Vol. 61 No 02 (238) 2021
DOI: https://doi.org/10.5564/pmas.v61i2.1758

PMAS
Proceedings of the Mongolian Academy of Sciences

ARTICLE

Morphological classification and origin of lake depressions in Mongolia

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ARTICLE INFO: Received: 27 Nov, 2020; Accepted: 13 Aug, 2021

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].

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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.

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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	Exogenous	Glacial
4		Sinkholes (Karst)
5		Gravity
6		Aeolian
7		Fluvial

This classification is the first general definition of Mongolian lake depressions. However, we have compared related dominant classifications, which are known to international readers, including Mongolian lake classification by Tserensodnom (1971) (Table 2).

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
		Davis, 1883; Penck,1894	Pervukhin, 1937	Hutchinson, 1957	Zaikov, 1960	Tserensodnom, 1971	Beletskaya, 1987	Wetzel, 2001	Gohen, 2003	Chernov, 2013	Sevastyanov, 2014	
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

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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).

DOI: https://doi.org/10.5564/pmas.v61i2.1758

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. Ever 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.

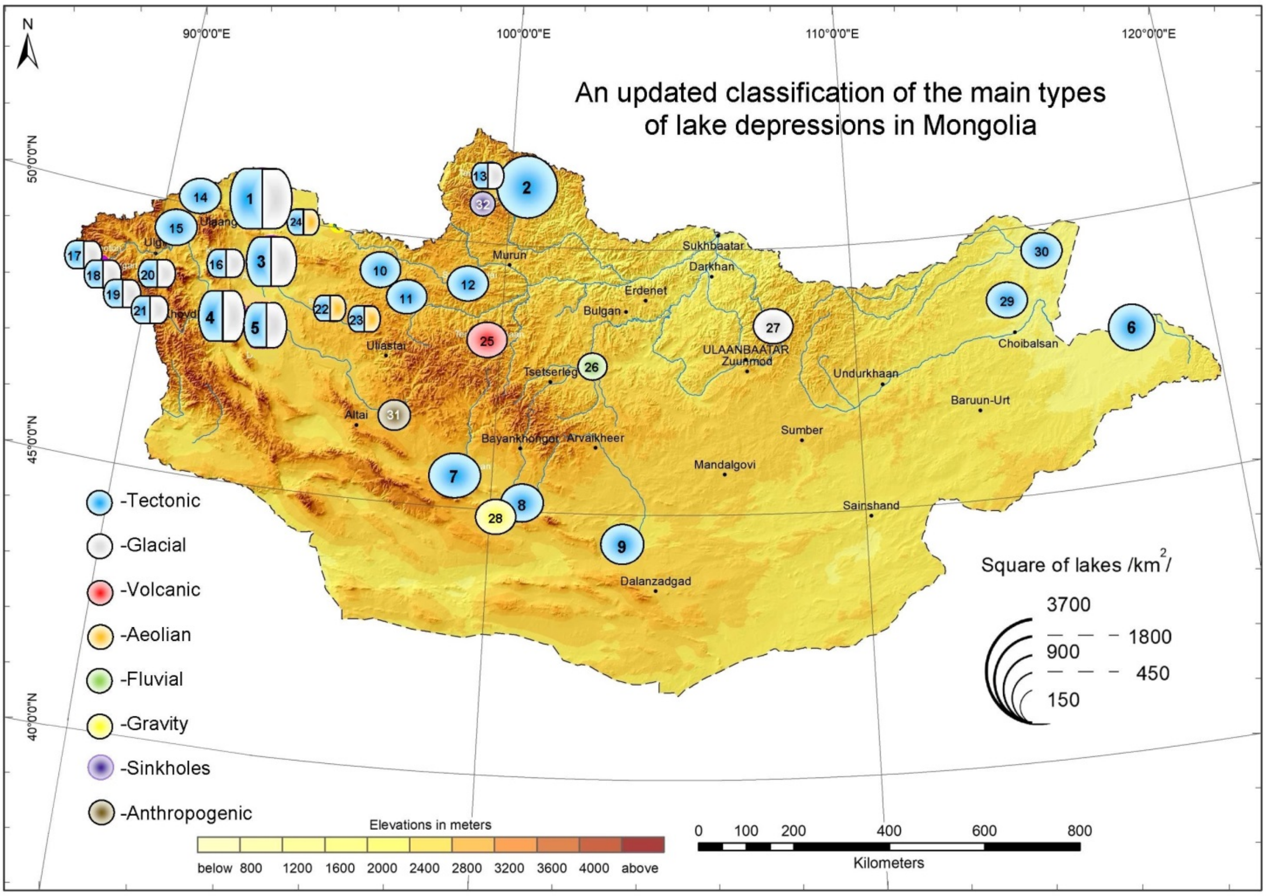

Figure 1. An updated classification of the main types of lakes depressions in Mongolia

The previous morphological type and classification of lakes is updated and compared as follows (Figure 1 and Table 4).

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Table 4. Comparison of Lake Depression Types in Mongolia

№	Lake name	Tserensodnom, 1971	New classification	
		Main type	Main type	Subtype
1	Uvs	Tectonic	Glacial	Abrasion depression
			Tectonic	Epeirogenic depression
2	Khuvsgul	Tectonic	Tectonic	Rift depression
3	Khyargas and Airag	Tectonic	Glacial	Abrasion depression
			Tectonic	Graben depression
4	Khar-Us	Tectonic	Glacial	Abrasion depression
			Tectonic	Graben depression
5	Khar and Durgun (Khovd province)	Tectonic	Glacial	Abrasion depression
			Tectonic	Graben depression
6	Buir	Tectonic	Tectonic	Epeirogenic depression
7	Buun Tsagaan	Tectonic	Tectonic	Graben depression
8	Orog	Tectonic	Tectonic	Graben depression
9	Ulaan	Tectonic	Tectonic	Epeirogenic depression
10	Oigon and Bust	Tectonic	Tectonic	Fault depression
11	Telmen	Tectonic	Tectonic	Epeirogenic depression
12	Sangiin Dalai	Tectonic	Tectonic	Fault depression
13	Dood Tsagaan and Targan	Glacial	Glacial	Abrasion depression
			Tectonic	Rift depression
14	Uureg	Tectonic	Tectonic	Graben depression
15	Achit	Tectonic	Tectonic	Graben depression
16	Khar (Namir)	Tectonic	Tectonic	Graben depression
			Glacial	Abrasion depression
17	Khoton	Glacial	Tectonic	Graben depression
			Glacial	Glacial deposit dammed depression
18	Khurgan	Glacial	Tectonic	Graben depression
			Glacial	Glacial deposit dammed depression
19	Dayan	Glacial	Tectonic	Graben depression
			Glacial	Glacial deposit dammed depression
20	Tolbo	Glacial	Tectonic	Graben depression
			Glacial	Abrasion depression
21	Tal	Glacial	Tectonic	Graben depression
			Glacial	Glacial deposit dammed 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
26	Ugii	Fluvial	Fluvial	Oxbow lake
27	Khagiin Khar	Glacial	Glacial	Glacial deposit dammed depression
28	Oyu and Nomin	Gravity	Gravity	Rockslides dammed
29	Yakhi	Tectonic	Tectonic	Epeirogenic depression
30	Khukh (Dornod province)	Tectonic	Tectonic	Epeirogenic depression
31	Gegeen	-	Anthropogenic	Hydropower station dammed
32	Tsoitson	-	Sinkholes	Termokarst depression

The result of study shows that lakes of Mongolia developed in 3 stages, or, were, firt, 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.

Acknowledgements: We would like to thank the editor and anonymous reviewers for their frank and thoughtful comments regarding the manuscript. Financial support for this study was kindly provided by the Young Scientist Grant (P2020-3944) of the National University of Mongolia.

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