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Spatial Distributions of Lakes across the Eight Largest Deserts of China (2000–2019)

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Abstract: Desert lakes are an essential link in maintaining the biodiversity and ecosystem stability in desert areas. A timely and accurate understanding of their temporal and spatial characteristics is significant for revealing the regional water cycle and ecological environmental changes. This study is based on the global surface water datasets (JRC GSW and GLAD). The research objects are China's eight deserts (Taklimakan, Gurbantungut, Kumtagh, Chaidamu, Badain Jaran, Tengger, Ulan Buh, and Hobg Deserts), which are combined with manual interpretation and quality control to form a dataset of the spatial and temporal distribution of lakes in China's eight significant deserts from 2000 to 2019. The spatial data include: (1) the maxextent water body distribution data of lakes in China's eight deserts during the year (.shp); (2) the permanent water body distribution data of lakes in China's eight deserts during the year (.shp). The table data include: (1) number and area of maxextent water bodies in desert lakes of China from 2000 to 2019; (2) number and area of permanent water bodies in desert lakes of China from 2000 to 2019. The dataset is stored in shapefile format, 38 groups of files, and the data volume is 32.3 MB (compressed into one file, 13.4 MB).

Keywords: China desert; lakes; spatial-temporal distribution; area change

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Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2021.09.05.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2021.09.05.V1.

1 Introduction

China is one of the most widely distributed deserts countries in the word, with the majority located in the arid and semi-arid climate areas of the northwest[1]. Although the desert is

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associated with significant climatic dryness, droughtlow-lying areas within the desert also form small lakes[2] due to local surface runoff and groundwater recharge. These lakes accumulate precious water sources in desert areas and play an important role in maintaining regional biodiversity and ecosystem stability. Meanwhile, these desert lakes are prone to climate change and have significant fluctuations in the inter year and within the years. At present, some studies have conducted remote sensing surveys on the change characteristics of desert lakes in China[2,4–6]. However, these studies mainly focus on the lakes in the Badanjaran and Tengger Deserts and lack the dynamic changes of desert lakes at the national scale.

Remote sensing technology and data are needed to study the dynamic lake changes at a large regional scale, especially in desert areas with the harsh natural environment. In recent years, there are has been an increase in the number of remote sensing data products that can be used to monitor lake dynamic changes, ranging from Landsat, Sentinel-2, and other optical images to a variety of publicly released global lake, reservoir, and water data products[7], all of which allow for the exploration of surface water changes in large regions and long time series. In this study, eight major deserts in China were selected as research areas, and JRC GSW, and GLAD water data products were extensively used[8,9] to construct a dataset of lake spatial and temporal distribution in eight major deserts in China from 2000 to 2019. The data reveal the overall change trend and spatial and temporal patterns of desert lakes in China in the past 20 years and will provide basic data for desert hydrology, ecology, and climate research.

2 Metadata of the Dataset

The metadata of the Dataset of temporal-spatial distribution of lakes in the eight deserts of China (2000–2019) dataset is summarized in Table 1. It includes the dataset's full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data sharing policy, etc.

3 Methods

The processing process of this study is shown in Figure 1, and it mainly consists of four steps. First, the scope of this study area was determined by referring to the vector range of the eight deserts in China provided by the dataset[12] of the 1:100,000 distribution atlas of deserts in China. Second, the global surface water dataset of JRC GSW[1] was downloaded according to the desert area, and it provides water data with different definitions. In this study, the layer of annual maximum water area and annual permanent water layer were mainly selected. The GLAD Global Water Dataset[2] produced by the global land analysis and discovery research team at the University of Maryland was used as a supplement to the problem of missing data in some years and regions of JRC GSW data. Given that GSW and GLAD data represent all surface water information, the other natural water bodies, such as reservoirs and rivers, need to be removed in the third step. Lakes in desert areas are mostly shallow lakes, wherein division and merger of lakes more frequently occur[2]. Based on the determination of lake water area, the attributes of water patches adjacent to space must be further merged. Finally, the water boundary is manually checked to eliminate the tiny voids and excellent boundaries in the water in combination with the historical image data. In addition, we have marked the lake area[3] and desert area for each lake. The lakes in China

[1] Global surface water dataset of JRC GSW. https://global-surface-water.appspot.com/download.

[2] GLAD Global Water Dataset. https://glad.umd.edu/dataset.

Table 1 Metadata summary of the Dataset of temporal-spatial distribution of lakes in the eight deserts of China (2000–2019)

Items	Description
Dataset full name	Dataset of temporal-spatial distribution of lakes in the eight deserts of China (2000–2019)
Dataset short name	DesertLakes_2000-2019
Authors	Feng, Q., Y., Nanjing Institute of Geography and Lakes, Chinese Academy of Sciences, School of Remote Sensing and Surveying and Mapping Engineering, Nanjing University of Information Engineering, 201813350012@nuist.edu.cn Liu, K., Nanjing Institute of Geography and Lakes, Chinese Academy of Sciences, kliu@niglas.ac.cn Fan, C. Y., Nanjing Institute of Geography and Lakes, Chinese Academy of Sciences, fanchenyu_1996@163.com Song, C. Q., Nanjing Institute of Geography and Lakes, Chinese Academy of Sciences, cqsong@niglas.ac.cn
Geographical region	Eight deserts of China
Year	2000–2019
Temporal resolution	Inter-annual
Spatial resolution	30 m
Data format	.shp
Data size	13.4 MB (compression)
Data files	Spatial data: (1) Maximum water distribution data of lakes in eight deserts in China from 2000 to 2019; (2) Annual permanent water distribution data in eight deserts in China from 2000–2019 Table data: (1) Statistics of maximum water quantity and area of lakes in eight deserts in China during 2000–2019; (2) Statistics of permanent water quantity and area of lakes in eight deserts in China from 2000 to 2019
Foundations	Ministry of Science and Technology of P. R. China (2019YFA0607101); Chinese Academy of Sciences (XDA23100102)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[7]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

can be divided into five major lakes according to the distribution, origin, water environment, resource occurrence, and hydrological characteristics of lakes, combined with the geomorphic characteristics of high west and low east of China and the climatic conditions of wet south and dry north and considering the statistical convenience of administrative division of China. This dataset involves two lake areas: the Qinghai–Tibet Plateau lake area (including Qinghai and Tibet) and the Meng–Xin lake area (including Inner Mongolia, Xinjiang, Gansu, Ningxia, Shaanxi, and Shanxi). Some differences can be observed between the boundary of the Qinghai–Tibet Plateau lake area and the natural boundary of the Qinghai–Tibet Plateau. The scope of the Meng–Xin lake area includes the Loess Plateau[3]. Finally, the annual dataset of lake distribution in eight desert regions of China from 2000 to 2019 was formed (>0.1 km^2).

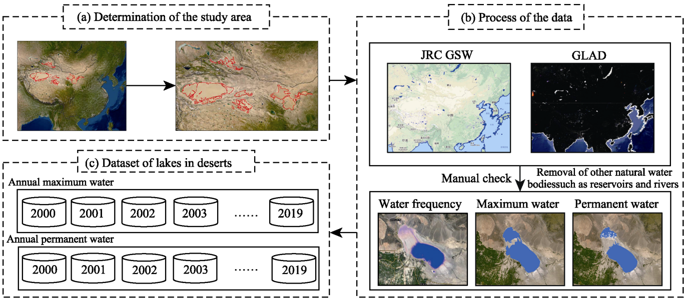

Figure 1 Processing process of the dataset development

4 Data Results

4.1 Data Composition

The spatial and temporal distribution dataset of lakes in the eight deserts of China (2000–2019) provides year-by-year spatial distribution data of lakes in the eight deserts of China during the study period. Considering that desert lakes have significant annual fluctuations, this dataset contains two sets of lake water products, including annual permanent water distribution data and annual maximum waterbody data. These data are stored in shapefile format. The dataset also provides the statistical results of the maximum water quantity and area of desert lakes in China from 2000 to 2019. Moreover, the statistical results of the permanent water quantity and area of desert lakes in China from 2000 to 2019 are also illustrated in the tables.

4.2 Data Products

4.2.1 Interannual Variation of Desert Lakes

The lakes in the eight deserts of China have significantly varied from 2000 to 2019. The total number and area of desert lakes have also significantly increased. In 2000, the total number of desert lakes was 219 with a total area of 1,502.62 km². In 2019, the number of desert lakes were increased by 98 compared with 2000, which is an increment of 44.75%. Meanwhile, the respective lake areas were also increased by 258.64 km², accounting for 17.21%. However, the interannual variation of lakes in the eight deserts has shown certain fluctuation characteristics, as shown in Figure 2. For instance, the lake area values were relatively low in 2001, 2009, and 2015 and exhibited obvious peaks in 2003, 2011, and 2018. An evident decline trend was observed from 2011 to 2015. Accordingly, the total area of the lake was decreased by 38.70% from 2,088.11 km² in 2011 to 1,280.11 km² in 2015.

The increment in the total area of the lakes from 2009 to 2010 is attributed to the rapid increase of Lake Taijiner in the east (west). By contrast, the sudden increase in the total area of desert lakes in 2015–2016 was mainly led by the significant increase in the area of Ebi Lake (an increase of 263.19 km²). These two rapid jumps in lake areas are related to the ecological water replenishment in the lake basin. The total water flows into the lake and rivers has guaranteed the rapid expansion of the lake area through artificial measures to control the water consumption in the lake basin. We also noticed that there is not only the rapid annual increase in the area of Ebi Lake but also the area of lakes having area less than 10 km² have significantly expanded in 2015–2016. Apart from the effect of human activities, this abnormal change can be attributed to the influence of the super El Nino in 2016. This year's meteorological data show that the average annual precipitation for the entire country is 730.0 mm, which is 16% higher than that of the previous year, among which Xinjiang accounts for more than 43%, which is the highest value since 1961[12]. Meanwhile, the abnormal increase in precipitation has triggered the rapid expansion of desert lakes, especially small ones. Statistics data from 2015 to 2016 have shown that the total area of small lakes (0.1–10 km^2) in China's eight deserts increased to 71.66% (from 149.18 km^2 to 256.07 km^2). This dramatic expansion in lakes also indicates that desert lakes are more sensitive to climate change than other types of lakes.

Our study has also shown that the variation trend of lakes in different deserts also exhibited certain regional differences (Figure 3). Lakes in two deserts, namely Gurbantunggut and Ulan Bu Deserts, have shrunk in recent years, while lakes in the other six deserts have shown different degrees of expansion. The most significant expansion of lakes areas, approximately 269.35 km^2 (518.75%), was observed in Taklimakan Desert, where the number of lakes has increased by 56 in the past 2 decades. The increase in desert lake area in this region is mainly led by Inkul Haizi (86.83°E, 40.79°N), Saisayit Kule (86.73°E, 40.87°N), and Taitma Lake (88.29°E, 39.34°N). Taitma Lake is the main contributor, which was added since 2000. In 2019, the area reached 100.50 km^2. The Badain Jaran and Tengger Deserts are two areas that are involved in many studies of desert lakes. The research has shown that: since 2000, the number of lakes in the Badain Jaran Desert has increased by nine, and the total area of the lakes has increased from 22.55 km^2 to 69.93 km^2. The lake leading the area is Giinnur (101.67°E, 41.93°N), which has risen by 35.10 km^2, accounting for 74.08% of the added value of lake area in the desert. The number of lakes in Tengger Desert also increased by 13 in the recent 20 years, and the lake area increased by 4.09 km^2. Moreover, no lake appeared in the Kumtag Desert until 2016.

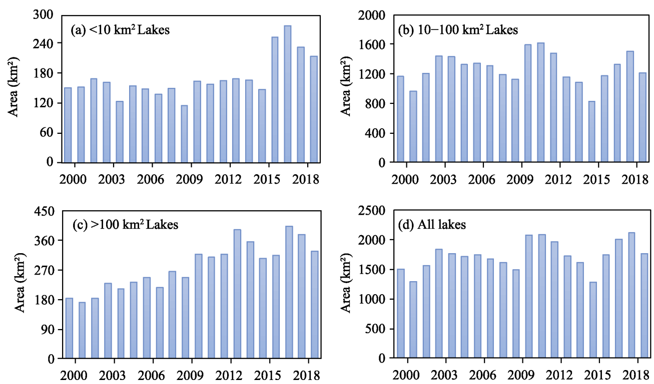

Figure 2 Change trend of the total lake area in China's eight deserts from 2000 to 2019

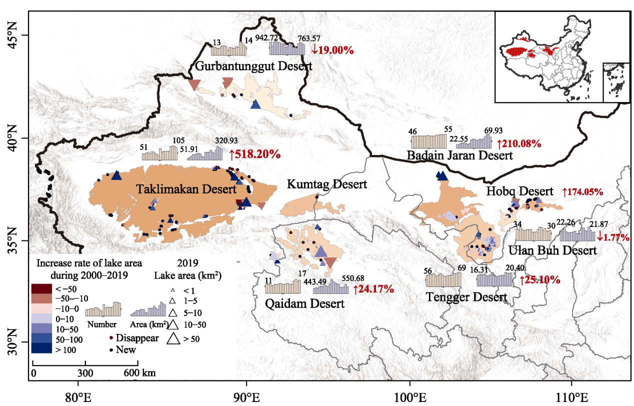

Figure 3 Regional characteristics of changes in the number and area of lakes in China's eight deserts from 2000 to 2019

4.2.2 Seasonal Variation Characteristics of Desert Lake

In this study, the seasonal water body is defined as the difference between the range of the largest water body in a year and the permanent water body in a year. The proportion of the seasonal water body is the ratio of the seasonal water body to the largest water body. The deserts that are greatly affected by seasonal water changes, that is, those with more than 50% seasonal water in most years, are the Taklimakan, Tengger, Ulan Buhe, and Kumtag Deserts. In the Taklimakan Desert, the seasonal water body proportion peaked at 88.49% in 2000 and gradually decreased with the increase in lake area to 46.26% in 2019. The proportion of seasonal water bodies in Tengger Desert is very stable, basically fluctuating between 60% and 70%, and stable at approximately 63.64%. In addition, the number and area of lakes in Tengger Desert are also relatively stable based on the inter-annual variation. The proportion of seasonal water bodies in the Ulan Buh desert is almost above 60%, only decreasing by 55.92% in 3 years from 2009 to 2011, and reaching the highest value of 76.80% in 2016. The lake area of the desert itself is relatively small. Hence, the seasonal water body has a great influence on the overall lake area.

Deserts that are less affected by seasonal water bodies, that is, the Gurbantunggut, Qaidam, and Badain Jaran Deserts, account for less than 50% of the seasonal water in most years. Gurbantunggut Desert is the least affected by seasonal water bodies, accounting for less than 30% in all years and even only 7.50% in 2019. The particularity of this desert lies in that the area of Ebi Lake accounts for more than 90%, and the seasonal fluctuation of large lakes is relatively small. The seasonal variation of lakes in the Qaidam Desert is not stable. In 2009, the proportion of seasonal water reached 57.72% but decreased by 25.24% in 2012, but it is between 30% and 50% in most years. The proportion of seasonal water bodies in the Badain Jaran Desert also shows an increasing trend with the increase in lake area year by year. The proportion of seasonal water bodies in the Badian Jadran Desert was 26.16% in 2000, but it has been more than 50% since 2016. Given that the lake area of the Kubuqi Desert is less than 10 km^2, the seasonal water body proportion greatly fluctuates, with the lowest of 27.99% in 2011 and the highest of 75.05% in 2019. The annual average is approximately 52.26%.

4.2.3 Discussion on the Driving Factor

Adequate water supply is the basis for maintaining desert lakes. However, there is no unified conclusion about the water source of desert lakes, and the existing views are mainly summarized as precipitation supply, remote source supply, and near-source supply. Meteoric water recharge believes that lakes are mainly replenished by local meteoric water and groundwater formed by precipitation infiltration[14,15]. Remote replenishment believes that lake water is derived from precipitation and snow and ice meltwater in remote areas and is replenished through underground leakage channels, such as faults and fissures[16,17]. Near-source replenishment believes that the lake water comes from the precipitation infiltration recharge around the desert[18]. This study does not involve the specific discussion on the replenishment sources and routes of desert lakes. However, the replenishment ways of desert lakes summarized in the existing studies are highly susceptible to the impact of climate change. Years of observation data show that the climate in northwest China, where desert lakes are concentrated, has shown a warming and humidification trend of rising temperature and increasing precipitation in the past 20 years[19–21]. Desert lakes are less directly affected by human activities, and the significantly increased precipitation can explain the significant expansion trend of lakes in the eight deserts of China in the past 20 years. Not only the desert lakes but also most of the lakes in northwest China are less affected by human activities and show a significant trend of expansion. By contrast, the fluctuation characteristics of desert lakes are significant, indicating that desert lakes have sensitive response characteristics to climate change. In addition, the lake changes in the arid and semi-arid areas of northwest China, especially in the Taklimakan Desert, are also affected by anthropogenic measures, such as the ecological water replenishment of Taitma Lake in recent years, which is one of the important reasons for the significant expansion of the lake area. Nonetheless, the wet climate and a certain degree of artificial ecological restoration can explain China's desert lakes in the recent 20 year trend of scale expansion of the overall features. The difference between the desert and desert lakes within the change characteristics of the regional diversity also requires a combination of more detailed meteorological and hydrological, geological, geomorphic multi-factor comprehensive analysis. This mechanism is the only approach to grasp the mechanism of desert change after exposing its features.

4.3 Comparative Analysis on the Dataset

Existing studies on the temporal and spatial changes of desert lakes in China mainly focus on the Badian Jaran and Tengger Deserts. Research[2,4] has shown that the area and number of lakes in these two deserts have displayed a certain trend of increase since 2000, which is basically consistent with our research conclusion. However, the specific change range significantly varied. Yan *et al.* (2020)[2] found that the area of lakes larger than 0.1 km^2 in Tengger Desert increased by 6.85 km^2 during 2000–2015. Meanwhile, this study exhibited that the maximum water area of lakes increased by 0.08 km^2 during this period. The main reason for the difference is that the two studies used different data sources and definition criteria for the lake extent. Yan *et al.* (2020) used the instantaneous water range presented by remote sensing images at a certain time to define the lake range of the year[2]. Specifically, they had utilized TM or OLI images to extract the water range at a certain time between June and September every year when the cloud cover was less than 10%. The lake range in this study is a statistical concept. The maximum and permanent boundary ranges of lake water can be obtained by using all available images and the distribution frequency data of water bodies in the year. The above-mentioned two ideas have been applied in the study of lake temporal and spatial changes at a large regional scale. However, we believe that the latter is more reasonable for desert lakes. The main reason lies in that the desert lake itself is small, and the proportion of seasonal water is much larger than that of large lakes. Therefore, if instantaneous water is used for inter-annual analysis, then the analytical result is easily affected by the annual fluctuation of water. In this study, the annual maximum water body range and annual permanent water body range are simultaneously provided, avoiding the interference of seasonal water bodies introduced by the difference of data time phase selection.

5 Discussion and Conclusion

This dataset provides spatial and temporal distribution data of lakes (>0.1 km^2) situated in eight deserts of China from 2000 to 2019. In combination with the data analysis, the number and area of lakes in the eight deserts of China have shown a significant interannual variation in the last 20 years. Accordingly, the desert lakes showed a significant expansion trend, with the total area increasing by 17.24% from 1,502.63 km^2 in 2000 to 1,761.65 km^2 in 2019. The lakes in Taklimakan, Badain Jaran, Qaidam, Tengger, Kubuqi, and Kumtag Deserts have exhibited an expanding trend. By contrast, the lakes in Gurbantunggut and Ulan Buhe Deserts showed an overall shrinking trend. The largest increase in lake area was in the Taklimakan Desert, and it was caused by the rapid expansion of several lakes, including the Inkur Sea, Sesayet, and Tetema Lakes. The largest decrease was observed in the Gurbantungut Desert. Compared with the existing analysis results, this study generated the maximum water range and permanent water range of the lake in a year based on the water frequency data. This method overcomes the defect that the annual variation analysis of desert lakes is easily affected by the seasonal water body when using a single instantaneous water range, and makes the annual analysis results more reasonable and reliable. This dataset provides long-term and high-precision spatial and temporal distribution information of desert lakes in China in the past 20 years, which can provide basic data for water resource utilization and ecological environmental protection in desert areas. Moreover, this dataset also provides scientific reference for discussing the response characteristics of hydroecology in arid and semi-arid areas of China under the background of climate change.

Author Contributions

Liu, K., Song C. Q. designed the algorithms of dataset. Feng, Q. Y., Fan, C. Y. contributed to the data processing and analysis. Feng, Q. Y., Liu, K. wrote the data paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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