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ARTICLE

A review of modern trends and historical stages of development of lake research in Mongolia

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Abstract: There is the need to divide Mongolia's lake research into trends of development stages and to provide a detailed analysis of modern lake research. The aim of this study is to identify the development stages of lake research in Mongolia and to analyse lake research development. This study provides a comparative analysis of the development trends of lake research carried out in the country. The historical development of lake research in Mongolia was divided into 4 stages in chronological order, highlighting the current research direction, scope, and contribution to geography. Since 1990, researchers from many countries have been able to conduct extensive research in Mongolia, and especially since the 2000s, lake research intensified owing to global warming and environmental change. Studies, in particular, focus on paleogeography, paleoclimate changes, lake water regimes and water level fluctuation. Mongolian lake-based studies have tended to identify environmental evolution from the Pleistocene to the Holocene. The investigated areas were primarily Khuvsgul Lake and Darkhad Basin, Lakes Valley and Gobi Lakes, the Great Lake Depression, Mongolian Altai and Khangai Mountain lakes. Since 1990, scientists from Russia, Mongolia, Germany, China, Japan, USA and South Korea have been increasingly focusing on research into lakes in Mongolia. Paleogeographic and paleoclimatic reconstruction, based on the lakes of Central Asia, is being conducted in an innovative manner. Dividing Mongolia's lake research into development stages and identifying research trends will help determine which areas of research can be developed in the future.

Keywords: *Lake research; Mongolian lakes; Development stage; Comparative analysis; Mongolia; Lake thematic research;*

INTRODUCTION

It is important to study lakes, which are an important component of maintaining the balance in nature [1]. A lake is a form of surface water with ecosystem features that is located in depressions of various sources, located within the continents of 0.1 km² or more [2].

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Lakes cover 2.0 per cent of the earth's surface, which is equivalent to 0.1 per cent of the total water volume [1-3]. The appearance of the lake depression, lake area, and its geographical location have changed over the course of geological history due to external and internal global influences [4].

In Mongolia, lakes are relatively small in size and distribution due to their mid-latitudes, but Mongolian lakes have always had a significant impact on the environmental evolution [5]. Climatic factors, such as weathering, wind and glaciation have all influenced the appearance and distribution of Mongolian lake areas, and the accumulation of sediments [6].

The study of the lake, which is one of the components of the physical geography of Mongolia, has a long history [6]. According to Tserensodnom (1971), the history of lake research is divided into two periods, pre- and post-People's Revolution, based on the historical chronology of Mongolia's physical geography. In modern Mongolian geography, researchers have extended the history of research into specific periods after the Revolution [7]. We have divided the history of the development of lake science in Mongolia into a number of stages. This is largely consistent with the historical stages of Mongolian geography as identified [7].

There is a need to divide Mongolia's lake research into forms of development stages and to provide a detailed analysis of modern lake research. The purpose of this study is to identify the development stages of lake research in Mongolia and to analyse lake's thematic research.

MATERIALS AND METHODS

A review of previously published research materials, which were collected during the study of lakes in Mongolia, provides the basis for dividing lake studies into different development stages based on scientific trends and creating a relevant database.

Internationally published articles and monographs on this topic, based on the Mongolian lakes, were filtered from Google Scholar database (In English). Since 1990 (June 1990-2022), 164 internationally published studies on lakes in Mongolia have been reviewed. Based on published research materials, research into Mongolia's lakes were compared, analysed and synthesised, and the areas of research were identified in detail.

The main results of the study were based on the method of comparative analysis. Widely used in comparative studies if the comparison of numerical data to secure secondary analysis results [8]. Under the comparative research method, the data are divided into S or times compared and N or comparison between qualitative comparison [9]. The most important issue in geographical research is to compare data that have changed in space and time [10]. This study provides a comparative analysis of the development trends of lake research that have been carried out in Mongolia.

The comparative analysis methodology has been structured into a sequence of four phases that allow the proposed developed analysis. These include 1. Determining the search criteria 2. Data compilation 3. Adjustment of criteria 5. Performance analysis of results (Figure 1).

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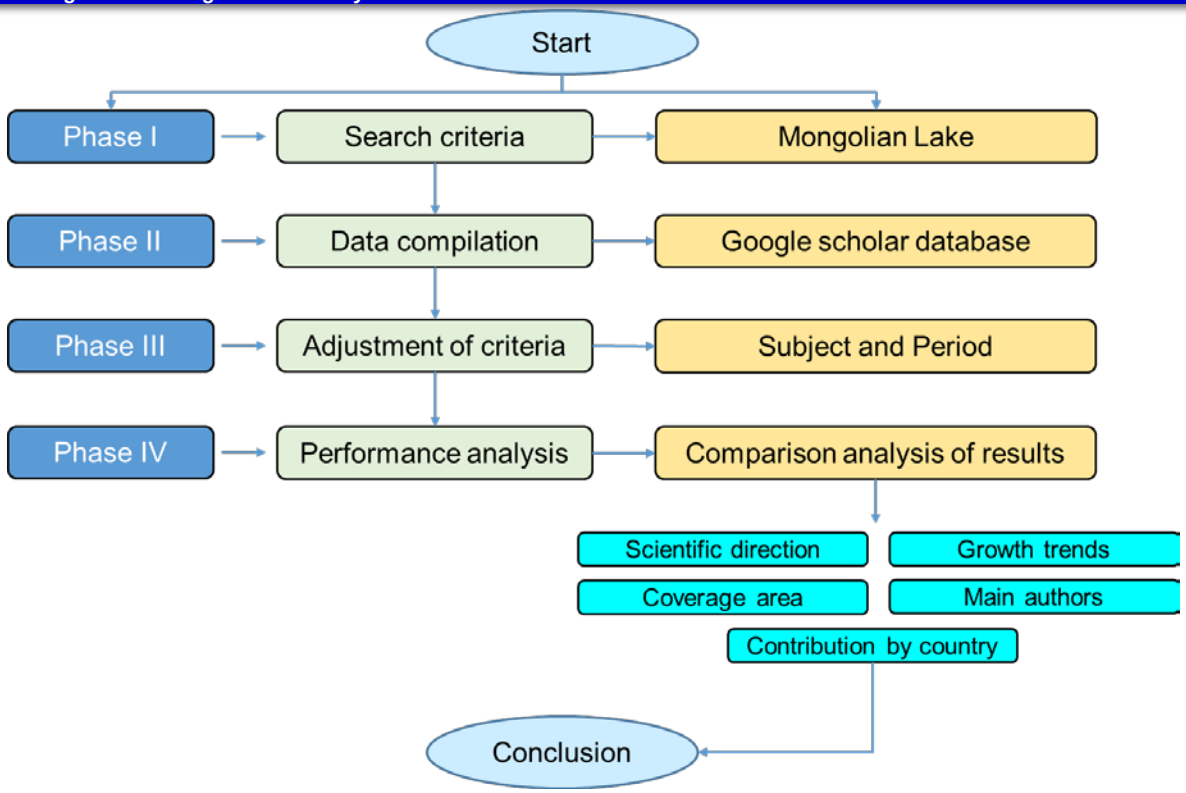

Figure 1. Scheme of the methodology in the study

RESULTS AND DISCUSSION

Analysis of development stages of lake science in Mongolia

The historical development stages of lake science in Mongolia can be considered as follows based on the results of current research and development trends. These are: The early period of development before 1921, the second period spanning 1921-1961, the third period of 1962-1989, and the fourth period starting in the 1990s, that is, the modern development period.

The basic principles of division into development stages are shown schematically based on the content of the current social change, the scope of science, the specific direction, the level of research, and the development trend (Figure 2).

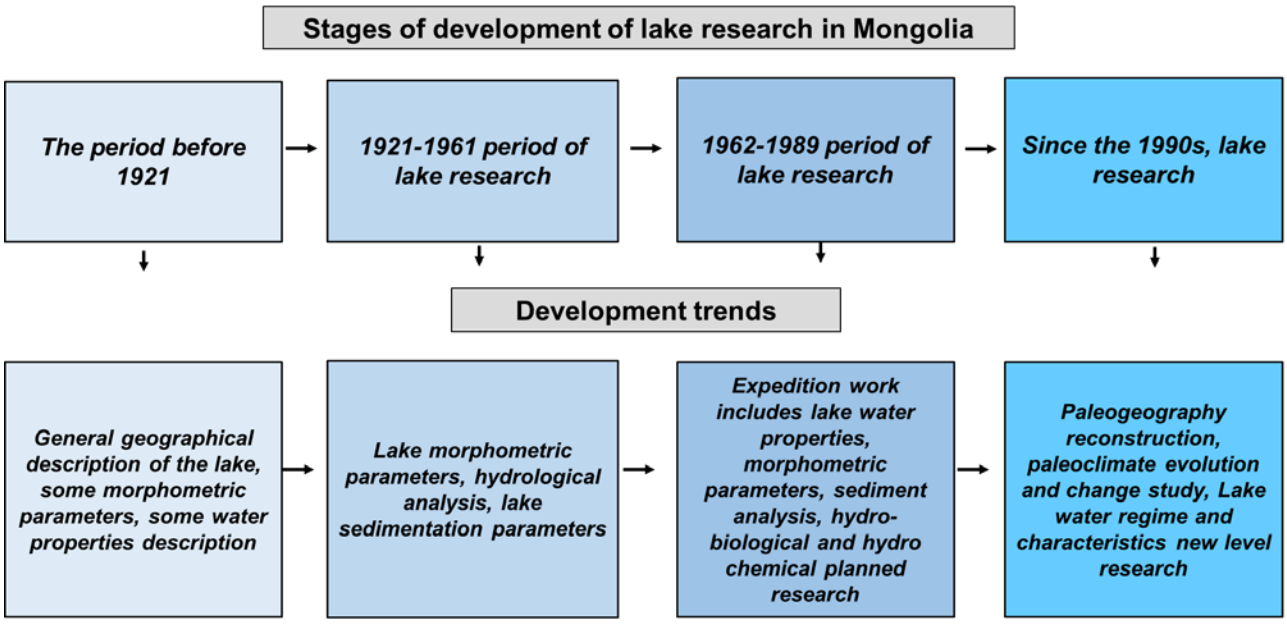

Figure 2. Stages of development of lake research and general research trends

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The period before 1921

According to the history of lake research in Mongolia, when the first lake research papers were published, western tourists and researchers made the first predictions about the lake's name, location, general condition, water characteristics, regime, water supply and lake depression origin [11]. It is reasonable to believe that the establishment of the Russian Geographical Society in 1845, which began to study the geological and geographical features of Mongolia in a planned manner, provided an opportunity to expand the study of lakes [7].

The first lake studies were published by researchers who had carried out research in Mongolia in the late ninetheenth and early twentieth centuries [6].

Summarising the main results of this period, Przhevalsky (1870-1888), who did not study the lakes of Mongolia in detail, gave the first description of the location and origin of the lakes encountered along the way [6-7].

Potanin (1876-1899) made several trips to Mongolia. Interesting facts about the size, water regime, geographical location and origin of the depression of the Dayan, Tal, Üüreg, Khulman, Uvs, Khar-Us, Sangyn Dalay, Khiargas and Buir Lakes in Western and Eastern Mongolia were published [6, 11].

Pevtsov (1878-1879) studied the Great Lakes Depression and the Valley of Lakes and collected a significant number of cognitive materials about rivers and lakes lying in the region between the Khangai and Gobi-Altay mountains [11].

Kozlov (1899) began his individual study of Mongolia and Central Asia and had published some information on morphometric and water properties, water nutrition, runoff, regime and mineralisation [6].

Kaznakov and Ladygin (1899) traveled from the Mongolian Altai to Khovd and made in-depth measurements of lakes such as Khoton, Khurgan, concluding that these lakes were located in glacial depressions [12].

Peretolchin (1897-1903) worked on Khuvsgul Lake and studied the water regime, lake feed, lake depth, shoreline, bottom sediments and accumulation features in detail and came up with the first monograph on Mongolian lakes [6].

In addition, Komarov (1902) and Elpatyevsky (1903) studied the origin and morphometry of Khuvsgul Lake [6, 11].

Sapozhnikov (1905-1909) collected the first interesting information about the origin of coastal depression, water and thermal regimes, aquatic plants and animals in the Mongolian Altay Khoton, Khurgan, Dayan, Tal, Khar and Onkhot Lakes and he also measured the depth of some of these lakes [6-7, 13].

Carruthers (1910-1911) wrote geographical and morphometric descriptions of Uvs, Üüreg and Achit Lakes [6, 13].

Grane (1906-1909) traveled through the Altai and Khangai mountain ranges of Mongolia and described glaciation and glacial lakes [12].

The research of this period focused on the general definition of the lake, some morphometric parameters, and some water properties. The first recorded lake data included a brief overview of the general geography, the current understanding of the lake's paleogeography, the general definition of the lake, and some morphometric parameters.

Lake research between 1921 and 1961

In the twentieth century, a Division of Geography was ste up at the Institute of Letters (the forerunner of the present-day Academy of Sciences of Mongolia) in 1924 [7].

Summarising the study of lakes of this period, Kondratiev (1927) studied the area around Telmen Lake in Khangai Mountain and wrote a monograph [13].

Smirnov (1926-1928) studied the chemistry of Mongolian lakes and mineral springs. He visited large lakes in northwestern Mongolia, such as Uvs, Khiargas, Airag, Gobi-Altai Sangiin Dalai, Khar-Nuur, Dörgön, Tsookhor and Üüreg, to take water samples and analyse them [6, 13].

Kozlova (1929) was the first to map the morphometric parameters and bathymetry of Örög Lake and to give the first definition of water properties [7].

Murzaev (1940-1944) was the first to give a unified definition of the origin of lakes in Mongolia, the basic characteristics of morphometric, water regimes and mineralisation [6-7].

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Bespalov (1940-1934) conducted research on the origin of fresh and mineral lakes in Mongolia, the pattern of salt accumulation, and the chemical composition of lake water [7].

Alekseychik (1942) determined the chemical composition of the salt reserves of some lakes in Mongolia and the geological structure of the lake depression [6].

Marinov, Nevzorov and Perelman (1943) conducted salt surveys in some lakes in eastern Mongolia [6, 13].

Turischev (1943) estimated the salt resources of the Great Lake Depression and determined the potential resources for use [6, 13].

From the middle of the twentieth century, Mongolian researchers began to study the lake intensively. The Mongolian Academy of Sciences, the National University of Mongolia, the Hydro-meteorological Service and the Ministry of Agriculture's Water Resources Authority have begun research on the lake.

Tsegmid (1948-1949) was the first to analyze the Khentii Mountain lakes and to determine their glacial origin. In addition, Tsegmid (1951-1953) conducted research in the Mongolian Altai Mountains, the Great Lake Depression, and the Lake Valley and published study papers on the origin of the lakes, paleogeographic condition, modern changes and chemical composition of water [11, 13].

In terms of expedition research, in 1949-1952, 1957-1958, the Water Research Department of the Ministry of Agriculture covered the entire territory of the country [6]. They studied the distribution of surface and groundwater regimes in Mongolia, the main feed and water chemical composition, and the water balance of some lakes, and created surface and groundwater distribution, mineralisation and hydrogeological maps of Mongolia.

In 1959-1960, the National University of Mongolia and the Russian Irkutsk State University conducted hydrobiological and hydrochemical research on Khuvsgul Lake [6-7].

Davaasüren and Avirmed (1956-1958) analysed the water of the mineral lakes of the Great Lake Depression and conducted a comprehensive study of food and industrial salts [6, 13].

Studies from 1921-1961 focused on how Lake Morphometric measurements and hydrological properties could be used in practice. In addition, some geological and geomorphological evidences and sedimentary properties of the lake were studied during this period.

Lake research during the period from 1962 to 1989

The foundation of the Mongolian Academy of Sciences in 1962 had a positive impact on the more detailed and comprehensive study of Mongolian lakes, and many institutes were able to conduct research under an extensive integrated policy [6-7].

During this period, Tserensodnom (1962-1971) highlighted the number of all lakes in Mongolia with an area of more than 0.1 km², the size of the area, geographical location, coastline, length and width, and classified them into geographical regions and natural zones. During this period, hydrological measurements were carried out on large lakes in Mongolia with an area of more than 20 km², water depth and resources were determined and observations were made, and several scientific works were published [11, 14].

Scientific studies of the lakes from an economic point of view began in the country in 1964. From this period onward, the Institute of Biology of the Mongolian Academy of Sciences began to study aquatic animals and plants of some lakes, their shapes, species and seasonal location [7, 14].

The Hydro-meteorological Service (1962) began a detailed study of the thermal and water regimes of Mongolian lakes and established water barriers on large fresh and mineralised lakes such as Khuvsgul, Uvs, Airag, Khar-Us and Buir lakes [6, 11].

“Lakes of Mongolia” by Tserensodnom (1971) provides a historical overview of the study of lakes in Mongolia, surface and climatic regimes affecting the lakes, a unified definition of the morphometry of the lakes, and bathymetric mapping [6].

A joint Soviet-Mongolian research led by Sevastyanov (1972-1989) conducted a comprehensive study of Mongolia's lakes, and the Limnology and Paleolimnology of Mongolia (1972, 2014). Major works such as “Lakes of the Mongolian People's Republic and

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their Mineral Resources" (1989) reflect the ancient geographical evolution of lakes, the origin of depressions, lake water regimes, morphometry, lake water properties and composition biodiversity [15].

Luvsandorj (1973) studied the composition and properties of salt of about 20 large and small lakes in the Great Lake Depression and identified the salt resources of these lakes that could be used for household and public catering needs [14].

"Geomorphology of the Mongolian People's Republic" (edited by Florensov and Korzhuev, 1982) provides definitions of the geomorphological patterns and origins of the Mongolian lake basin [11].

Since 1984, within the framework of the international joint research "Uvs Lake-Experimental Study", biological and geographical studies have been conducted in the transboundary Uvs Lake basin of the Soviet Union and Mongolia, and recommendations have been made on the rational use and protection of Uvs Lake [14].

Dorofeyuk (1988) studied the ancient geographical environment of Mongolia and its evolution by analysing sediment samples from Buir Lake in Eastern Mongolia, Terkhiin Tsagaan and Davaa lakes in Central Mongolia, Khoton Lake in the Mongolian Altai mountain ranges and Uvs Lake in the Great Lake Depression, based on the fossils contained in sediments, and published a study of the ancient geographical environment of the late Quaternary Holocene [14].

In 1989, "Atlas Lake Khuvsgul" was published by more than 100 researchers from the Soviet Union and Mongolia. The atlas covers geological, tectonic, engineering-geological, seismological, hydrogeological, geomorphological, hydrological, water properties, regimes, water composition, sedimentary properties, and lakes morphometric analysis of Lake Khuvsgul since the 1980s. Respiration, biomass, landscape, and soil cover are also described in detail [16].

During this period, the depth of the lake was measured at regular intervals in the field of geography and hydrology, various bathymetric maps were made, morphometric characteristics of water and shoreline were measured and compared, and the water level and thermal regime of the lake were studied. Hydrobiology began to study the distribution patterns of some lake's flora and fauna, while hydrochemists began to study the chemical composition of freshwater and mineral lakes, their properties, condition and lake sediments. At that time, the study of lakes had a definite purpose, results, time plan, and set goals for each field, and the sciences began to develop in a relatively coherent manner.

During the development period of 1962-1989, the joint expedition surveyed the lake's water properties, morphometric parameters, sediment analysis, hydro-biological and hydrochemical studies, and carried out results and time-planned activities for a specific purpose.

Lake research starting in the 1990s

This was a period turning point in the social and political life of the country as democratic changes that took place created better opportunities for facilitating mutual international cooperation in the research area as well. From this time, researchers from Russia, Germany, Japan, China, Korea and USA began to make significant contributions to the study of lakes in Mongolia.

Researches carried out on Mongolian major lakes during this period is summarised below.

Key studies conducted in Mongolia during this period are summarized by Sevastyanov et al (1990) in the study on the geographical zoning of lakes in Mongolia, the location of lakes, morphometric parameters and composition and water properties [4]. The same year, the National Atlas of Mongolia was published and for the first time a map of the origin of lakes in Mongolia was created [17].

Dorofeyuk, Sevastyanov (1992) analysed the results of sedimentary studies of lakes in Mongolia and addressed the characteristics of lake sediment accumulation, historical time dependence, and ecosystem issues [18].

Harrison et al (1996) published a summary study of late Quaternary Lake water variability. This study summarises the results of water level fluctuations and sedimentary studies of more than 100 lakes in northern Eurasia since the late Quaternary [19].

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Tarasov (1996) also analysed carbon in such lakes as Achit, Khoton, Khuvsgul and Khar-Us as part of the Soviet-Mongolian lakes' sedimentary analysis [20].

A monography by Batnasan (1998) clarified the water regime, hydrological systems and features of their development in the major Gobi lakes of Mongolia [14].

Tserensodnom's (2000) "Mongolian Lake Catalogue" describes the morphometric classification, hydrological regime, morphometric and characteristics of lakes in the country [14].

Sevastyanov and Dorofeyuk (2005) published a review of Mongolian lakes basing on the results of a joint Russian-Mongolian expedition. The study of modern and ancient lakes in Mongolia provided an opportunity to assess natural resources associated with the lake and to identify trends in environmental change [21].

An et al (2008) study identified Holocene Paleogeographic conditions based on lake sediments in Mongolia [5].

In the years from 2001 to 2010, joint research teams from the Institute of Geology and Mineral Resources, Mongolian Academy of Science, Institute of Limnology and Geochemistry, the Siberian branch of the Russian Academy of Sciences, Japan's Kanazawa University and Korea Institute of Geoscience and Mineral Resources have undertaken long-term research at lakes of Khuvsgul and Darkhad basins. They have defined the paleoclimate condition during Pleistocene and Holocene for Northern Mongolia, its correlation to Central Asia, based on detailed analysis of lake sediments from drilling. Key results of these numerous studies are included in many Mongolian, Russian and English publications [22-26].

Robinson et al (2011) studied the ecosystem changes and evolution of lakes in northern and central Mongolia and the water regimes, chemical composition, and biological resources of lakes [27].

A study by Kang et al (2015) specifically examines the interrelationship between climatic factors that affected the lake's water area and for this purpose, 165 lakes with an area of more than 10 km² in Mongolia, were selected and the lake water area, precipitation and evaporation balance were estimated in the period since 1980 [28].

Davaa et al (2018) identified the possibility of assessing water resources of Mongolia's lakes and monitoring them regularly. Their study notes that the water level in the lakes has been steadily declining in recent years, based on ground and satellite data, and have recommended that further research is needed to determine the water resources of Mongolia's lakes [29-30].

Klinge and Sauer (2019, 2019) analysed the climate change in Mongolia after the last glaciation and the subsequent Pleistocene glaciation. They analysed the sedimentary material of the Mongolian Altai, Khuvsgul, Khangai, the Great Lake Depression and the Valley of Lakes [31-32].

Altanbold et al (2021, 2022) revised the classification of the origin and morphological types of the Lake Depression in Mongolia. This study details the origins and morphological type patterns of Mongolia's 32 largest lake depressions [33-35].

Lan et al (2021) conducted an analysis review of the lakes in the Central Asian and Mongolian plateaux and reconstructed the Holocene climate features [36].

During this period of development, it became possible to use modern technical and technological advances in lake research, which took paleogeographic and ancient climate research to a new higher level. The lake sediments were used for detecting and restoring paleogeographic changes in the region based on the plant and animal remains contained in them, and for clarifying the dynamic patterns of ancient climatic conditions. In modern times, new methods have been introduced into lake research, and research on paleogeographic evolution and dynamic processes is developing rapidly. At the same time, there is a tendency for research to highlight the importance of science and practice in the rational use and protection of lake-related natural conditions and resources in the national economy.

Analysis of modern thematic research in the field of lake research

Recent thematic research work related to modern development of lake research in Mongolia has been classified according to the chronology, content and direction of the study.

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Since the 1990s, priority was given to determining which areas of the lake are being developed. The thematic research was grouped by direction trend and were analysed (Table 1 and Figure 3) accordingly.

Table 1. Modern thematic research in the direction of lake research in Mongolia (1990-2022), in percentage

№	Main directions of research	Papers	Present
1	Paleogeography	36	21.95
2	Paleoclimate	35	21.34
3	Hydrological regime	32	19.51
4	Water composition	24	14.63
5	Geomorphology	14	8.54
6	Geology	11	6.71
7	Glacial	7	4.27
8	Methodology	3	1.83
9	Permafrost	2	1.22
	Total	**164**	**100**

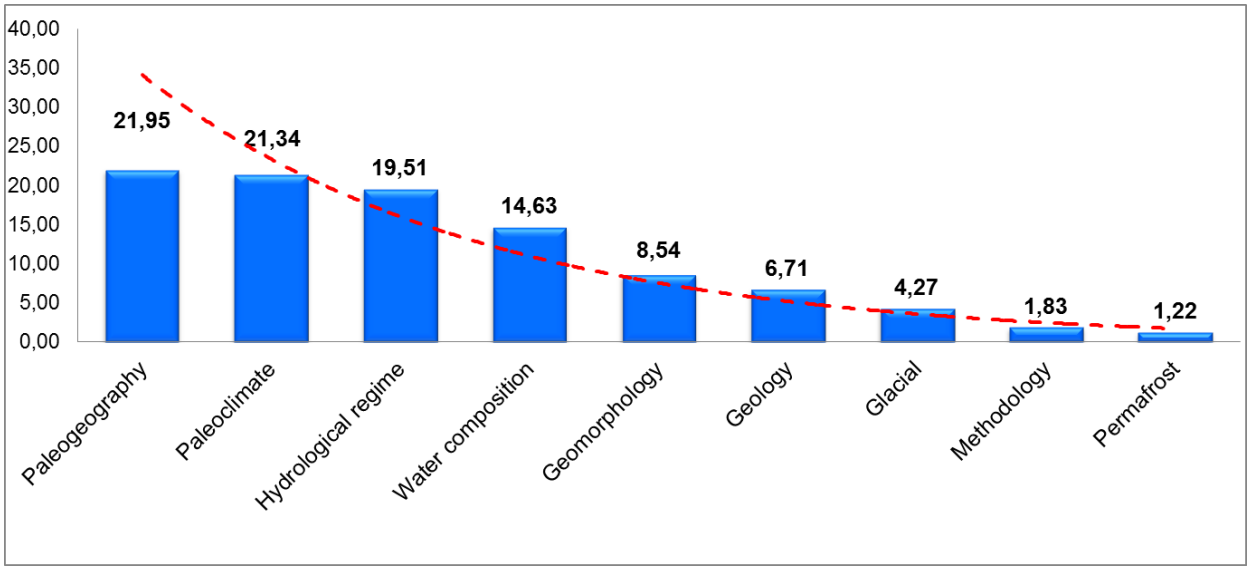

Figure 3. Areas of thematic research

Comparative analysis carried out since 1990 shows that lake-based palaeogeography constituted 22 per cent, which foes to show that the lake is the main archive for determining the patterns of palaeogeographic evolution and changes. Paleoclimate research accounted for 21 per cent of all the researches. Based on the analysis of sediments accumulated in the lake, there was a tendency to identify climate changes from the Pleistocene to the Holocene Periods. The hydrological regime and water composition studies account for about 34 per cent. The study of lakes is well developed in this area, as it is important to determine the historical trends of the lake's water regime and water level fluctuations to predict future trends. However, the study of geomorphology, geology and glaciation of the lake water was relatively small or about 4-9 per cent of all the related researches. But thematic studies accounted for about 1-2 per cent of the study, which focused on lakes permafrost processes and methodology research.

In terms of the chronology of studies, published since 1990, the number of studies has been increasing relatively since 2008 (Figure 4).

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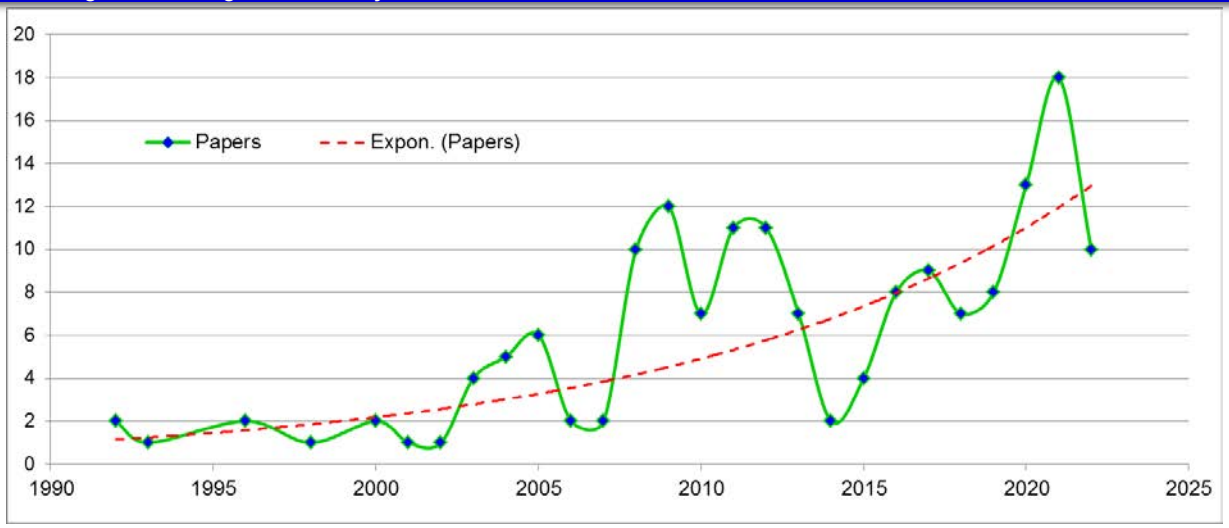

Figure 4. Growth trends in Lake-based research in Mongolia (Years of publication)

Thematic studies of lakes in Mongolia were analysed by grouping them by areas (Table 2 and Figure 5).

Table 2. Mongolian Lakes-based research (1990-2022) in percentage

№	By coverage area	Papers	Present
1	Khuvsgul Lake & Darkhad Basin	36	21.95
2	Valley of Lakes and Gobi	30	18.29
3	Great Lake Depression	28	17.07
4	Khangai lakes	23	14.02
5	Total lakes of Mongolia	17	10.37
6	Mongolian Altai	17	10.37
7	Khentii lakes	7	4.27
8	Eastern Mongolia	6	3.66
	Total	**164**	**100**

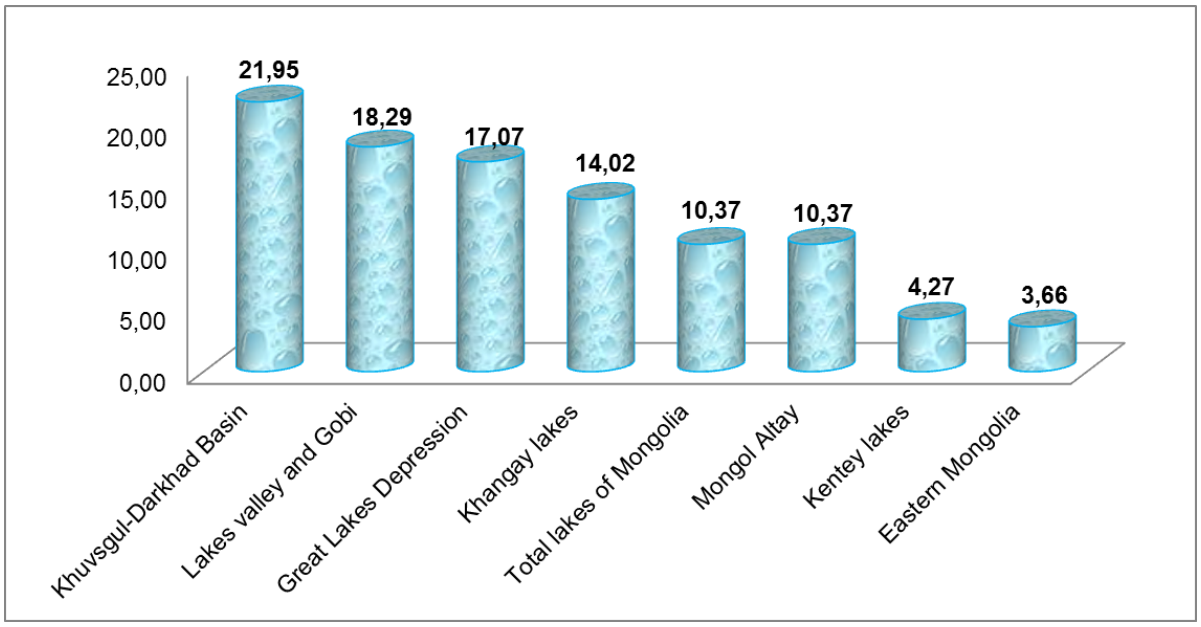

Figure 5. Mongolian Lakes-based research (by coverage area)

Since 1990, 22 per cent of research into Mongolia's lakes were carried out inthe Khuvsgul and Darkhad Basin areas. The Lake Valley and Gobi Lakes research and the Great Lake Depression research each accounted for 17-18 per cent of the total survey.

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The main focus of the study of lakes in the above regions has been to identify the Quaternary glaciation, the paleogeographical and paleoclimate of the subsequent Holocene, and the hydrological regime evolution of lakes.

Research on lakes in the mountainous areas of Khangai and the Mongolian Altai accounted for about 10-14 per cent of all the research, however, the study of Khentii Mountain lakes accounts for only 4 per cent. The study of lakes in Mongolian mountainous areas was dominated by Quaternary glaciation and paleoclimatic studies.

Research covering the entire territory of Mongolia accounts for about 10 per cent of hydrological regimes and characteristics studies. Research in this area is mainly based on remote sensing and water composition analysis.

The survey of lakes in Eastern Mongolia is relatively poor, standing at about 3 per cent. In the future, there is a need to study the lakes of Eastern Mongolia in much more detail.

The jurisdiction of the first researchers who have carried out survey of the lakes of Mongolia and which have been published internationally is shown in the following Table 3 and Figure 6 respectively.

Table 3. Developing countries for thematic lake research in Mongolia (1990-2022) and their share in percentage

№	Country	Papers	Present
1	Russia	37	22.56
2	Mongolia	34	20.73
3	Germany	31	18.90
4	China	20	12.20
5	Japan	17	10.37
6	USA	13	7.93
7	Korea	6	3.66
8	Netherland	1	0.61
9	Iceland	1	0.61
10	Taiwan	1	0.61
11	France	1	0.61
12	The United Kingdom	1	0.61
13	Sweden	1	0.61
		164	**100**

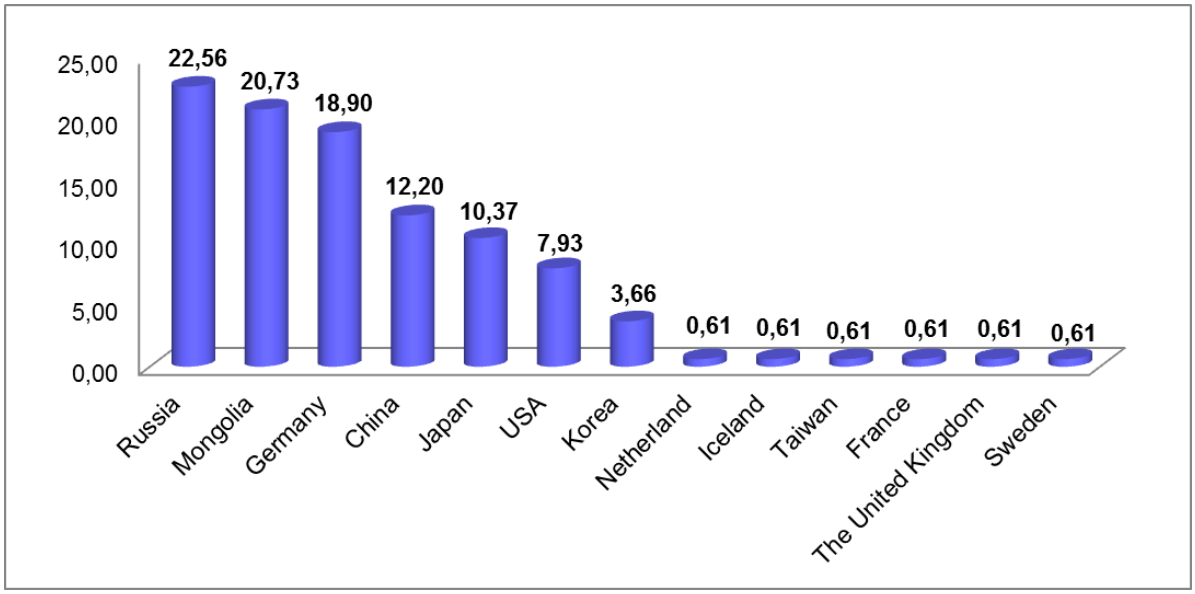

Figure 6. Developing countries for thematic lake research in Mongolia (Jurisdiction to the first author)

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Russian and Mongolian researchers have surveyed 43 per cent of all the lakes in Mongolia. Russian researchers have focused on Lake Khuvsgul and the Darkhad Basin, and the Mongolian researchers have focused on the Great Lake Depression, Khuvsgul and the Darkhad Basin.

German researchers have focused on the Valley of Lakes, Gobi lakes in the Mongolian Altai and Khangai mountain areas.

Chinese researchers are focused on the lakes of the Mongolian Altai, Khangai and Khentii mountains, the Japanese researchers have worked in the Khuvsgul and the Valley of Lakes area, and the Korean researchers have studied lakes in the Gobi and some of the lakes in the Khentii mountain areas. Also, American researchers have done a study in the Great Lake Depression.

CONCLUSIONS

The historical development of lake research in Mongolia was divided into four stages in chronological order to assess the current scope of research direction and contribution to Mongolian geography.

Since the beginning of the scientific development of the lake (1921-1961), research into the lakes has been based on the morphometric and hydrological analyses of the lake. During the Lake Research (1962-1989), natural conditions and resources of the lakes were studied from an economic point of view.

Since 1990, researchers from many countries have been able to conduct more extensive research in Mongolia and in the new millennium, the study of lakes has developed on the basis of more advanced science and evidence.

Such research tends to be carried out in an innovative manner by comparing, evaluating and assessing not only in Mongolian but also regional and Central Asian, as well as northern hemisphere-wide lake studies. An analysis of thematic studies has shown that lakes are the main archive for determining the patterns of palaeogeographic evolution and changes.

There was also a predominance of lake water regimes, trends in water level fluctuations, and the identification of climate change from the Pleistocene to the Holocene through paleoclimate reconstruction.

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