia’s large lake system was created along this tendency. Geomorphological process significantly influenced the geographical location of the lakes, and their appearances, as well as the types of lakes depressions in Mongolia, similarly to that in Central Asia [16].

The first classification of Lakes in Mongolia was carried out several decades ago [11]. According to Tserensodnom (1971, 2000), Mongolian lakes are classified into seven genetic types, including tectonic, volcanic, glacial, fluvial, karst, gravity and aeolian [11], however, their sub-types were not classified.

We suggest a new holistic classification for Mongolian lakes, revising previous uncertainties. The main purpose of this paper is to provide an update of the origin and morphological type of lake depressions, tie them with international classification, and to focus on Mongolian lake development, relating to the formation of lakes depressions.

MATERIALS AND METHODS

Comparative Method

Comparative analysis enhances the understanding of one’s own perception by outlining the familiar structures and routines against those of other systems [17-18]. Comparative research method is a process of comparing two or more data to compared one or more items [19]. In the comparative research method, the data are divided into S or time compare and N or comparison between the data [17-19]. The most important issue in geographical research is to compare data that have changed in space and time [20-21]. Comparison of numerical data to secure secondary analysis result is widely applied in comparative studies [22].

This method of study can be used in combination with other methods, such as remote sensing, geophysical survey and morphological analysis.

Case study methods

The base of an integrated research methodology is the geomorphological criteria for determining the morphological characteristics of the lakes’ depressions [23-25]. On other hand, geomorphological analysis can be defined as a combination of methods based on neotectonic amplitude of territory, morphological features of lakes’ depressions and development of morphic agents.

Some field measurements and combined data processing for classification of lake depressions were made between 2016 and 2020, including the first main morphometric measurements, second, geomorphological mapping, third, morphometric measurements showing the topography profile, and fourth, photography of lake depression. In addition, we have used the following methods in the study, including morphometric, morphostructural and morphofacial, plus spatial improvement method of remote sensing and geophysical magnetic survey. The main results are processed by Arc GIS, Arc Scene and ENVI 5.3 software’s.
RESULTS AND DISCUSSION

Comparison of lake depression classification

According to Tserensodnom (1971), the genetic classification of the origin and morphological types of the lakes’ depressions in Mongolia is divided into two types, including endogenous and exogenous (Table 1).

Table 1. Genetic classification of the origin of lake depression in Mongolia (Tserensodnom, 1971)

| №  | Category               | Main type         |
|----|------------------------|-------------------|
| 1  | Endogenous             | Tectonic          |
| 2  |                        | Volcanic          |
| 3  |                        | Glacial           |
| 4  |                        | Sinkholes (Karst) |
| 5  |                        | Gravity           |
| 6  |                        | Aeolian           |
| 7  |                        | Fluvial           |

Table 2. Comparison of the main categories of Lake Depression (Compliance +)

| №  | Main types of lake depression / Authors, year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Overlap of comparative indicators |
|----|---------------------------------------------|---|---|---|---|---|---|---|---|---|----|-----------------------------------|
| 1  | Tectonic                                   | + | + | + | + | + | + | + | + | +  | 10                                |
| 2  | Glacial                                    | + | + | + | + | + | + | + | + | +  | 10                                |
| 3  | Fluvial                                    | + | + | + | + | + | + | + | + | +  | 10                                |
| 4  | Volcanic                                   | + | + | + | + | + | + | + | + | +  | 10                                |
| 5  | Aeolian                                    | + | + | + | + | + | + | + | + | +  | 9                                 |
| 6  | Gravity                                    | + | + | + | + | + | + | + | + | +  | 7                                 |
| 7  | Sinkholes (Karst)                          | + | + | + | + | + | + | + | + | +  | 6                                 |
| 8  | Anthropogenic                              | + | + | + | + | + | + | + | + | +  | 3                                 |
| 9  | Meteorite                                  | + | + | + | + | + | + | + | + | +  | 3                                 |
| 10 | Coastal                                    | + | + | + | + | + | + | + | + | +  | 3                                 |
| 11 | Biogenic                                   | + | + | + | + | + | + | + | + | +  | 2                                 |
|    | Main types                                 | 4 | 8 | 11 | 6 | 7 | 9 | 6 | 10 | 6  | 6   |                                   |
|    | Subtypes                                   | 7 | 13 | 22 | - | - | 22 | 16 | 23 | 8  | 17  |                                   |

Comparison of the classifications indicates that lake depressions can be divided into 11 main types, and according to Table 2, the main category corresponds to tectonic, glacial, fluvial, volcanic, aeolian, gravity and sinkholes lake depressions.

New classification of lake depression of Mongolia

We proceed from the premise that there exist the possibility of making a new morphological classification of Mongolian lakes depression by revising the previous
classification and adding new categories. Our holistic classification include the main and subtype categories, developed on the basis of comprehensive scientific advances (Table 3).

**Table 3. New morphological classification of lake depression**

| №  | Main type | Subtypes                                                                 | Description                                                                 |
|----|-----------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| 1  | Tectonic  | 1. Graben depression  
               2. Rift depression  
               3. Fault depression  
               4. Epeirogenic depression | Lake depressions of these types are found in Mongolia                      |
| 2  | Glacial   | 1. Abrasion depression  
               2. Glacial deposit dammed depression  
               3. Glacial lake basins–ice contact |                                                                             |
| 3  | Fluvial   | 1. Punge-Pool depression  
               2. Competitive fluvial aggradation  
               3. Oxbow lake |                                                                             |
| 4  | Volcanic  | 1. Crater-Maars  
               2. Lava-dammed depression  
               3. Calderas |                                                                             |
| 5  | Aeolian   | 1. Deflation depression  
               2. Dune field dammed lake |                                                                             |
| 6  | Gravity   | 1. Rockslides dammed  
               2. Landslides dammed |                                                                             |
| 7  | Sinkholes | 1. Karst depression  
               2. Thermokarst depression |                                                                             |
| 8  | Anthropogenic | 1. Pond  
               2. Hydropower station dammed  
               3. Mine hole |                                                                             |
| 9  | Meteorite | 1. Meteorite crater | Lake depressions of these types are not found in Mongolia                   |
| 10 | Coastal   | 1. Coastal terrace dammed |                                                                             |
| 11 | Biogenic  | 1. Dammed of organic deposits  
               2. Coral lake |                                                                             |

The previous one-tier classification is made with two-tier classification in terms of origin and morphological features of the lakes according to geomorphological study.

This is a two-tier classification in terms of origin and morphological feature of the lakes, thus changing the previous one-tier classification. Mongolia has identified 11 main and 26 subtypes of origin, and 8 main types of morphologies, based on the features of 32 lake depressions. In Mongolia, meteorite, coastal and biogenic lake depressions were not detected.

**Comparison of morphological types for depression of large lakes in Mongolia:**

The distribution of lakes in Mongolia is closely related to the topographic patterns of the country. The Western Mongolian Lake Depressions are larger than the Central, Southern and Eastern Mongolian lakes [26]. In Central and Northern Mongolia, the lake system and associated lakes along the Khangay and Khuvsgul Mountain Ranges are relatively widespread [27-28]. Alternatively, the distribution of lakes in the South Gobi region is few and small in size [29]. Although there are large lakes in the Valley of the Lakes, they are highly unstable in terms of hydrological systems [27-29]. In Eastern Mongolia, a number of lake systems have been formed with the remains of large ancient reservoirs [26]. The location and size of the Gobi and Eastern Mongolian lakes are directly related to the effects of modern climate change [29].

According to the new classification, lake depressions are divided into several main and subtypes. The main types of 32 lake depressions were identified by comparing the origins of the Lake Depressions in Mongolia (Figure 1).
The Mongolian Altay lakes were considered to be located in glacial depressions [11, 26]. According to Altanbold (2020), lakes are identified as intermountain or graben depressions of tectonic origin [30].

The Bayan (Uvs province), Ulaagchiny Khar and Bayan (Zavkhan province) lake depressions in western Mongolia were considered to be of aeolian origin [11, 26]. According to Enkhbold (2021), the depressions of these lakes, which were caused by tectonic faults also have the influence of aeolian event [31-32].

Research on lakes depression morphology, and the origin of depression of Great Lakes in Western Mongolia have been related to global glaciation [33]. Khukhuudei (2015) suggested that during the Pleistocene epoch, the world's most recent period of repeated glaciations, a super glaciated valley was formed, which corresponds with the Great Lakes Valley. The morphology of the depression of the Great Lakes is a glaciated super valley. Glacial drumlins forms have been preserved [33-34] in the central part of the depression.

The lakes in the Darkhad basin were thought to be of tectonic origin [11]. According to Krivonogov (2005), these lake depressions are related to glaciation [35]. In addition, due to modern climate change, thermokarst lakes have become numerous [36].

The Gegeen Lake is the largest anthropogenic lake in Mongolia. Even since 2008, the Lake was formed by the damming of the river on the Taishir hydropower plant [37].

In the case of other lake depressions, the main and subtypes of morphology have been identified in Figure 1 and Table 4.

![An updated classification of the main types of lake depressions in Mongolia](image)

**Figure 1. An updated classification of the main types of lake depressions in Mongolia**

The previous morphological type and classification of lakes is updated and compared as follows (Figure 1 and Table 4).
Table 4. Comparison of Lake Depression Types in Mongolia

| № | Lake name                          | Tserensodnom, 1971 | Main type     | Subtype                  | New classification          |
|---|------------------------------------|---------------------|---------------|--------------------------|-----------------------------|
| 1 | Uvs                                | Tectonic            | Glacial       | Abrasion depression      | Tectonic                    |
|   |                                    |                     | Tectonic      | Epeirogenic depression   | Epeirogenic depression      |
| 2 | Khuvsgul                           | Tectonic            | Tectonic      | Rift depression          | Tectonic                    |
| 3 | Khyargas and Airag                 | Tectonic            | Glacial       | Abrasion depression      | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Tectonic                    |
| 4 | Khar-Us                            | Tectonic            | Glacial       | Abrasion depression      | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Graben depression           |
| 5 | Khar and Durgun (Khovd province)   | Tectonic            | Glacial       | Abrasion depression      | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Graben depression           |
| 6 | Buir                               | Tectonic            | Tectonic      | Epeirogenic depression   | Tectonic                    |
| 7 | Buun Tsagaan                       | Tectonic            | Tectonic      | Graben depression        | Tectonic                    |
| 8 | Orog                               | Tectonic            | Tectonic      | Graben depression        | Tectonic                    |
| 9 | Ulaan                              | Tectonic            | Tectonic      | Epeirogenic depression   | Epeirogenic depression      |
| 10| Oigon and Bust                     | Tectonic            | Tectonic      | Fault depression         | Tectonic                    |
| 11| Telmen                             | Tectonic            | Tectonic      | Epeirogenic depression   | Epeirogenic depression      |
| 12| Saniin Dalai                       | Tectonic            | Tectonic      | Fault depression         | Tectonic                    |
| 13| Dood Tsagaan and Targan            | Glacial             | Glacial       | Abrasion depression      | Tectonic                    |
|   |                                    |                     | Tectonic      | Rift depression          | Tectonic                    |
| 14| Uureg                              | Tectonic            | Tectonic      | Graben depression        | Tectonic                    |
| 15| Achit                              | Tectonic            | Tectonic      | Graben depression        | Tectonic                    |
| 16| Khar (Namir)                       | Tectonic            | Tectonic      | Graben depression        | Tectonic                    |
|   |                                    |                     | Glacial       | Abrasion depression      | Tectonic                    |
| 17| Khoton                             | Glacial             | Glacial       | Glacial deposit dammed depression | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Graben depression           |
| 18| Khurigan                           | Glacial             | Glacial       | Glacial deposit dammed depression | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Graben depression           |
| 19| Dayan                              | Glacial             | Glacial       | Glacial deposit dammed depression | Tectonic                    |
| 20| Tolbo                              | Glacial             | Glacial       | Glacial deposit dammed depression | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Graben depression           |
| 21| Tal                                | Glacial             | Glacial       | Abrasion depression      | Tectonic                    |
|   |                                    |                     | Tectonic      | Graben depression        | Graben depression           |
| 22| Bayan (Zavkhan province)           | Aeolian             | Tectonic      | Fault depression         | Aeolian Dune field dammed lake |
| 23| Ulaagchiny Khar                    | Aeolian             | Tectonic      | Fault depression         | Aeolian Dune field dammed lake |
| 24| Bayan (Uvs province)               | Aeolian             | Tectonic      | Fault depression         | Aeolian Dune field dammed lake |
| 25| Terkhiin Tsagaan                   | Volcanic            | Volcanic      | Lava-dammed depression   | Tectonic                    |
| 26| Ugii                               | Fluvial             | Fluvial       | Oxbow lake               | Tectonic                    |
| 27| Khagin Khar                        | Glacial             | Glacial       | Glacial deposit dammed depression | Tectonic                    |
| 28| Oyu and Nomin                      | Gravity             | Gravity       | Rockslides dammed        | Tectonic                    |
| 29| Yahi                               | Tectonic            | Tectonic      | Epeirogenic depression   | Tectonic                    |
| 30| Khukh (Dornod province)            | Tectonic            | Tectonic      | Epeirogenic depression   | Tectonic                    |
| 31| Gegeen                             | Anthropogenic       | Hydropower station dammed | Tectonic                    |
| 32| Tsoi taken                         | Sinkholes           | Termokarst depression | Tectonic                    |

The result of study shows that lakes of Mongolia developed in 3 stages, or, were, first, affected by tectonic action, followed by glacial and other exogenic factors.

According to a geomorphological study of the Mongolian lake depressions, the graben and rift subtypes in the framework of main tectonic characteristics are included in the lakes in the mountainous areas. The lakes located in the steppe surface, belong to the depression of fault or epeirogenic subtypes.
Lake depressions created by glaciations are often blocked by moraine dammed in trough valleys of the glacier [38]. Lake depressions created by fluvial effects are predominated by oxbow lakes [39]. The lakes originated through intrusion are often widespread in the large valleys between the mountains, while thermokarst or karst lakes are located in areas with mountain valleys [36, 40]. This is directly related to the characteristics of the bedrock of the area’s surface and climate impact. Volcanic lake depressions are caused by lava damming [41], Aeolian lake depressions are caused by damming because of dune accumulation, gravity lake depressions are caused by the impact of earthquakes [11, 26], and anthropogenic lake depressions are caused by hydro-electric station damming [37].

CONCLUSIONS

The new classification of Mongolian lakes is a two-tier classification in terms of origin and morphological feature of the lakes, replacing the previous one-tier classification. According to the new classification, it has been identified that Mongolia has 11 main and 26 subtypes of origin, and 8 main types of morphology, based on the features of 32 lake depressions. However, due to the topography and climatic conditions of the country, meteorite, coastal and biogenic lake depressions were not detected.

The lakes of Mongolia developed in 3 stages, or, were affected first by tectonic action, followed by glacial and other exogenic factors.

The significance of this study becomes more important as it determines the depression of the lake in relation to its origin. This morphological classification study will create the basic conditions for preserving and utilizing these lakes more efficiently and ecologically in the future by making the classification of the origin and morphological characteristics of the lake depression.

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