Application of Remote Sensing and GIS Techniques for Analysis of Lake Water Fluctuations and the Potential Impact of Human Activities: Case Study on Ogii Lake Basin in Mongolia

A Thesis
submitted in partial fulfillment of the requirement for the degree of
Doctor of Philosophy

by

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湖水変動と人間活動の潜在的影響分析に対する
リモートセンシング及びGIS技術の適用
:モンゴルOgii湖流域のケーススタディ

博士論文

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Contents

List of tables

List of figures

List of acronyms

AHP – Analytical Hierarchy Process
BOD – Biological Oxygen Demand
COD – Chemical Oxygen Demand
DEM – Digital Elevation Model
DO – Dissolved Oxygen
DD – Drainage density
ECMWF – European Centre for Medium – Range Weather Forecast
ERA – Fifth major global reanalysis produced by ECMWF
ESRI – Environmental System Research Institute
GIS – Geographic Information System
GPCC – Global Precipitation Climatology Centre
GWPZs – Groundwater potential zones
JICA – Japan International Cooperation Agency
IPCC – Intergovernmental Panel on Climate Change
LULC – Land use and land cover
MCDM – Multi criteria decision making
MNDWI – Modified Normalized Difference Water Index
MNE – Ministry of Nature and Environment of Mongolia
MSS– Multispectral Scanner
NDVI – Normalized Difference Vegetation Index
NDWI – Normalized Difference Water Index
NIR – Near infrared reflectance
NOAA National Oceanographic Atmospheric Administration
OLI – Operational Land Imager
RED – Visible red reflectance
RS – Remote Sensing
SM – Standard method
SS – Suspended solid
TIRS – Thermal Infrared Sensor
TM – Thematic Mapper instruments
TN – Total nitrogen
TP – Total phosphorus
PSL – Physical Science Laboratory
UNESCO – United Nations Educational, Scientific and Cultural Organization
UTM – Universal Transverse Mercator
WMO – World Meteorological Organization
WQI – Water Quality Index

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Summary

This study focused on one of the Mongolian Lake, Ogii Lake located in the valley of the Orkhon River comprising extensive alluvial areas of grassland, river channels, pools and marshes surrounded by grassy steppe. Ogii Lake is registered as an International Ramsar Convention site, particularly due to its status as a waterfowl habitat in 1998. In this research, the impact of global climate change and human activities on Ogii Lake Basin were studied using Remote Sensing (RS), and Geographical Information System (GIS). Mongolia is the most vulnerable country in the world to adverse impact of climate change, and livestock is one of the main sectors that consist of Mongolian gross domestic products. In recent decades, the number of livestock is rapidly increasing while the available water resources have been dried out due to several impacts of human activities as well as climate change. Due to the increase in livestock number along the river and lake shore, the potential discharge of livestock excreta pollutants to water bodies increase, that leads to the degradation of water quality and pastureland. In the literature, livestock waste generation related studies are rarely found in the case of Mongolia. This research was based on the three main part of research.

In the first part of research, the GIS techniques were applied for generating the livestock distribution map around the Ogii Lake based on the statistical data and herders' location in 2016. Based on livestock waste generation, excreta pollutants such as chemical oxygen demand, biological oxygen demand, total nitrogen, total phosphorus, and ammonia were calculated using livestock population in different radiuses from the lake. Also, water samples from Ogii Lake Basin were analyzed in 2017, and 2018. Questionnaire survey was also conducted to estimate the human activities and influence in the lake ecosystem. According to the water quality analysis Ogii Lake and Khugshun Orkhon River's water was classified as clean and slightly polluted water both in 2017 and 2018. However, human waste generation was found to be a harmful consequence of seasonal tourism in the Ogii Lake environment due to a lack of proper management of lake-based tourism, as well the living habits of local people. The result was illustrated that the livestock-related pollutants and the water demand for the expected livestock in 2036 would be increased by 3.8 times, that would be account as 1288.07 ton NH_3-N, 11358.11 ton COD, 9062.76 ton BOD, 1461.03 ton TP, and 5427.33 ton TN, and 876.809 cubic meters, respectively.

The second part of this research was focused on correlation between climatic variables and monthly lake water surface area changes based on obtained climatic data, RS, and GIS techniques. Globally, many researchers applied the RS and GIS for hydrological studies. Delineation of surface water area using the satellite images is the most applicable, low-cost method. During the last decades, Ogii Lake's surface area has fluctuated, surface inflow and outflow of the lake has dried out for several years. The on-site measurement was conducted three times in May, July, and September in 2020 to measure the lake water surface area as a reference. Landsat 8 OLI images which has close acquisition dates with field survey was obtained from the Earth Explorer to estimate the surface area of Ogii Lake using four different indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI-1 and MNDWI-2). Based on the field survey result, the most accurate water index for delineating the surface area of Ogii Lake was MNDWI-1 (R=0.94, $p < 0.01$). Moreover, the energy-budget

method was used to estimate the lake water evaporation based on the historical reanalysis (ERA5) daily data between 1986 and 2019 which was provided by the European Centre for Medium–Range Weather Forecast. The results illustrated that total annual evaporation from the lake has increased since 1995. The total annual evaporation from Ogii Lake increased steadily over the last three decades; comparing to 1989, annual evaporation increased by 20.02, 25.79, and 32.4 mm in 1999, 2009, and 2019, respectively. Comparison of climatic variables and estimated surface area was illustrated that Ogii Lake's surface area has weak correlation with precipitation, and evaporation. Therefore, precipitation is not a main part of the water source for Ogii Lake. The result of the estimated water balance between 2016 and 2019 was demonstrated that the both surface and groundwater have a considerable influence on Ogii Lake's water balance.

The third part of this research was studied the groundwater potential zones (GWPZs) of Ogii Lake through integrating the Analytical Hierarchy Process, Multi Criteria Decision Making methods. According to the classification of GWPZs, Ogii Lake area was coincided in high to very high zones. The highest GWPZs of the Ogii Lake Basin was coincided with the deepest part of the lake, where the tectonic fault cross Ogii Lake. The results of delineation of potential groundwater zones show that there is a possibility to solve the source of drinking water that is essential for both herders and livestock through drilling wells, which could reduce the potential discharge of livestock related pollutants to the lake and inflow river. The case study on Ogii Lake shows that is possible to reduce budget expenditures on hydrological surveys while integrating the RS and GIS technology. Such results could provide valuable information for decision makers to implement a water resource management and reduce the environmental pollution.

In order to protect the Ogii Lake ecosystem, the lake based tourism needs to be urgently improved through announcing a tender for companies those who could serve environmentally friendly tour services. Sufficient number of waste containers should be installed at the dumpsites; parking lots, and a composting toilets also need to be installed considering on the number of tourists and herders. The livestock access to the lake and inflow river should be restricted.

Summary in Japanese
要旨

本研究は、モンゴルのオルホン渓谷にある Ogii 湖を対象とした研究である。この湖は川や池、草原に囲まれた湖であり、1998 年にラムサール条約に登録された自然保護区でもある。本研究では、地球規模での気候変動と人間活動が Ogii 湖流域に与える影響を、リモートセンシング（RS）と地理情報システム（GIS）を使用して調査した。モンゴルは気候変動の悪影響に対して世界で最も脆弱な国の一つである。また、モンゴルにおいて畜産業は主要な産業の 1 つであり、ここ数十年で、家畜の数は急速に増加している。一方で、利用可能な水資源は、人間活動や気候変動の影響により減少している。特に、川や湖の沿岸域での家畜頭数の増加により、家畜排泄物由来の汚染物質が増加し、その影響による水質や牧草地への悪化が指摘されている。しかしながら、モンゴルにおいて家畜排泄物の環境影響に焦点を当てた研究はほとんどないのが現状である。

本研究は、大きく 3 つの項目で構成している。

第 1 部では、まず GIS を用いて、2016 年の統計データと遊牧民の位置情報をもとに Ogii 湖周辺の家畜分布図を作成した。その際、家畜の個体数をもとに家畜廃棄物由来の、化学的酸素要求量と生物化学的酸素、全窒素、全リン、アンモニアなどの排泄物汚染物質を試算した。さらに、2017 年と 2018 年の Ogii 湖流域の水をサンプリングし、分析するとともに、人間の活動と湖の生態系への影響を推定するためにアンケート調査を実施した。水質分析によって、Ogii 湖とクグシュンオルホン川の水域は、2017 年と 2018 年のいずれにおいてもきれいではあるが、わずかに汚れていると分類された。しかしながら、湖を基盤とした観光と地元住民の生活習慣によって、観光シーズンは Ogii 湖の環境が悪くなることが判明した。シミュレーションによると、家畜由来の汚染は、2036 年には 3.8 倍に増加すると推計されその量は、NH_3-N が 1,288.07 トン、COD が 11,358.11 トン、BOD が 9,062.76 トン、総リン（TP）が 1,461.03 トン、総窒素（TN）が 5,427.33 トンと、876.809㎥ になることが推計された。

第 2 部では、得られた気候データ、RS、GIS データを用いて、湖の表面積の月ごとの変化と気候の関係を把握した。なお、世界中で、多くの研究者が水文学研究に RS と GIS を適用しており、衛星画像を使用して地表水域を把握することは、最も適切で費用対効果の高い方法である。過去数十年間の間に、Ogii 湖の表面積は変動し、数年前から乾燥している。2020 年 5 月、7 月、9 月に 3 回現地調査を実施し、湖の地表水域面積を測定した。現地調査に最も近い Landsat8 OLI の画像をは、衛生から取得し、正規化植生指数（NDVI）、正規化水指数（NDWI）、改良正規化水指数（MNDWI-1、MNDWI-2）の 4 つの異なる指標を用いて Ogii 湖の表面積を推定した。現地調査の結果によると、Ogii 湖の表面積を表す最も正確な指標は MNDWI-1（$R = 0.94$、$p < 0.01$）であった。さらに、エネルギー収支法を用いて、ヨーロッパ中期天気予報センターから提供された 1986 年から 2019 年までの過去の再分析（ERA5）の日次データをもとに湖の水分蒸発量を推定した。その結果、湖からの年間総蒸発量が 1995 年以降増加していることが示された。Ogii 湖からの年間総蒸発量は、1989 年と比較して、年間蒸発量は 1999 年、2009 年、2019

年でそれぞれ 20.02mm、25.79mm、32.4mm と過去 30 年間で着実に増加していることがわかった。気候と推定表面積を比較すると、Ogii 湖の表面積は降水量と蒸発量と弱い相関関係があることがわかった。したがって、Ogii 湖にとって降水量は主な水源ではないことがわかった。2016 年から 2019 年まで水の収支を推計した結果、地表水と地下水の両方が Ogii 湖の水収支に大きく影響を及ぼしていることが示された。

第 3 部では、階層分析法と多基準意思決定法を統合することにより、Ogii 湖の地下水ポテンシャルゾーン GWPZs を解析した。GWPZs の分類によると、Ogii 湖流域ではとても高いゾーンにおいて一致していた。Ogii 湖流域の最も高い GWPZ は、構造断層が Ogii 湖を横切る湖の最深部と一致していた。地下水域のポテンシャル量を推計した結果、井戸を掘削することにより、遊牧民と家畜の両方にとって必要な飲料水源を確保することができる可能性が示された。これによって、家畜に起因する汚染の湖や流入河川への流出を減らすことができると考えられる。Ogii 湖を対象としたケーススタディにおいて、RS と GIS 技術を統合することで、水文調査における経費を削減できる可能性があることも示された。この結果は、環境汚染を減らすために水資源の管理を実施している意思決定者に貴重な情報を提供することが可能となる。

Ogii 湖の生態系を保護するためには、環境に配慮した観光サービスを供給することが可能な企業への入札を発表することにより、湖を基盤とした観光を早急に改善することが必要である。また、ごみ箱を十分に設置するとともに、観光客数や遊牧民数を考慮して、駐車場やバイオトイレを設置するとともに、湖や流入河川への家畜のアクセスは制限するべきである。

Chapter 1 Introduction

1.1 Climate condition

Central Asia, including Mongolia, is located in the triangle of the Westerlies, the East Asian Monsoon and Indian Monsoon. Mongolia occupies a region of extreme continentally. The climate becomes increasingly moist from south to north due to decrease in temperature and increases in precipitation[1]. Mongolia is one of the most vulnerable countries in the world to adverse impacts of climate change because of its specific geographical location, weather and climate conditions. Extremely dry air causes a strong radiative cooling of the surface and temperature regime in winter in most part of Mongolia controlled by high pressure, including the stable so called Siberia-Mongolian High (SMH) with short period interruption due to infrequent cyclonic activities[2].

B.Jambaajamts (1989) divided Mongolia into 3 climate zones such as a humid-cold, subhumid-cool, and semidry-cooler. A *humid-cold zone*, which is elevated more than 1800 m, a *subhumid-cool zone* - elevated between 1300 m and 1800 m, and a *semidry-cooler zone* which is elevated between 700 m and 1300 m above sea level. Ogii Lake is located in the subhumid-cool zone which is elevated 1332 m above sea level (**Fig. 1.1)**. The Ogii Lake Basin is characterized by an extremely continental climate with cold and dry winters dominated by the SMH, and warm and humid summers.

The mean annual temperature is about −2°C, and the mean annual precipitation ranges from 250 to 300 mm and occurs mostly in June, July and August. The continentally causes a strong seasonality in temperature and precipitation. Highest precipitation rates generated by heavy rainfalls are found in summer, while precipitation in winter (November to March) occurs mostly in solid form and rarely exceeds 10 mm per month. Percentage of annual total precipitation in the Kharkhorin station which is 60 km distance from the lake is shown in **Fig. 1.2**.

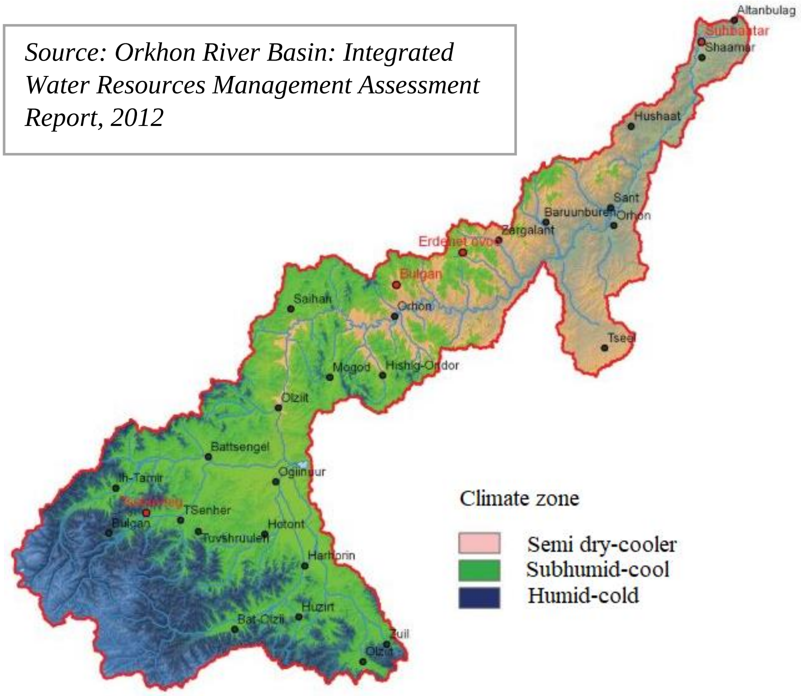


Fig. 1.1 Climate zone classification of Orkhon River Basin

According to the observation data at the Kharkhorin meteorological station, average percentage of the rainfall (summer precipitation) accounts approximately 88 percent of total annual precipitation. The percentage of summer rainfall and winter precipitation (snowfall) has changed slightly since 1974.

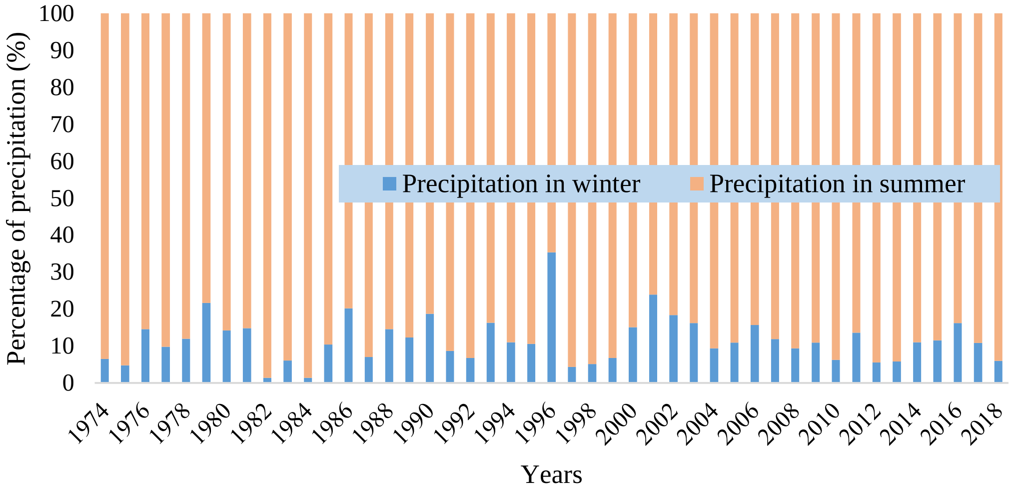


Fig. 1.2 Percentage of annual total precipitation in the Kharkhorin station /1974-2018/

The precipitation trends at the Kharkhorin station between 1974 and 2018 are shown in **Fig. 1.3**. Considering the historical precipitation trend, the total annual precipitation sharply dropped from 1992 to 1996, and 2003 to 2007. The highest total annual precipitation (352 mm) occurred in 1977, while the lowest value accounted 18.1 mm in 1996. In 2007, the total annual precipitation accounted for 34.6 mm, which is the lowest amount during the last decade. Winter precipitation exceeded 50 mm several times, which could strongly affect the local livestock herders. For instance, snowfall accounted as 79.9 mm and 71.6 mm, while mean air temperature in the winter account -13.9 °C and -18.0 °C in 1979 and 2001 respectively. Changes in precipitation due to climate change affect the seasonal and annual runoff.

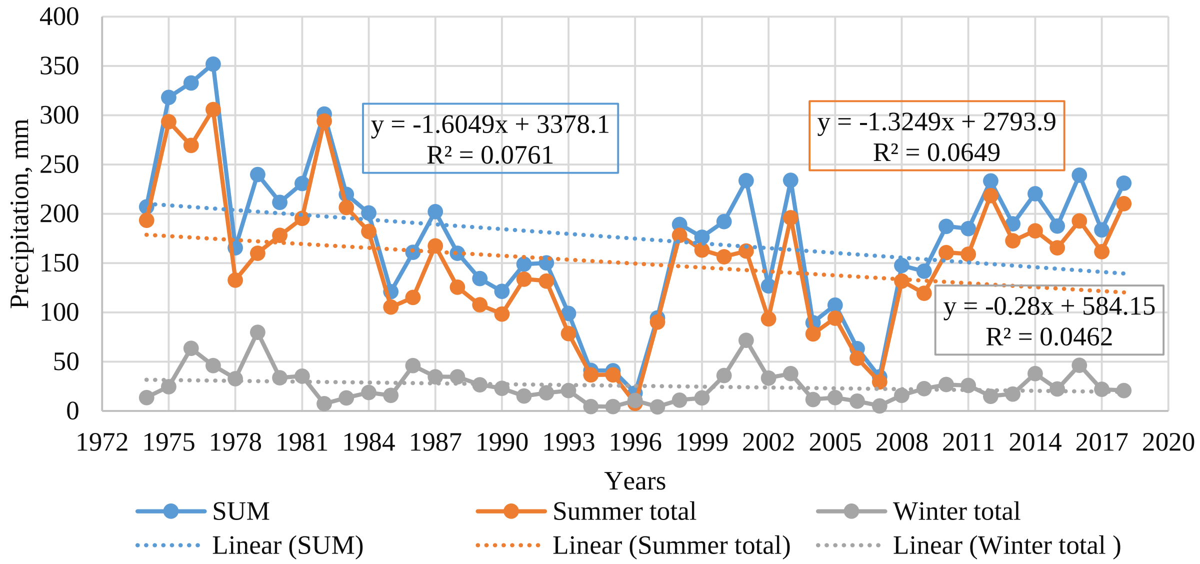


Fig. 1.3 Annual total rainfall and snowfall in the Kharkhorin station /1974–2018/

The impacts of global warming on lakes include an extended growing period at high latitudes, where climate models indicate increased precipitation, while water levels at mid- and low latitudes are projected to decline. Endorheic (terminal or closed) lakes are most vulnerable to a change in climate because of their sensitivity to changes in the balance of inflows and evaporation[3]. Changes in inflows to such lakes can have very substantial effects under some climatic conditions. Wetlands are especially vulnerable to changes in precipitation relative to evaporation because of their shallow depths and large surface to volume ratio. Special Report on Emissions Scenarios set up by IPCC, Batimaa et al., 2011 suggested that the rate of future winter warming in Mongolia would vary from 0.9 °C to 8.7 °C, while summer temperature would increase in a range from 1.3 °C to 8.6 °C, winter precipitation increase by range from 12.6 to 119.4% when the amount of summer rainfall varied from minus 2.5% to plus 11.3%.

Fig. 1.4 shows rapid increases starting from 1995 to 1997. In 1997, the highest temperature was observed during the period. And then, the summer temperature decreased rapidly between 1997 and 2006. According to the mean air temperature trend, air temperature from April to October has been increased (R^2=0.3468) between 1974 and 2018, while the mean air temperature in the winter season (November to March) has increased slightly (R^2=0.0044). Winter temperature has dropped several years up to -21.7 °C in 2005, -19.7 °C in 2011 and 2012. However, in recent years the winter temperatures have increased, which accounted for -15.6 °C to -13.5 °C.

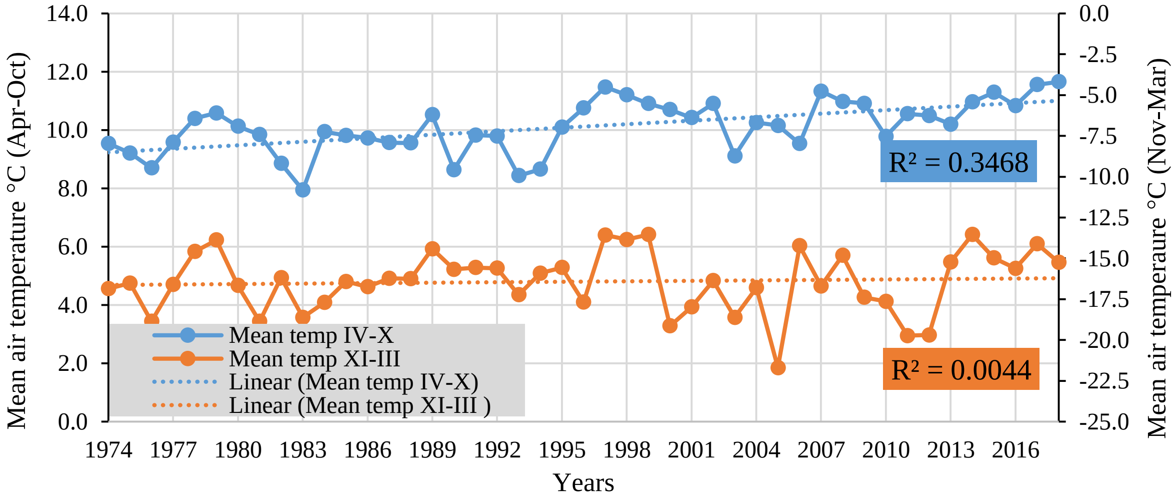


Fig. 1.4 Mean air temperature in the Kharkhorin station (1974–2018)

A monthly average temperature ranges between -23.16 °C and 17.94 °C during 1974–2018. An average minimum temperature ranges between -4.47 °C and -30.30 °C during October and March, the lowest temperature in February reaches -31.93 °C, while the highest temperature reaches about 14.88 °C in July. During this period, monthly average precipitation occurs 1.47 mm in January and 49.60 mm in July.

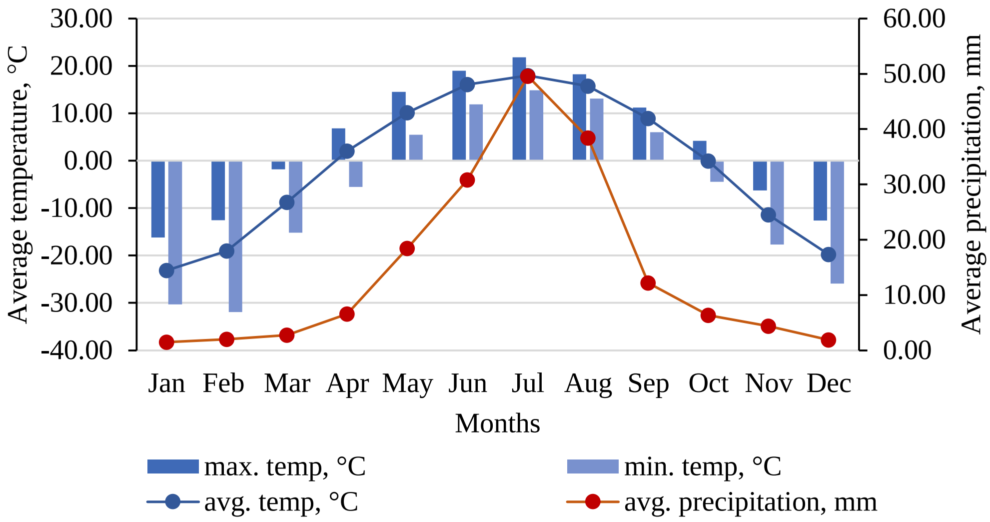
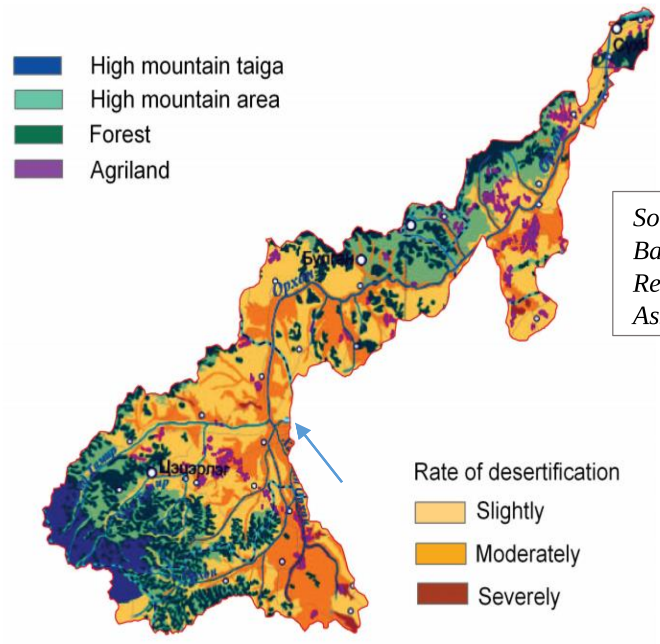


Fig. 1.5 Monthly average temperature and precipitation in the Kharkhorin station (1974–2018)

1.2 Soil, vegetation and land resources

The study site is situated within the area of dry, grass steppes and is dominated by grasses (Cleistogenes, Stipa), forbs (Allium), and shrubs (Artemisia, Caragana) while trees are generally lacking[4]. Festuca-Poa-Carex montane steppe and Stipa-Cleistogenes-Artemisia steppe are the main vegetation types in the catchments of the Ogii Lake, where montane steppe mixed with Agropyron, Carex, Stipa, Artemisia, Thymus, etc. is distributed between 2300 and 1900 m a.s.l, and Stipa-Cleistogenes-Artemisia steppe mainly develops below 1900 m a.s.l[5]. Along with climate change and global warming, negative human activities including mining, road network concentration increase and they cause a change of land cover. The aridity is increased in the river basin and number of surface water sources is decreasing, including small rivers and springs. A total of 82 plant species of Orkhon River and Ogii Lake Basins belong to low land plant species. It means that this area is having some sort of pasture degradation. The desertification map developed by the Institute of Geo-Ecology of the Mongolian Academy of Science shows that the desertification in the Orkhon River Basin covers a total of 246.823 km^2 of land or 45.9 percent of the total territory of the river basin. Desertification of Ogii Lake Basin is shown that northern site of the lake belonged to slightly, and southern site of the lake belonged to severely desertification. High density of livestock or overgrazing is one of the causes of desertification. The forest steppe plants in the pasture land, the percentage of many types of plants has decreased and low quality plants that tolerate livestock grazing very well increased. In such places, soil moisture is decreased and soils are compacted and become hard[6].



Source: Orkhon River Basin: Integrated Water Resources Management Assessment Report, 2012

Fig. 1.6 Desertification rate in Orkhon River Basin

Wang et al studied the lithology and chronology of the study area using an 854-cm-long core (UG04 core) which drilled with gravitational piston corer in 2004 at the east-central part of the Ogii Lake where the water depth was 14.5 m. Three major lithofacies are distinguished from their study based on field visual inspection and laboratory analysis. Unit 1 (854–480 cm) and unit 3 (242–0 cm) are clayey silt layers, unit 2 (480–242 cm) is a silt layer with two carbonate-rich interlayers at 450–492 cm and 368–348 cm[5]. The Ogii Lake Basin is located within the zone of highly continental steppe soil formation. Soils found in the Ogii Lake Basin predominantly consist of Kastanozems while Regosols and Leptosols dominate on steep slopes and ridges. Soils are loamy to sandy riddled with a considerable amount of debris and pebbles that are often layered and adjusted[5]. Kastanozem are humus-rich soils that were originally covered with early-maturing native grassland vegetation, which produces a characteristic brown surface layer. Kastanozem found in relatively dry climate zones (200–400 mm) of rainfall per year, usually bordering arid regions such as southern and central Asia, northern Argentina, the western United States and Mexico[7]. The soil has light, sandy and clay combination of mechanic composition, medium size of petrifaction, with 18 cm humus depth and solution pH is neutral and alkaline (pH=7.17-7.57). Steppe kastanozem with combination of sand and light clay soil is located east and north east valley of the lake under grass-herb and grass –herb-wormwood types of vegetation. Light kastanozem soil with clay and sandy stratum distributed in the west and north-west side of the lake and formed under vegetation type with Achnatherum splendens. Light and carbonated kastanozem soil is formed under caragana bush-needle grass type of vegetation around north-western area of the lake. Sandy kastanozem soil with clay is formed under grass-herb and needle grass-wormwood vegetation in south plateau of the lake[8].

1.3 Description of study area and water resources

Mongolia is situated on three international river basins such as the Arctic Ocean Basin, Pacific Ocean Basin, and Central Asian Internal Drainage Basin which covers an area of 20 percent, 12 percent and 68 percent of the country, respectively[9]. The Orkhon River (1124 km) is major tributary of Selenge Basin which originates in the Khangay mountains and it's one of the major river of the Arctic Ocean Basin.

Total water resource of Mongolia is estimated to be 599 km^3/year, and is composed mainly from water stored in lakes (83.5%), glaciers (10.5%) and rivers (5.8%)[10]. In the last 30 years the territory of glaciers and permanent snow in Mongolia decreased by 34.4–74%. There are around 1730 lakes, small lakes and shallow waters in the Orkhon Basin with around 100 of those having an area of more than 0.1 km^2 by 1984. Previous studies[11],[12] have reported that Ogii Lake was formed by the meandering of the Khugshin Orkhon River, which is originates from the eastern Khangay Mountains meanders across mountain steppes. The Khugshin Orkhon River flows into the Ogii Lake in the southwest, and the lake water overflows into the Orkhon River in the northwest after a distance of 7 km (**Fig. 1.7**), this outflow river is only ephemerally active due to overflow from Ogii Lake. The inflow rate of Khugshin Orkhon River was reported as 0.43 m^3/s in 2005 and 0.58 m^3/s in 2006[8]. The Khugshin Orkhon River's length is approximately 90 km, with a catchment area of 6210 km^2. The lake is situated 1332 m above sea level[13] and has a maximum depth of 15.3 m (mean of 6.6 m), length of 7.4 km, and width of 5.3 km (mean of 3.4 km). The lake has a shoreline of 24.7 km and carries a water volume of ~0.171 km^3 [14], and covers an area of 25.7 km^2, approximately 50 percent of which is less than 3 m deep as a result of fluvial process[4]. Regarding the groundwater flow of the lake studied by literature, however, there is no highlights on the lake water supply[11]. In Ogii Lake, one gauging station is under operation since 2002. According to the observed water level at the Ogii Lake station, water level has been under fluctuation each year. In 2011, lake water level measured approximately 160 cm, which accounts more than 50 percent of decrease compare to 2004 (353 cm). Unfortunately, during the period of lake water fluctuation there is not available information about the Khugshin Orkhon River discharge, because the hydrological station in Khugshin Orkhon River closed in 1995 due to the several reasons.

The Ogii Lake Basin is a representative location of the dry steppe region of Mongolia[11], which is located at ~102.77º E, 47.76º N in the foothill piedmont area at the northern flank of the Khangay Mountains[15]. It has an extensive alluvial area of grasslands. River channels, pools and marshes at the western end and is surrounded by grassy steppe. Ogii Lake was registered as an International Ramsar Convention site in 1998, particularly due to its status as a waterfowl habitat. The site is very important breeding and staging area for a wide variety of waterfowl, particularly Anatidae[16].

There are 17 fish species of 12 families, 4 amphibian species, 70 mammal species of 17 families of 7 orders, and 245 bird species in the Orkhon Valley[17]. Due to mining activities in the upstream part of Orkhon River water quality of Orkhon and Khugshin Orkhon decreased, and fish species percentages of Ogii Lake have changed in some parts of the river channels[6]. In the last two decades, lake-based tourism, local stockholders with a lot of livestock concentrated surrounding the lake and its tributaries. The result is a consequence of land degradation, overgrazing, and desertification. Livestock husbandry of residents and unplanned tourism facilities development in the shore of the lake, predator mammals are escaping from those areas that result in increased rodents' population around the lake. More specific information on climate condition, and hydrological characteristics of the study area are given in the subsections.

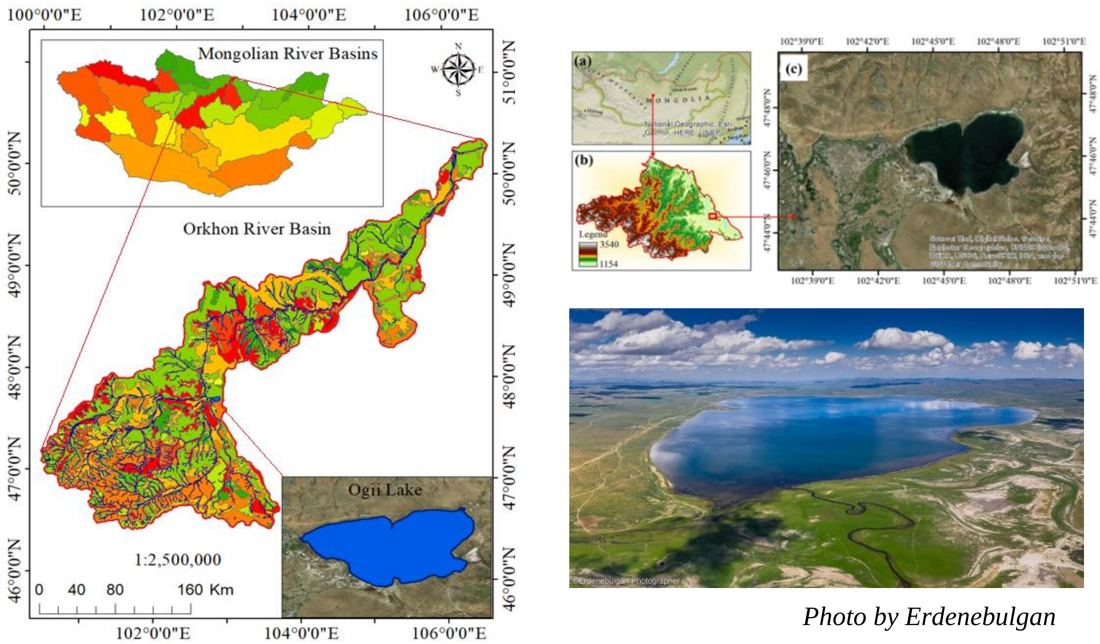


Photo by Erdenebulgan

Fig. 1.7 Location of the study area

1.4 Literature review

Globally, researchers have been investigating the impacts of climate change on lake and freshwater ecosystems for over two decades, and several comprehensive reports have been published by the Intergovernmental Panel on Climate Change (IPCC). Lake ecosystems are vital resources for aquatic wildlife and human needs. It always has been subject to the impacts of climate change, and natural climate variations in the past. Changes in air temperature and precipitation have direct effects on the physical, chemical, and biological characteristics of lakes indirectly via modifications in the surrounding watershed through shifts in hydrological flow pathways, landscape weathering, catchment erosion, soil properties, and vegetation[18]. Changes in the precipitation regime that accompany climate change have the potential to cause shifts in the connectivity of lakes (with biological implications, e.g., for migratory fish species), as well as in erosion rates that could affect the inflow and outflow dynamics of lakes. Shifts in precipitation relative to evaporation (the P/E ratio) cause changes in the water budget and hydraulic residence time of lakes, as well as in their depth and areal extent. Ponds and wetlands are especially vulnerable to changes in P/E because of their shallow depths and large surface to volume ratio[18]. Current global circulation models predict an increase in air temperatures of several degrees by the end of the twenty-first century, combined with large changes in the regional distribution and intensity of rainfall. These shifts in climate forcing appear to have already begun, and the onset of changes in the physical, chemical, and biological attributes of lakes is affecting their ability to maintain the present-day communities of aquatic plants, animals, and microbes, and their capacity to provide ecosystem services such as safe drinking water and inland fisheries. Glaciers in many parts of the world are undergoing accelerated retreat, and glacial fed lakes and reservoirs are therefore particularly vulnerable to changes in their inflow regime. For example, the Chinese Academy of Sciences estimates that by 2050, up to 64% of China's glaciers may have disappeared, with serious consequences for the estimated 300 million people who live in China's arid west and who depend upon this vital water supply. At Lake Biwa, Japan, the reduced flow from snowpack in the surrounding mountains is thought to be a mechanism reducing cold underflows that play an important role in recharging the bottom waters of the lake with oxygen[18].

Various studies were carried out on the local climate and hydrological relationship on Ogii Lake Basin. Khosbayar et al., (2003) reported that Ogii Lake's water level was about 5 to 6 meters higher than current water level in the early and mid-Holocene. Based on the distribution of plant dust in the lake, lake sediments were accumulated inconstantly, which is a sign of rapid climate change in a short period of time. Walter et al., (2005) were carried out paleo environmental studies of lake water fluctuations and Holocene climate change through sampling the bottom sediments of the lake at three different water level. The study found that the climate was cool in the early and middle Holocene, and relatively dry in the region during the late Holocene[13]. Wolfrang et al., (2008) analyzed lake sediment of the Ogii Lake based on chemical and mineralogical properties of the lake sediments (630 cm sediment core) to estimate the Holocene climate evolution of the Ogii Lake Basin. According to the principal component analysis (PCA) of the elemental composition of the samples from Ogii Lake sediment, the Ogii Lake record indicated that stable high lake levels from 2.8 kyr BP to present, thus suggesting enhanced moisture supply during the late Holocene. Low lake condition was identified during the Early Holocene (10.6–7.9 kyr BP. It is proposed that lakes in this area benefitted from increased discharge induced by glacier melting in the Khangay Mountains during a warm but relatively arid period. The Mid-Holocene (7.9–4.2 kyr BP) was characterized by generally higher lake levels and thus increased moisture supply. Yet, this period was prone to strong climate fluctuations. More arid conditions prevailed from 4.2–2.8 kyr BP and were followed by a stable, more humid phase until today[4]. Chinese researcher Wang Wei et al., (2009, 2011) analyzed the vegetation and climate change dynamics during the last 8660 cal. a BP in central Mongolia, based on a high resolution pollen record from Ogii Lake. They inferred four stages of climate changes such as a mild and semi-humid climate before 6860 cal. a BP with a remarkable cool and humid interval (8350–8250 cal. a BP), a prolonged warm and dry climate from 6860 to 3170 cal. a BP, a cooler and wetter climate between 3170 and 1600 cal. a BP, and an increased climatic instability after 1600 cal. a BP[5]. A similar study was conducted by the Japanese researcher Fukumoto (2012) based on the accumulation of plant and animal remains in Ogii Lake to identify environmental changes since the beginning of the Holocene. The study found that in the early Holocene, the climate was humid and cooler, and in the middle of the Holocene, the climate was dry. They also highlighted that regional climate change affected not only Mongolia but also Euro-Asia. However, during the Late Holocene, the low glaciation and short periods of drought periods were alternated. According to lake researcher J.Tserensodnom (1971 & 2000), the Ogii Lake watershed is fed by the Khugshin Orkhon River and runoff of Khugshin Orkhon River is regulated by the Orkhon River. Recently, S. Erdenesukh et al., (2020) investigated the impact of recent global climate change on the water surface area of Ogii Lake. They analyzed various measured hydro-meteorological variables of the lake basin and lake surface area, which was estimated from Landsat series satellite images of each August from 1986 to 2018. They concluded that total annual evaporation and inflow river discharge were the essential hydro-meteorological factors affecting the surface area of the Ogii Lake.

The literature[27)] found a tectonic fault (**Fig. 1.8**) crossing the lake from west to east through the highest depth (center) of Ogii Lake using Hypsometric Integral analysis, spatial improvement method, morphostructural and morphgeographic methods. They highlighted, the tectonic fault has same direction with Khoid Tamir River, and it crosses the lake after cross the Orkhon River horizontally. They concluded that, the Ogii Lake's water fed by the surface and groundwater flow of Khugshin Orkhon River, Khoid Tamir River, and Orkhon River.

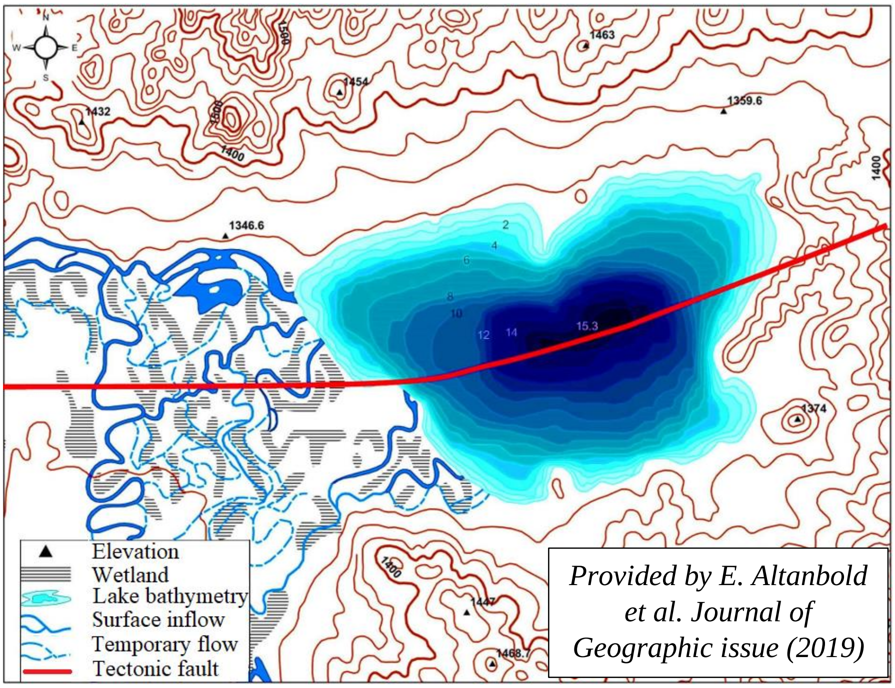


Fig. 1.8 Tectonic fault and depression of Ogii Lake

Chapter 2 Research objective and methodology

2.1 Research objective

As mentioned in the previous chapter, Ogii Lake is one of the ecologically important lakes in Mongolia, registered at Ramsar's Convention in 1998. It is a freshwater lake located in the semi-arid region, which is the main tourist place in Arkhangai Province, central Mongolia. In recent years, due to increase in human activities along the lake shore, Ogii Lake's ecosystem is under anthropogenic impact. Moreover, the Ogii Lake water surface area has been changed, and outflow from the lake has dried out for several years. Therefore, it's important to study the impact of human activities and climate change impact on the ecologically important lake in the semi-arid steppe region in Mongolia. Objective of this research is to estimate the environmental characteristics of Ogii Lake considering the impact of climate change and anthropogenic effects on Ogii Lake's water quality and quantity.

2.2 Research methodology

To achieve this goal, a qualitative and a quantitative analysis were conducted which may be divided into three steps.

Step one, field surveys were conducted in the summer of both 2017 and 2018. Water samples were collected from several springs, streams, rivers, and lake water in Ogii Lake Basin. A water quality analysis was carried out in the Recycling Engineering Laboratory at the Faculty of Environmental Engineering, The University of Kitakyushu. In 2018, a questionnaire survey also contacted both local households and tourist camp's owners around the lake to evaluate the impact of human activities on the Ogii Lake environment. During the field surveys, I observed that herders grass their livestock close to the lake, and mostly horses, sheep and goats over stay near to lake shore, and along Khugshin Orkhon River during the day. Therefore, the potential excreta pollutants from livestock around Ogii Lake were estimated based on herder's location and livestock numbers provided by the National Statistical Office (NSO). Based on statistical data, potential excreta pollutants of livestock in the Ogii Lake County were predicted in Excel.

Step two, the climate change impact on Ogii Lake Basin were studied based on monthly changes in lake water surface area and estimated evaporation from the Ogii Lake's water surface area using satellite images and historical reanalysis data, respectively.

Step three, groundwater potential zone of Ogii Lake Basin was delineated based on integration of AHP, MCDM, RS, and GIS using six thematic layers.

A detailed information of each research method is described in the following chapters. The research framework–1 given in **Fig. 2.1**.

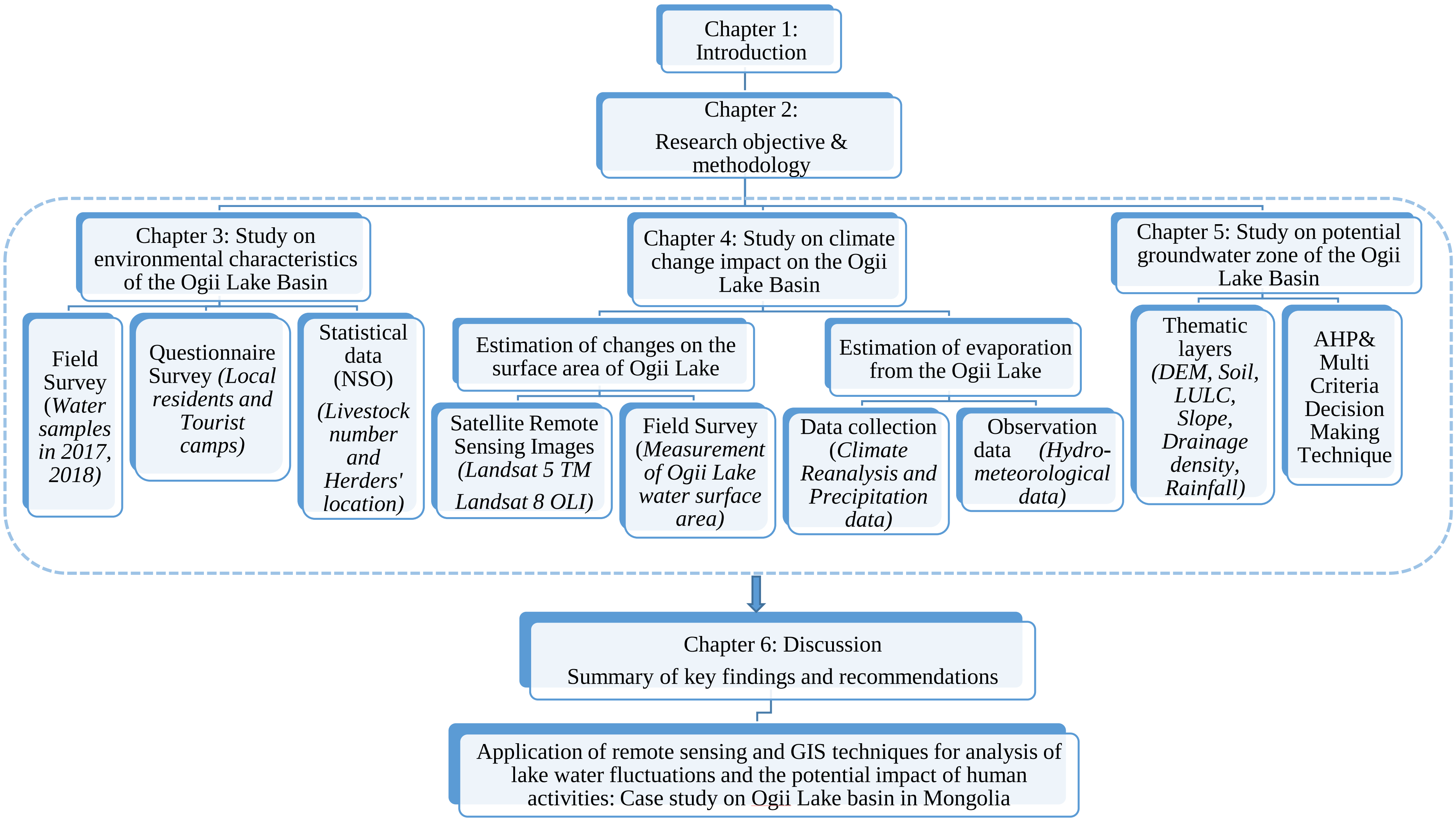
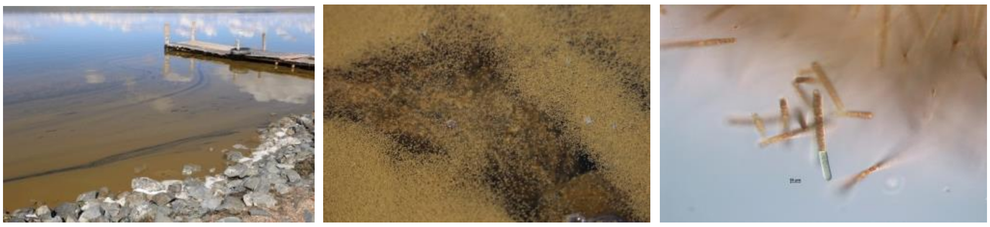


Fig. 2.1 Research framework–1

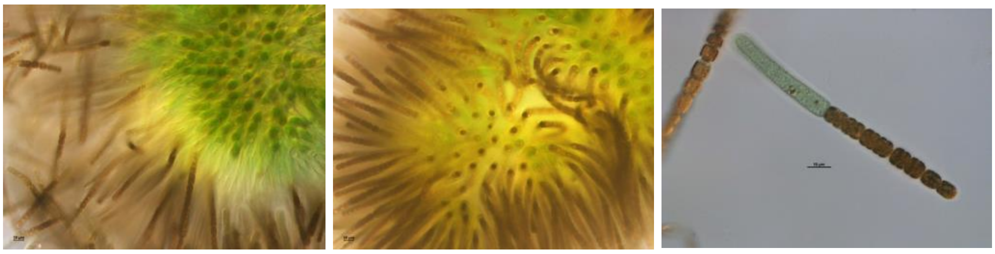
Chapter 3 Study on environmental characteristics of Ogii Lake

3.1 Research background

Water pollution and land degradation is mostly related to population density, livestock density and overgrazing pastureland. Mongolia is a landlocked country in the Central Asian plateau. It is experiencing a significant modification of herding practices, combined with an increase in livestock numbers[19]. The livestock is one of the main sectors that consist of gross domestic products GDP, followed by the mining sector. Traditionally, nomadic herders have grazed the vast but fragile grassland by rotating animals over shared pasture in a seasonal species segregated pattern. Co-operation among herders was common, such as the traditional *Khot-ail* (group of nomadic families), for sharing labor resources and controlling grazing use without degrading the environment. Political and economic changes associated with the shift from command economy to market economy since 1990 have had a significant impact on herders and pasture land. Several studies revealed that nowadays the pastures are exposed to considerably higher grazing pressure, whereby sharp increases in animal numbers as a result of the introduction of market economy in the 1990s[20]. Increase of herders, livestock numbers and herding behavior/grazing patterns and breaking of wells has resulted in an overuse of pasture land and an expansion of grazing grounds into formerly unused areas, including protected areas. Overgrazing favors unpalatable plant species, reduces the vegetation cover and thereby reduces the moisture storage in the soil, leading to acceleration of desertification processes. Traditional herd composition has also shifted and the number of goats almost doubled. It is widely known that the goats have the most negative impact on grazing land due to their natural grazing behavior which involves uprooting the vegetation. This leads to almost irreversible degradation of pastures[16]. Almost 70% of total pastureland degraded to some extent, and widespread over-grazing has been documented[21]. Moreover, the impacts on stream water quality from livestock have changed in recent times; between 1990 and 2010, livestock numbers increased significantly in Mongolia[19]. According to livestock census data in 2018[22], 66.46 million livestock officially counted in Mongolia, and livestock densities reached approximately 42 head per km^2 nationally, and 165 head per km^2 in Ogii Lake County. Livestock population consist by 5.92 % horse, 6.6 % cattle/yak, 0.7 % camel, 45.97 % sheep, and 40.81 % goat at country level. Pastureland and drinking water availability are both important resources for herding livestock. As a result of the increase of livestock population, pastureland pressure raised, which instigated the pasture and soil cover degradation process[23]. In contrast, result of land degradation and climate change a drought (extended periods of deficient rainfall) occurs has increased in Mongolia which increase vulnerability and cause of mortality of livestock to harsh winters. Mongolian herders commonly classify dzuds into five types depending on the characteristics of the severe winter weather: (1) white dzud, deep heavy snow and cold temperatures; (2) black dzud, freezing temperatures and the absence of surface water and forage; (3) combined dzud, deep snow with a sudden drop in temperature; (4) iron dzud, impenetrable ice cover over the forage area; and (5) storm dzud, high winds and heavy snow[24]–[27]. Historical records indicate that fifteen dzuds occurred in the 18th century, thirty-one in the 19th century, and forty-three in the 20th century[28]. While dzuds were once predicted to occur every eight to twelve years, now expected every other year[29]. In the past two decades, six dzuds have occurred in Mongolia. In the winter of 2009–2010 Mongolia experienced the most severe dzud about 8.5 million livestock had died, approximately 20% of the country's livestock population[30]. However, the livestock population census has shown increased livestock population in the past 25 years' period. On the other hand, a high density of livestock population also negatively influences water quality when free access to the water body. The current situation of drinking water sources of livestock is mostly surface water such as a river, stream, and a lake in the summer season. A considerable amount of literature has studied the influences of livestock production on water quality. Literature [19] found that livestock impacts affecting the water quality of streams have changed recently between 1990 and 2010 in Mongolia. A higher livestock density increases the risk of nutrients leaching into the environment[31]. Nutrient enrichment, along with excess sediment inputs, is the primary water quality issue for the most freshwater ecosystem in the world[32]. Maasri and Gelhaus (2011) found that the increase of livestock numbers is reaching beyond the grassland and affecting the stream ecosystem in Mongolia. Two major impacts were highlighted based on their study. Firstly, the extensive watershed and stream bank erosion, and secondly, the increase in the concentration of suspended particle and orthophosphate in the stream. At both the pasture and watershed scales, grazing animals negatively affect water quality when the number of animals exceeds the carrying capacity of the land[33]. A literature review[34] found a strong correlation between high livestock numbers and high biological oxygen diamond (BOD) from the direct discharge of farm effluents. The disposal of animal waste is a potential nonpoint source of water quality degradation, and it is characterized by a diffuse discharge of pollutants, generally over large areas such as pastures[35]. Livestock excreta contain a considerable amount of nutrients such as nitrogen, phosphorus, and potassium, as well as drug residues, heavy metals, and pathogens [36]. A consequence of significant enrichment of nitrogen and phosphorus in aquatic environments is eutrophication. Due to the high density of livestock located around Ogii Lake, the lake has found that having the phenomenon of eutrophication. Currently, no information is available regarding phosphorus excretion from the livestock in Mongolia [8]. Due to the huge number of livestock settling around the lake, and along the river that is only surface inflow to the lake livestock-related pollutants has been increased recently. The eutrophication in the northern side of the lake might be one of the indicators of the livestock-related pollutants. Since the hydrological station in Khugshin Orkhon River closed in 1995, water quality information limited until 2005. The Ministry of Nature and Environment of Mongolia (MNE), and the Japan International Cooperation Agency (JICA) implemented the Ogii Lake Ecosystem Conservation Project from August 15 to September 30, 2005, from July 18 to October 29, 2006. This previous study confirmed that the concentration of nutrients in Ogii Lake water was as low as 0.04 mg N/L, 0.001 mg N/L, 0.10 mg N/L, and 0.005 mg P/L for ammonia (NH_3–N), nitrite (NO_2), nitrate (NO_3), and Phosphorus (P), respectively [8]. However, the concentration of easily oxidized organic matter such as the concentration of BOD in the water was relatively high at several points, such as the western parts and the bottom layer of the central point of the lake[8]. Geo-Ecological Institute of Mongolian Academy of Science (MAS) implemented the project that named "Ecological assessment of the Terkhiin Tsagaan Lake and Ogii Lake" in 2015. Ecological assessment of Ogii Lake has been carried out under this project. They found that dominant algal species in the northern side of the Ogii Lake was *Rivularia planctonica* in 2015. Colonies could be seen by eyes and were floating near water surface during on Sep 8, 2015.



Rivularia planctonica algal colonies are floating on the water surface



Rivularia planctonica algal cells (Source: Pictures obtained from the report of Ecological assessment of the Terkhiin Tsagaan Lake and Ogii Lake, 2015)

During the project at least 17 species belonging to 5 phyla have been observed in Ogii Lake on July 14, 2016. The dominant algal species is still *Rivularia planctonica*, one of the cyanobacteria, and the second large population was *Aphanocapsa delicatissima*, which is also a species of cyanobacteria. The literature highlighted that 1) Microbial populations were similar in samples collected form the lakeshore and lake center. Microbial population composition from the lake intake stands apart from all other lake water samples; 2) From the microbial population comparison, cow feces may be the major contamination sources (among three fecal samples tested) in Ogii Lake; 3) At least 15 common bacterial Operational taxonomic unit (OTUs) were found from all water and fecal samples and some of them were host-specific species. It is possible that lake water has been affected by all three types of feces[37].

Ogii Lake water quality

The Ogii Lake is the largest and ecologically important lake in Orkhon River Basin which is locates at relatively lower altitude than the upstream part, and mineralization in the Ogii Lake tends to increase. Ogii Lake water exchange process is relatively slow due to only one inflow and outflow in its west part which exists when the lake water level has increased. Ogii Lake water mineralization ranges 210–274 mg/L and it is subject to "fresh" according to classification by A.M. Ovchinnikov. There are two small lakes on the east of the Ogii Lake, big one's mineralization is 312 mg/L and another one 620 mg/L. Water hardness of Ogii Lake ranges 2.70–3.20 mg-eqv/L, and Mg ion is dominant in its hardness that is different from other fresh water lakes[6].

The water quality of Ogii Lake depends on the water quality of Khugshin Orkhon River[38], which is unique surface inflow into the Ogii Lake[11]. In recent years, due to lake-based tourism and livestock settlements, the lake environment has been under pressure and has suffered degradation of its wetland area. Concentration of livestock around the lake led to the loss of habitats for migratory birds nesting around the lake. In addition, some part of the lake faced to the eutrophication.

Animal residues around the Ogii Lake in 2018

Since the lake-based tourism developed around Ogii Lake, transport and livestock holdings have been concentrated around the lake and its tributaries. According to the information from the Ogii Lake Information Center, tourist visits to the lake begin each year between June and August due to the suitable weather conditions during the summer vacation period in Mongolia. A preliminary sampling and analysis of the water conducted in 2017 under a joint research project funded by the Mongolia–Japan Higher Engineering Education Development (MJEED) Project. The results of joint research project in 2017 implied that the main cause of the water quality deterioration was the livestock in this region, with Ogii Lake experiencing eutrophication in recent years. It is, therefore, necessary to assess the potential load of the recent increase of livestock numbers on the lake and stream ecosystem by calculating the gross amount of pollutants, expressed as the amount of chemical oxygen diamond (COD), BOD, NH_3–N, total phosphorus (TP), and total nitrogen (TN) from the annual total population of livestock.

3.2 Research methods

Based on current environmental issue of Ogii Lake Basin, the field and questionnaire surveys conducted in 2017 and 2018 according to the following research framework to investigate the environmental characteristics of Ogii Lake (**Fig. 3.1**).

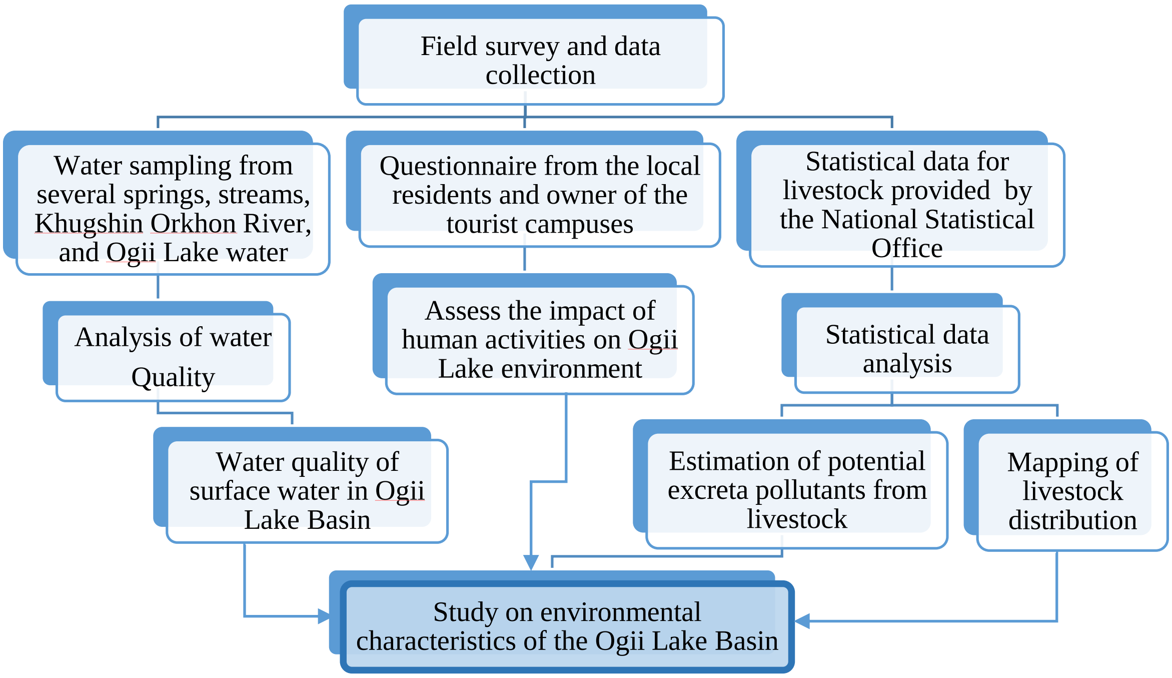


Fig. 3.1 Research framework–2

3.2.1 Field survey – water sampling

The water samples collected from stream, spring, Khugshin Orkhon River, and Ogii Lake during July 7–8, 2017 and August 23–24, 2018 (**Fig. 3.2**). In 2018, water sampling sites from the lake were extended based on the water analysis results of 2017.

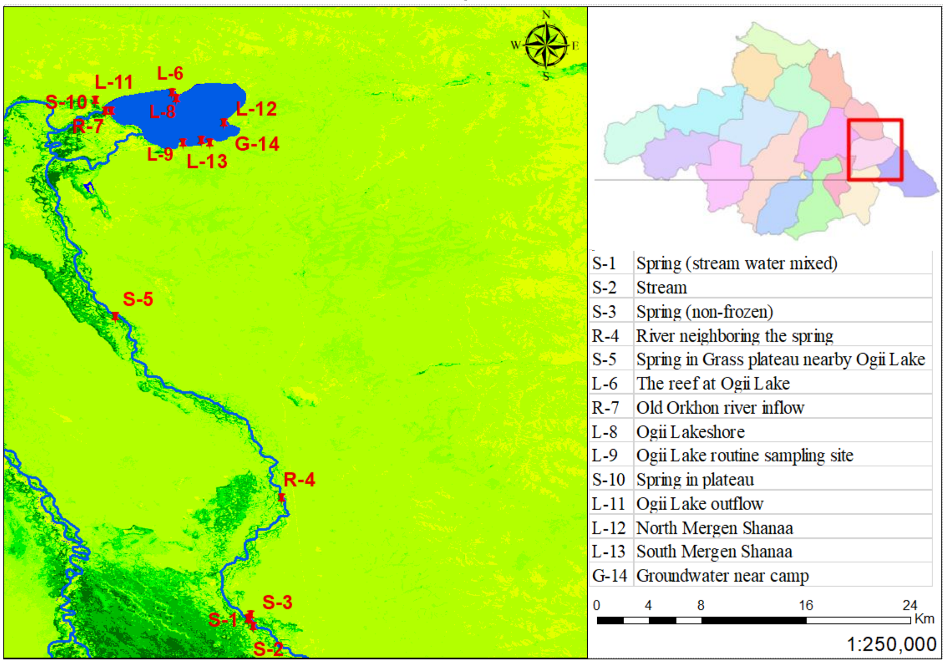


Fig. 3.2 Map of water sampling sites along Orkhon Valley, Mongolia (R–river water; S–spring and stream; L–Lake water; G–Groundwater)

Photoshoot during the field survey in 2018

3.2.2 Research methods for water quality analysis

Water temperature, dissolved oxygen (DO), and pH were measured immediately at the sampling sites using calibrated portable meters (Oxi 3310; Multi 3630 IDS, WTW, Germany). Suspended solids (SS) were determined by first filtering water samples through membrane filter papers (GF/F Whatman, UK), which were then dried at 105 °C for 24 h in the laboratory at the University of Kitakyushu, Japan. Dried filters were subsequently weighed for SS. Chemical parameters were analyzed according to the Standard Methods for the Examination of Water and Wastewater [39], which associates a number for the standard method (SM) of each individual parameter. Concentrations of Ca, Al, Fe, Cr, Cu, Mn, Na, Pb, Zn, Li, Cd, Au, and As were measured by ion chromatography (ICP-MS #7900, Agilent, USA) as per SM 3125 B. K and Mg concentrations were analyzed by an atomic absorption spectrophotometer (AA240FS, Varian, USA) following SM 3111. NH_3-N concentrations were measured by a spectrophotometer (#7012, Hitachi, Japan) using a 5 cm glass cell in accordance with SM 4500 for NH_3 H (flow injection analysis). Concentrations of Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, F^-, and PO_4^{3-} were measured by inorganic ion chromatography (ICS-1500 Thermo Fischer, USA) as per SM 4500-Cl G, SM 4500-NO_2^- B, SM 4500-NO_3^- I, and SM 4500-SO_4^{2-} G, respectively. Total organic carbon (TOC) was measured using a TOC analyzer (TOC-V csn Shimadzu, Japan) according to SM 5310.

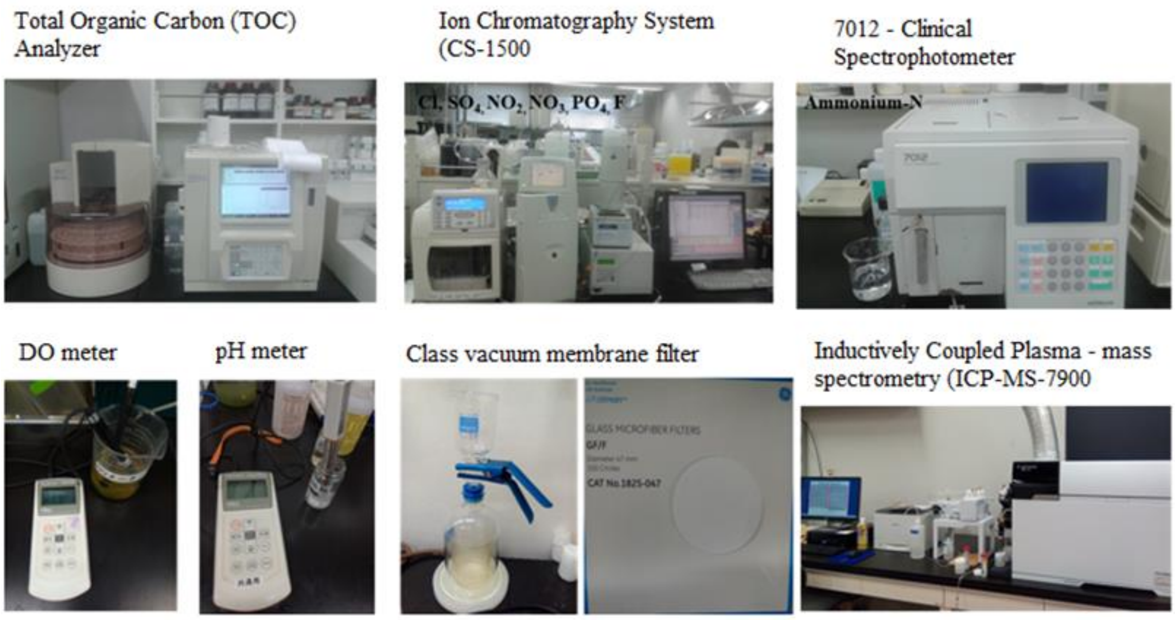


Fig. 3.3 Equipment used for water quality analysis

Based on the existing surface water quality standard MNS 4586:1998 (**Table 3.1**), the specified values of each variable, including DO, NH_4^+, NO_2^-, NO_3^-, Cl^-, PO_4^{3-} and SO_4^{2-} were used to calculate the water quality index (WQI) at each sampling site. This method is used to assess the ecological state of surface water in Mongolia, which classified into six classes, ranging from very clean (WQI < 0.3) to dirty (WQI > 6) [40]. WQI was estimated using **Eq. 3.1,** which was developed by the Mongolian National Center for Standardization and Meteorology (CSM) in 1998 [41]. The classification of WQI is shown in **Table 3.2**.

$$WQI = \frac{\sum_{i=1}^{n} \frac{C_i}{Pl_i}}{n} \quad 3.1$$

where,
WQI: Water Quality Index
Pl_i: The specified value of the ith variable of the MNS 4586:1998
C_i: Concentration of ith variable
n: Number of variables

Table 3.1 Permissible level of surface water variables in Mongolian National Standard

Variables name	Chemical formula	MNS 4586:1998 standard
Biochemical Oxygen Demand – 5 day	BOD	3 mg/L
Chemical Oxygen Demand – Manganese	COD	10 mg/L
Dissolved oxygen	DO	6~4 mg-O/L
Hydrogen ion activity	pH	6.5-8.5
Total organic carbon	TOC	-
Chloride	Cl	300 mg/L
Nitrate	NO_3	9.0 mg-N/L
Sulphate	SO_4	100 mg/L
Phosphorus	PO_4	0.1 mg-O/L
Fluoride	F	1.5mg/L
Nitrite	NO_2	0.02 mg-N/L
Ammonium	NH_4	0.5 mg-N/L
Aluminum	Al	200 mg/L
Calcium	Ca	100 mg/L
Chromium	Cr	0.05 mg/L
Manganese	Mn	0.1 mg/L
Copper	Cu	0.01mg/L
Arsenic	As	0.01 mg/L
Cadmium	Cd	0.005 mg/L
Lead	Pb	0.01 mg/L
Magnesium	Mg	30 mg/L

Table 3.2 Classification of water quality index

Quality index	Water quality	Classes
<0.30	1	Very clean
0.31-0.89	2	Clean
0.90-2.49	3	Slightly polluted
2.50-3.99	4	Moderately polluted
4.00-5.99	5	Heavily polluted
6.00-10.0	6	Dirty
>10.0	7	Very dirty

Water hardness is the amount of dissolved calcium and magnesium in the water. It is usually expressed as the equivalent quantity of calcium carbonate. Total water hardness was estimated using **Eq. 3.2**

$$CaCO_3 = 2.5 \cdot [Ca^{2+}] + 4.1 \cdot [Mg^{2+}] \qquad 3.2$$

Where:
$CaCO_3$: Water hardness mg of $CaCO_3$ equivalent hardness in 1 liter of water (mg/L)
Ca^{2+}: Concentration of calcium (mg/L)
Mg^{2+}: Concentration of magnesium (mg/L)

General guidelines for classification of waters are: 0 to 60 mg/L (milligrams per liter) as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard.

3.2.3 Questionnaire survey

A questionnaire survey was conducted in August 2018 under a cooperation with the Ogii Lake Wetlands Information and Training Center to evaluate anthropogenic impacts on the lake's environment. The survey conducted on 49 households, four tourist camp owners, and 28 small private camps called "Eco-houses" located around the lake. Questions included in this survey are the number of family members, number of grazing livestock, water sources for both humans and livestock, lavatory and sanitation systems, waste generation and disposal, number of tourist visits to the lake every year, and observed any environmental changes. Surrounding to the lake there was only four containers was designed for garbage disposal. Also, around the lake except for four tourism campus no lavatory for private tourist. Therefore, during the time when tourist visited to the lake, human waste and solid waste disposals are becoming a big problem. The current condition of lake based tourism shown below.

Private tourist around the lake 2018.08.21-22 (Photo by author)

Waste disposal by private tourists

Waste containers that installed around Ogii Lake

Livestock access on river and lake in July 2017 Photo by author;
Photo obtained from online: Access link

Tourist camp's lavatory around Ogii Lake

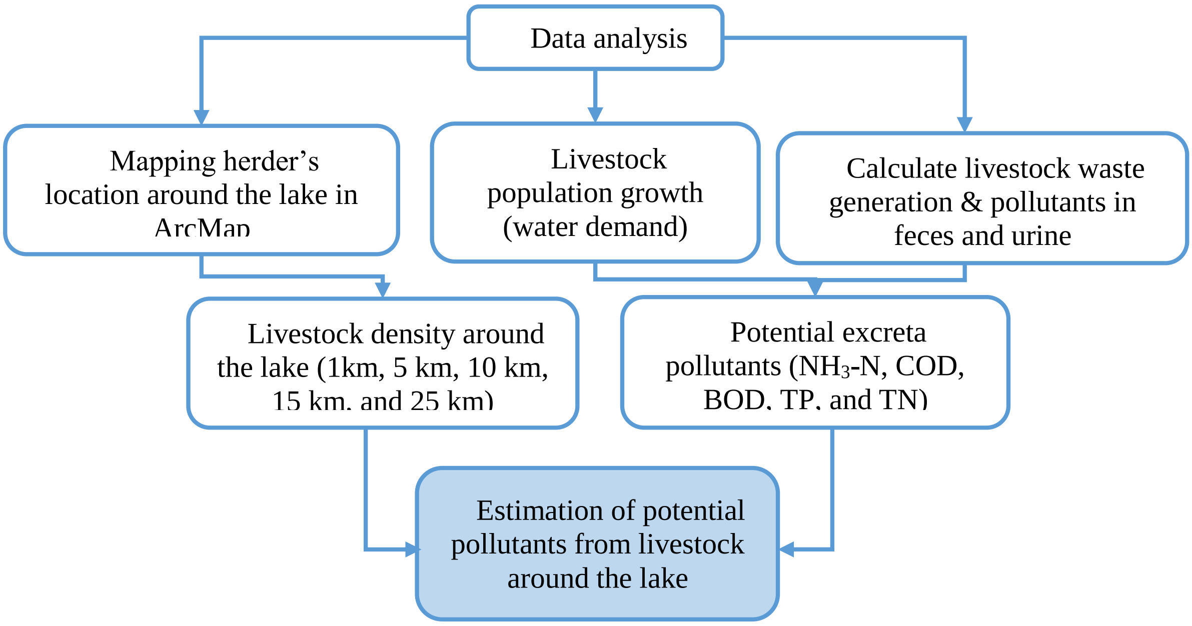


Fig. 3.4 Research framework–3

The historical livestock data, which is provided by the National Statistical Office of Mongolia [42] were analyzed according to the research framework–3 (**Fig. 3.4**).

Table 3.3 Population, livestock, and herder's census data

Years	2004	2005	2006	2012	2013	2014	2015	2016	2017	2018
					Population					
Ogii Lake County	3025	3015	3047	1003	1041	1060	1065	1087	1147	1162
Around Ogii Lake	490	497	494	171	194	197	199	201	216	225
					Households					
Ogii Lake County	777	782	788	894	919	926	912	947	953	969
Around Ogii Lake	130	129	128	156	159	156	159	158	167	170
					Livestock (thou)					
Ogii Lake County	86.5	108.7	129.8	166.3	202.7	217.5	232.9	252.8	291.5	278.3
Around Ogii Lake	13.9	16.3	19.9	38.8	44.5	45.6	50.8	55.4	58.4	55.2

Data source: Data of 2004 – 2006 [17]; Data of 2012 – 2018 [2] Access link

3.2.4 Research method for investigating the potential generation of livestock related pollution

The livestock growth rate was calculated by **Eq. 3.3** at country and subdivision levels.

$$Growth\ rate = \left[\frac{Current\ poulation - Population\ in\ past}{Population\ in\ past} * 100\%\right] / Period \quad 3.3$$

Based on the estimated livestock yearly growth rate in Ogii Lake County from 2008 to 2018, livestock population growth and the livestock excreta pollutants were predicted. The livestock population growth estimated by the exponential growth function (**Eq. 3.4**).

$$P(t) = P_0 \cdot e^{kt} \quad 3.4$$

where,
$P(t)$: Population after time t
P_0: Initial population
e: Exponential constant ($e = 2.718$)
k: Growth rate

The waste generation data and amount of contaminants (COD, BOD, NH_3-N, TP, and TN) in the livestock feces and urine were obtained from Gu et al. (2008) [43]. Goats were assumed as sheep, and horses and camels were assumed as cattle by using conversion factors (1 goat = 0.9 sheep; 1 horse = 1 cattle; 1 camel = 1.5 cattle) that are used in Mongolia. The obtained data for NH_3-N, TP, TN, COD, and BOD of cattle and sheep are compiled in **Table 3.4**.

The annual number of livestock and herder's locations were obtained from the National Statistical Office of Mongolia [44]. Livestock density around the lake at the different radiuses (1 km, 5 km, 10 km, 25 km) was mapped using the buffer zone tools of ArcMap 10.1 (**Fig. 3.8**).

The gross amount of pollutants produced by livestock was estimated based on the amount of pollutants produced per day per head by **Eq. 3.5** using the total number of livestock in 2016 in Ogii Lake County.

Table 3.4 Average waste generation and pollutants of cattle and sheep

Livestock categories	Waste type	Waste amount (kg/day)	NH_3–N	TP	TN	COD	BOD
					(kg/head/year)		
Cattle	feces	20	12.48	8.61	31.9	226.3	179
	urine	10	12.66	1.46	29.2	21.9	14.6
Sheep	feces	2.6	0.76	2.47	7.11	4.39	3.89

$$Ap = F \times N \times P \times 365 \quad (3.5)$$

Where,
Ap: The annual gross production of pollutants (kg/year)
F: The amount of feces and urine (kg/head/day)
N: Number of livestock (head/year)
P: Amount of pollutants per kg of feces and urine (kg/kg)

3.3 Result of field survey

3.3.1 Water quality of Ogii Lake, Khugshin Orkhon River, and streams in Orkhon Valley

The physicochemical parameters of water samples for July 7–8, 2017 and August 23–24, 2018 are shown in Error! Reference source not found.. The results of these two years' water analyses are summarized below based on their sampling location.

Water quality in the Orkhon Valley DO concentrations in the samples from Orkhon Valley (S-1, S-2, S3, S-5) ranged between 5.17–6.52 mg/L in July 2017, and 6.31–6.85 mg/L in August 2018. The pH value varied between 7.8 and 8.7, and the SS concentrations ranged from 0.5 to 19.4 mg/L in both sampling periods. In July 2017, the SS concentration in the stream (S-2) and non-frozen spring water (S-3) were determined to be 12.3 and 2.2 mg/L, respectively. In August 2018, the SS concentration were decreased by almost half at sampling site S-2 in comparison to the previous year. The observed daily discharge data (**Table 3.5**) shows that during the sampling period, the flow rate was determined to be 0.62 and 0.32–0.36 m^3/s on July 7–8, 2017, and August 23–24, 2018 respectively.

Therefore, SS concentrations at these locations might depend on the movement of livestock as well as the water flow rate. Also PO_4^{3-} concentrations were 2.7–2.8 times higher than the water quality standard (0.1 mg/L) at these two sampling sites (S-2 and S-3). In both years, the water quality at these sites and at S-1 was classified as moderately hard to hard water with hardness value 82.01–237.76 mg/L. In 2017, the sample from the spring (S-1) was classified as clean water with a WQI of 0.19, while other nearby two water samples from stream (S-2) and non-frozen spring (S-3) were classified as dirty with a WQIs of 8.82, and 12.06, respectively (Error! Reference source not found.). In 2018, the samples from the spring and stream (S-1 and S-2) were classified as slightly polluted as both had WQIs of 1.33. The calculated WQI at non-frozen spring water (S-3) was classified as dirty with a WQI of 8.14 due to concentrations of PO_4^{3-} and NO_2^- that exceeded the water quality standards (see **Table 3.6** and **Table 3.7**). The non-frozen spring water (S-3) is the main drinking water source for surrounding households throughout the year, and it contained relatively high concentrations of P and N; hence water from S-3 should be avoided to use as drinking water. Multiple analyses should be conducted, especially for the non-frozen spring water (S-3), to determine any seasonal changes on the physicochemical parameters.

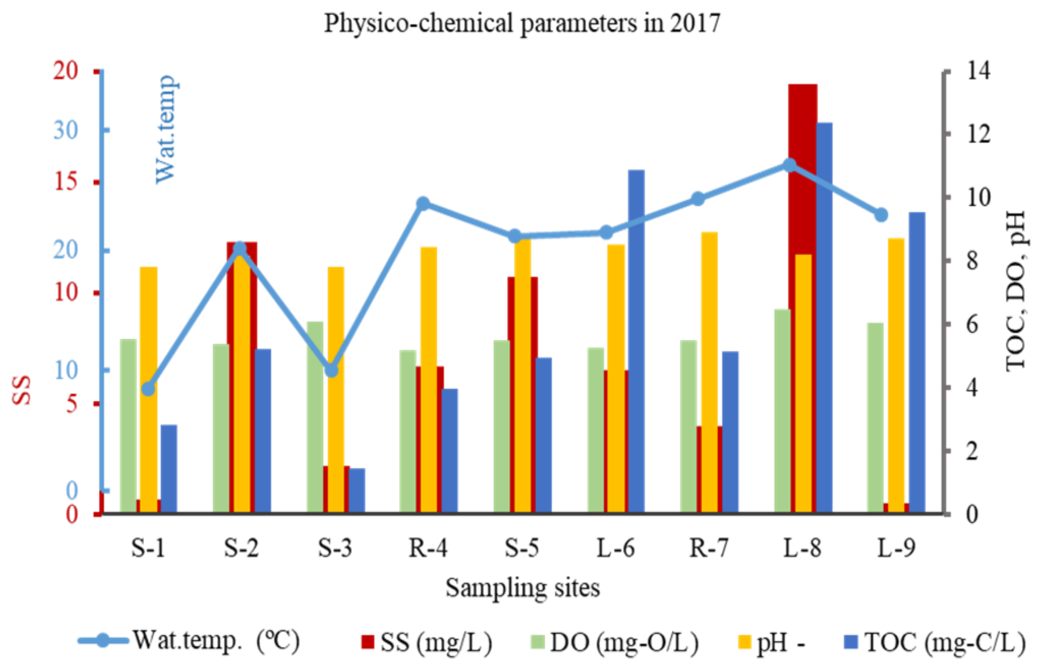
Water quality in Khugshin Orkhon River DO concentrations in the Khugshin Orkhon River (R-4 and R-7) water sample ranged between 5.2–5.5 mg/L in 2017, which is below the specified value in the MNS4586:1998 (6 mg/L) for the summer season. In August 2018, DO concentrations ranged between 6.29–7.61 mg/L in water samples of R-4 and R-7. The pH varied from 8.84–9.26 in July 2017, and 8.43–8.91 in August 2018. The SS concentration increased in the water sample (R-4) from 6.7 mg/L in July 2017 to 7.2 mg/L in August 2018, and from 4.0 mg/L in 2017 to 6.7 mg/L in 2018 at R-7 sampling point. In both years, the WQI of the Khugshin Orkhon River was classified as clean; NO_2^- and NO_3^- concentrations were relatively low, however, PO_4^{3-} concentrations were determined to be 1.3–2.6 times higher than the standard level (0.1 mg/L). In both years, the Khugshin Orkhon River water at site R-4 was classified as being very hard. The water hardness was decreased to moderately hard (70.62–83.54 mg/L) at sampling point R-7 near Ogii Lake (**Fig. 3.7**).

Water quality in Ogii Lake DO concentrations in samples from Ogii Lake (L-6, L-8, and L-9) ranged between 5.27–6.49 mg/L in July 2017, and 6.58–7.46 mg/L in August 2018. Water samples were alkaline; pH varied from 8.2–8.7 in July 2017, and 8.33–9.26 in August 2018. The SS concentrations in samples taken in July 2017 ranged between 0.5–19.4 mg/L and in August 2018 (7.5–16.9 mg/L). The highest SS concentration (19.4 mg/L) was found at the sampling site on the northern side of the lake (L-8) in July 2017, but SS concentrations decreased in August 2018. According to the WQI (**Fig. 3.6**), the lake water was classified as clean at the L-6 and L-9 sampling points in both years (WQI 0.22–0.36), as well as at the L-11, L-12 and L-13 sampling points in 2018 (WQI 0.33–0.69), and was classified as slightly polluted at L-8 in both years (WQI 1.12–1.21). The PO_4^{3-} concentration was determined to be 0.27 mg/L and 0.34 mg/L only at the northern side of the lake (L-11 and L-8), and 0.32 mg/L at the spring water site (S-10) near the lake in 2018, which was higher than in 2017 as well as a previous study by JICA in 2006. NO_2^- concentration was determined higher than standard level at L-8 sampling point in the both year. In July 2017, the lake water hardness was classified as moderately hard water (88.15–108.69 mg/L) at all sampling location (**Fig. 3.7**). In August 2018, lake water samples L-12 and L-13 were classified as soft water (53.33–54.22 mg/L) due to low Mg concentrations (0.94–0.96 mg/L) in samples from the eastern and western side of the lake.

Table 3.5 Daily discharge data of Old Orkhon River at Kharkhorin Station (m^3/s)

2017						2018					
Days	July	August	Days	July	August	Days	July	August	Days	July	August
1	3.27	0.24	16	0.19	0.41	1	0.56	0.77	16	0.60	0.48
2	1.91	0.28	17	0.20	0.37	2	0.44	2.52	17	0.71	0.44
3	2.27	0.28	18	0.28	0.45	3	0.44	2.43	18	0.83	0.36
4	1.58	0.49	19	0.33	0.81	4	0.40	1.56	19	1.06	0.36
5	0.81	0.62	20	0.37	1.25	5	0.40	1.95	20	1.48	0.28
6	0.87	0.68	21	0.33	1.41	6	0.36	1.17	21	0.60	0.28
7	0.62	0.75	22	0.28	1.25	7	0.44	1.06	22	0.52	0.28
8	0.62	0.75	23	0.33	1.66	8	0.60	1.33	23	1.79	0.36
9	0.49	0.54	24	0.41	1.66	9	0.44	1.06	24	0.94	0.32
10	0.37	0.45	25	0.45	1.12	10	0.44	1.17	25	0.56	0.36
11	0.37	0.54	26	0.45	1.00	11	0.60	1.17	26	0.44	0.44
12	0.37	0.54	27	0.94	0.68	12	0.77	1.06	27	0.36	0.40
13	0.28	0.45	28	0.28	0.54	13	0.60	0.77	28	0.40	0.40
14	0.24	0.54	29	0.28	0.45	14	0.48	0.60	29	0.60	0.40
15	0.20	0.28	30	0.20	0.49	15	0.52	0.52	30	0.52	0.44
			31	0.20	0.54				31	0.52	0.77

Note: Access raw data table in here



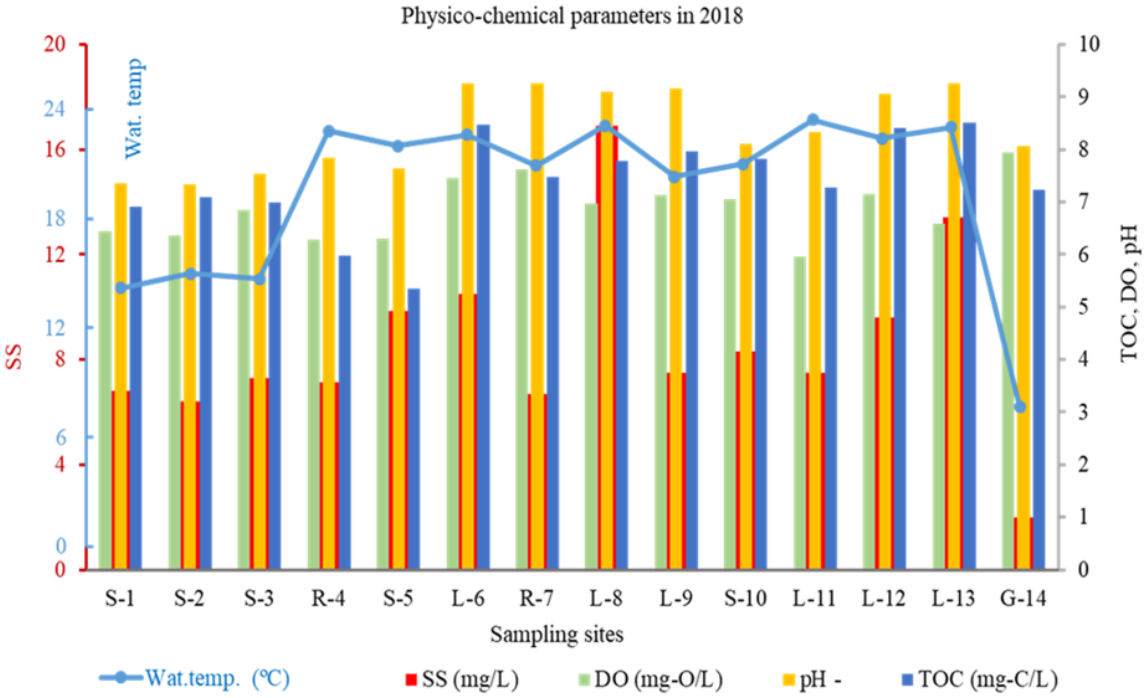


Fig. 3.5 Physicochemical parameters of water samples a) 7–8 July 2017; b) 23–24 August 2018

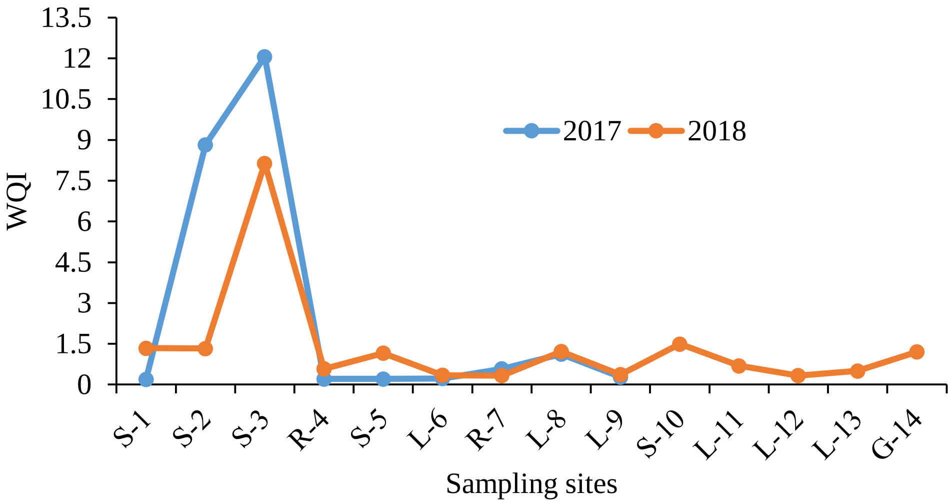


Fig. 3.6 Water quality of sampling sites in 2017 and 2018

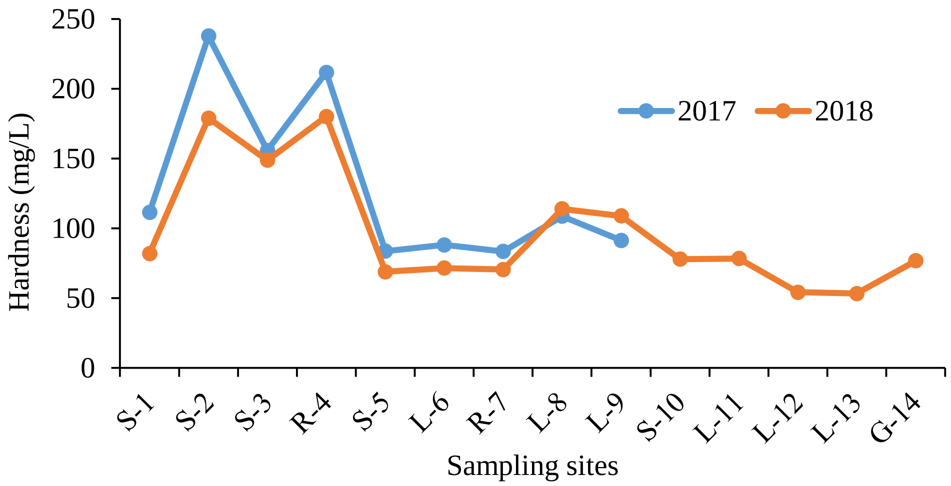


Fig. 3.7 Hardness water samples in 2017 and 2018

Table 3.6 Water analysis results of July 2017

2017		S-1	S-2	S-3	R-4	S-5	L-6	R-7	L-8	L-9
Water temp	°C	8.5	20.2	10	23.9	21.2	21.5	24.3	24.1	23
SS	mg/L	0.7	12.3	2.2	6.7	10.7	6.5	4	19.4	0.5
DO	mg-O/L	6.52	5.37	6.07	5.17	5.48	5.27	5.5	6.49	6.04
pH	-	7.8	8.18	7.81	8.43	8.72	8.53	8.91	8.2	8.73
TOC	mg-C/L	2.82	5.21	1.45	3.96	4.96	10.89	5.16	12.38	9.53
Cl	mg/L	6.84	9.83	7.57	8.31	9.12	16.57	8.5	0	15.96
NO_3	mg-N/L	0.09	0.08	4.32	0.1	0	0.48	0	0	1.7
SO_4	mg-S/L	26.89	44.83	30.89	39.84	43.28	35.14	34.61	1.48	34.76
PO_4	mg-P/L	0	0.28	0.2	0	0	0	0.26	0	0
F	mg/L	0	0	0	0	0	0	0	0	0
NO_2	mg-N/L	0	1.15	1.61	0	0	0	0	0.1	0
NH_4	mg-N/L	0.056	0.028	0.056	0.085	0.056	0.113	0.085	0.901	0.169
Li	ug/L	0.52	1.11	0.44	1.01	0.7	1.18	0.57	0.98	1.24
Na	mg/L	24.03	32.4	16.1	32.34	31.57	58.44	32.03	49.83	53.42
Al	mg/L	0	0.93	0.25	0	0	0.25	0	0.86	0.83
Ca	mg/L	16.24	34.99	22.67	50.14	12.32	13.19	12.43	16.02	11.45
Cr	ug/L	0.12	0	0.04	0.03	0	0	0.03	0.13	0
Mn	ug/L	0.04	0.03	0.03	0.03	0.17	0.03	0.25	0.51	0.06
Fe	mg/L	0	0.49	0	0.45	0	0	0	0	3.9
Cu	ug/L	1.08	0.81	0.46	0.97	1.03	1.04	1.35	5.58	1.15
As	ug/L	9.36	0	0	0	0	7.23	7.12	14.58	19.18
Cd	ug/L	0.01	0	0	0	0	0.01	0.03	0.03	0.04
Au	ug/L	0.01	0	0	0	0	0.01	0	0.01	0
Pb	ug/L	0.04	0.02	0.03	0.03	0.01	0.01	0.04	0.07	0.02
Mg	mg/L	17.22	36.52	24.09	21.04	12.86	13.41	12.75	16.68	15.26
K	mg/L	3.46	4.01	3.18	3.94	3.65	6.53	3.32	24.77	6.51
Water hardness	mg/L	111.46	237.76	155.81	211.81	83.721	88.158	83.543	108.69	91.435
WQI		0.19	8.82	12.06	0.21	0.21	0.223	0.58	1.12	0.276

Table 3.7 Water analysis results of August 2018

2018		S-1	S-2	S-3	R-4	S-5	L-6	R-7	L-8	L-9	S-10	L-11	L-12	L-13	G-14
Water temp	°C	14.2	15	14.7	22.8	22	22.6	20.9	23.1	20.3	21	23.4	22.4	23	7.7
SS	mg/L	6.8	6.4	7.3	7.15	9.85	10.5	6.7	16.9	7.5	8.3	7.5	9.6	13.4	2
DO	mg-O/L	6.45	6.36	6.85	6.29	6.31	7.46	7.61	6.98	7.14	7.06	5.95	7.15	6.58	7.95
pH	-	7.35	7.33	7.53	7.84	7.64	9.25	9.26	9.1	9.15	8.11	8.33	9.05	9.25	8.06
TOC	mg-C/L	6.91	7.09	7	5.97	5.36	8.466	7.48	7.78	7.97	7.827	7.28	8.4	8.503	7.23
Cl	mg/L	8.23	16.83	8.35	9.34	15.23	14.12	7.58	13.76	14.69	16.83	16.55	14.52	15.6	18.84
NO_3	mg-N/L	0.14	0	3.28	0.85	0.58	0.84	0.6	0.11	0	0	0	0	0.13	0.58
SO_4	mg-S/L	31.67	38.78	51.43	42.09	47.63	37.99	34.79	41.26	39.35	59.98	50.08	38.82	38.87	35.31
PO_4	mg-P/L	0.21	0.27	0.28	0.13	0.1	0	0	0.34	0	0.32	0.27	0	0	0
F	mg/L	1.05	1.86	1.02	1.15	0.79	1.81	0.9	2.01	1.88	1.18	2.07	1.88	1.87	0.8
NO_2	mg-N/L	0.11	0.09	0.1	0	0.09	0	0	0.05	0	0.09	0	0	0	0.02
NH_4	mg-N/L	0.17	0.31	0.32	0.58	0.48	0.32	0.31	0.48	0.47	0.46	0.28	0.35	0.39	0.31
Li	ug/L	0.45	0.05	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.05	0.05	0.05	0.04	0.05
Na	mg/L	37.29	40.42	43.25	42.96	46.98	53.66	21.51	48.97	48.68	0.00	58.08	50.95	64.76	24.34
Al	mg/L	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Ca	mg/L	14.26	29.75	24.36	39.47	9.81	12.41	9.68	15.86	10.79	15.26	16.45	20.14	19.82	14.25
Cr	ug/L	0.09	0.02	0.02	0.03	0.01	0.02	0.01	0.09	0.02	0.02	0.02	0.02	0.02	0.02
Mn	ug/L	0.05	0	0	0.02	0.04	0	0	0.05	0	0	0	0	0	0
Fe	mg/L	0.04	0.02	0.02	0.11	0.02	0.02	0.01	0.06	0.02	0.08	0.04	0.01	0.03	0.02
Cu	ug/L	0.09	0	0	0.05	0.07	0	0	0	0	0	0	0	0	0
As	ug/L	7.87	0.0022	0.0019	0.005	0.0029	0.009	0.0002	0.0023	0.0073	0.002	0.008	0.006	0.007	0.003
Cd	ug/L	0.02	0.02	0.02	0.01	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03
Au	ug/L	0.68	0.74	0.74	0.69	0.77	0.73	0.70	0.81	0.73	0.76	0.75	0.73	0.74	0.78
Pb	ug/L	0.09	0.11	0.11	0.08	0.05	0.09	0.08	0.15	0.09	0.12	0.11	0.09	0.10	0.13
Mg	mg/L	11.27	25.43	21.39	19.83	10.79	9.86	11.28	18.07	19.91	9.68	9.07	0.96	0.94	10.03
K	mg/L	3.15	0.01	0	0.15	0.09	0	0	0.08	0.05	0	0.10	0.05	0.08	0.00
Water hardness	mg/L	82.014	179.01	148.91	180.2	68.93	71.58	70.62	114.02	108.94	77.97	78.42	54.22	53.33	76.88
WQI		1.339	1.33	8.141	0.579	1.157	0.343	0.332	1.213	0.367	1.49	0.69	0.33	0.5	0.49

Moderately hard water (71.58–114.02 mg/L) was found at sampling sites L-6, L-8, L-9, S-10, and L-11. Groundwater (G-14) was classified as clean (WQI 0.49) and moderately hard (76.88 mg/L). In both years, the dominant anions in all water samples were Cl^-, SO_4^{2-}, NO_2^- and the anion concentration exhibited the following order: $Cl^- > SO_4^{2-} > NO_2^- > F^- > PO_4^{3-} > NO_3^-$. The F^- concentration was 1.87–2.07 mg/L at the lake sampling sites L-18, L-19, L-20, and L-21 in August 2018, which exceeded both the MNS 4586:1998 standard (1.5 mg/L) and the World Health Organization (WHO) guideline value for drinking water (0.50–1.05 mg/L). Metal concentrations were below the specified value at all sampling sites in both years. However, in 2017, the As concentration in the Ogii Lake routine sampling site (L-9) was 0.02 mg/L, which was nearly double the value specified in the MNS standard (0.01 mg/L). However, in 2018, As concentrations were below the specified value at all sampling sites. Arsenic is naturally present in water and soil, therefore due to the free access of tourists and livestock to the lake, arsenic in the lake shore might have been dissolved into the lake water at this sampling site in 2017.

3.3.2 Results of the questionnaire survey

The results of the questionnaire survey revealed that 17% of the household uses water from the 2 m to 35 m depth wells, and 83% of the household uses water from the lake. Nineteen households have a wooden lavatory (1.5 m to 2m depths). Other thirty households do not have any kind of lavatory, with each house also does not have any sanitation system. Therefore, human waste and household wastewater directly loads to the soil surface. Approximately 8000—10000 tourists visit the lake each year, particularly from the middle of June to the end of August. The lake provides fish resources, therefore, tourists also visit the lake for fishing during the winter season. Currently, there are no regulations on lake-based tourism. Most tourists left their garbage along the lakeshore, and washes their cars very close to the lake due to a lack of regulations. In addition, there are only four waste containers surrounding the lake, which is installed within a 100–200 m distance from the lakeshore. The largest of these containers had a capacity of approximately one ton, which could only serve to contain a small volume of waste, considering the shoreline length of 24.7 km. Hence, these containers are inadequate both in volume and numbers considering the extremely high tourism. Additional issue is the dust from unpaved roads around the lake, which influences the degradation of the soil surface. With the average solid waste generation for humans as 0.5 kg per day, approximately 60.5 tons of solid waste are generated around the lake annually. When comparing to waste generation rate, 62.8% of total waste was accounted for by residents, and 37.2% was accounted for by tourists. Based on the information obtained from the Ogii Lake Wetlands Information and Training Center, approximately 50 tons of garbage was collected over four cleaning activities from the area surrounding Ogii Lake and was subsequently disposed to landfill in 2017. In Mongolia, people use wooden lavatories, and these are a main contributor to soil quality degradation in areas where it has installed. However, even such wooden lavatories not yet installed around the lake. Therefore, human excrement was found dispersed around the lake. To reduce the amount of generated waste that is discharged into the lake environment, bio-toilets instead of wooden lavatories and waste containers should be installed around the lake in sufficient numbers. In 2018, a total of 19775 livestock (1360 head of a horse, 1506 head of cattle, 10263 head of sheep, and 6646 head of goats) belonged to the interviewed households.

3.3.3 Result of estimated livestock excreta pollution around Ogii Lake

Based on the waste generation amount of each livestock category (**Table 3.4**), the amount of potential pollutants around Ogii Lake were estimated based on livestock herder's location in 2016. Depending on the watering period, the pollutants that contained in the livestock feces and urine can discharge to the water body. The annual potential pollutants load around the Ogii Lake within different radiuses are shown in **Table 3.8**.

Table 3.8 The annual potential pollutants load around Ogii Lake

Distance	NH3–N	TP	TN	COD	BOD
			ton/year		
1 km	9.52	11.46	41.74	83.02	66.40
5 km	45.86	59.31	210.95	393.97	316.11
10 km	87.05	76.79	230.93	199.83	169.91
25 km	181.8	1679.8	1327.6	154.8	637.4

In total, 158 households were herding 55367 head of livestock, which consisted of five head of a camel, 3632 head of horses, 3900 head of cattle, 29471 head of sheep, and 18359 head of goat around the lake within 25 km distance in 2016. Sixty-four percent of the total livestock (35575 heads) were distributed within 10 km to the lake. The household distribution map has shown that herders mostly settled at the northern side of Ogii Lake and along Khugshin Orkhon River (**Fig. 3.8**). In 2016, a total of 181.8 tons of NH_3–N, 154.8 tons of TP, 637.4 tons of TN, 1679.8 tons of COD and 1327.6 tons of BOD generated within 25 km distance from the lake.

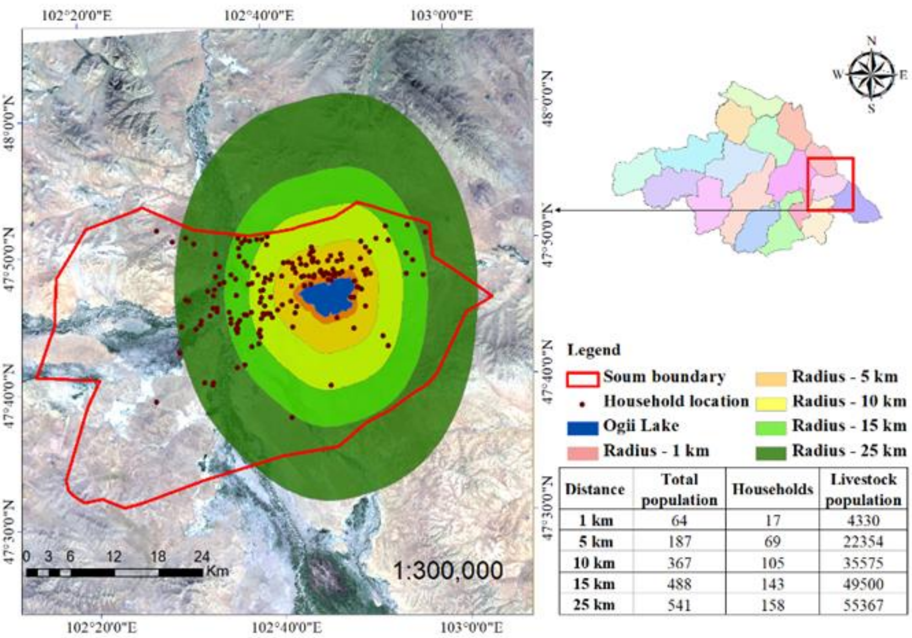


Fig. 3.8 Household distribution around Ogii Lake in 2016

3.3.4 Emission prediction of livestock waste generation in the Ogii Lake County

According to the historical livestock data, totally 21.5 million livestock perished at country level during the 1999-2002 and 2009-2010 dzuds. Arkhangai province lost 50 % of total herd animal during the winter in 2009-2010. However, the livestock population steadily increased since the harshest dzud lasted in 2010. Comparing to the three-time series from 1970-1990, 1990-2009, and 2010-2018 livestock population has been grown rapidly in country-level by 0.72 %, 3.51 %, and 12.88 % respectively (**Table 3.9**). Historically, Arkhangai province is one of the subdivisions that usually ranks first three places by livestock population in Mongolia. **Table 3.10** shown the livestock growth rate in Arkhangai province and Ogii Lake County by livestock categories in three-time series. In Ogii Lake County, the cattle, goat, and sheep population has grown by 8.39 %, 7.59 %, and 12.82 % since 2010, followed by 5.70 % growth rate for the horse population.

Table 3.9 Population growth rate in country and subdivision

	1970-1990	1990-2009	2010-2018
Country	+0.72 %	+3.51 %	+12.88 %
Arkhangai Province	+0.057 %	+7.09 %	+13.07 %
Ogii Lake County	+0.14 %	+4.39 %	+10.27 %

Table 3.10 Growth rate by livestock categories

	1970-1990		1990-2009		2010-2018	
	Arkhangai	Ogii Lake	Arkhangai	Ogii Lake	Arkhangai	Ogii Lake
Cattle	+1.30 %	+0.88 %	+1.54 %	-1.39 %	+13.21 %	+8.39 %
Horse	-0.26 %	-0.17 %	+1.46 %	-0.96 %	+11.62 %	+5.70 %
Camel	-1.18 %	+2.5 %	-3.09 %	-2.72 %	+4.73 %	-2.52 %
Sheep	-0.32 %	-0.45 %	+5.97 %	+4.70 %	+15.57 %	+12.82 %
Goat	+0.74 %	+2.28 %	+26.33 %	+15.25 %	+9.47 %	+7.59 %

Considering on the extreme event such as dzud's frequency that occurs in the winter season, the growth rate was calculated each year between 2008 and 2018 (**Table 3.11**). The average growth rate for cattle and sheep population equal to 4.68%, and 6.38% respectively. During this period, dzud occurred two times; therefore, livestock population estimation under the growth rates in each year can give more accurate results. Predicted cattle and sheep population was reasonable with actual data with R–squared value that equal to 0.85, and 0.91, respectively (**Fig. 3.9**). Also a significant positive relationship between those two values has a probability value $p < 0.005$. Livestock population growth predicted for thirty years based on the growth rate in Ogii Lake County. The results shown that population growth predicted from 2008 to 2036 with an R-squared value of 0.89 and 0.83 (**Fig. 3.10**). The future livestock population prediction has shown that 1.76 times increase in sheep population, 1.8 times increase in cattle population between 2019 and 2036. The sheep population growth prediction shows similar results with the previous study by Shab et.al, while, cattle population proliferates. Those different results could explain by the difference in mortality rate or data periods.

Table 3.11 The yearly growth rate for both cattle and sheep in Ogii Lake County

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cattle (thousand heads)											
Actual	10.1	10.48	8.1	8.95	10.87	13.08	15.18	17.03	19.98	20.11	13.54
Predicted	10.1	10.88	6.45	9.94	13.47	16.05	17.82	19.23	23.75	20.24	9.76
Growth rate (%)	-	3.76	-22.7	10.49	21.45	20.40	16.03	12.16	17.3	0.65	-32.6
Sheep (thousand heads)											
Actual	133.9	133.2	129.8	141.1	173.0	183.8	195.5	211.3	243.8	243.97	242.7
Predicted	133.9	132.5	126.6	153.9	216.9	195.7	208.3	229.1	284.5	244.07	241.6
Growth rate (%)	-	-0.52	-2.54	8.69	22.59	6.25	6.32	8.08	15.41	0.03	-0.49

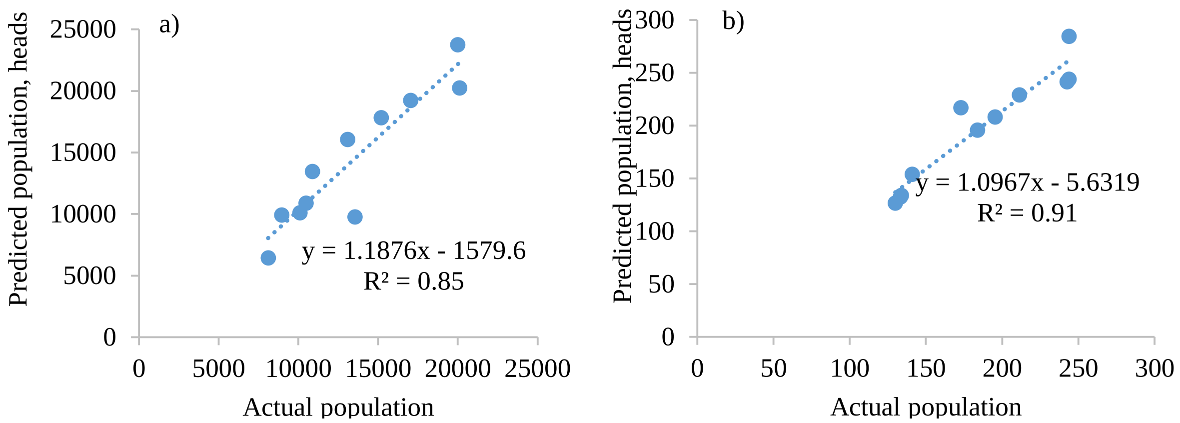


Fig. 3.10 Correlation between actual and predicted livestock population in Ogii Lake County, a) cattle and b) sheep

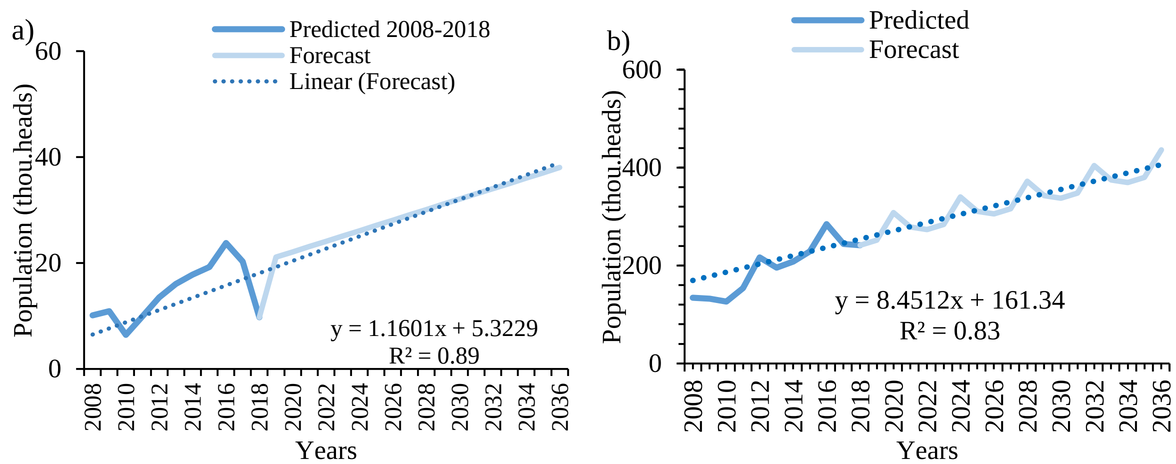


Fig. 3.9 Livestock population growth prediction in Ogii Lake County a) population of cattle, b) population of sheep

Based on the expected population, potential pollutants from cattle and sheep (**Fig. 3.11**), and water demand **(Fig. 3.12**) were also estimated.

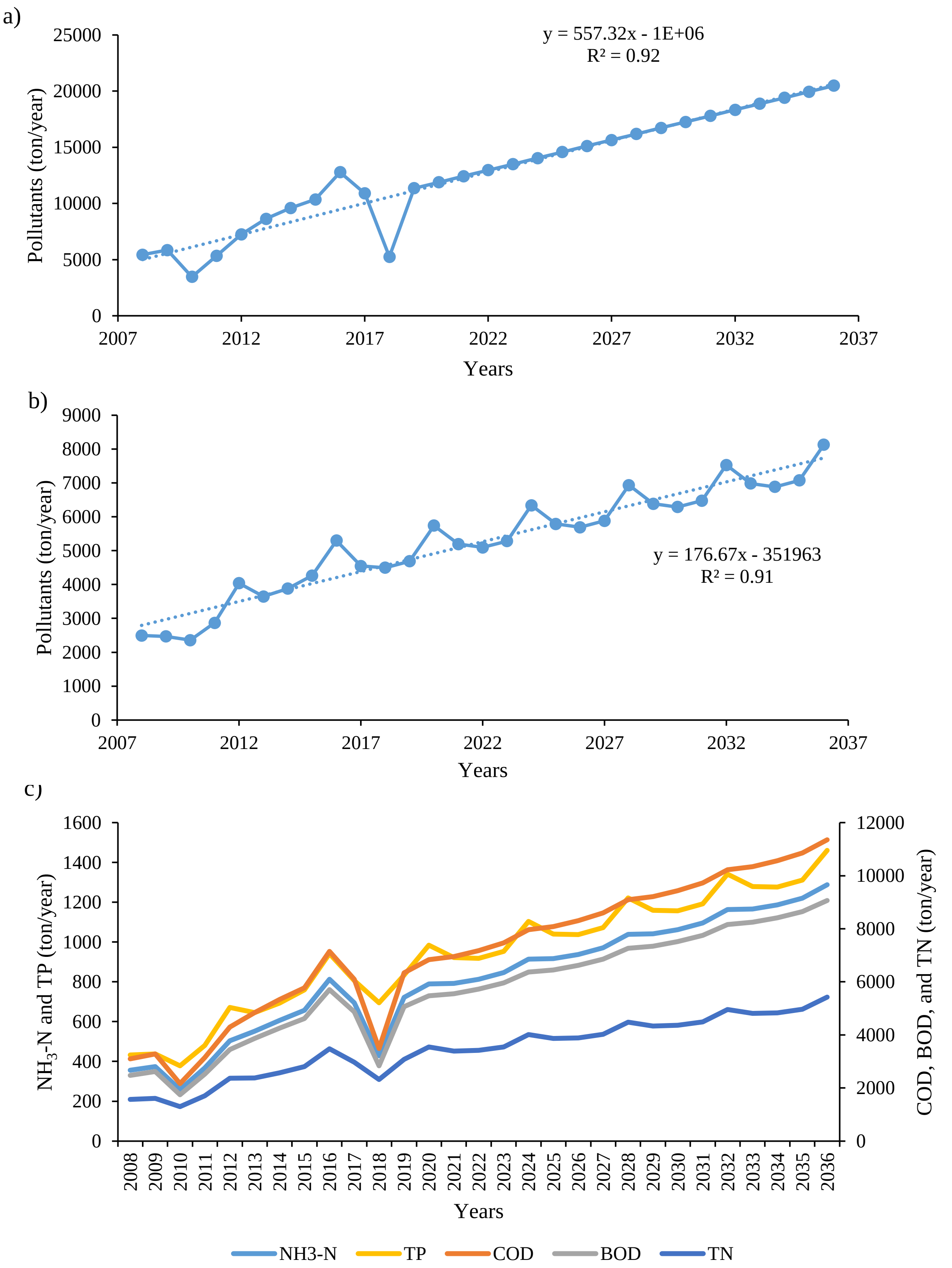


Fig. 3.11 Prediction for livestock potential excreta pollutants (kg/year) a) Pollutants from cattle, b) Pollutants from sheep c) Total amount of potential excreta pollutants in Ogii Lake County

According to the livestock growth prediction, livestock water demand and livestock-related pollutants would increase. The total amount of potential contaminants would be account as 1288.07 ton NH_3-N, 11358.11 ton COD, 9062.76 ton BOD, 1461.03 ton TP, and 5427.33 ton TN in 2036. The water demand also increased up to 876.809 cubic meters while the livestock population increase by 3.86 times in 2036. Therefore, local government and herders should pay attention to the growing vast number of livestock, due to the current environmental situation such as degradation of pasture and water sources.

Available drinking water sources such as wells, reservoirs, and aquifers in Ogii Lake County decreased by 12 wells, and remaining wells are 45, while livestock population reached in 2018 at 13543 thousand head cattle, 12931 thousand head horse, 164757 thousand head sheep, 86692 thousand head goat, and 0.367 thousand head camel those belong to 969 households. Those water sources mostly used during the winter season by herders to supply drinking water for livestock. Livestock access to the riverside and lake increases from middle of April to consume daily water. The Ogii Lake and Khugshin Orkhon River are the main water source for livestock for most of the year except the winter.

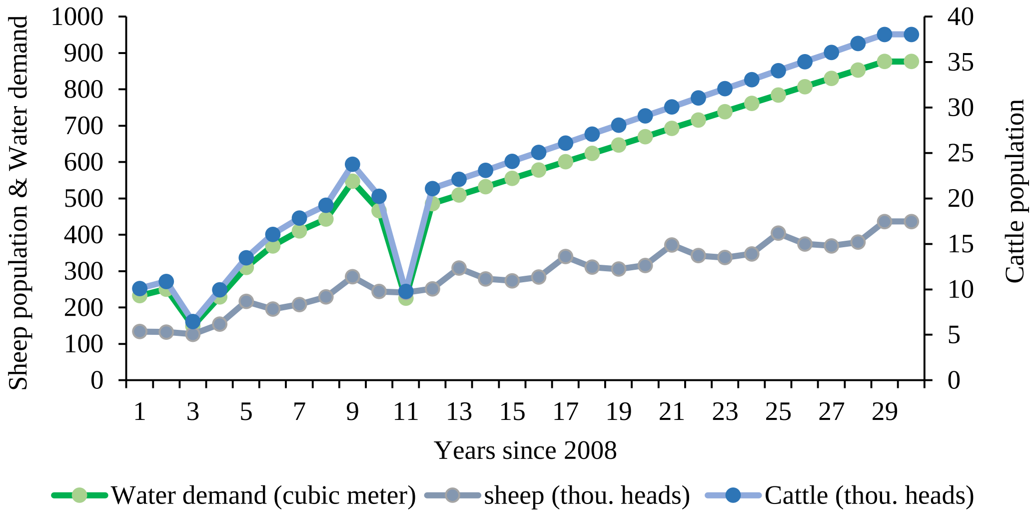


Fig. 3.12 Total livestock water demand in Ogii Lake County

Furthermore, due to climate change such as increasing temperature, evapotranspiration would be increased, that would impact on the vegetation growth cycle and species. Moreover, livestock water intake rate might increase in the future. It's essential to grow the livestock while considering the available pasture land, water availability, and so on. While facing the environmental changes in the recent decade, the local government need to implement some approaches that can solve the current problems in the rural area. In the future, livestock continuously one of the significant sectors of the Mongolian GDP; therefore, the livestock sector should develop under a new strategy that considering more about environmental situations. Therefore, different water sources such as wells or water tank should be operated to supply drinking water for livestock. Each household should build up a water tank to collect raining water and snow. Those approaches reduce livestock accessing time to the riverside to decrease livestock-related water pollution.

3.4 Summary

In this study, the environmental characteristics of Ogii Lake Basin were assessed based on field surveys in 2017 and 2018. The water samples along the Khugshin Orkhon River and Ogii Lake were analyzed, including several springs, and streams as well as groundwater. This study confirmed that the water quality of both Ogii Lake and Khugshin Orkhon River was classified as clean and slightly polluted. The NO_2^- and NO_3^- concentrations were determined to be similar to prior studies by JICA in 2006 in most of the water sampling sites. However, NO_2^- concentration was deemed high in stream and spring water samples in both years. PO_4^{3-} concentrations were relatively high (0.26 mg/L) at the sampling site where the Khugshin Orkhon River flows into the lake, as well as in the streams and spring water samples (0.20–0.28 mg/L) in both July 2017 and August 2018.

The water quality index of S2 and S3 was classified as dirty water, due to the high concentration of phosphorus and nitrogen. The free livestock access, as well as the settlement around S2 and S3 might be induced to increase the concentration of phosphorus and nitrogen.

Human waste generation was found to be a harmful consequence of seasonal tourism in the Ogii Lake environment due to a lack of proper management of lake-based tourism, as well the living habits of local people. According to the results of the questionnaire survey, 83% of households use lake water in daily life without any regard to water quality. Therefore, frequent water quality surveys need to be conducted to provide information to the residents in order to safeguard their well-being. According to the livestock census [44] in Ogii Lake County, the livestock population has increased over the last decade, while the total number of available water resources such as surface water reservoirs, wells, and aquifers has changed over time from 36 in 2012 to 57 in 2015, and then 45 in 2018. Mostly, livestock spend a long time along the Khugshin Orkhon River and Ogii Lake shoreline for grazing, watering, and resting. Therefore, livestock generated pollutants are able to leach to soil profile, and dissolve to the water bodies.

Considering the domestic settlements and livestock distribution around the lake, observed high PO_4^{3-} concentrations might have been more likely attributable to livestock, which has free access to the lake. The pollutants contaminated in the daily waste generation of cattle and sheep & goat around the Ogii Lake is accounted to the 87.05 ton NH_3-N, 76.79 ton TP, 230.93 ton TN, 199.83 ton COD, 169.91 ton BOD per year within 10 km distance. The simulation results indicated that the livestock population would be increased significantly in the future. In the year 2036 the amount of the contaminants and water demand would be increased by 3.8 times, while total cattle population reached around 38.043 thousand heads, and sheep and goat would reach about 436.415 thousand heads.

Chapter 4 Study on climate change impact on the Ogii Lake Basin

4.1 Research background

Lakes act as the essential components of the hydrological cycle, which would have affected on many aspects of ecosystems and human activities. Lakes remain sensitive to the natural changes, so as to serve as an important proxy of global climate change and regional environment variations[45]. The lake area is an important indicator of climate change, and it has a relationship with climatic factors that is critical for understanding the mechanisms that control changes in water levels[46]. Most inland lakes in arid regions were supplied by seasonal snow-melt water and rainfall, so they were sensitive to the volume of water flowing into the lake and evaporation losing from the lake surface[47]. Mapping lake area using RS images are important to detect their changes and to understand the relevance of lake variations to climate changes. RS is rapidly growing technology that can provide low-cost and reliable information for environmental changes at local, regional, and global scales, with their long-collected repeatable, and even real-time data[48].

In Mongolia, climate varies widely regionally due to differences in altitude and latitude. The large variation in the landscape makes Mongolia a sensitive area for climate change[49],[50] and evidence of current global warming has shown that this is occurring at a faster than the global average[51].

Mongolia has four distinct seasons, large temperature fluctuations, and relatively low precipitation. The annual mean temperature ranges from -8 ℃ and 6 ℃, and the annual mean precipitation is between 50 mm (Gobi Desert) to 400 mm (northern mountain district)[52]. According to the "Mongolian Second Assessment Report on Climate Change (MARCC)" in 2014, the mean air temperature at the land surface increased by approximately ~2.07 ºC from 1940 to 2013, and approximately 70 % of the annual total precipitation is occurs during the warm season[53]. The increasing annual temperature causes a decrease in the area of glaciers and permafrost in Mongolia. According to the report[52], the impact of climate change has been confirmed by the following evidence: i) the area of barren land expanded 3-fold while the area of woodland decreased by 26 % between 1992 and 2006; ii) Biomass in the rangeland decreased by 20–30 % over the past 40 years; iii) approximately 70 % of grassland is affected by desertification; iv) the time taken for the accumulated snow to disappear has advanced by approximately one month. Based on the representative concentration pathway (RCP) scenario set by the Intergovernmental Panel on Climate Change (IPCC), the annual mean global air temperature in Mongolia is forecasted to increase by nearly 2.2 ℃ in the near future (2016–2035), and by ~6.1 ℃ in the distant future (2081–2100) under RCP 8.5 scenario[53]. The data shown in **Fig. 4.1** was obtained from the Goddard Institute for Space Studies (GISS) at the National Aeronautics and Space Administration (NASA). According to the annual temperature trend, the surface temperature at Tsetserleg in Arkhangai Province decreased by -0.057 ºC during 1937–1967, increased by 0.59 ºC during 1968–1998, and increased by 1.67 ºC during 1999–2019. An increasing land surface temperature could contribute to decrease in available water resources, in part by the associated increase in evaporation from grassland and open water sources. Based on a water census report conducted between 2007 and 2016 in Arkhangai Province, a total of 403, 424, 508, and 100 water resources such as rivers, streams, springs, and lakes dried out during 2007, 2011, 2014, and 2016, respectively, thus accounting for 31.02 %, 22.11 %, 26.13 %, and 5.07 %, respectively, of the total number of these entities in each year[54]. Depending on the geographical location, most precipitation falls during the summer (June to August) in Mongolia, and contributes to an increase surface water discharge and increased lake water level. However, 70–90 % of precipitation evaporates back into the atmosphere[41].

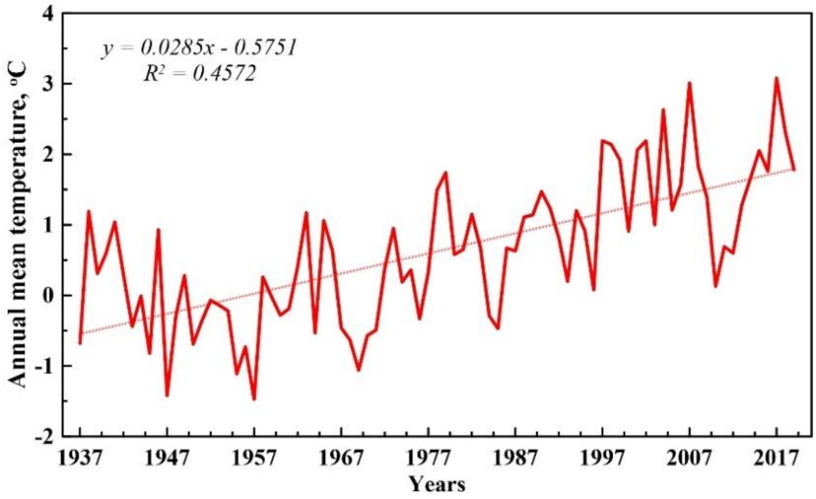


Fig. 4.1 Land surface temperature change trend at Tsetserleg station in Arkhangai Province

The rising temperature, increased evaporation, and associated evolution of the atmospheric flow circulation of the lake cause a reduction in the lake area[12]. According to the station data, average annual water level of the Ogii Lake has been under fluctuation. As shown in **Fig. 4.2** the highest water level was observed in 2004 (353 cm), however lake water level has been decreased gradually between 2004 and 2011. The lowest water level was observed in 2011 (179 cm), and then it has increased steadily until 2017 (323 cm), and decreased by 63 cm in 2018. As mentioned above, Ogii Lake has only one surface inflow to the lake.

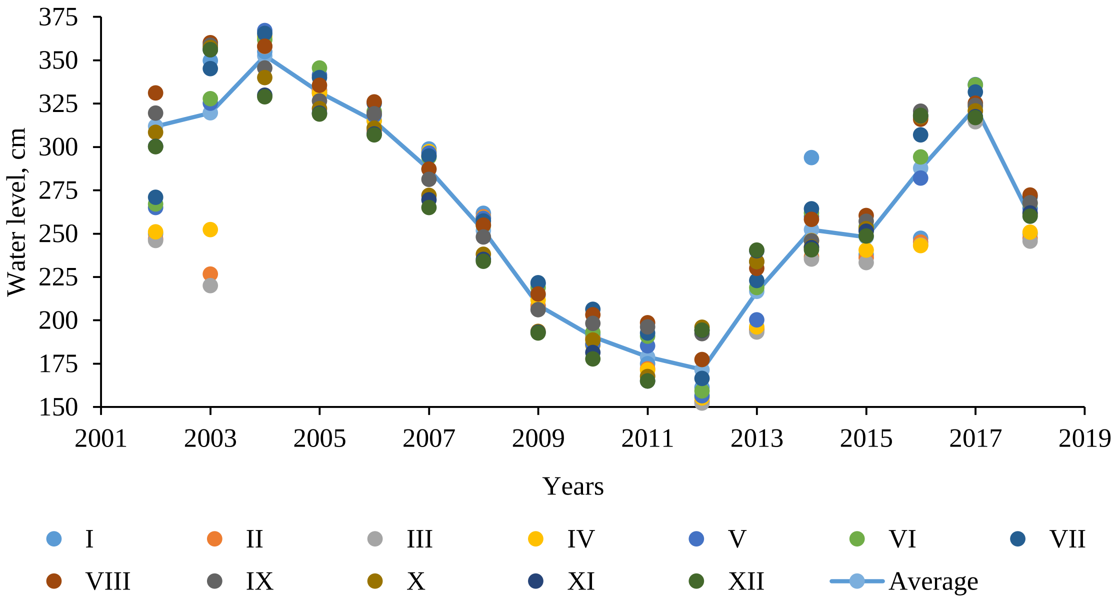


Fig. 4.2 Ogii Lake water level fluctuation, cm

Unfortunately, surface discharge data is not available during last two decades (1995–2015), because hydrological station at Khugshun Orkhon River was closed during the period.

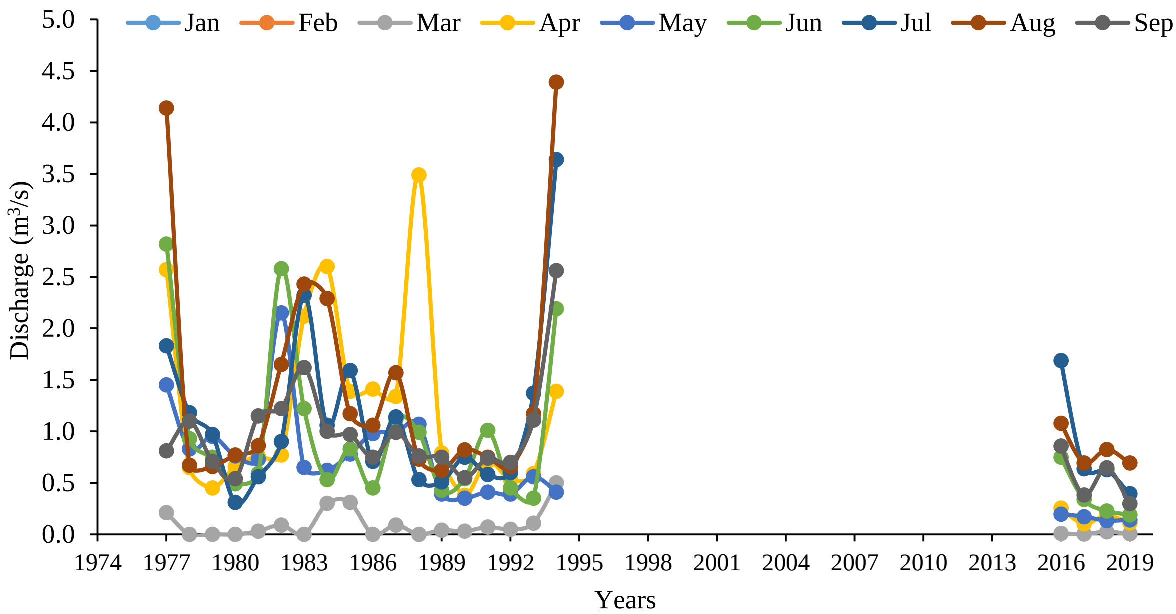


Fig. 4.3 Monthly averages discharge of Khugshin Orkhon River /1977–2019/

According to the discharge of Khugshin Orkhon River, highest value recorded mostly in August, it could contribute with rainfall that falls during the period between June to September. Discharge of Khugshin Orkhon River has decreased by more than two times in recent years comparing to the 1980s. For instance, the discharge of Khugshin Orkhon River accounted for 0.93 m^3/s, 0.88 m^3/s, 0.73 m^3/s, 0.77 m^3/s, and 0.36 m^3/s between 1977–1979, 1980–1984, 1985–1989, 1990–1994, and 2016–2019 respectively. Due to lack of long-term station data, its diffucult to assess the climate change impact on local hydrology which is valuable information on lake water balance. However, its clear that decrease in discharge may contribute to the global warming that influence the rate of evaporation from both water body and surrounding land. Moreover, it may influenced by the impact of human activities in the upper part of the basin.

Water balance of lakes a complicated research topic that requires a considerable amount of information regarding the local hydrology, climate conditions, and morphology amongst others. Ogii Lake’s water balance can be expressed by the following equation.

$$\mathrm{P} - \mathrm{E} + \mathrm{Y}_{SI} \pm \Delta V - Y_{SO} = \Delta Y_{GW} \qquad 4.1$$

where,

ΔV volume change of Ogii Lake, P precipitation, E evaporation, Y_{SI} surface inflow, Y_{SO} surface outflow, ΔY_{GW} groundwater change.

A case of Ogii Lake, water flow out from the lake at northern west side and joins the Orkhon River when water level of the lake has increased. However, due to the lake water level fluctuation in recent decades, outflow river from the lake has been dried out. Due to the absence of river discharge measurement, it’s difficult to estimate the lake water balance of Ogii Lake.

However, it's important to estimate the correlation of climatic variables with the changes in surface area.

The Ministry of Nature and Environment of Mongolia (MNE), and the Japan International Cooperation Agency (JICA) implemented the Ogii Lake Ecosystem Conservation Project from August 15 to September 30, 2005, from July 18 to October 29, 2006. The evaporation rate of Ogii Lake was estimated using 10-day intervals in September 2005 and September 2006. According to the results of the JICA scientific survey in Ogii Lake, the water level and volume increased by 3.9 mm and 9.5×10^{-5} km^3 when total precipitation was determined to be 22.1 mm, lake surface evaporation was calculated as 97 mm in September 2005. The water level and volume increased by 19.3 mm and 49.6×10^{-5} km^3 when total precipitation was determined to be 17 mm and lake evaporation was estimated as 54.5 mm in September 2006[8],[17]. Erdenesukh et al. (2019) studied correlation between hydro-meteorological variables of the Ogii Lake Basin and annual lake surface area changes. They concluded that annual temperature and summer temperature exhibited a weak, negative correlations with the surface area of Ogii Lake (R= –0.3 and R= –0.23 respectively). The total annual evaporation from the lake was estimated 110.5 mm as the average between 1986 and 2018 using the empirical equation by G. Davaa (1994). The maximum evaporation was calculated in 2017 (222.2 mm), and a minimum in 1990 (50.8 mm)[11].

With the exception of these previous studies, the correlations between climatic variables and the water balance of Ogii Lake over time has not yet been studied. Evaporation is one of the most important parameters for investigating the water balance of lakes. Accurate quantification of evaporation is important for water resources management, lake water balance studies, and the prediction of the hydrological cycle in response to climate change[55],[56],[57]. Previous studies used empirical equation based on Dalton's theory to estimate the evaporation from the lake water surface.

A wide variety of methods for estimating open water evaporation have been reported in the literature. Those methods can be categorized into seven types; pan evaporation, mass balance, energy budget models, bulk transfer models, combination models, the equilibrium temperature method and empirical factors.

Various methods for estimating evaporation from lakes have been tested[55], and a comprehensive comparison of these has indicated that the Priestly-Taylor[58], Penman[59], and the De Bruin-Keijman[60] methods can generally generate reasonable and relatively accurate evaporation values[55]. The estimation of evaporation from lakes or reservoirs via the energy-budget method using the Penman equation has been accepted as one of the more reliable indirect methods[61]. The energy-budget method requires standard meteorological measurements, such as air temperature, water surface temperature, relative humidity, wind speed. It also requires the net all-wave radiation flux at the water surface and the heat storage change for a given lake or reservoir. Therefore, the evaporation from the Ogii Lake's water surface was estimated using the energy-budget method which can generate more accurate results than other evaporation methods. The correlation between climatic variables and surface area of Ogii Lake using a long-term historical reanalysis data and satellite RS images were analyzed according to the following research framework–4 (**Fig. 4.4**).

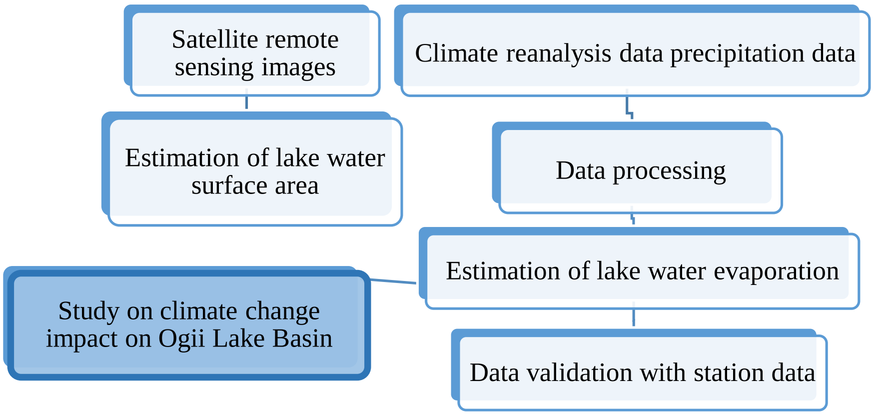


Fig. 4.4 Research framework–4

4.2 Data collection

4.2.1 Satellite remote sensing images

Remote sensing is an effective technology for monitoring water resources. In this study, both Landsat 5 TM and Landsat 8 OLI satellite RS imagery data were used to derive the surface area of Ogii Lake between 2002 and 2019 based on water indices rations in multiple-spectral RS water identification method. According to the requirement, cloudless satellite images of Ogii Lake was obtained. Landsat 5 was launched from Vandenberg Air Force Base in California on March 1, 1984, and like Landsat 4, carried the Multispectral Scanner (MSS) and the Thematic Mapper (TM) instruments and it delivered Earth imaging data nearly 29 years - and decommissioned on June 5, 2013. Landsat-8's operational land imager (OLI) and Thermal Infrared Sensor (TIRS) satellite was launched in February of 2013[62]. Each satellite data (pixel size of 30 m) were downloaded from the Earth Explorer at https://earthexplorer.usgs.gov/, which was developed by the United States Geological Survey (USGS). Due to the lack of cloudless satellite images of Ogii Lake in 2012, the monthly surface area of Ogii Lake in 2012 was excluded from this study. The difference in band range and resolution between the OLI and TM sensor is given in **Table 4.1**.

4.2.2 Available station data:

Ogii Lake Hydrological station (~102.77º E, 47.75º N) launched on August 2002, the daily water level, water temperature, air temperature, precipitation and wind speed parameters are under measure by manually twice a day at 8:00 AM, 20:00 PM at local time zone (GMT +8). Due to the lack of night time measurement, and several absences during the cold season, only daily water level data were obtained from the Ogii Lake hydrological station to analyze the seasonal changes on the lake water level. Then, monthly average water level was calculated from the daily water level data that were measured at the station between 2002 and 2018. Monthly precipitation data observed from the nearest hydro-weather station (Kharkhorin station) locates in 60 km distance from the lake. Due to the distance and lack of useful variables, the Kharkhorin station data was not suitable to use for calculating the lake water evaporation. Therefore, the fifth generation of climate reanalysis (ERA5) data were used to estimate evaporation from the lake water surface. Kharkhorin station data used as a reference for daily precipitation data.

Table 4.1 The difference in band range and resolution between the OLI sensor and TM sensor

	Landsat 8 OLI				Landsat 5 TM/ETM+		
№	Band	Wavelength (μm)	Resolution (m)	№	Band	Wavelength (μm)	Resolution (m)
1	Coastal aerosol (CA)	0.435–0.451		1	Blue	0.450–0.515	
2	Blue	0.452–0.512		2	Green	0.525–0.605	
3	Green	0.513–0.590		3	Red	0.630–0.690	
4	Red	0.636–0.673	30 m	4	NIR	0.775–0.900	30 m
5	Near Infrared (NIR)	0.851–0.879		5	Mid Infrared (MIR)	1.550–1.750	
6	Shortwave NIR1 (SWIR1)	1.566–1.651		6	Thermal Infrared Sensor (TIRS)	10.40–12.50	60 m
7	Shortwave NIR2 (SWIR2)	2.107–2.294		7	MIR	2.080–2.350	30 m
8	Pan	0.500–0.680	15 m	8 (ETM+)	Pan	0.520–0.900	15 m
9	Panchromatic	1.363–1.384	15 m				

4.2.3 Global reanalysis data:

A required climate data was obtained from the ERA5 database produced by the European Centre for Medium – Range Weather Forecast (ECMWF). ERA5 is an hourly reanalysis data with a spatial resolution of 0.25 ° latitude by 0.25 ° longitude grid. Obtained hourly data was used to produce a daily data for estimating the daily evaporation from the lake water surface from 1986–2019. The data consisted of a wind speed at 10 m level; air temperature (max, min, mean); dew point temperature at 2 m level; surface water temperature and surface temperature of ice cover in the warm and cold season respectively; roughness length governing momentum transfer; atmospheric pressure; net solar radiation at the lake surface.

4.2.4 GPCC precipitation data:

GPCC database consists of a large amount of daily and monthly data from different data sources[63] and it has been found to be a very good agreement with climatic atlases of WMO/UNESCO for Europe, South America, North and Central America and Asia[64]. A global daily precipitation gridded data with a spatial resolution of 0.5 ° latitude by 0.5 ° longitude from the Global Precipitation Climatology Centre (GPCC) was obtained from the Physical Science Laboratory (PSL) at the National Oceanographic Atmospheric Administration (NOAA) from their website *(*https://psl.noaa.gov/*)*. The obtained data were located between 102.71º–102.82º E, 47.74º–47.79º N, and the central point of this area is at ~102.75º E, 47.75º N, coinciding with the ERA5 grid point. The observed total annual precipitation data from the

Kharkhorin Station was used to validate the observed GPCC precipitation data. Based on geographical location, rainfall usually occurs within a relatively short period (June–August) after the dry spring months (March–May). **Fig. 4.5** indicates that the GPCC model data is in good agreement with station data (R=0.87; $p < 0.01$).

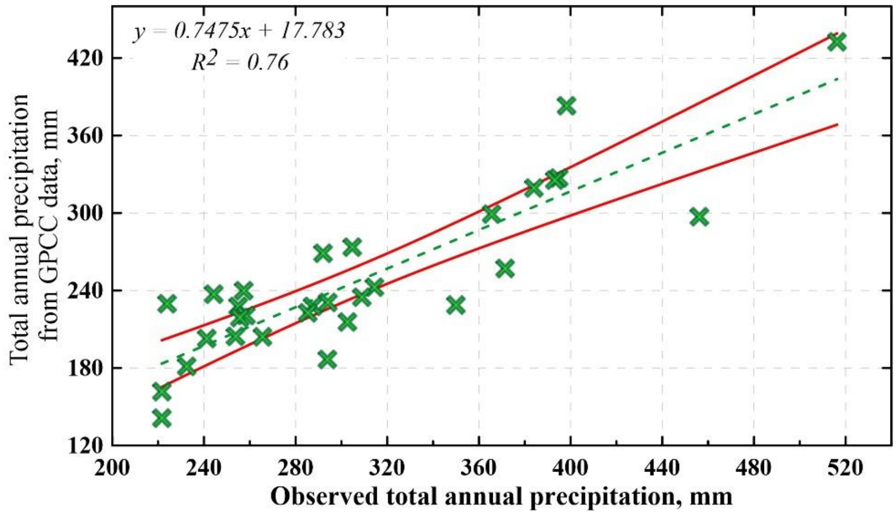


Fig. 4.5 Linear regression for a relationship between GPCC model and precipitation data of the Kharkhorin station

4.3 Research methods

4.3.1 Satellite image processing & analysis

Satellite images should be pre-processed before conducting any analysis. Because satellite images contain noise and digital number value offsets that are result of the viewing geometry of the satellite, atmospheric depth due to viewing angle of the sun's incoming radiation. Landsat 5 satellite images were pre-processed with the radiometric calibration tool in ENVI 4.7 which converted the digital number (DN) images to top of atmosphere (TOA) reflectance. A Landsat 8 images were also pre-processed using the **Eq. 4.2–4.3**.

$$\rho\lambda' = M_\rho * Q_{cal} + A_\rho \qquad 4.2$$

where,
$\rho\lambda'$ TOA planetary spectral reflectance, without correction for solar angle
M_ρ Reflectance multiplicative scaling factor for the band
Q_{cal} Quantized and calibrated standard product pixel value in DN
A_ρ Reflectance additive scaling factor for the band
TOA reflectance with a correction for the sun angle is then:

$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{SZ})} = \frac{\rho\lambda'}{\sin(\theta_{SE})} \qquad 4.3$$

where,
$\rho\lambda$ TOA planetary reflectance
θ_{SZ} Local solar zenith angle; ($\theta_{SZ} = 90^\circ - \theta_{SE}$)

θ_{SE} Local sun elevation angle (degrees)

The scene center sun elevation angle provided in the metadata, after the conversion process lake water surface delineated using different water indices. Then, the surface area of Ogii Lake was calculated using ArcMap 10.1 software.

There are various water indices developed to extract the surface water from surrounding land from RS imagery based on the spectral characteristics. In this study, the lake area was extracted by water indices ratios in multi-spectral RS water identification method, which includes: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index-1 (MNDWI-1), and Modified Normalized Difference Water Index-2 (MNDWI-2). **Table 4.2** is shown the multiband indices used for water feature extraction in this research.

NDVI is an index of plant greenness that is due to red light absorption and NIR reflection by plants. Its value ranges from −1 to +1. However, water does quite the opposite, which absorbs most of the NIR light; hence, NDVI could be used as the tool to delineate surface water features, i.e., negative value range[65]. NDWI is introduced by McFeeters in 1994, one of the most commonly used water indices to detect open surface water bodies and was first created by the green and near-infrared (NIR) spectral bands of Landsat TM. NDWI is designed by to (1) maximize reflectance of water by using green wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by vegetation and soil features. Xu (10, 11) noted that the threshold 0 was not an appropriate distinguishing feature and proposed the Modified Normalized Difference Water Index (MNDWI). The extracted water distributions in cities based on the MNDWI index using Landsat Enhanced Thematic Mapper Plus (ETM+) imageries, finding that the MNDWI was much better than NDWI in distinguishing water from shadow. Zhang et al. (12) and Yang et al. (13) compared the results of the indices and single-band threshold to find that NDWI and MNDWI were both capable of quickly extracting water information and obtained accurate water information using an appropriate threshold.

Table 4.2 Multiband indices used for water feature extraction

Multiband index	Equation	Water value	Reference
Normalized Difference Vegetation Index (NDVI)	NDVI=(NIR-Red)/(NIR+Red) (4.4)	-	Rouse et al., (1973) [66]
Normalized Difference Water Index (NDWI)	NDWI=(Green-NIR)/(Green+NIR) (4.5)	+	McFeeters (1996) [34]
Modified Normalized Difference Water Index(MNDWI)	MNDWI1=(Green-SWIR1)/(Green+SWIR1) (4.6) MNDWI2=(Green-SWIR2)/(Green+SWIR2) (4.7)	+ +	Xu (2006) [67]

4.3.2 Historical reanalysis data analysis

The Penman energy-budget method for lake evaporation [55] is given in **Eq. 4.8**. The energy balance combination method for estimating evaporation requires the net all-wave radiation, heat storage changes, and slope of saturation vapor pressure curve, saturated vapor pressure and actual vapor pressure at the air temperature, aerodynamic resistance to be known. The heat gained or lost by the water mass proportional to the depth of the water body and temperature changes according to the relationship[68] given in the **Eq. 4.9**.

$$\lambda E = \frac{\Delta(R_n - Q_t)}{\Delta + \gamma} + \frac{C_p \rho_a (e_s - e_a)/r_a}{\Delta + \gamma} \quad 4.8$$

where,
λE Latent heat flux (W m^{-2}),
R_n Net radiation (W m^{-2}),
Q_t Heat storage change (W m^{-2}),
Δ Slope of the saturated vapor pressure-temperature curve at air temperature (kPa ºC^{-1}),
γ Psychometric constant (kPa ºC^{-1}),
λ Latent heat of vaporization (MJ kg^{-1}),
ρ_a Density of air (kg m^{-3}),
C_p Specific heat of $(C_p = 1.013 \times 10^{-3})$ air (MJ kg^{-1}·ºC^{-1}),
e_s Saturated vapor pressure at the air temperature (kPa),
e_a Vapor pressure at the air temperature (kPa),
r_a Aerodynamic resistance (s m^{-1})

$$Q_t = \rho \times C \cdot d \times \left(\frac{\Delta T}{\Delta t}\right) \quad 4.9$$

where,
ρ Density of water (kg m^{-3}),
C Heat capacity of water ($C = 4.186 \times 10^{-3}$ MJ kg^{-1} ºC^{-1}),
d Mean lake depth (m),
$\frac{\Delta T}{\Delta t}$ Change in the water temperature during the period Δt

As saturation vapor pressure is related to air temperature, it can be calculated from the air temperature. The most convenient form for saturated vapor pressure created by Magnus (1844)[69], and several scientists developed the Magnus formula. The equation developed by Matveev (1967)[11],[69] was used for this research (**Eq. 4.10**). As the dew point temperature is the temperature to which the air needs to be cooled to make the air saturated, the actual vapor pressure is the saturation vapor pressure at the dew point temperature[70]. Therefore, the actual vapor pressure can be derived from dew point temperature.

$$e = 6.108 \cdot 10^{(at)/(b+t)} \quad 4.10$$

where,
if t<0 °C, then a=9.5, b=265.5;
if t>0 °C, then a=7.63, b=241.9,
t is mean air temperature.

The transfer of heat and water vapor from the evaporating surface into the air above the canopy is determined by the aerodynamic resistance. The aerodynamic resistance can be represented as **Eq. 4.11** for open water bodies[55].

$$r_a = \frac{4.72 \cdot \left(ln\left(\frac{z_m}{z_0}\right)\right)^2}{(1 + 0.536 \cdot u_{zm})} \quad 4.11$$

where,

z_m Wind speed measurement height (m),
z_0 Roughness length governing transfer of heat and vapor (m),
u_{zm}Wind speed at $z_m$height (m s^{-1}).

The wind speed at 2 m above the ground surface were used for the aerodynamic resistance calculation in this study. The empirical equation suggested by the WMO based on the law by Hellman was used for estimating wind speed at 2 m above the ground surface[11] from the obtained wind speed at 10 m level **Eq. 4.12**.

$$v_h = v_{10}[0.233 + 0.656 \cdot \log(h + 4.75)] \quad 4.12$$

where,

v_{10} Observed wind speed at 10 m level,
v_h Estimated wind speed at given h level.
For calculating the evaporation, the slope of the relationship between saturation vapor pressure and temperature is required and it's calculated as below (**Eq. 4.13**)

$$\Delta = \frac{4098\left[0.6108 \cdot \exp\left(\frac{17.27 \cdot T_{mean}}{T_{mean} + 237.3}\right)\right]}{(T_{mean} + 237.3)^2} \quad 4.13$$

where,
T_{mean} is mean daily air temperature, (°C); exp=2.7183 (base of natural logarithm)

The psychometric constant is the ratio of specific heat of moist air at constant pressure (C_p) to latent heat of vaporization. The specific heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure[71].

For average atmospheric conditions C_p value of 1.013×10^{-3} MJ kg^{-1} $°C^{-1}$ can be used. As an average atmospheric pressure is used for each location, the psychometric constant (**Eq. 4.14**) is kept constant for each location depending of the altitude.

$$\gamma = \frac{C_p \cdot P}{\varepsilon\lambda} \times 10^3 = 0.00163 \cdot \frac{P}{\lambda} = 0.000665 \cdot P \qquad 4.14$$

where,

γ Psychometric constant, (kPa $°C^{-1}$);

P Atmospheric pressure, (kPa)

λ Latent heat of vaporization, (2.45, MJ kg^{-1});

C_p Specific heat at constant pressure, 1.013×10^{-3}, MJ kg^{-1} $°C^{-1}$;

ε Ratio molecular weight of water (vapor/dry air = 0.622).

In order to estimate the lake volume changes, the topographic map (**Fig. 4.15**) of the Ogii Lake was obtained from the literature with the lake depth measurement (**Table 4.8**). Firstly, surface area of each depth was calculated using ArcGIS, then volume of the lake was calculated using the **Eq. 4.15**.

$$V = \sum_{i=1}^{n} [(A_i - A_{i+1}) \times d_i] \qquad 4.15$$

where,

V Volume of the lake,

A Surface area,

d Depth of the lake level

n Number of each water depth, $i = 1, 2, 3.., n$

4.4 Estimation of changes on Ogii Lake water surface area using satellite remote sensing

Field survey result

The water surface area and water level are interrelated parameters of lake morphometry. Lake surface area changes are an indicator of local climate change. Previous studies[11], [12] analyzed the changes in surface water area of the lake based on satellite RS images each August from 1986–2018. The strength of the previous study is the illustration of temporal changes in the water surface area of the lake. Because of geographical location, most precipitation falls during the summer from June to August (**Fig. 4.10**), and contributes to an increase surface water discharge and increased lake water level. Therefore, monthly estimation of the lake water surface area is important to understand the changes in lakes in the steppe region. In this study, satellite RS images were used to calculate the monthly surface area of the lake from 2002–2019. Due to snow and cloud cover, satellite images were obtained from May to October. In addition, the length of the lake shoreline was measured three times between May to September, 2020 to assess the extraction accuracy of the different water indices. **Table 4.3** shown the detailed information of satellite images as well as field survey dates. Cloudless satellite images from path 134 and row 27 with 30 m resolution were collected and each water indices are estimated accordingly. The difference between water indices are shown in **Table 4.4,** and **Fig. 4.6**.

Table 4.3 Details of Landsat 8 OLI images and field survey dates

Field survey	Acquisition date	Landsat product ID	Path	Row	Resolution (m)
2020.05.16	2020.05.12	LC08_L1TP_134027_20200512_20200526_01_T1	134	27	30
2020.07.11	2020.07.15	LC08_L1TP_134027_20200715_20200715_01_RT	134	27	30
2020.09.19	2020.09.17	LC08_L1TP_134027_20200917_20201006_01_T1	134	27	30

Table 4.4 Comparison between the in-situ measurement and different water indices for estimating the surface area of Ogii Lake

Field survey date	Area (km^2)	Satellite name	Acquisition date	Area (km^2)			
				NDVI	NDWI	MNDWI1	MNDWI2
2020.05.16	25.099	Landsat 8 OLI	2020.05.12	24.818	24.837	24.905	25.072
2020.07.11	25.103		2020.07.15	24.647	24.767	24.984	25.528
2020.09.19	25.058		2020.09.17	24.65	24.75	24.95	25.27

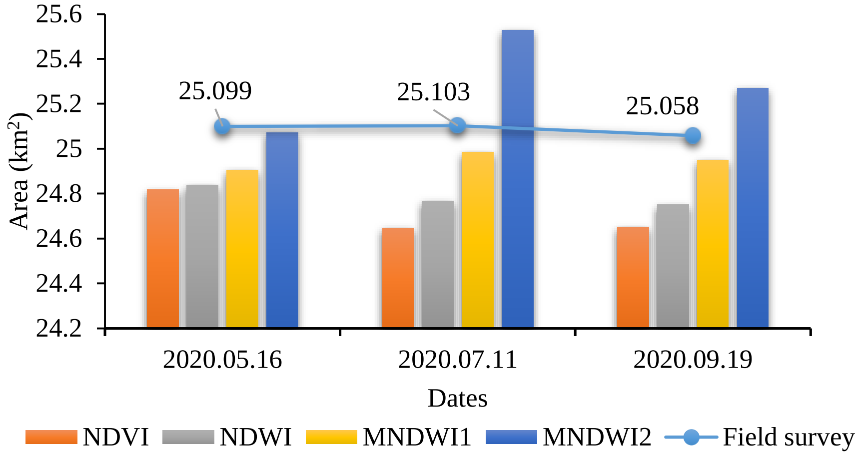


Fig. 4.6 Comparison of different water indices

According to the estimated lake water surface area both NDWI and MNDWI-1 were performed more close result than NDVI and MNDWI-2. A totally, 64 satellite images were used to estimate the monthly lake water surface area using both NDWI and MNDWI-1 within the study period from May to October (2002–2019). The estimated lake water surface area results were compared to the water level data from Ogii Lake station. **Fig. 4.7** illustrates that the estimated surface area of the lake had a strong, positive correlation (R=0.93 and R=0.94, $p < 0.01$) with the water level of Ogii Lake. Therefore, the lake water surface area can be estimated based on both NDWI and MNDWI-1 method for further studies.

As shown in **Fig. 4.8**, surface area of the lake changed slightly each month during the study period. It increases in August and September each year, which may contribute to the increases in both surface and groundwater discharge during the summer (rainy) season. Starting from the beginning of November, lake surface area covers by ice with thickness of 1–1.5 m depth during the winter season until mid of April. Once, the snow and ice cover get melted, surface water discharge and lake water level get increases depending on how much snow accumulated during the winter period. Since 2016, lake water surface area changes illustrate a steady increase in next two years.

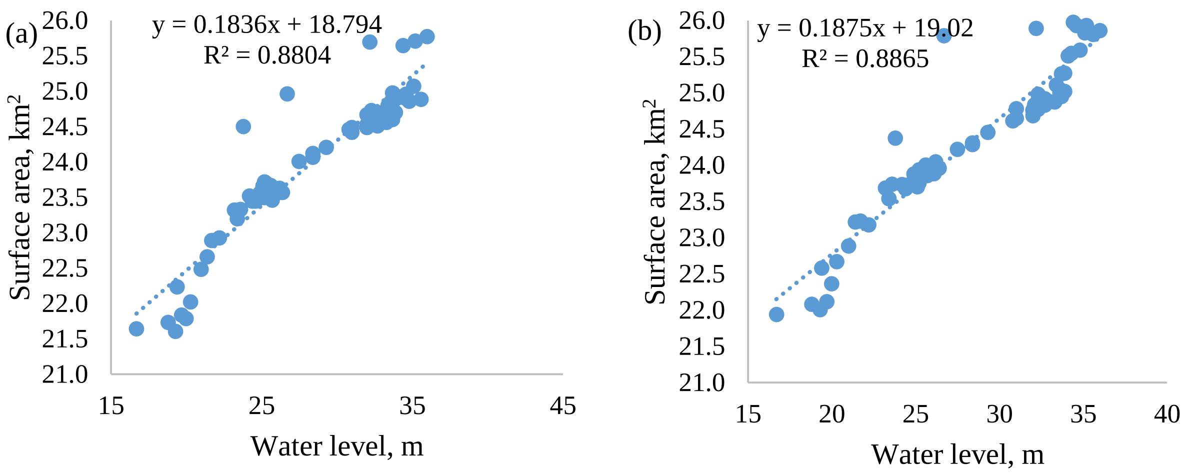


Fig. 4.7 Correlation between lake level and surface area (a) NDWI, (b) MNDWI-1

Table 4.5 Monthly average lake surface area fluctuation (km^2) using MNDWI-1

	May	June	July	August	September	October
2002	-	25.79	-	25.04	24.83	24.61
2003	-	-	25.27	25.86	25.98	25.89
2004	-	-	-	25.81	25.55	25.51
2005	-	-	-	24.95	24.88	24.77
2006	-	-	-	24.83	24.69	24.78
2007	-	-	24.45	-	24.22	-
2008	-	-	-	23.88	23.73	24.38
2009	-	-	-	23.22	22.89	22.58
2010	-	-	-	22.67	22.12	22.08
2011	-	-	-	22.37	22.00	21.94
2013	-	23.23	23.18	23.69	23.54	23.74
2014	-	23.89	23.96	23.86	23.68	23.73
2015	23.70	23.76	24.00	24.05	23.96	23.85
2016	24.29	-	24.65	24.76	24.76	-
2017	25.02	25.01	24.88	24.92	24.9	-
2018	24.82	24.76	24.98	25.93	25.93	-
2019	25.93	25.83	-	25.59	25.11	-

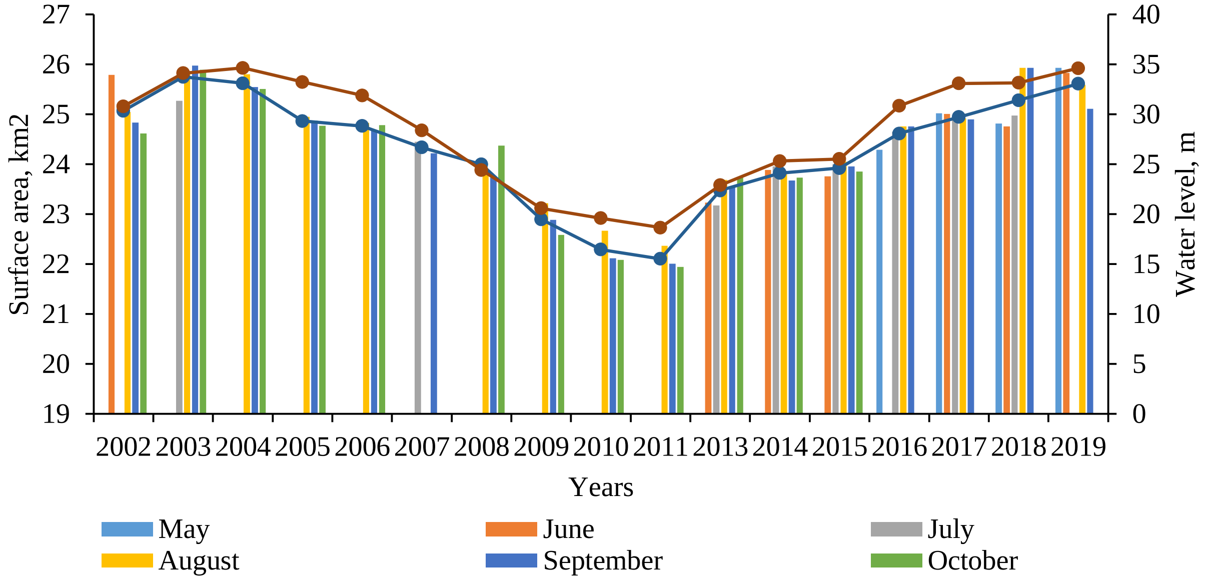


Fig. 4.8 Monthly lake surface area fluctuation between 2002 and 2019

The highest value of lake surface area was estimated in September of each year, **Fig. 4.9** is shown the difference between each year in September. As seen below, water flows out from the lake when the lake surface area get increase.

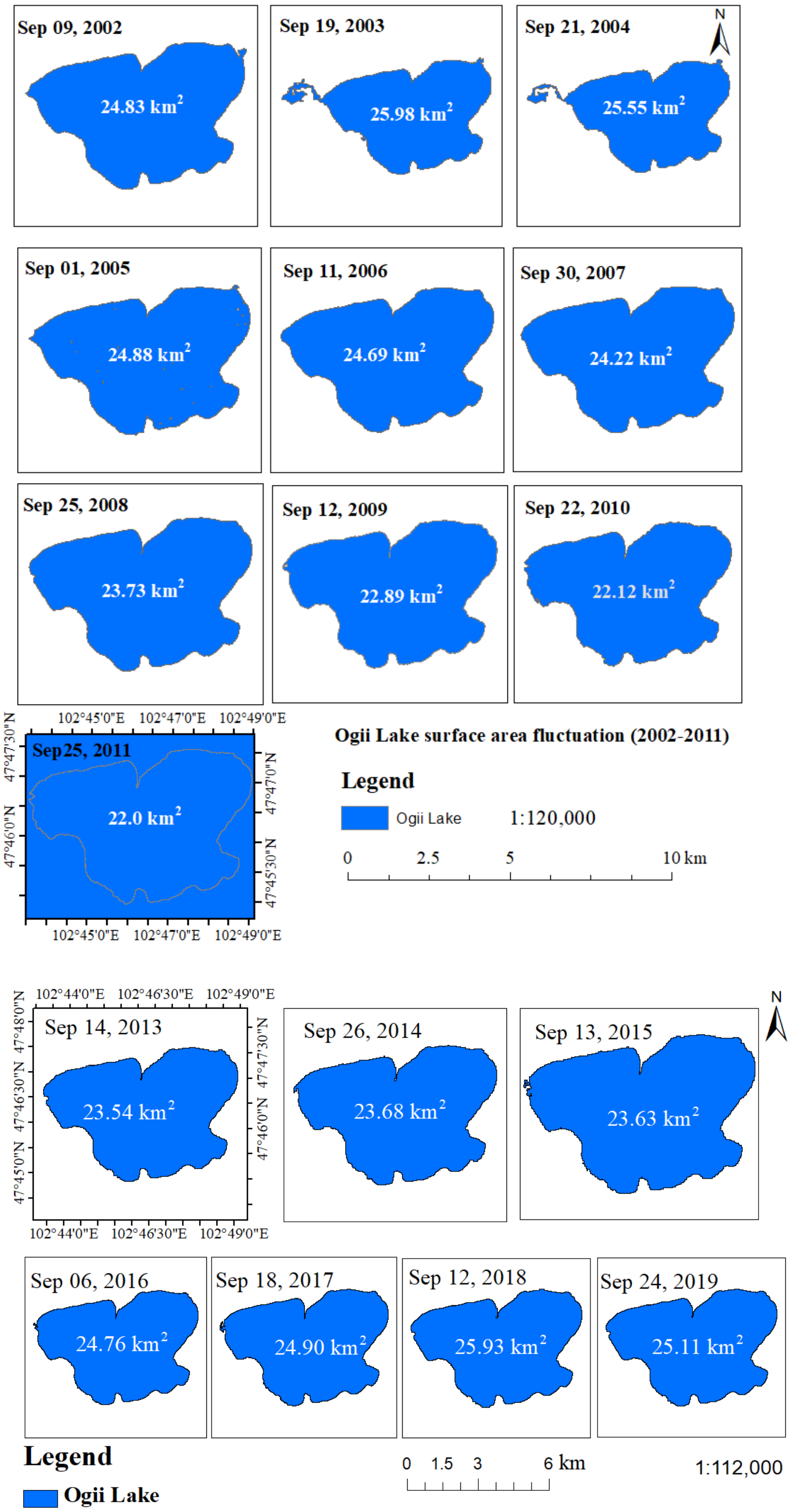


Fig. 4.9 Mapping of surface area of Ogii Lake in September of every year between 2002 and 2019

The monthly precipitation data along with the estimated lake surface area from 2002–2019 are displayed in **Fig. 4.10**. The highest recorded monthly precipitation was in July 2018 (113.25), which may have contributed to an increase in the lake's surface area of 0.95 km^2 at the following month (August 27, 2018). The lowest recorded monthly precipitation was in July 2017 (27.94 mm), which may have contributed to an increase in the lake surface area of 0.04 km^2 in the following month (August 01, 2017). **Fig. 4.10** illustrates that summer precipitation consist predominant amount of total annual precipitation, mostly it occurs during the month of July and August each year during the study period. According to the total annual precipitation trend since 2001, total amount of precipitation in the Ogii Lake Basin has been increased ($R=0.60$, $p<0.01$). However, within the study period total annual precipitation was increased and decreased. The lowest amount of summer precipitation recorded in 2001 and 2002, also between 2008 and 2010 which may have contributed to decline the surface area of the lake especially between 2008 and 2011 from 23.73 km^2 to 22.0 km^2 (**Table 4.5**).

Table 4.6 Monthly total precipitation (mm) in Ogii Lake basin /2001–2019/

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
2001	4.01	1.77	4.38	18.12	26.20	54.12	38.82	38.80	16.93	15.56	4.30	3.49	226.51
2002	2.24	1.79	1.67	13.29	21.55	16.37	45.81	12.14	9.51	24.00	3.88	3.97	156.22
2003	2.23	3.54	4.40	5.30	36.14	51.00	65.77	44.87	20.43	4.88	6.05	1.94	246.55
2004	1.28	1.47	5.54	0.58	12.59	29.44	79.27	22.58	17.39	1.53	1.70	2.08	175.46
2005	1.59	1.73	1.56	6.10	13.73	44.30	63.98	47.11	31.96	4.76	2.54	1.09	220.46
2006	0.96	1.87	3.89	12.16	28.59	44.64	85.25	40.10	6.77	10.24	1.31	1.42	237.20
2007	4.76	1.76	2.85	3.36	26.58	32.69	47.91	106.71	14.00	4.01	0.72	1.56	246.92
2008	1.82	0.63	11.24	3.88	14.93	85.08	56.65	39.30	13.41	9.21	0.28	3.33	239.77
2009	0.32	1.23	5.90	8.05	16.76	30.79	52.39	44.10	4.43	6.99	6.23	2.75	179.94
2010	2.41	1.78	9.22	10.14	20.48	52.55	57.81	65.19	9.09	11.44	7.06	3.48	250.65
2011	4.26	3.94	5.13	8.49	23.22	41.66	94.79	78.05	14.00	6.45	9.14	1.02	290.15
2012	0.55	0.80	2.16	6.84	16.44	45.50	112.95	81.51	13.74	7.15	10.27	4.52	302.40
2013	1.31	1.57	5.26	14.53	25.21	37.37	60.67	73.21	13.68	15.63	3.51	1.92	253.88
2014	0.35	2.16	4.46	13.58	38.69	59.05	57.18	41.32	36.19	9.15	2.67	1.05	265.86
2015	0.65	5.25	5.64	11.22	19.93	20.10	92.16	75.10	35.27	6.46	5.77	1.62	279.17
2016	2.90	3.45	6.85	22.02	23.68	83.83	89.91	65.90	43.82	10.57	8.26	5.16	366.35
2017	1.22	3.39	7.60	6.25	13.04	34.78	26.45	98.05	18.40	6.12	6.03	1.21	222.54
2018	5.19	2.21	3.05	15.69	1.54	62.97	113.25	73.73	39.17	5.68	2.68	1.53	326.69
2019	1.17	1.21	3.82	9.91	24.30	34.66	82.53	38.92	22.38	6.70	3.60	3.16	232.36

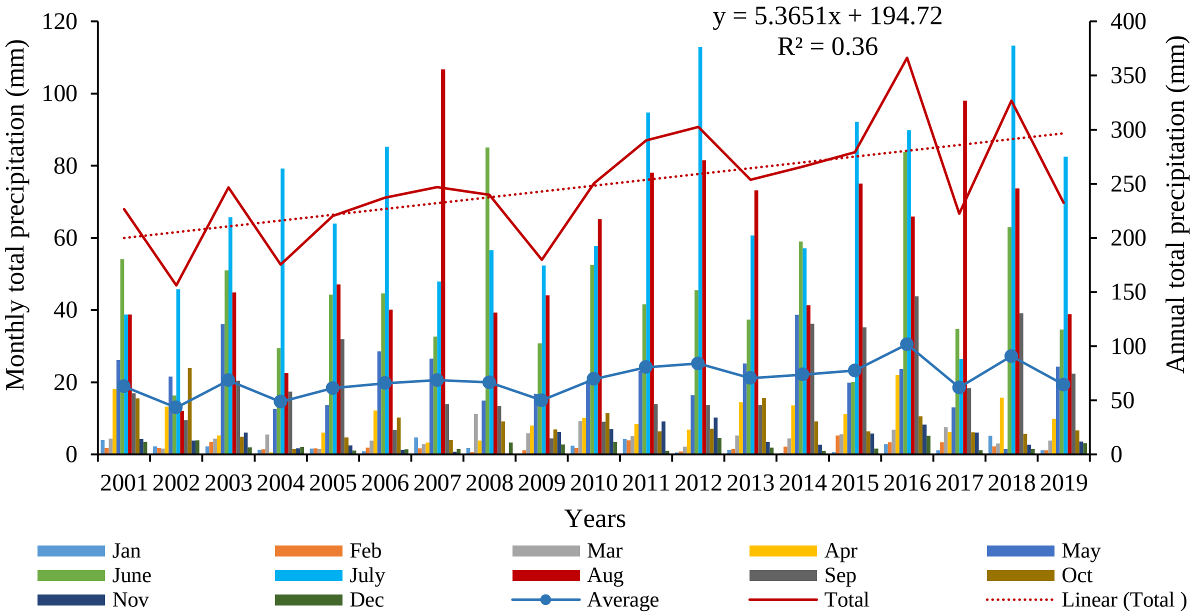


Fig. 4.10 Monthly total precipitation in Ogii Lake Basin (GPCC)

4.5 Estimation of evaporation from Ogii Lake using the energy budget method

Evaporation from the lake water surface is one of the primary components for understanding the correlation between lake water fluctuation and local climate change. Therefore, it should be estimated using the most accurate method based on long-term data. In this study, the Penman method were used to estimate evaporation from the Ogii Lake using historical reanalysis data set.

Fig. 4.11 shows the comparison between the estimated total annual evaporation and observed data on mean annual solar net radiation, total annual precipitation, and long-term lake surface area obtained from the literature[11]. Annual changes in the surface area of Ogii Lake were analyzed by the literature using ArcGIS software with Landsat satellite data each August between 1986–2018, and the surface area showed a strong, positive correlation with the water level changes (R=0.95, p < 0.01)[12],[11]. According to the estimation, the total annual evaporation from the lake surface was higher than the total annual precipitation especially since 1995. A comparison of the estimated total annual evaporation revealed reasonable agreement with the lake surface area changes in the literature, whereby the surface area primarily decreased when evaporation from the lake exceeded precipitation. The trend line in **Fig. 4.11** indicates a steady increase in evaporation from 1986 to 2019, with highest and lowest values of 338 and 282.08 mm in 2002 and 1986, respectively. Since 1995, lake water evaporation was estimated to be higher than 304 mm in most years. According to the estimated lake water surface area in September from 2002 to 2019, lake water surface area has decreased by 3.98 km^2 in 2011 comparing to 2003 levels. Since 2011, lake water surface area has increased rapidly, however, the lake water surface area remains lower than in 2003. The highest annual evaporation from Ogii Lake estimated in 2002 (338 mm), which may have influenced to decrease the lake water surface area. The lowest evaporation estimated in 2016 (303.63 mm), that may have induced to the increase in lake water surface area in 2016 as 24.2 km^2, which is 1.1–2.4 km^2 higher than in previous years. Evaporation from the lake has increased gradually that had a moderate, positive correlation with time (R=0.75), which was statistically significant (p<0.01). The increases in evaporation from the lake could be explained by the increases in solar net radiation, that had estimated average values of approximately 42.86 and 45.50 MJ m^{-2} d^{-1} from 1986–1994 and 1995–2019, respectively. It reveals increases in the temperature affecting the evaporation rate from the lake water, which is one of the consequence of the local climate change impact in this steppe region.

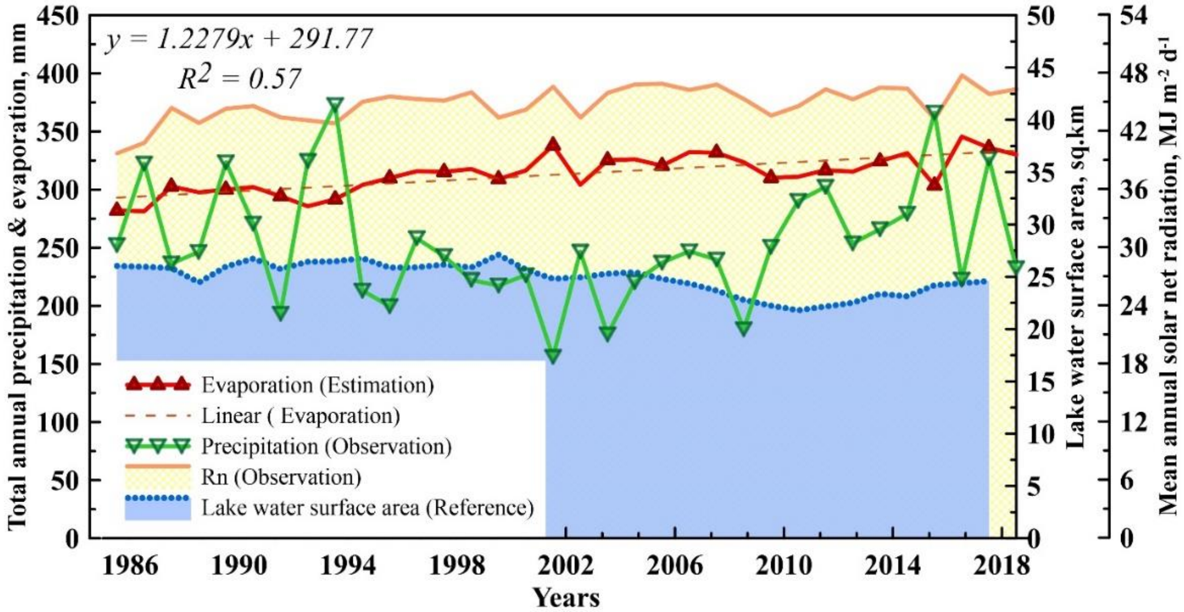


Fig. 4.11 Comparison of the total annual evaporation and precipitation, mean annual solar net radiation with mean annual lake surface area changes in August (1986–2019)

The variations between total annual precipitation and evaporation (**Table A. 2**) in Ogii Lake shows that mostly evaporation exceeds precipitation, which accounts approximately 24.27 mm, 82.89 mm, and 50.44 mm respectively, between 1986–1996, 1997–2007, and 2008–2019 (**Fig. 4.12**).

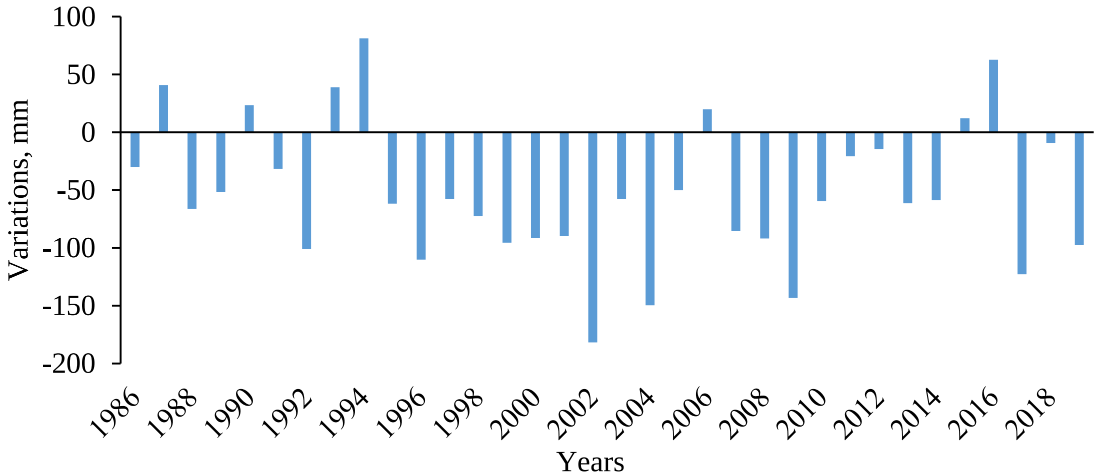
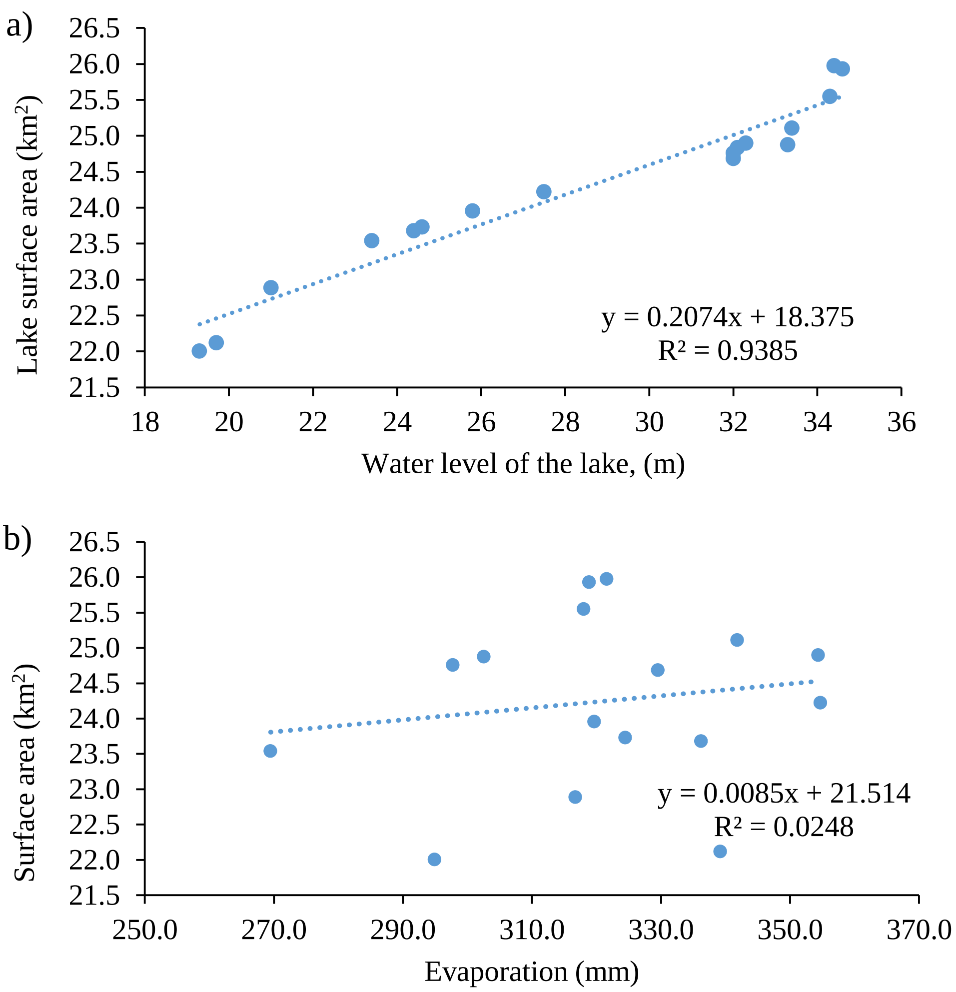


Fig. 4.12 Variations between total annual precipitation and evaporation in Ogii Lake

Correlation between the estimated lake water surface area, monthly total precipitation from GPCC, and the estimated monthly total evaporation from the lake during the study period

(2002–2019) are shown in **Fig. 4.13**. The estimated lake surface area result in each September has strong, positive correlation (R=0.96) with observed station data at Ogii Lake station (*p=6.36E-10)*. As the result showed in the previous subsection, Ogii Lake's surface area reaches at the highest value especially in September. Therefore, in order to study the impact of climatic variables such as evaporation and precipitation on changes in Ogii Lake's morphometric parameters, lake surface area was compared with the evaporation and precipitation between 2002 and 2019. Total amount of precipitation and evaporation were compiled between satellite image's acquisition dates in each September during the study period. For instance, the total evaporation and precipitation amount were compiled between June 01, 2002 and June 28, 2002 (28 days), and between June 29, 2002 and August 15, 2002 (48 days) that was compared with lake water surface area in June 28, 2002, and August 15, 2002, respectively (**Table A. 3**).

The estimated total evaporation from the lake had a weak, positive (R=0.15**)** correlation with lake water fluctuation which was statistically insignificant (p = 0.56; **Fig. 4.13 b)**. The monthly surface area of Ogii Lake had a weak, positive correlation (R=0.11) with total precipitation, that was statistically insignificant (p = 0.67).



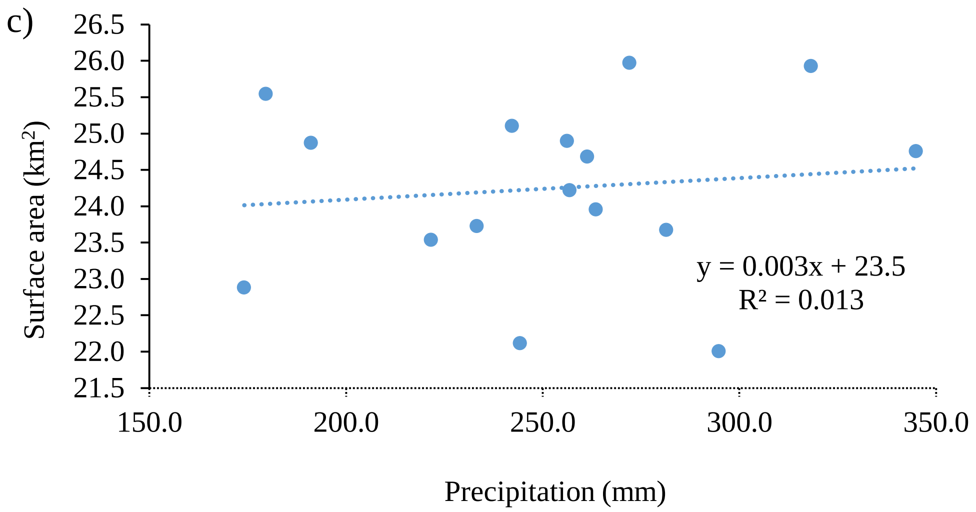


Fig. 4.13 Correlation of estimated lake water surface and a) observed lake water level, b) estimated lake water surface evaporation, c) observed precipitation (GPCC)

In last two decades, evaporation rates from Ogii Lake were estimated higher than total annual precipitation almost every year between 2002 and 2019. The results of surface area of Ogii Lake in September were decreased rapidly from 2003 to 2011, which may result of decreased rainfall during this period. The amount of total annual precipitation was accounted between 115.6 mm and 191 mm, while total annual evaporation accounted in average approximately 300 mm. In 2011, surface area was calculated similar with previous year (~22 km^2) when the evaporation rate was almost similar with the amount of precipitation between those periods. Lake surface areas were calculated higher than previous years in 2016 and 2018, while the total evaporation amount were lower and equal than precipitation (**Fig. 4.14**). Due to the lack of long-term surface water flow data, the contribution of evaporation from the surface area of the lake and precipitation on the lake was compared to monthly fluctuations in the water surface area of the lake (**Table 4.7**). The results illustrated that the water surface area of Ogii Lake has a weak, positive correlation with the evaporation and precipitation. The positive weak correlation between the surface area and precipitation could be explained by the increases of the evaporation from the lake, however, the evaporation from the lake and lake surface area also had weak and positive correlation during this study period. This unexpected correlation results suggest that the lake water balance is significantly affected by parameters not considered in this comparison. Based on the weak correlations between climatic variables and surface area fluctuations, the primary source for Ogii Lake could be surface and groundwater flow. Therefore, based on the available surface water inflow measurement, the water balance of the lake was estimated. An increase in the lake water surface area estimated in the literature (temporal changes) and estimated monthly changes could be related to groundwater discharge to the lake, because the literature found the tectonic fault that crosses through center of Ogii Lake from west to east. Therefore, mapping of the potential groundwater source of Ogii Lake is important.

Table 4.7 Comparison of climatic variables and morphometric parameters of the Ogii Lake in September (2002–2019)

Years	NDWI (km^2)	MNDWI-1 (km^2)	Water level (m)	Precipitation (mm)	Evaporation (mm)
2002	24.68	24.83	32.1	115.60	269.38
2003	25.65	25.98	34.4	272.07	321.59
2004	24.92	25.55	34.3	179.59	318.02
2005	24.56	24.88	33.3	191.08	302.56
2006	24.49	24.69	32	261.32	329.56
2007	24.01	24.22	27.5	256.85	354.73
2008	23.45	23.73	24.6	233.25	324.49
2009	22.49	22.89	21	174.08	316.76
2010	21.84	22.12	19.7	244.25	339.24
2011	21.61	22.00	19.3	294.75	294.93
2013	23.30	23.54	23.4	221.62	269.48
2014	23.45	23.68	24.4	281.45	336.27
2015	23.63	23.96	25.8	263.47	319.66
2016	24.53	24.76	32	344.88	297.78
2017	24.68	24.90	32.3	256.19	354.40
2018	24.96	25.93	34.6	318.21	318.90
2019	24.80	25.11	33.4	242.15	341.85

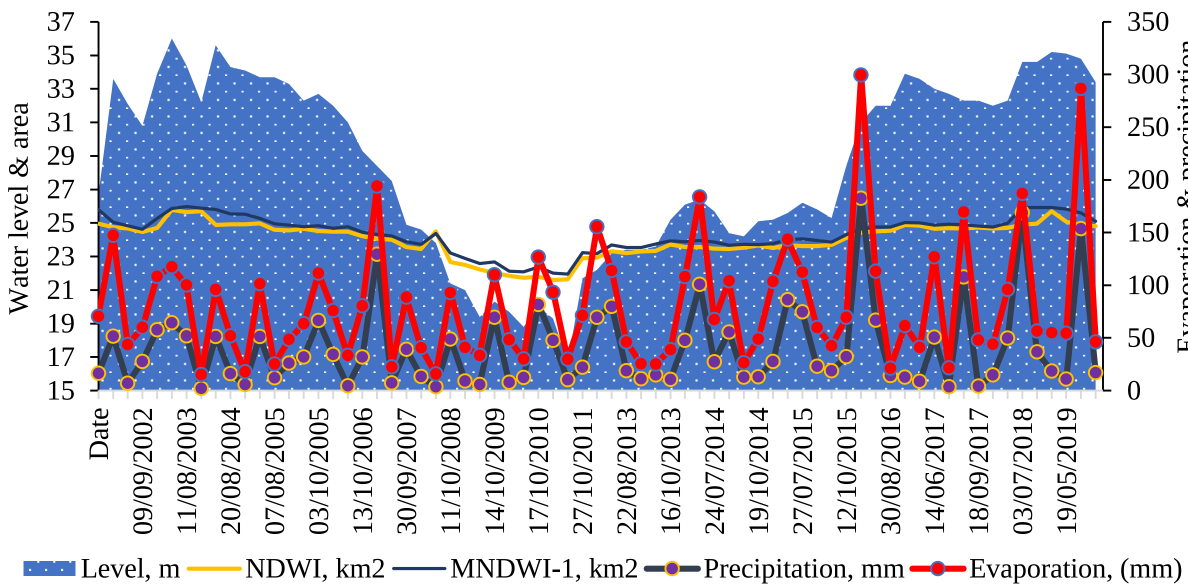


Fig. 4.14 Comparison of climatic variables and changes on lake morphology, monthly lake area fluctuation using NDWI, MNDWI1 /2002-2019/

4.6 Estimation of water balance of the Ogii Lake

As described earlier, the water balance of Ogii Lake can be expressed by **Eq. 4.1**. By using the topographic map (**Fig. 4.15**) of Ogii Lake that was provided by the literature the lake surface area and volume of the lake on each lake water depth was calculated using ArcMap 10.1. From

Table 4.7 it's clear that lake water depth get increases when the lake water surface area decreases. For instance, the estimated lake surface area 25.49 km^2 is belong to the 0.5 m depth, 23.59 km^2 is belong to 1 m depth, and 21.71 km^2 is belong to 2 m depth etc. Therefore, the estimated lake water surface area of September between 2016 and 2019 was used to calculate the lake water volume changes during the study period (**Table 4.9**) considering on the estimated lake water surface area and the reference morphometric data.

Table 4.8 The morphometric parameters of reference data

No	Reference lake depth (m)	Lake surface area of each depth (km^2)	Lake volume (km^3)
n	d	A	V
1	0.5	25.49	0.00095
2	1	23.59	0.00188
3	2	21.71	0.00362
4	3	19.90	0.00474
5	4	18.32	0.0056
6	5	16.92	0.0081
7	6	15.30	0.0141
8	7	12.95	0.01645
9	8	10.60	0.01248
10	9	9.04	0.01602
11	10	7.26	0.0196
12	11	5.30	0.01188
13	12	4.22	0.012
14	13	3.22	0.01833
15	14	1.81	0.0126
16	15	0.91	0.00825
17	15.3	0.36	0.00551
Total volume of the lake (km^3)			0.1721

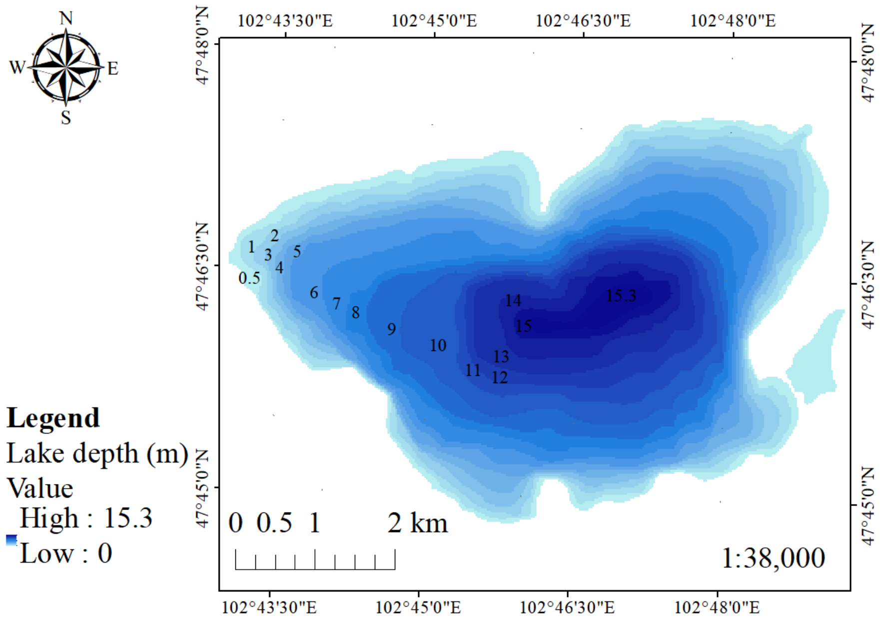


Fig. 4.15 Depth of the Ogii Lake

The volume of the lake between 2002 and 2019 were estimated using the lake morphometric data given in **Table 4.8**. The result (**Table 4.9)** shows that the estimation of the lake water volume is similar with the reference by the JICA in 2005. Therefore, it's possible to estimate the volume of the lake based on the satellite RS images (lake surface area) and morphometric data (lake depth). During the study period, volume of the lake decreased by 0.0006 km^3, 0.0014 km^3, and 0.0015 km^3 in 2009, 2010, and 2011, respectively compare to reference data in 2005 by JICA. Since 2013, volume of the lake steadily increased until 2018, and decreased by 0.0004 km^3 in 2019 compare to the previous year.

Table 4.9 The volume of the Ogii Lake between 2002 and 2019

Years	Surface area (km^2) (September)	Volume (km^3)	Reference by JICA in 2005 (km^3)	Lake volume changes (km^3)
Reference (2018)	25.49	0.1721		0.0011
2002	24.83	0.1717		0.0007
2003	25.98	0.1723		0.0013
2004	25.55	0.1721		0.0011
2005	24.88	0.1718	0.171	0.0008
2006	24.69	0.1717		0.0007
2007	24.22	0.1715		0.0005
2008	23.73	0.1712		0.0002
2009	22.89	0.1704		-0.0006
2010	22.12	0.1696		-0.0014
2011	22.0	0.1695		-0.0015
2013	23.54	0.1711		0.0001
2014	23.68	0.1712		0.0002
2015	23.96	0.1713		0.0003
2016	24.76	0.1717		0.0007
2017	24.90	0.1718		0.0008
2018	25.93	0.1723		0.0013
2019	25.11	0.1719		0.0009

Based on the estimated water volume of the lake between 2015 and 2019, firstly, the changes on the lake volume was calculate within the study period. Then, water balance of the Ogii Lake was calculated using water balance equation given in **Eq. 4.1** based on the compiled data in **Table 4.10**. The result shows that volume of the lake gets increased steadily from 2016 to 2018, and decreased by 0.0004 km^3 in 2019. According to the result, the sum of surface inflow and outflow of the lake was negative which means the evaporation from the lake was higher than surface inflow and precipitation in 2017 and 2019. **Table 4.10** shows that the volume of the lake get increased by 0.0004 km^3 in 2016 comparing to the initial volume in 2015. Total surface inflow and outflow was calculated as 0.0028 which is expected increases of the volume of the lake in 2016, as mentioned, the estimated lake volume showed only 0.0004 km^3, which means rest of the total surface inflow and outflow (0.0024 km^3) discharged to the groundwater. Similarly, the changes on groundwater was calculated each year until 2019. In 2018, the total surface inflow and outflow was equal to the increases of the lake volume. As seen, the groundwater contribution to the Ogii Lake is considerable parameter, therefore, it's important to study the groundwater influence in the future.

Table 4.10 Water balance of the Ogii Lake

Year	Precipitation (km^3/year)	Evaporation (km^3/year)	Surface Inflow (km^3/year)	Total surface inflow/ outflow (km^3/year)	Lake volume (km^3)	Lake volume change (km^3)	GW inflow/ outflow (km^3)
	P	E	I	P-E+I	V	ΔV	ΔV_{GW}
2015	-	-	-		0.1713	-	-
2016	0.009077	0.007523	0.001278	0.0028	0.1717	0.0004	-0.0024
2017	0.005545	0.008611	0.000598	-0.0025	0.1718	0.0001	0.0026
2018	0.00848	0.008715	0.000766	0.0005	0.1723	0.0005	-
2019	0.005838	0.008294	0.000467	-0.0020	0.1719	-0.0004	0.0016

4.7 Summary

Evaporation from Ogii Lake between 1986 and 2019 was estimated for the first time using the energy-budget method. The impact of climate change on Ogii Lake Basin could be explained by the estimated evaporation from the lake, which exceed the total amount of precipitation since 1995. The total annual evaporation from Ogii Lake increased steadily over the last three decades; compared to 1989, annual evaporation increased by 20.02, 25.79, and 32.4 mm in 1999, 2009, and 2019, respectively. The variations between total annual precipitation and evaporation in Ogii Lake was accounted approximately 24.27 mm, 82.89 mm, and 50.44 mm respectively, between 1986–1996, 1997–2007, and 2008–2019. The monthly surface area of Ogii Lake had a weak, positive correlation (R=0.11) with the total monthly precipitation in September each year from 2002–2019. The lake water surface area using both NDWI and MNDWI-1 illustrated a strong, positive correlation (R=0.93 and R=0.94, $p < 0.01$) with the water level data from Ogii Lake station. The volume of the lake was calculated using the morphometric data and estimated lake surface area from satellite data, the result was consistent with the result of previous study by JICA in 2005. As mentioned, the gauging station of Khugshin Orkhon River (surface inflow to the lake) has restarted the measurement of water discharge since 2016, the water balance of the Ogii Lake was calculated and the result proved that the influence of the both surface and groundwater on the water balance of the lake are valuable parameters, which can be seen from the difference between the estimated lake volume and of the total inflow and outflow of the lake. Therefore, the potential zones of groundwater study are much important for further water balance studies as well as for decision makers to develop sustainable water management. Finally, this study provides a valuable information about the influence of the climate change on the lake of the steppe region in Mongolia.

Chapter 5 Study on potential groundwater zone of the Ogii Lake Basin

5.1 Research background

Groundwater is considered as the main portion of the water supply in arid and semi-arid regions[72]. Mongolia has uneven distribution of surface and groundwater. The high mountain range which includes Altai, Khangay, Khuvsgul and Great Khyangan produce 70% of surface water[73]. These mountain ranges constitute the catchment areas for main rivers. The Orkhon River is one of the main river and tributary in Mongolia with total length of 1066 km[6]. The Ogii Lake is the biggest lake in Orkhon River Basin, which covers an area of 25.7 km^2. In Mongolia, lakes are one of main surface water source as well as recharge source for groundwater. The potential exploitable groundwater resources of the Orkhon River Basin were identified under the project named "Strengthening Integrated Water Resources Management in Mongolia" with support from the Government of the Netherlands in 2012. The maximum amount of renewable groundwater resources in the whole Orkhon River Basin was found to be 0.19 km^3/km^2/year in the upper part of the Tamir River Valley near Ogii Lake[6]. The generation of a groundwater potential zone (GWPZ) map is particularly important in steppe regions, such as Ogii Lake Basin, as it would help in the development of a systematic action plan for the sustainable use of water resources. However, there is lack of available mapping of the GWPZs of Ogii Lake Basin, which, if available, could provide valuable information for both decision makers and for further research on the lake water balance studies. Conventional research and prospection methods (hydro chemical, geophysical, etc.) are time consuming and require a lot of financial resources and qualified personnel[74]. RS and GIS techniques have emerged as a very effective and reliable tool in the assessment, monitoring, and conservation of groundwater resources[75]. In recent years, most studies[72], [76]–[81] have widely applied RS data and GIS tools by integrating and analyzing thematic layers to delineate the GWPZs with effective results based on analytical hierarchy process (AHP) method. Therefore, in this study, RS, GIS and AHP were integrated to delineate the GWPZs of Ogii Lake Basin using different geo-environmental factors. The Ogii Basin area covers an area of 286.03 km^2 in the territory of Arkhangai Province in the center of Mongolia, situated in the sub-humid-cool zone at 1332 m above sea level between 102°38′37.351″–102°54′21.161″E, 47°36′34.576″–47°50′18.439″N (**Fig. 5.1**).

5.2 Data collection and research methods

The geo-environmental data used for the delineation of GWPZs in the Ogii Lake basin were digital elevation model (DEM), land use and land cover (LULC), rainfall, soil, slope, and drainage density (DD). Each geo-environmental data was obtained from several sources and produced according to the methods below individually.

5.2.1 Land use land cover classification technique

The LULC was mapped from the Landsat 8 OLI data (Landsat Scene Identifier: LC81330272017261LGN00; date of acquisition: 18 September 2017). The scene was corrected for geometric distortions and atmospheric noise and pre-processed to enhance the quality of the image using ERDAS Imagine 2015. The LULC of the basin was extracted using an unsupervised classification technique, followed by a ground-truth verification through the Google Earth Pro.

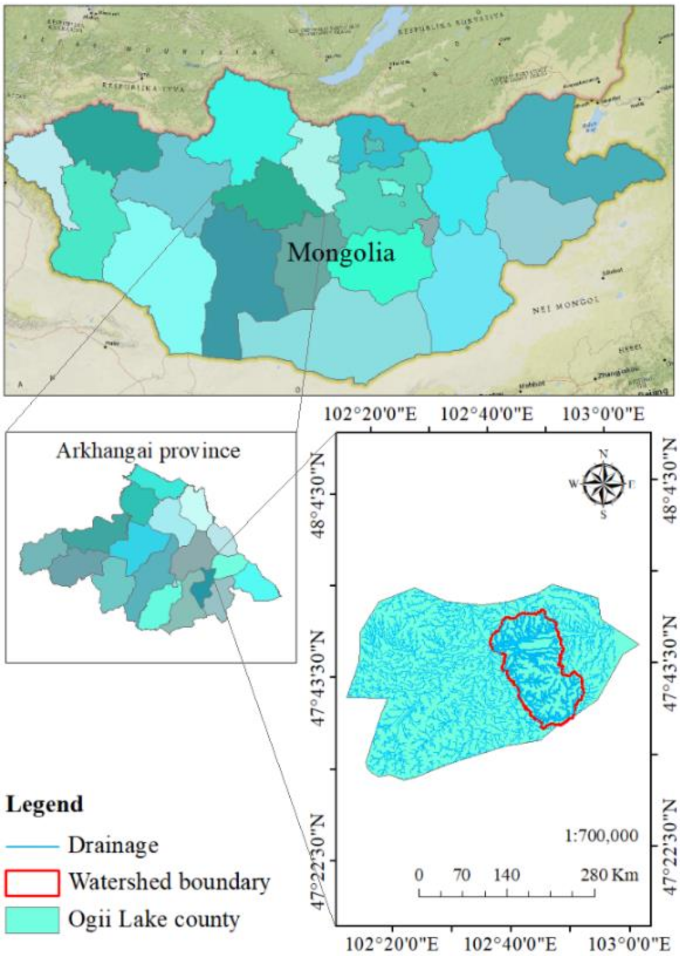


Fig. 5.1 Location map of the study area

5.2.2 Soil map generation

The digital world soil map was provided by the Food and Agriculture Organization (FAO) as an ESRI shape file format. The soil map of Ogii Lake Basin was obtained from the world soil map using the watershed boundary. Properties of soil map was also provided by the FAO document.

5.2.3 Rainfall map generation

The monthly precipitation with a high-resolution multivariate gridded data set from 2011–2019 was obtained from the Climatic Research Unit (CRU) time series (TS) from their website at https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.04/crucy.2004161557.v4.04/countries/pre/. The Network Common Data Form (NetCDF) rainfall data covers the monthly rainfall data between 2011 and 2019 that consist of 108 bands (108 months). The NetCDF rainfall data was extracted to raster layer using the multi–dimension tools in Arc Toolbox. The total annual precipitation of 2019 was calculated using the data management tool and spatial analyst tool in ArcGIS 10.1, and re-projected as a point data using the conversion tool for interpolation. Finally, interpolated raster data used to classify the rainfall into five classes through natural break classification method.

5.2.4 Digital elevation model

The advanced space borne thermal emission and reflection radiometer (ASTER) DEM was obtained at a spatial resolution of 30 m from the Earth Data at: https://earthexplorer.usgs.gov/. DEM was used to define the watershed area using spatial analyst tools in ArcGIS 10.1 software.

5.2.5 Slope and drainage density generation

Flow direction and flow accumulation were calculated to generate the drainage of the study area. Then, DD was estimated as the total length of streams of all orders in the unit area (**Eq. 5.1**) using the line density in the spatial analyst tools.

$$DD = \frac{\sum_{i=1}^{n} L_i}{A} \qquad 5.1$$

Where, $\sum_{i=1}^{n} L_i$ is the total length of drainage L, A is the total area of the study site (L^2), and n is the number of drainage networks in the basin. The slope map was generated on the DEM basis with a spatial resolution of 30 m.

After preparing all the thematic maps of DEM, soil, rainfall, and DD, the maps were reclassified using the natural breaks method in ArcGIS 10.1. The research flowchart of the delineation of the GWPZs is shown in **Fig. 5.2**.

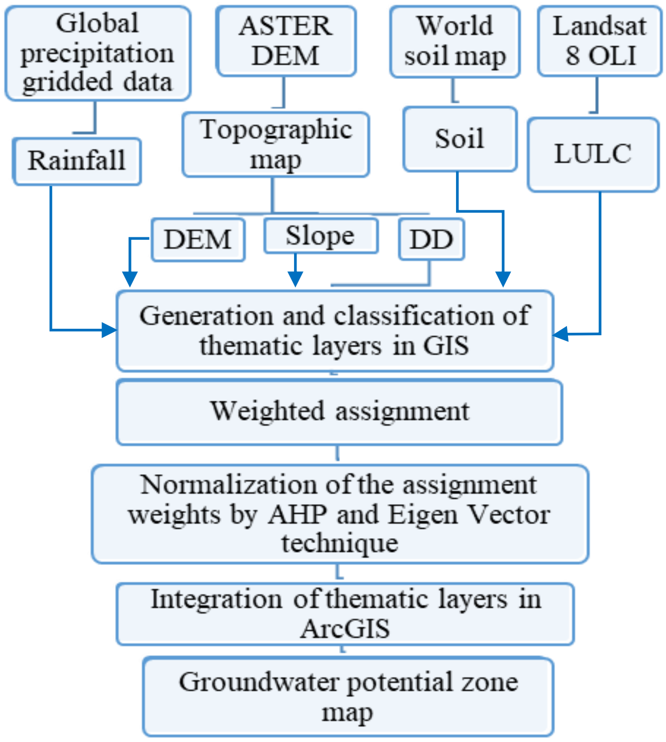


Fig. 5.2 Flowchart for groundwater potential zone

GIS-Based AHP method

In this study, the AHP method was applied to rate the selected factors that affect the groundwater potential of the study area. The AHP is one of the most widely used structured methods for analyzing and organizing multi-criteria decision making (MCDM) using the principle of psychology and mathematics, which was developed by Thomas L. Saaty in 1977. In this study, six hydrological and hydrogeological criteria were considered as the influencing factors on groundwater, namely, DEM, Slope, LULC, DD, rainfall properties, and soil properties. GIS-based MCDM is an expert-knowledge-based approach that is very useful for solving complex problems[82]. Therefore, a total of 10 experts (geologists and hydrogeologists) were interviewed through a questionnaire to seek their opinions on the relative importance of the hydrologic/hydrogeological factors influencing groundwater occurrence. The experts provided their opinions on the relative importance or weight of each pair of selected criteria based on a fundamental scale of values ranging from 1 (equally important) to 9 (extremely important) according to Saaty's scale (**Table 5.1**).

Expert pairwise comparison matrices are provided in the supplementary material (**Table A.4**). Priorities (P_i) were calculated using the row geometric mean method based on 6×6 comparison matrices from each expert using **Eq. 5.2** and **Eq. 5.3**.

$$P_i = \frac{r_i}{\sum_{i=1}^{n} r_i} \tag{5.2}$$

$$r_i = exp\left[\frac{1}{n}\sum_{j=1}^{n} \ln(a_{ij})\right] \tag{5.3}$$

Where

r_i : Elements in the obtained complementary matrix

a_{ij} : Transformed positive reciprocal matrix $i, j = 1,2, .. n$.

The final pairwise comparison matrix for this study was obtained from each expert's pairwise comparison matrices and each individual decision makers' weight for the six criterion using the weighted geometric mean through an online software tool for the analytical hierarchy process[83] created by Dr. Klaus D. Goepel (**Table 5.3).** The weighted geometric mean equation is shown below (**Eq. 5.4)**.

$$C_{ij} = exp\frac{\sum_{k=1}^{N} w_k \cdot ln a_{ij(k)}}{\sum_{k=1}^{N} w_k} \tag{5.4}$$

Where

C_{ij} : Consolidated decision matrices

$a_{ij(k)}$: Decision matrices element

w_k : Individual expert's weight for each criterion.

k : Number of experts

The weightings were then normalized to obtain an average weight of each criterion. The normalization of the weights was assigned by the AHP and an Eigen vector of the square reciprocal matrix was used to compare all possible pairs of criteria (**Table 5.4**).

Table 5.1 AHP numerical value classification

AHP numeric values (scales)	Definition
1	Equally important
2	Equally to moderately important
3	Moderately important
4	Moderately to strongly important
5	Strongly important
6	Strongly to very strongly important
7	Very strongly important
8	Very strongly to extremely important
9	Extremely important

Consistency associated with the pair-wise comparison matrix is estimated using the consistency ratio (CR) shown in **Eq. 5.5** to verify the coherence of the criteria weights.

$$CR = \frac{CI}{RCI} \quad 5.5$$

CI: Consistency index,
RCI: Random consistency index.
The value of RCI was taken from the standard table provided by Saaty (1980) and depends on the number of factors **Table 5.2**.

Table 5.2 Random index (RI) corresponding to the number of criteria (n)

m	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency index (**Eq. 5.6**) is the ratio of the difference between the Principal Eigen value (λ_{max}) (**Eq. 5.7**) and the number of factors or thematic layers (n) under investigation ($n = 6$).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad 5.6$$

A pair-wise comparison matrix is consistent only if the λ_{max} is greater than or equal to the number of the criteria (n) investigated[84]. The value of CR is recommended to be less than 0.1 or 10% for consistent weights[85].

$$\lambda = \frac{\sum_{i=1}^{n} (P_i W) \cdot n}{N.W} \quad 5.7$$

where $N.W$ is the normalized weight's vector.

Consistency of weightage on each thematic maps for delineating the GWPZs of the study were ($GCI = 0.02$; $Psi = 3.3\%$; $CR = 0.5\%$; $\lambda = 6.031$; $MRE = 11.3\%$).

After confirming the consistency of weightage for all of the thematic maps, the analysis process was performed with the spatial analysis and weighted overlay tools in ArcGIS 10.1 version. The weighted overlay analysis is a simple method to analyze multiclass maps based on the relative importance of each thematic layer and the layer's class[86]. This method was used to analyze the thematic maps into five classes starting from 1, which is less important, to 5, which is more important in terms of the occurrence of a groundwater potential zone in the study area. The GWPZs were computed using the weighted linear combination method[87] as follows (**Eq. 5.8**):

$$GWPZ = \sum_{j=1}^{m} \sum_{i=1}^{n} (W_j \cdot X_i) \qquad 5.8$$

where
$GWPI$: Groundwater potential index,
W_j: Normalized weight of the j thematic layer,
X_i: Rank value of each class with respect to the i layer
m: Number of thematic layers
n: Total number of class/features in a thematic layer

5.3 Result

The GWPZs of Ogii Lake Basin were delineated based on six thematic maps in GIS using the weighted overlay tool with weights for each factor being: LULC 4%, DEM 32%, DD 19%, rainfall 21%, soil 4%, and slope 20% in accordance with their influence on groundwater. The rates starting from 1 to 5 represent the reclassification of the thematic factors based on their contribution to the occurrence of groundwater (**Table 5.5**).

Table 5.3 Pair-wise comparison matrix for the AHP process

Matrix	DEM	Slope	LULC	DD	Soil	Rainfall
DEM	1.00	1.57	6.50	1.68	8.74	1.68
Slope	0.64	1.00	3.99	1.07	4.87	1.07
LULC	0.15	0.25	1.00	0.30	1.00	0.16
DD	0.60	0.94	3.38	1.00	4.70	1.00
Soil	0.11	0.21	1.00	0.21	1.00	0.20
Rainfall	0.60	0.94	6.09	1.00	4.99	1.00

Table 5.4 Normalized pair-wise comparison matrix and weights obtained for the thematic parameters

	DEM	Slope	LULC	DD	Soil	Rainfall	Normali -zation
DEM	0.32	0.32	0.30	0.32	0.35	0.33	0.322
Slope	0.21	0.20	0.18	0.20	0.19	0.21	0.199
LULC	0.05	0.05	0.05	0.06	0.04	0.03	0.045
DD	0.19	0.19	0.15	0.19	0.19	0.20	0.185
Soil	0.04	0.04	0.05	0.04	0.04	0.04	0.040
Rainfall	0.19	0.19	0.28	0.19	0.20	0.20	0.207
Eigenvalue							6.031

Table 5.5 Probability rating for the parameters

Parameters	Value range	Rating	Contribution to the GWPZ
DEM (m)	1331-1359	5	Very high
	1359-1405	4	High
	1405-1454	3	Moderate
	1454-1510	2	Low
	1510-1630	1	Very low
Slope (degree)	0-2	5	Very high
	2-5	4	High
	5-9	3	Moderate
	9-13	2	Low
	13-35	1	Very low
LULC	Water body	5	Very high
	Grassland	4	High
	Sand	3	Moderate
	Shurbland	2	Low
	Settlement	1	Very low
Drainage density (km/km^2)	0-0.784	5	Very high
	0.784-1.597	4	High
	1.597-2.521	3	Moderate
	2.521-3.894	2	Low
	3.894-7.145	1	Very low
Soil	Kl39-2b-4399	1	Very low
Rainfall (mm)	265.5-267.3	1	Very low
	267.3-268.8	2	Low
	268.8-270.3	3	Moderate
	270.3-271.9	4	High
	271.9-274.1	5	Very high

5.3.1 Digital elevation model

According to the classification of DEM, the study area consists of five different elevations, with highest at 1630 m above sea level (a.s.l), and the lowest at 1331 m a.s.l (**Fig. 5.3**). The Ogii Lake area is situated at the lowest elevation, which is classified as 1331–1359 m a.s.l. A low elevation has a higher impact on groundwater occurrence, while a higher elevation has a lower impact.

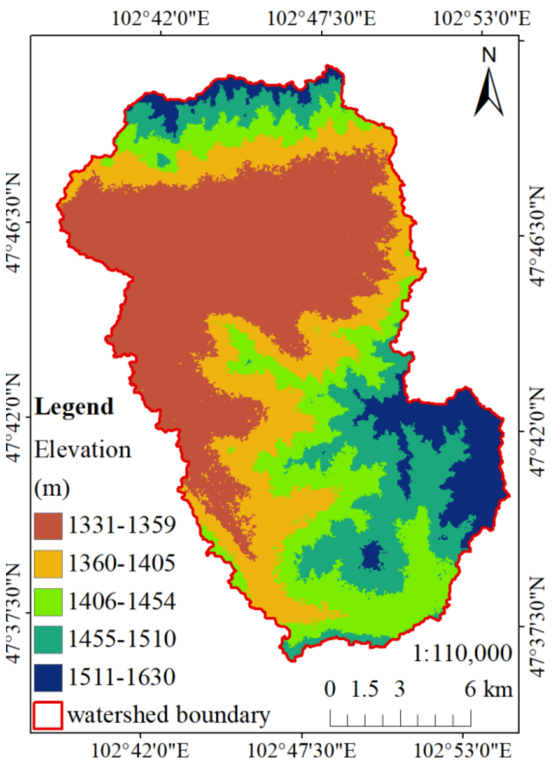


Fig. 5.3 Mapping of the DEM of the study area

5.3.2 Drainage density

DD is an important component when evaluating water recharge properties, although it is also important to consider its inverse function of permeability. A high DD develops on surfaces with low permeability as surface runoff exceeds infiltration[88], while a low DD occurs on permeable surfaces with greater infiltration and decreased runoff, resulting in potential areas for groundwater development[72]. A DD map of this study site was prepared using hydrology tools in ArcGIS 10.1 from an ASTER DEM, and then classified into five classes (**Fig. 5.4**) which vary between 0 and 7.14 km/km^2. The rates have been assigned according to each areas importance to potential groundwater recharge; defined as very high (0–0.784 km/km^2), high (0.785–1.597 km/km^2), moderate (1.598–2.521 km/km^2), low (2.522–3.894 km/km^2), and very low (3.895–7.145 km/km^2), which cover areas of 72.29 km^2, 81.47 km^2, 80.70 km^2, 42.20 km^2, and 9.37 km^2, respectively (**Table 5.5**). Mainly, the low DD areas are scattered along the drainage for whole basin including the Ogii Lake, while the high DD areas are scattered in the north-western part of the basin where the river networks are closely spaced. In total, 53.76%, 28.21%, and 18.03% of study site were areas with high–very high, moderate, and low–very low potentiality of groundwater occurrence.

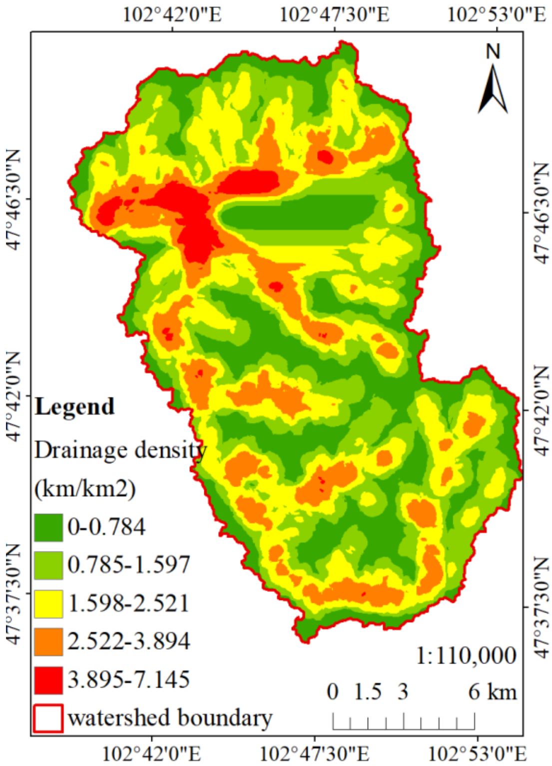


Fig. 5.4 Drainage density of the study area

5.3.3 Slope

Topography is a crucial factor governing the surface runoff as well as infiltration, and hence, the slope of the terrain has a significant effect on the groundwater recharge and occurrence[78]. The slope influences the hydrological characteristics of a given watershed, which mainly affects the surface runoff process. The areas with lower slope make rainfall infiltration and percolation higher than those of higher slope areas. Therefore, groundwater recharge increases as the speed of surface runoff is reduced. The southern and eastern parts of the basin are characterized by a gentle undulating terrain with broad saucer-shaped valleys, while the northern part is hilly and mountainous with elevations of up to 1600 m[4]. In the southern part of the Ogii Lake Basin, the relief is gently undulating/almost flat, with an absence of distinct forms indicating concentrated surface run-off[89]. The slope map of the study area was generated on a digital elevation model (DEM) with a spatial resolution of 30 m. There are five classes of slope identified in the Ogii Lake watershed using the slope spatial analyst tool in the GIS package (**Fig. 5.5**). Range of slope in the study site are approximately as follows: 87.92 km^2 plateau (0–2°), 80.38 km^2 gentle (3–5°), 67.06 km^2 more gentle (6–9°), 38.23 km^2 slightly steep (10–13°), and 12.44 km^2 steep (14–35°). Based on the generated slope classes, 58.84% of the study site could consist of very high to high GWPZs owing to the fact that plateau and gentle slope areas have a high possibility of holding rainfall and a high percolation to the aquifer of the basin. The steep slopes are mostly scattered at the northern and southern part of the watershed, and the plateau slopes are mainly situated along the riverbed, including the lake.

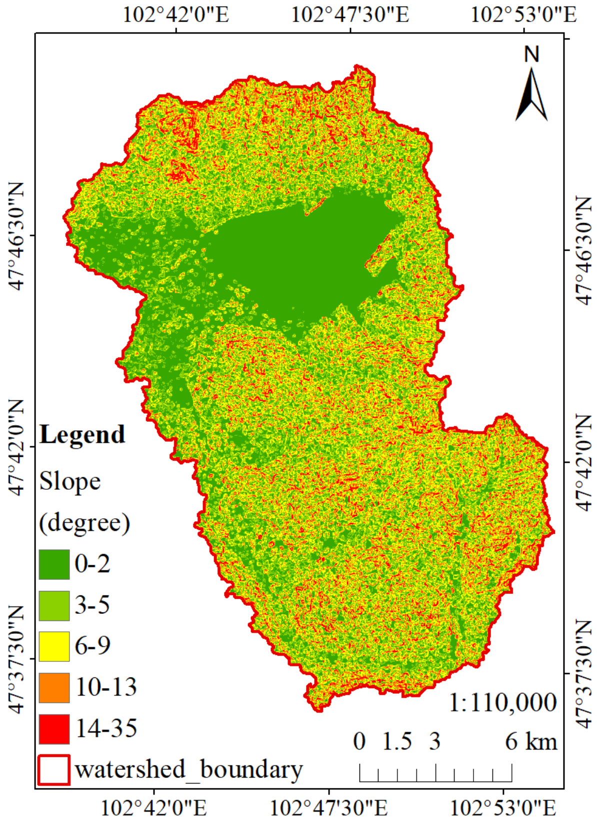


Fig. 5.5 Slope of the study area

5.3.4 Rainfall

Rainfall plays an important role in the hydrological cycle and controls the groundwater potential[90]. Owing to the geographical location, precipitation occurs mostly during the summer season starting from June to August, while precipitation in winter (November to March) occurs mostly in solid forms of up to 30 to 50 mm per year. The possibility of groundwater recharge would be high in areas where the rainfall is high and low where rainfall is low. The total annual precipitation of the study area was classified into five classes starting, 265.5 mm to 274.1 mm (**Fig. 5.6**) based on the data management tool in ArcGIS 10.1 using the total annual precipitation of 2019 with high-resolution multivariate gridded data. In 2019, the highest rainfall in the study area was recorded at the northern side of the basin, while the lowest occurred at the southern side. According to the classification, Ogii Lake area is belong to the high to very high rainfall zone of the basin where the average rainfall occurs approximately 270.4 mm to 274.1 mm respectively. As shown in **Table 5.5** the rates starting from 1 to 5 was given to the each classification of the factors depending on their contribution to the groundwater occurence. As seen, the ranges of rainfall between the 5 classes are very small within this study area, therefore, the rainfall was also classified into different classes as 1 classes, 2 classes, and 3 classes in order to identify the difference between the classification for rainfall for the result of GWPZs (**Fig. A.** 1).

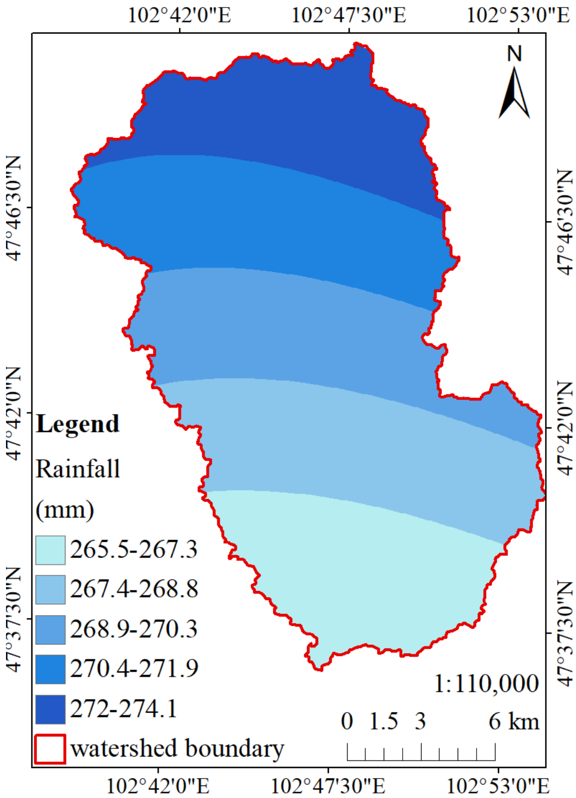


Fig. 5.6 Rainfall classification of the study area

5.3.5 Land use

The study site is situated within the area of dry grass steppes and is dominated by grasses (Cleistogenes, Stipa), forbs (Allium), and shrubs (Artemisia, Caragana), while trees are generally lacking[4]. The LULC of the study area was classified using the unsupervised classification in ERDAS Imagine 2015. According to this classification, 9.35% (26.75 km^2) are water bodies including Ogii Lake and Khugshin Orkhon River; 14.37% (41.1 km^2) grassland, 1.16% (3.33 km^2) sand, 73.60% (210.5 km^2) shurbland, and 1.52% (4.35 km^2) settlement (**Fig. 5.7**). Rates are given to each classification depending on their contribution to groundwater discharge (**Table 5.5**). The LULC determines the amount of precipitation that reaches the water table to recharge the groundwater[91]. Therefore, waterbodies have a high impact on groundwater, while settlement areas have a very low impact.

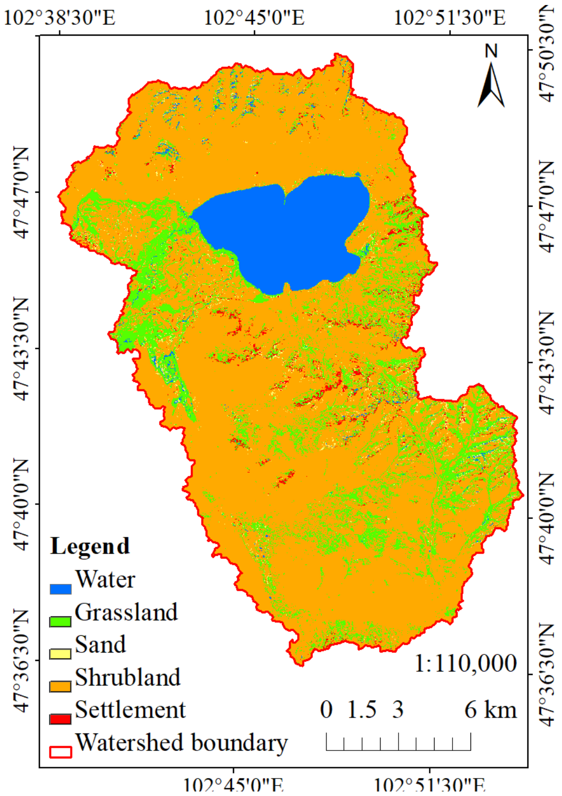


Fig. 5.7 LULC classification of the study area

5.3.6 Soil properties

Soil is a key variable determining the groundwater occurrence, as the soil texture controls the rate of infiltration[78] into the subsurface. According to the FAO soil unit classification, luvic kastanozem (Kl39-2b-4399), which is made of 19% clay, 44% silt, and 37% sand, is formed at this study site. Kantanozems are humus-rich soils that were originally covered with early-maturing native grassland vegetation, found in relatively dry climatic zones (200–400 mm of rainfall per year). The Ogii Lake Basin is located within the zone of highly continental steppe soil formation. Soils found in the Ogii Lake Basin predominantly consist of Kastanozems while Regosols and Leptosols are dominant on the steep slopes and ridges. Soils are loamy to sandy, riddled with a considerable amount of debris and pebbles that are often layered and adjusted[89]. In 2004, Wang et al.[5] reported that the east-central part of Ogii Lake (water depth of 14.5 m) had clay and silt layers at the 854–480 and 242–0 cm levels, respectively, while there was a silt layer at 480–242 with two carbonate-rich interlayers at 450–492 and 368–348 cm, investigated through laboratory analysis of a 854 m drilled sample. Schwanghart et al. also found fluvial sands at bottom depths of approximately 600 cm, clay/silty and organic rich sediments at approximately 200–600 cm, and organic poor loam in the overlying sediments (<140 cm)[4].

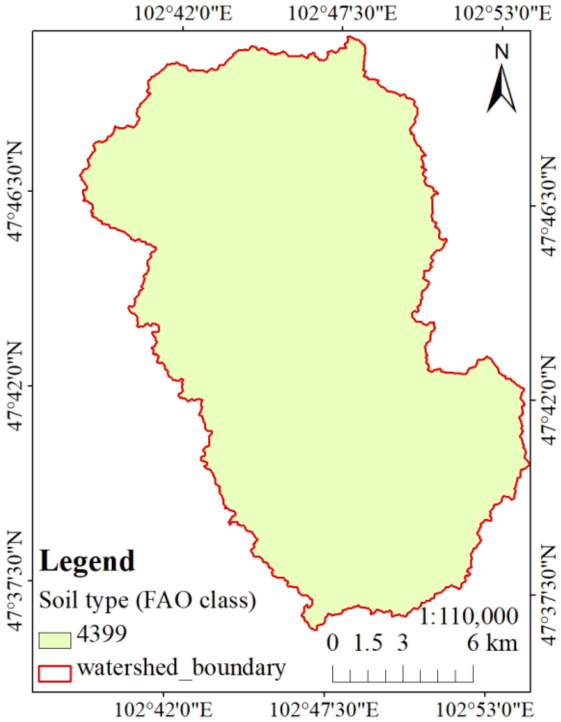


Fig. 5.8 Soil type of the study area

5.4 Delineation of groundwater potential zone

In this research, the advantage of the recent techniques was used to identify the GWPZs of small basin located in the remote and steppe area. The weighted overlay analysis results showed that a 0.68 km^2 area of the basin consisted of very poor GWPZs and 38.36 km^2 area of poor GWPZs (**Table 5.6**). Large watershed portion (83.5%) consisted of a moderate to high GWPZs. Very high to high GWPZs of the watershed were generated under the lake, and along the Khugshin Orkhon River and Orkhon River with the lowest elevation (1331–1359 m) and DD (0–0.784 km/km^2) and plateau category slope (0–2°). According to literature[11] Ogii Lake was formed by the meandering of Khugshin Orkhon River. Additionally, the literature[92] also concluded that the tectonic fault, which has the same direction as the Tamir River, crosses the Ogii Lake through its deepest part, from west to east. Therefore, the classification of the delineated GWPZs in this basin is reasonable.

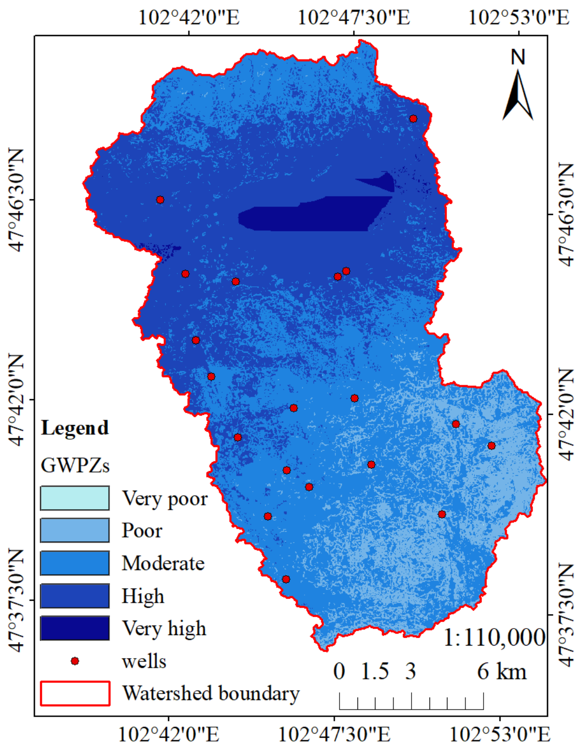


Fig. 5.9 Groundwater potential zone of the study area

5.4.1 Validation of groundwater potential zones

The coordinates of the study area's wells were obtained from the National Statistical Office of Mongolia (NSO). Due to the population density scarcity and scattered locations, the groundwater use in this study area is relatively low, which is only 19 wells were plotted in the Ogii Lake Basin. Local herders use groundwater mostly during the winter season when the available surface water is frozen. Therefore, mapping the GWPZs is essential for local people and government to manage the water resources without financial cost and explore potential groundwater sources through conventional methods. According to the classification of GWPZs 2 wells' location plotted in poor zone, 8 and 9 wells were plotted in the moderate and high GWPZs, respectively (**Table 5.6**). As there were no well depth measurements, the GWPZs map was validated by overlying the wells' location in the GWPZs map **(Fig. 5.9**).

Table 5.6 Groundwater potential zone of the study area

Value	Description	Area of GWPZs		Existing wells	
		(km^2)	(%)	Number	Success rate, %
1	Very poor	0.68	0.23	0	0
2	Poor	38.36	13.41	2	10.52
3	Moderate	125.03	43.72	8	42.11
4	High	113.83	39.80	9	47.37
5	Very high	8.13	2.84	0	0

5.5 Summary

The GWPZs of the Ogii Lake Basin were delineated by integrating RS, GIS, and AHP techniques. Six thematic layers were prepared individually, then applied for a weighted overlay analysis according to the AHP analysis result with a 0.5% consistency. The weights assigned to each thematic layers were 4% (LULC), 20% (slope), 21% (rainfall), 19% (drainage density), 32% (DEM), and 4% (soil). The GWPZs of the study area were classified into five zones, namely 2.84% of the study area (8.13 km^2) was situated in very good zone, 39.80% (113.83 km^2) in good zone, 43.72% (125.03 km^2) in moderate, 13.41% (38.36 km^2) in poor, and 0.23% (0.68 km^2) in very poor. The Ogii Lake area falls under high to very high GWPZ because of the geographical location characteristics. It could be explained by the aquafer water inflow through the tectonic fault from the upper side (west) of the lake.

Chapter 6 Discussion: Summary of key findings and recommendations

6.1 Summary of key findings

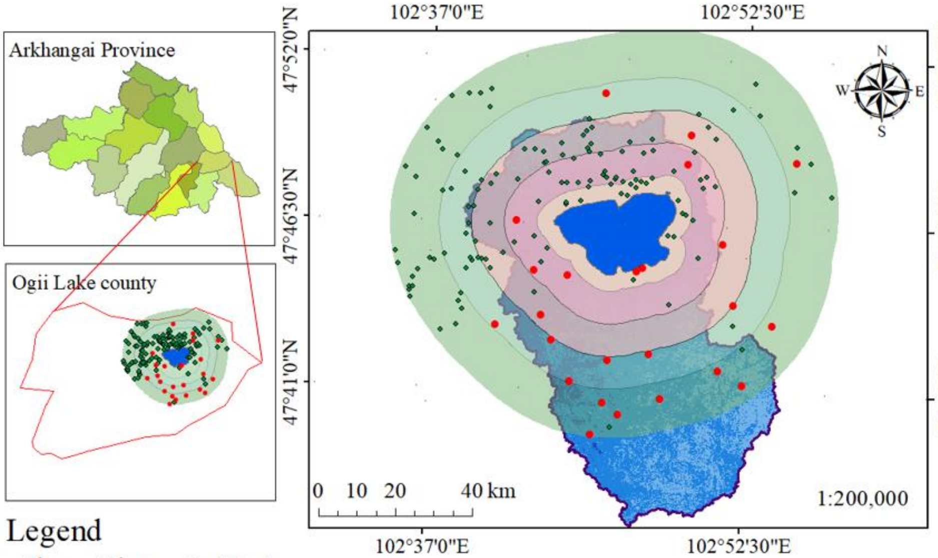
In this study, I conducted a research to estimate the human activities and climate change impact on the Ogii Lake Basin in Mongolia which is completed under three main parts of research.

Within the first part of the research, the environmental characteristics of Ogii Lake water has been carried out under two year's field surveys on surface water sampling and questionnaire survey. The analysis of water samples was carried out at the University of Kitakyushu and water quality of Ogii Lake and Khugshin Orkhon River was classified as clean and slightly polluted. Livestock related pollutants were observed in the water samples, especially water samples from Khugshin Orkhon River and the northern side of the lake, where livestock mainly have an access for pasturing along the water body. NO_2^- concentration was deemed high in stream and spring water samples in both 2017 and 2018. PO_4^{3-} concentrations were relatively high (0.26 mg/L) at the sampling site where the Khugshin Orkhon River flows into the lake, as well as in the streams and spring water samples (0.20–0.28 mg/L) in both July 2017 and August 2018. Human waste generation was found to be a harmful consequence of seasonal tourism in the Ogii Lake environment due to a lack of proper management of lake-based tourism, as well the living habits of local people. Therefore, without proper management, Ogii Lake's environment would have degraded in the future. According to the results of the questionnaire survey, 83% of households use lake water in daily use without any regard to water quality. Therefore, frequent water quality surveys need to be conducted to provide information to the residents in order to safeguard their well-being. According to the livestock census [44] in Ogii Lake County, the livestock population has increased over the last decade, while the total number of available water resources such as surface water reservoirs, wells, and aquifers has changed over time from 36 in 2012 to 57 in 2015, and then 45 in 2018. Due to the decrease in available water sources, herders mostly settle nearby the river and lakes, which increases the discharge of livestock related pollutants along the shore. During the field survey, I observed that livestock spent most of their time along the Khugshin Orkhon River and Ogii Lake shoreline for grazing, watering, and resting. Considering the domestic settlements and livestock distribution around the lake, observed high PO_4^{3-} concentrations might have been more likely attributable to livestock, which has free access to the lake. Generated pollutant discharge load would increase along with the size of livestock. The pollutants contaminated in the daily waste generation of cattle and sheep & goat around the Ogii Lake is accounted to the 87.05 ton NH_3-N, 76.79 ton TP, 230.93 ton TN, 199.83 ton COD, 169.91 ton BOD per year within 10 km distance in 2016. The simulation results indicated that the livestock population would be increased significantly in the future. In the year 2036 the total amount of potential contaminants would be increased by 3.8 times (1288.07 ton NH_3-N, 11358.11 ton COD, 9062.76 ton BOD, 1461.03 ton TP, and 5427.33 ton TN), while total cattle population reached around 38.043 thousand heads, and sheep and goats would reach about 436.415 thousand heads. Water demand would also increase 3.8 times higher than current usage that accounts for approximately 876.809 cubic meters in Ogii Lake County. In addition, human activities such as unregulated tourism as well as waste and wastewater discharge have become a considerable problem leading to environmental impact around the lake.

The second part of the study was covered the climate change impact on the Ogii Lake Basin. The study was carried out based on the satellite RS images and long-term historical reanalysis data between 1986 and 2019. The daily evaporation from the lake were estimated using the Penman's energy-budget method. The result illustrated that total annual evaporation from the lake increased steadily over last three decades; compared to 1989, annual evaporation increased by 20.02, 25.79, and 32.4 mm in 1999, 2009, and 2019, respectively. On the other hand, the annual evaporation from the lake mostly exceeded since 1995. The variation between total annual precipitation and evaporation accounted approximately 24.27 mm, 82.89 mm, and 50.44 mm respectively, between 1986–1996, 1997–2007, and 2008–2019. The comparison between the estimated lake water surface area and the climatic variables illustrated that the morphometric parameters has positive week correlation with the evaporation and precipitation. The water balance of the Ogii Lake was also estimated based on the available data between 2016 and 2019. The result shows that the water balance of the Ogii Lake is regulated by the contribution of the both surface and groundwater.

As described in the previous chapter, the third part of this study was applied the advantages of the recent techniques to delineate the GWPZs of the basin based on the six thematic layers, and it was classified into five classes as very high, high, moderate, poor, and very poor. The delineated GWPZs were reasonable comparing with result of the depression morphology of Ogii Lake by Altanbold et.al. and the results were validated using the coordinates of the existing wells in the Ogii Lake Basin. According to the wells' location, 89.48% are plotted in moderate to high GWPZs, and remaining 2 wells (10.52%) were plotted in poor GWPZs. From the above result, the integration of RS, GIS, and the AHP applied in this study has shown valuable result. Even there was a slightly difference between the classified zones of rainfall in this study area, the GWPZs of the lake in 2019 was delineated based on the different classification to identify the difference between the classification (**Table A.5**). The delineated GWPZs of the each classes are shown in Annex (**Fig. A.2**). The results were illusrated that, there is a slightly difference between the delineated GWPZs.

Summarizing the result of this study, the current state of the Ogii Lake water qualiy was classified as a clean to slightly polluted. The lake based tourism and livestock grazzing nearby the lake and Khugshin Orkhon River have an potential impact on lake ecosystem and its water quality. The location of herders and existing wells at the different distance from the lake are compiled and shown in **Fig. 6.1** and **Table A.1**. The herders mostly change their location at least 2 times per year. The wells are usually in use during the winter season to supply a drinking water for both herders and livestock when the surface water is frozen. Considering on the herders' location in 2016, it's clearly seen that herders are mostly grazing their livestock at the northern side of the lake, where the existing wells are lower than southern side of the lake. It proves that during the warm period none of the herders are willing to use the wells, and moves their location nearby where the surface water available. Therefore, the water analysis result might have showed the PO_4^{3-} concentrations was 2.6–3.4 times higher than MNS4586:1998 standard which is one of the livestock related pollutants.



Distance	Number of herders	Herder population	Livestock population	Number of wells
1 km	17	64	4330	2
3 km	52	161	13578	5
5 km	69	187	22354	6
7 km	87	258	29736	11
10 km	105	367	35575	12

Fig. 6.1 Location of the herders and existing wells at the different distances from the lake

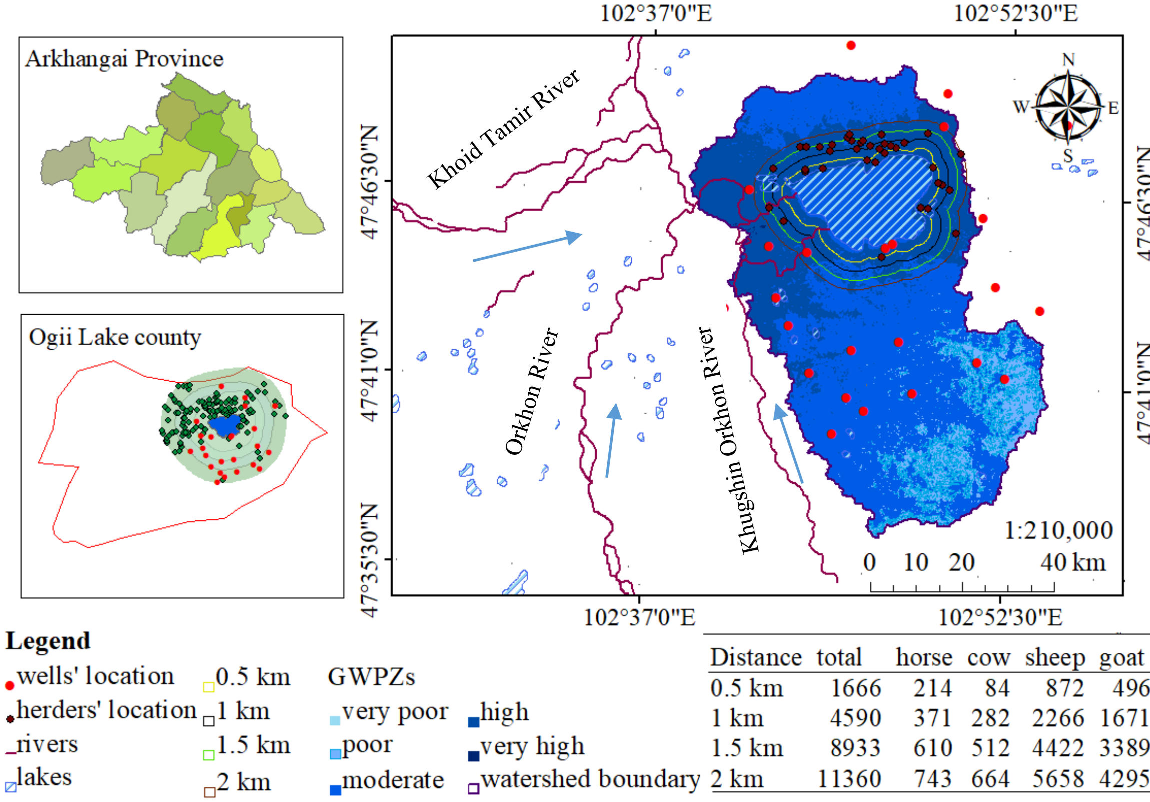
In order to protect the lake ecosystem, the free acces of livestock to lake and its tributaries should be restricted. Currently, there are 24 wells under the operation within 10 km distances from the lake, and 19 of them belong to the Ogii Lake Basin, however, two wells nearby the lake are owned by the tourist camps. According to the result of Chapter 5, approximately 86.36% of the Ogii Lake Basin has a moderate to high potential of the groundwater. Therefore, there are a possibilities to manage the water resources in proper way through making a wells and use them in all seasons of the year as a drinking water for both herders and livestock in order to protect the environment as well as their well being.

As mentioned earlier, the drinking water consumption of the livestock is expected to increase 3.8 times over the next 15 years. In addition, because of the geographical location, Mongolia is experiencing the global warming and evapotranspiration rate is also expected to increase in the future. It might also increase the water demand of livestock in the future. Beside the livestock related pollutants, solid waste disposal and wastewater discharge along the lake shore has a negative impact on the Ogii Lake ecosystem. This study confirmed that, without implementing the regulations in proper way, anthropogenic impact on Ogii Lake would harm the Ogii Lake wetland in the future.

6.2 Recommendations

The case study on Ogii Lake shows that the implementation of existing laws and regulations that related to the protection of the environment and the development of environmentally friendly tourism is very weak. The local government and related authorities need to pay more attention on how to properly implement the existing laws and regulations. In order to protect the lake ecosystem, my suggestion to the local government is below.

The local government need to work on implementation of the current regulations and need to make eco-friendly plans while collaborating with environmental agencies, and tourism companies. Approximately 8,000 to 10,000 tourist visit to the lake for short-time per year, but there are no public toilets around the lake that can be used for private tourist who camp on the shores of the lake. Also the dumpsites are not described well. Therefore, due to the uncomfortable condition for the tourists, a large amount of garbage and human excreta is dumped on the shores of the lake. To solve this current problem, the lake based tourism needs to be urgently improved through announcing a tender for companies those who could serve environmentally friendly tour services. This kind of approach may reduce the number of private tourist along the lake. In order to protect the lake ecosystem, I recommend the tourist camps to install a composting toilets instead of flush toilets that need lots of extra construction work in that remote area. Also, it's important to clearly describe the access points to the lake for tourists while building enough parking lot. There will be an opportunity to increase revenue from tourism in provinces and counties by developing an environmentally friendly tourism. In addition, there are possibilities to manage the water resources for both herders and livestock, while creating sufficient number of wells based on the result obtained from this study. Therefore, livestock access to the lake should be restricted in order to protect the lake ecosystem. **Table 6.1** and **Table 6.2** shown the potential pollutants discharge from cattle and sheep at different distances from the lake. The estimated pollutants were based on the livestock population in 2016 (**Fig. 6.2**), however, if the local government could manage and restrict the livestock access to the lake and river, there are possibilities to reduce the potential pollutants discharge near the lake and river. For instance, in case of livestock population and its distribution around the lake approximately, 8.49 ton NH_3-N, 79.74 ton COD, 59.819 ton BOD, 6.2 ton TP, and 27.57 ton TN potential pollutants could be reduced in 0.5 km distance from the lake per year. As mentioned before, the herders' change their locations at least twice a year and the number of livestock is not stable, which means the potential pollutants discharge around the lake is different. Therefore, as mentioned before it's important to implement restrict management for livestock access, it could help to protect the water quality in the future. In addition, when livestock access restricted the breeding and staging area for the waterfowl could be also protected.



Distance	total	horse	cow	sheep	goat	well
0.5 km	1666	214	84	872	496	2
1 km	4590	371	282	2266	1671	2
1.5 km	8933	610	512	4422	3389	2
2 km	11360	743	664	5658	4295	3

Fig. 6.2 Potential pollutants around Ogii Lake

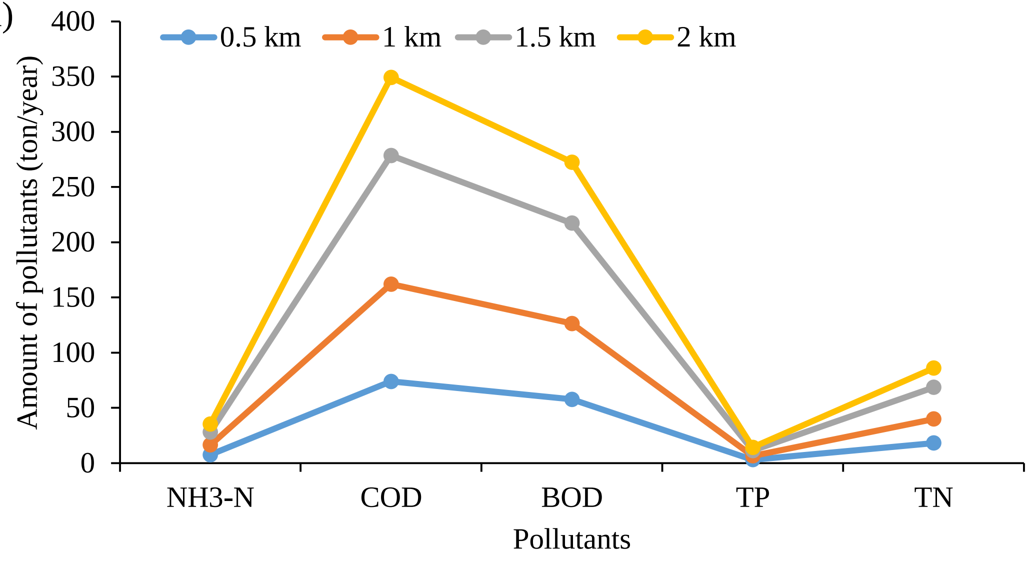
Table 6.1 Potential pollutants from cattle (ton/year)

Distance from lake	Cattle				
	NH_3-N	COD	BOD	TP	TN
0.5 km	7.49	73.96	57.69	3.00	18.20
1 km	16.41	162.07	126.42	6.57	39.89
1.5 km	28.20	278.48	217.21	11.29	68.55
2 km	35.37	349.21	272.39	14.16	85.96

Table 6.2 Potential pollutants from sheep (ton/year)

Distance from lake	Sheep				
	NH_3-N	COD	BOD	TP	TN
0.5 km	1.00	5.78	5.12	3.25	9.37
1 km	2.86	16.54	14.66	9.31	26.80
1.5 km	5.67	32.80	29.06	18.45	53.12
2 km	7.23	41.80	37.04	23.52	67.71

a)



b)

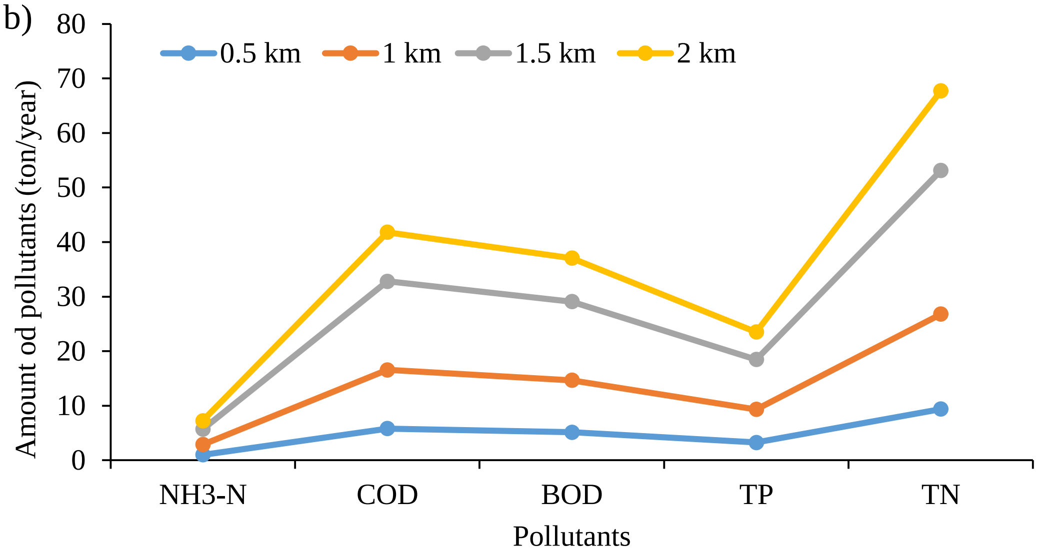


Fig. 6.3 Potential pollutants around the lake a) cattle, b) sheep

Chapter 7 Conclusion, limitation of this study and further studies

7.1 Conclusion

1. The water quality of Ogii Lake and Khugshin Orkhon River was classified as clean and slightly polluted. Dumping of human- and livestock- generated pollutants along the lakeshore was observed during the field surveys. The livestock-related pollutants and the water demand for the expected livestock in 2036 was predicted to increase by 3.8 times, that would be account as 1288.07 ton NH_3-N, 11358.11 ton COD, 9062.76 ton BOD, 1461.03 ton TP, and 5427.33 ton TN, and 876.809 cubic meters, respectively.
2. The most accurate water index for identifying the lake surface from the satellite RS images of both Landsat 5 TM and Landsat 8 OLI was MNDWI-1, which has high correlation with the measured lake water level (R=0.94, $p < 0.01$).
3. Amount of precipitation on Ogii Lake Basin has been almost stable, while the lake water evaporation has increased. The correlation of the estimated evaporation from the lake, precipitation, and lake water surface area changes illustrated that precipitation is not a main part of the water source for the Ogii Lake. The result of the estimated water balance between 2016 and 2019 was demonstrated that the both surface and groundwater have a considerable influence on Ogii Lake's water balance.
4. The highest GWPZs of the Ogii Lake Basin was coincided with the deepest part of the lake, where the tectonic fault cross Ogii Lake. The results of delineation of potential groundwater zones show that there is a possibility to solve the source of drinking water that is essential for both herders and livestock through drilling wells, which could reduce the potential discharge of livestock related pollutants to the lake and inflow river.
5. The case study on Ogii Lake shows that is possible to reduce budget expenditures on hydrological surveys while integrating the RS and GIS technology. Such results could provide valuable information for decision makers to implement a water resource management and reduce the environmental pollution.

7.2 Limitation of this study and further studies

The previous study by J. Tserensodnom (2000) was highlighted that Ogii Lake's water fed by the Khugshin Orkhon River. Erdenesukh et al., (2020) was concluded that Ogii Lake's water surface area has weak correlation with surface inflow. Due to the lack of the long-term surface water discharge data, the water balance of Ogii Lake was estimated only for short-time between 2016 and 2019. In this study, I estimated evaporation only form the lake water surface, in order to study the climate change impact on lake in the steppe region, evapotranspiration from the whole basin should be studied. In addition, lake water balance prediction is much more important especially for the ecological important lake such as Ogii Lake. Based on the delineated groundwater potential zones of Ogii Lake Basin, it's important to conduct research on the interaction between Ogii Lake water balance and groundwater accumulation in the further. I expect to develop a dynamic model of Ogii Lake water balance using the system dynamic modeling techniques based on the future result of groundwater interaction to Ogii Lake.

Reference

[1] C. B. An, F. H. Chen, and L. Barton, "Holocene environmental changes in Mongolia: A review," *Glob. Planet. Change*, vol. 63, no. 4, pp. 283–289, 2008.

[2] N. I. Dorofeyuk, S. N. Bazha, Y. I. Drobyshev, A. V. Andreev, S. K. D. Syrtypova, and N. Saruul, Eds., "Joint Russian - Mongolian Complex Biological Expedition Ecosystems of Central Asia Under Current Conditions of Socio - Economic Development," 2015, vol. 2.

[3] B. C. Bates, Z.W.Kundzewiez, S. Wu, and J. P. Palitikof, *Climate change and water*, vol. 71, no. 12. 1990.

[4] W. Schwanghart, B. Schütt, and M. Walther, "Holocene climate evolution of the Ugii Nuur basin, Mongolia," *Adv. Atmos. Sci.*, vol. 25, no. 6, pp. 986–998, 2008.

[5] W. Wang, Y. Ma, Z. Feng, H. Meng, Y. Sang, and X. Zhai, "Vegetation and climate changes during the last 8660 cal. a BP in central Mongolia, based on a high-resolution pollen record from Lake Ugii Nuur," *Chinese Sci. Bull.*, vol. 54, no. 9, pp. 1579–1589, 2009.

[6] P. Khishigsuren and T. Baldandorj, "Orkhon river basin: Integrated water resources management assessment report," Ulaanbaatar, 2012.

[7] "Kastanozem," *Encyclopedia Britannica*, 2019. [Online]. Available: https://www.britannica.com/science/Kastanozem.

[8] S. Gungaadorj and T. Damdin, *River basin management model project for the conservation of wetland ecosystem and its sustainable use in Mongolia*. Ulaanbaatar: Nemo printing, 2006.

[9] "Country profile – Mongolia," 2011.

[10] O. River, M. Amgalan, O. Enkhtsolmon, and T. Ulaanbaatar, "Water Quality and Quantity Assessment of Ogii Lake and Khugshin," 2016.

[11] E. Sumiya *et al.*, "Changes in water surface area of the lake in the steppe region of Mongolia: A case study of Ugii Nuur Lake, central Mongolia," *Water (Switzerland)*, vol. 12, no. 5, 2020.

[12] S. Erdenesukh, D. Sandelger, E. Altanbold, D. Batsuren, and G. Tuvshin, "The change of lake square in the mongolian steppe zone /A Case study of Ugii Lake," *Монгол орны газарзүй-геоэкологийн асуудал*, vol. 40, pp. 342–356, 2019.

[13] M. Walther and T. Gegeensuvd, "Ugii Nuur (Central Mongolia) Paleo environmental studies of lake level fluctuations and Holocene climate change," (MRC), Journal of MOLARE Research Centre, Ulaanbaatar, Mongolia, 2005.

[14] J. Tserensodnom, *Catalogue of Mongolian Lakes*. Ulaanbaatar: Shuvuun saaral, 2000.

[15] S. Tsegmid, *Physical Geography of Mongolia*. Ulaanbaatar, 1969.

[16] N. Batnasan, "Freshwater issues in Mongolia," *Natl. Semin. IRBM Mong. 24-25 Sept. 2003*, pp. 53–61, 2003.

[17] T. Gungaadorj, Sh Damdin, *River Basin Management Model Project for the Conservation of Wetland Ecosystem and its Sustainable Use in Mongolia*. Ulaanbaatar: The Ministry of Enviornment and Green Development of Mongolia, 2007.

[18] W. F. Vincent, "Effects of Climate Change on Lakes," *Encycl. Inl. Waters*, pp. 55–60, 2009.

[19] A. Maasri and J. Gelhaus, "The new era of the livestock production in Mongolia: Consequences on streams of the Great Lakes Depression," *Sci. Total Environ.*, vol. 409, no. 22, pp. 4841–4846, 2011.

[20] P. Batima, L. Natsagdorj, P. Gombluudev, and B. Erdenetsetseg, "Observed Climate Change in Mongolia," *AIACC Work. Pap.*, no. 12, p. 25, 2005.

[21] B. Dashbal and J. Thorsson, "Rangeland Degradation in Mongolia : Changes in

Vegetation Composition and Biomass , and potential effect on soil carbon," pp. 1–32, 2010.
[22] "Ogii Lake livestock population census," *National Statistics Office of Mongolia*, 2019. [Online]. Available: https://www.1212.mn/tables.aspx?tbl_id=DT_NSO_1001_021V1&BAG_select_all=0&BAGSingleSelect=_26516_2651655&TYPE_OF_LIVESTOCK_select_all=1&TYPE_OF_LIVESTOCKSingleSelect=&YearY_select_all=1&YearYSingleSelect=&viewtype=table.
[23] O. Batkhishig, "Chapter 12. Human Impact and Land Degradation in Mongolia," *Dryl. East Asia L. Dyn. amid Soc. Clim. Chang.*, pp. 265–282, 2013.
[24] M. E. Fernández-Giménez, B. Batkhishig, and B. Batbuyan, "Cross-boundary and cross-level dynamics increase vulnerability to severe winter disasters (dzud) in Mongolia," *Glob. Environ. Chang.*, vol. 22, no. 4, pp. 836–851, 2012.
[25] S. Begzsuren, J. E. Ellis, D. S. Ojima, M. B. Coughenour, and T. Chuluun, "Livestock responses to droughts and severe winter weather in the Gobi Three Beauty National Park, Mongolia," *J. Arid Environ.*, vol. 59, no. 4, pp. 785–796, 2004.
[26] K. Tachiiri, M. Shinoda, B. Klinkenberg, and Y. Morinaga, "Assessing Mongolian snow disaster risk using livestock and satellite data," *J. Arid Environ.*, vol. 72, no. 12, pp. 2251–2263, 2008.
[27] M. P. Rao *et al.*, "Dzuds, droughts, and livestock mortality in Mongolia," *Environ. Res. Lett.*, vol. 10, no. 7, 2015.
[28] P. H. Ysi and B. A. Si, "Ph ysi c a l g eo g r a ph y," no. January, pp. 1–13, 2019.
[29] B. Allison and H. Hahn, "Mongolian Dzud," vol. 22, no. 2, 2017.
[30] "Lessons from the Dzud : Adaptation and Resilience in Mongolian Pastoral."
[31] "Glossary:Livestock density index," 2014. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_density_index. [Accessed: 12-Dec-2014].
[32] P. O. Callaghan *et al.*, "Impact of Cattle Access to Watercourses : Literature Review on Behalf of the COSAINT Project," *Environ. Prot. Agency*, no. 260, p. 60, 2014.
[33] R. K. Hubbard, G. L. Newton, and G. M. Hill, "Water quality and the grazing animal.," *J. Anim. Sci.*, vol. 82 E-Suppl, pp. E255-263, 2004.
[34] R. Khaleel, K. R. Reddy, and M. R. Overcash, "Transport of potential pollutants in runoff water from land areas receiving animal wastes: A review," *Water Res.*, vol. 14, no. 5, pp. 421–436, 1980.
[35] H. Steinfeld, P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. De Haan, *Livestock's long shadow environmental issues and options*. The Food and Agriculture Organization of the United Nations, 2006.
[36] J. Mateo-Sagasta, S. M. Zadeh, and H. Turral, *Water pollution from agriculture: a global review Executive summary*. Rome: The Food and Agriculture Organization of the United Nations, 2017.
[37] S. Wu *et al.*, "Site investigations and analyses for physical and chemical parameters of Ogii Lake." 1989.
[38] T. Gungaadorj, Sh Damdin, *Nature guidebook of Ogii Lake area*. Ulaanbaatar: Nemo printing, 2007.
[39] L. S. Clesceri and A. E. G. A. D. Eaton, *Standard Methods for the Examination of Water and Wastewater*, 20th ed. USA: American Public Health Association, 1998.
[40] O. Altansukh, "Surface Water Quality Assessment and Modelling A Case Study in the Tuul River, Ulaanbaatar City, Mongolia," International institute for geo-information science and earth observation enschede, the Netherlands, 2008.

[41] G. Davaa, D. Oyunbaatar, and M. Sugita, “Surface water of Mongolia,” in *International Workshop on Terrestrial Change in Mongolia, Institute of Meteorology and Hydrology, Mongolia*, 2007, pp. 54–69.
[42] “National Statistical Office of Mongolia.” [Online]. Available: https://www.1212.mn/stat.aspx?LIST_ID=976_L10_1.
[43] P. Gu, R. F. Shen, and Y. D. Chen, “Diffusion Pollution from Livestock and Poultry Rearing in the Yangtze Delta, China,” *Env Sci Pollut Res*, vol. 15, no. 3, pp. 273–277, 2008.
[44] Ts. Samdan, *STATISTICAL YEARBOOK OF ARHANGAI PROVINCE*. 2017.
[45] I. M. Mason, M. Guzkowska, C. G. Rapley, and F. A. Street-Perrott, “The response of lake levels and areas to climate change,” *Clim. Change*, vol. 27, no. 2, pp. 161–197, 1994.
[46] S. Kang, G. Lee, C. Togtokh, and K. Jang, “Characterizing regional precipitation-driven lake area change in Mongolia,” *J. Arid Land*, vol. 7, no. 2, pp. 146–158, 2015.
[47] J. Bai, X. Chen, J. Li, L. Yang, and H. Fang, “Changes in the area of inland lakes in arid regions of central Asia during the past 30 years,” pp. 247–256, 2011.
[48] A. M. Melesse, Q. Weng, P. S. Thenkabail, and G. B. Senay, “Remote sensing sensors and applications in environmental resources mapping and modelling,” *Sensors*, vol. 7, no. 12, pp. 3209–3241, 2007.
[49] M. Sugita *et al.*, “An overview of the rangelands atmosphere-hydrosphere-biosphere interaction study experiment in northeastern Asia (RAISE),” *J. Hydrol.*, vol. 333, no. 1, pp. 3–20, 2007.
[50] Y. Fukumoto, K. Kashima, A. Orkhonselenge, and U. Ganzorig, “Holocene environmental changes in northern Mongolia inferred from diatom and pollen records of peat sediment,” *Quat. Int.*, vol. 254, pp. 83–91, 2012.
[51] J. Hansen, R. Ruedy, J. Glascoe, and M. Sato, “GISS analysis of surface temperature change,” vol. 104, 1999.
[52] J. Ministry of the Environment, “Climate change in Mongolia Outputs from GCM.”
[53] D. Dagvadorj, Z. Batjargal, and L. Natsagdorj, “MARCC-2014 Mongolia Second Assessment Report on Climate Change -2014.” The Ministry of Enviornment and Green Development of Mongolia, Ulaanbaatar, pp. 66–72, 2014.
[54] A. Ariunzaya, C. Bayanchimeg, A. Demberel, and M. Ganchimeg, Eds., *Mongolian Statistical Yearbook-2016*. Ulaanbaatar: National Statistics Office of Mongolia, 2016.
[55] Z. Duan and W. G. M. Bastiaanssen, “Evaluation of three energy balance-based evaporation models for estimating monthly evaporation for five lakes using derived heat storage changes from a hysteresis model,” *Environ. Res. Lett.*, vol. 12, no. 2, 2017.
[56] E. A. Practitioners, “Estimation of Open Water Evaporation Guidance for Environment Agency Practitioners R&D Handbook W6-043/HB.”
[57] H. Liu, P. D. Blanken, T. Weidinger, A. Nordbo, and T. Vesala, “Variability in cold front activities modulating cool-season evaporation from a southern inland water in the USA,” *Environ. Res. Lett.*, vol. 6, no. 2, 2011.
[58] C. H. B. Priestley and R. J. Taylor, “On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters,” *Mon. Weather Rev.*, vol. 100, no. 2, pp. 81–92, 1972.
[59] H. L. Penman, “Natural evaporation from open water, bare soil and grass,” pp. 1–27, 1948.
[60] H. A. R. De Bruin and J. Q. Keijman, “The Priestley-Taylor evaporation model applied to a large, shallow lake in the Netherlands.,” *Journal of Applied Meteorology*, vol. 18, no. 7. pp. 898–903, 1979.
[61] I. M. Vardavas and A. Fountoulakis, “Estimation of lake evaporation from standard meteorological measurements: Application to four Australian lakes in different climatic

regions," *Ecol. Modell.*, vol. 84, no. 1–3, pp. 139–150, 1996.
[62] Department of the Interior U.S. Geological Survey, "Landsat 8 Data Users Handbook," *Nasa*, vol. 8, no. June, p. 97, 2016.
[63] K. Schamm *et al.*, "Global gridded precipitation over land: A description of the new GPCC First Guess Daily product," *Earth Syst. Sci. Data*, vol. 6, no. 1, pp. 49–60, 2014.
[64] U. Schneider, A. Becker, P. Finger, A. Meyer-Christoffer, M. Ziese, and B. Rudolf, "GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle," *Theor. Appl. Climatol.*, vol. 115, no. 1–2, pp. 15–40, 2014.
[65] T. D. Acharya, A. Subedi, H. Huang, and D. H. Lee, "Application of water indices in surface water change detection using Landsat imagery in Nepal," *Sensors Mater.*, vol. 31, no. 5, pp. 1429–1447, 2019.
[66] S. K. McFEETERS, "The use of the Normalized Difference Water Index(NDWI) in the delineation of open water features," *Int. J. Remote Sensing1*, vol. 17, no. 7, pp. 1425–1432, 1996.
[67] H. Xu, "Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery," *Int. J. Remote Sens.*, vol. 27, no. 14, pp. 3025–3033, 2006.
[68] M. Alazard, C. Leduc, Y. Travi, G. Boulet, and A. Ben Salem, "Estimating evaporation in semi-arid areas facing data scarcity: Example of the El Haouareb dam (Merguellil catchment, Central Tunisia)," *J. Hydrol. Reg. Stud.*, vol. 3, pp. 265–284, 2015.
[69] O. A. Alduchov and R. E. Eskridge, "Improved Magnus' form approximation of saturation vapor pressure," 2001.
[70] R. G. Anderson and A. N. French, "Crop evapotranspiration," *Agronomy*, vol. 9, no. 10, 2019.
[71] L. Zotarelli and M. Dukes, "Step by step calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method)," *Inst. Food …*, pp. 1–10, 2010.
[72] O. Rahmati, A. Nazari Samani, M. Mahdavi, H. R. Pourghasemi, and H. Zeinivand, "Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS," *Arab. J. Geosci.*, vol. 8, no. 9, pp. 7059–7071, 2015.
[73] S. S. Withanachchi, A. Houdret, S. Nergui, and E. E. Gonzalez, *(Re) configuration of Water Resources Management in Mongolia : A Critical Geopolitical Analysis The International Center for Development and Decent Work*, vol. 269692805, no. 13. 2014.
[74] K. Benjmel, F. Amraoui, S. Boutaleb, M. Ouchchen, A. Tahiri, and A. Touab, "Mapping of groundwater potential zones in crystalline terrain using remote sensing, GIS techniques, and multicriteria data analysis (Case of the ighrem region, Western Anti-Atlas, Morocco)," *Water (Switzerland)*, vol. 12, no. 2, 2020.
[75] L. Kumari, "Delineation of Potential Groundwater Zone Using RS and GIS: A Review," *Int. J. Curr. Microbiol. Appl. Sci.*, vol. 7, no. 12, pp. 196–203, 2018.
[76] D. Abijith, S. Saravanan, L. Singh, J. J. Jennifer, T. Saranya, and K. S. S. Parthasarathy, "GIS-based multi-criteria analysis for identification of potential groundwater recharge zones - a case study from Ponnaniyaru watershed, Tamil Nadu, India," *HydroResearch*, vol. 3, pp. 1–14, 2020.
[77] C. Serele, A. Pérez-Hoyos, and F. Kayitakire, "Mapping of groundwater potential zones in the drought-prone areas of south Madagascar using geospatial techniques," *Geosci. Front.*, vol. 11, no. December 2019, pp. 1403–1413, 2019.
[78] A. L. Achu, J. Thomas, and R. Reghunath, "Multi-criteria decision analysis for delineation of groundwater potential zones in a tropical river basin using remote sensing, GIS and analytical hierarchy process (AHP)," *Groundw. Sustain. Dev.*, vol. 10, no. March, p. 100365, 2020.

[79] M. Rajasekhar, G. Sudarsana Raju, Y. Sreenivasulu, and R. Siddi Raju, "Delineation of groundwater potential zones in semi-arid region of Jilledubanderu river basin, Anantapur District, Andhra Pradesh, India using fuzzy logic, AHP and integrated fuzzy-AHP approaches," *HydroResearch*, vol. 2, pp. 97–108, 2019.
[80] A. Arshad, Z. Zhang, W. Zhang, and A. Dilawar, "Mapping favorable groundwater potential recharge zones using a GIS-based analytical hierarchical process and probability frequency ratio model: A case study from an agro-urban region of Pakistan," *Geosci. Front.*, no. July 2019, 2020.
[81] S. V. Razavi-Termeh, A. Sadeghi-Niaraki, and S. M. Choi, "Groundwater potential mapping using an integrated ensemble of three bivariate statistical models with random forest and logistic model tree models," *Water (Switzerland)*, vol. 11, no. 8, 2019.
[82] R. Çelik, "Evaluation of groundwater potential by GIS-based multicriteria decision making as a spatial prediction tool: Case study in the Tigris River Batman-Hasankeyf Sub-Basin, Turkey," *Water (Switzerland)*, vol. 11, no. 12, 2019.
[83] K. D. Goepel, "Implementing the Analytic Hierarchy Process as a Standard Method for Multi-Criteria Decision Making in Corporate Enterprises – a New AHP Excel Template with Multiple Inputs," no. June 2013, 2013.
[84] G. B. Lentswe and L. Molwalefhe, "Delineation of potential groundwater recharge zones using analytic hierarchy process-guided GIS in the semi-arid Motloutse watershed, eastern Botswana," *J. Hydrol. Reg. Stud.*, vol. 28, no. January, p. 100674, 2020.
[85] T. L. Saaty, "The Analytic Network Process," *Iran. J. Oper. Res.*, vol. 1, no. 1, pp. 1–27, 2008.
[86] S. Suganthi, L. Elango, and S. K. Subramanian, "Groundwater potential zonation by remote sensing and GIS techniques and its relation to the groundwater level in the coastal part of the Arani and Koratalai river basin, Southern India," *Earth Sci. Res. J.*, vol. 17, no. 2, pp. 87–95, 2013.
[87] J. Malczewski, *GIS and Multicriteria decision analysis*, First. New York: John Wiley & Sons, Inc., 1999.
[88] C. Serele, A. Pérez-Hoyos, and F. Kayitakire, "Mapping of groundwater potential zones in the drought-prone areas of south Madagascar using geospatial techniques," *Geosci. Front.*, vol. 11, no. November 2019, pp. 1403–1413, 2019.
[89] W. Schwanghart and B. Schütt, "Holocene morphodynamics in the Ugii Nuur basin, Mongolia - insights from a sediment profile and 1D electrical resistivity tomography," *Zeitschrift fur Geomorphol.*, vol. 52, no. SUPPL. 2, pp. 35–55, 2008.
[90] K. G. Berhanu and S. D. Hatiye, "Identification of Groundwater Potential Zones Using Proxy Data: Case study of Megech Watershed, Ethiopia," *J. Hydrol. Reg. Stud.*, vol. 28, no. January, p. 100676, 2020.
[91] G. Lemecha, "Mapping Groundwater Potential: A Guide for GIS Developers.," p. 2, 2008.
[92] E. A. Altanbold Enkhbold, Y. Gansukh, "Depression morphology of the Ugiinuur Lake: The impact of fluvial process and fault," *J. Geogr. Issues*, vol. 2, no. 19, pp. 22–41, 2019.

Annex

Table A.1 Total number of livestock and available wells

Distance	Number of herders	Herder population	Livestock population	Number of wells
1 km	17	64	4330	2
3 km	52	161	13578	5
5 km	69	187	22354	6
7 km	87	258	29736	11
10 km	105	367	35575	12

Table A. 2 Total annual precipitation and evaporation

Years	Precipitation, mm	Evaporation, mm	Years	Precipitation, mm	Evaporation, mm
1986	252.21	282.08	2003	246.55	304.13
1987	322.41	281.39	2004	175.46	325.25
1988	236.50	302.62	2005	220.46	270.57
1989	246.28	297.69	2006	237.20	217.36
1990	323.49	299.92	2007	246.92	332.19
1991	270.66	302.12	2008	239.77	331.67
1992	193.13	294.30	2009	179.94	323.47
1993	324.75	285.65	2010	250.65	310.10
1994	372.87	291.61	2011	290.15	311.06
1995	213.20	274.94	2012	302.40	316.71
1996	199.75	309.97	2013	253.88	315.42
1997	258.07	315.76	2014	265.86	324.45
1998	242.82	315.28	2015	279.17	267.00
1999	222.20	317.70	2016	366.35	303.63
2000	217.40	309.02	2017	222.54	345.58
2001	226.51	316.38	2018	326.69	335.87
2002	156.22	338.01	2019	232.36	330.09

Table A. 3 Lake morphology and climate variables

Date	NDWI, km^2	MNDWI-1, km^2	Level, m	Precipitation, mm	Evaporation, mm	Durations
6/28/2002	24.96	25.79	26.7	16.37	54.2	28 days
8/15/2002	24.74	25.04	33.6	51.6	95.75	48 days
9/9/2002	24.68	24.83	32.1	7.08	36.58	25 days
10/18/2002	24.46	24.61	30.8	27.72	32.34	39 days
7/10/2003	24.70	25.27	33.9	57.76	50.76	28 days
8/11/2003	25.77	25.86	36	64.32	53.21	32 days
9/19/2003	25.65	25.98	34.4	52.12	48.02	39 days
10/5/2003	25.70	25.89	32.2	2.23	12.92	16 days
8/20/2004	24.88	25.81	35.6	51.45	44.69	28 days
9/21/2004	24.93	25.55	34.3	16.1	35.77	32 days
10/7/2004	24.92	25.51	34.1	5.66	12.23	16 days

Date	NDWI, km^2	MNDWI-1, km^2	Level, m	Precipitation, mm	Evaporation, mm	Durations
8/7/2005	24.99	25.26	33.7	51.42	50.02	28 days
8/16/2005	24.60	24.95	33.7	12.27	13.08	9 days
9/1/2005	24.56	24.88	33.3	26.2	22.34	16 days
10/3/2005	24.64	24.77	32.3	31.96	31.42	32 days
8/10/2006	24.51	24.83	32.7	66.54	44.92	28 days
9/11/2006	24.49	24.69	32	34.36	41.63	32 days
10/13/2006	24.49	24.78	31	4.53	29.02	32 days
7/28/2007	24.21	24.45	29.3	31.88	48.72	28 days
9/14/2007	24.07	24.31	28.4	129.27	64.699	48 days
9/30/2007	24.0	24.22	27.5	7.46	15.15	16 days
8/31/2008	23.56	23.88	24.9	39.3	49.33	31 days
9/25/2008	23.45	23.73	24.6	13.41	27.23	25 days
10/11/2008	24.50	24.38	23.8	3.64	12.34	16 days
8/18/2009	22.66	23.22	21.4	49.03	44.07	28 days
9/12/2009	22.49	22.89	21	9.28	31.78	25 days
10/14/2009	22.24	22.58	19.4	5.73	27.85	32 days
8/21/2010	22.02	22.67	20.3	69.69	40.44	28 days
9/22/2010	21.85	22.12	19.7	7.91	40.51	32 days
10/17/2010	21.73	22.08	18.8	12.6	17.51	25 days
8/17/2011	21.79	22.37	20	81.82	44.83	28 days
9/25/2011	21.61	22.0	19.3	47.8	45.569	39 days
10/27/2011	21.65	21.94	16.7	10.23	19.57	32 days
6/10/2013	22.89	23.23	21.7	22.29	49.06	28 days
7/28/2013	22.93	23.18	22.2	69.5	86.04	48 days
8/22/2013	23.32	23.69	23.2	80	33.84	25 days
9/14/2013	23.2	23.54	23.4	18.73	27.48	23 days
9/30/2013	23.3	23.54	23.4	11.2	14.21	16 days
10/16/2013	23.33	23.74	23.6	14.84	10.53	16 days
4/26/2014	23.719	23.94	25.2	10.72	28.16	26 days
6/6/2014	23.57	23.89	26.1	47.72	60.57	41 days
7/24/2014	23.57	23.96	26.4	100.73	82.95	48 days
8/16/2014	23.46	23.86	25.7	27.39	39.97	23 days
9/26/2014	23.45	23.68	24.4	55.65	48.56	41 days
10/19/2014	23.52	23.73	24.2	12.74	13.63	23 days
5/15/2015	23.66	23.70	25.1	13.19	35.79	28 days
6/25/2015	23.5	23.76	25.2	27.64	76	41 days
7/27/2015	23.67	24.004	25.6	86.23	57.35	30 days
8/19/2015	23.63	24.05	26.2	74.83	37.45	23 days
9/13/2015	23.63	23.96	25.8	22.98	36.93	25 days
10/12/2015	23.7	23.85	25.3	18.94	23.49	29 days

5/17/2016	24.12	24.29	28.4	32.18	37.52	28 days
Date	NDWI, km^2	MNDWI-1, km^2	Level, m	Precipitation, mm	Evaporation, mm	Durations
7/29/2016	24.42	24.65	31	182.67	116.98	73 days
8/30/2016	24.5	24.76	32	66.95	46.42	32 days
9/6/2016	24.53	24.76	32	14.41	6.74	7 days
5/29/2017	24.89	25.02	33.9	12.71	49.05	29 days
6/14/2017	24.85	25.01	33.6	8.82	32.16	16 days
7/23/2017	24.66	24.88	33	50.68	76.4	39 days
8/1/2017	24.7	24.92	32.7	3.75	17.84	9 days
9/18/2017	24.68	24.9	32.3	107.94	61.51	48 days
5/23/2018	24.73	24.82	32.3	4.2	43.95	28 days
6/8/2018	24.67	24.76	32	14.8	29.42	16 days
7/3/2018	24.71	24.98	32.3	49.9	46.03	25 days
8/27/2018	24.9	25.93	34.6	168.9	18.21	55 days
9/12/2018	24.96	25.93	34.6	36.7	19.85	16 days
5/19/2019	25.71	25.93	35.2	18.61	36.46	28 days
6/11/2019	25.07	25.83	35.1	11.05	43.5	24 days
8/30/2019	24.86	25.59	34.8	153.62	133.11	80 days
9/24/2019	24.8	25.11	33.4	16.96	29.22	25 days

Analytical Hierarchy Process

Number of experts: k = 10

Number of criteria n = 6 (1 – DEM, 2 – Slope, 3 – LULC, 4 – DD, 5 – Soil, 6 – Rainfall)

Table A.4 Experts' pair-wise comparison matrices for the AHP

Expert 1

	1	2	3	4	5	6
1	1	3	9	3	9	3
2	1/3	1	5	1	5	1
3	1/9	1/5	1	1/3	1	1/7
4	1/3	1	3	1	3	1
5	1/9	1/5	1	1/3	1	1/3
6	1/3	1	7	1	3	1

Expert 2

	1	2	3	4	5	6
1	1	1	9	3	7	3
2	1	1	9	3	9	3
3	1/9	1/9	1	1/5	1	1/7
4	1/3	1/3	5	1	3	1
5	1/7	1/9	1	1/3	1	1/3
6	1/3	1/3	7	1	3	1

Expert 3

	1	2	3	4	5	6
1	1	3	7	3	7	3
2	1/3	1	3	1	5	1
3	1/7	1/3	1	1/5	1	1/3
4	1/3	1	5	1	3	1
5	1/7	1/5	1	1/3	1	1/3
6	1/3	1	3	1	3	1

Expert 4

	1	2	3	4	5	6
1	1	3	9	3	9	3
2	1/3	1	5	1	3	1
3	1/9	1/5	1	1/5	1	1/3
4	1/3	1	5	1	3	1
5	1/9	1/3	1	1/3	1	1/5
6	1/3	1	3	1	5	1

Expert 5

	1	2	3	4	5	6
1	1	3	9	3	9	3
2	1/3	1	7	1	3	1
3	1/9	1/7	1	1/3	1	1/5
4	1/3	1	3	1	3	1
5	1/9	1/3	1	1/3	1	1/3
6	1/3	1	5	1	3	1

Expert 6

	1	2	3	4	5	6
1	1	3	9	3	9	3
2	1/3	1	5	1	5	1
3	1/9	1/5	1	1/3	1	1/7
4	1/3	1	3	1	3	1
5	1/9	1/5	1	1/3	1	1/3
6	1/3	1	7	1	3	1

Expert 7

	1	2	3	4	5	6
1	1	3	9	3	9	3
2	1/3	1	7	1	5	1
3	1/9	1/7	1	1/3	1	1/5
4	1/3	1	3	1	3	1
5	1/9	1/5	1	1/3	1	1/3
6	1/3	1	5	1	3	1

Expert 8

	1	2	3	4	5	6
1	1	1	5	1	9	1
2	1	1	3	1	5	1
3	1/5	1/3	1	1/3	1	1/7
4	1	1	3	1	7	1
5	1/9	1/5	1	1/7	1	1/7
6	1	1	7	1	7	1

Expert 9

	1	2	3	4	5	6
1	1	1	5	1	9	1
2	1	1	3	1	5	1
3	1/5	1/3	1	1/3	1	1/7
4	1	1	3	1	7	1
5	1/9	1/5	1	1/7	1	1/7
6	1	1	7	1	7	1

Expert 10

	1	2	3	4	5	6
1	1	3	9	3	9	3
2	1/3	1	5	1	5	1
3	1/9	1/5	1	1/5	1	1/7
4	1/3	1	5	1	3	1
5	1/9	1/5	1	1/3	1	1/5
6	1/3	1	7	1	5	1

Table A.5 Possibility rating for the parameters

Parameters	Value range	Rating	Contribution to the GWPZ
DEM (m) (32%)	1331-1359	5	Very high
	1359-1405	4	High
	1405-1454	3	Moderate
	1454-1510	2	Low
	1510-1630	1	Very low
Slope (degree) (20%)	0-2	5	Very high
	2-5	4	High
	5-9	3	Moderate
	9-13	2	Low
	13-35	1	Very low
LULC (4%)	Water body	5	Very high
	Forest	4	High
	Sand	3	Moderate
	Wetland	4	High
	Barren land	2	Low
	Settlement	1	Very low
Drainage density (km/km^2) (19%)	0-0.784	5	Very high
	0.784-1.597	4	High
	1.597-2.521	3	Moderate
	2.521-3.894	2	Low
	3.894-7.145	1	Very low
Soil (4%)	Kl39-2b-4399	1	Very low
Rainfall (mm) (21%)	Rainfall 5 classes		
	265.5-267.3	1	Very low
	267.3-268.8	2	Low
	268.8-270.3	3	Moderate
	270.3-271.9	4	High
	271.9-274.1	5	Very high
	Rainfall 3 classes		
	265.5-268.8	1	Very low
	268.9-271.9	2	Low
	272-274.1	3	Moderate
	Rainfall 2 classes		
	265.5-268.8	2	Low
	268.9-274.1	3	Moderate
	Rainfall 1 classes		
	265.5-274.1	3	Moderate

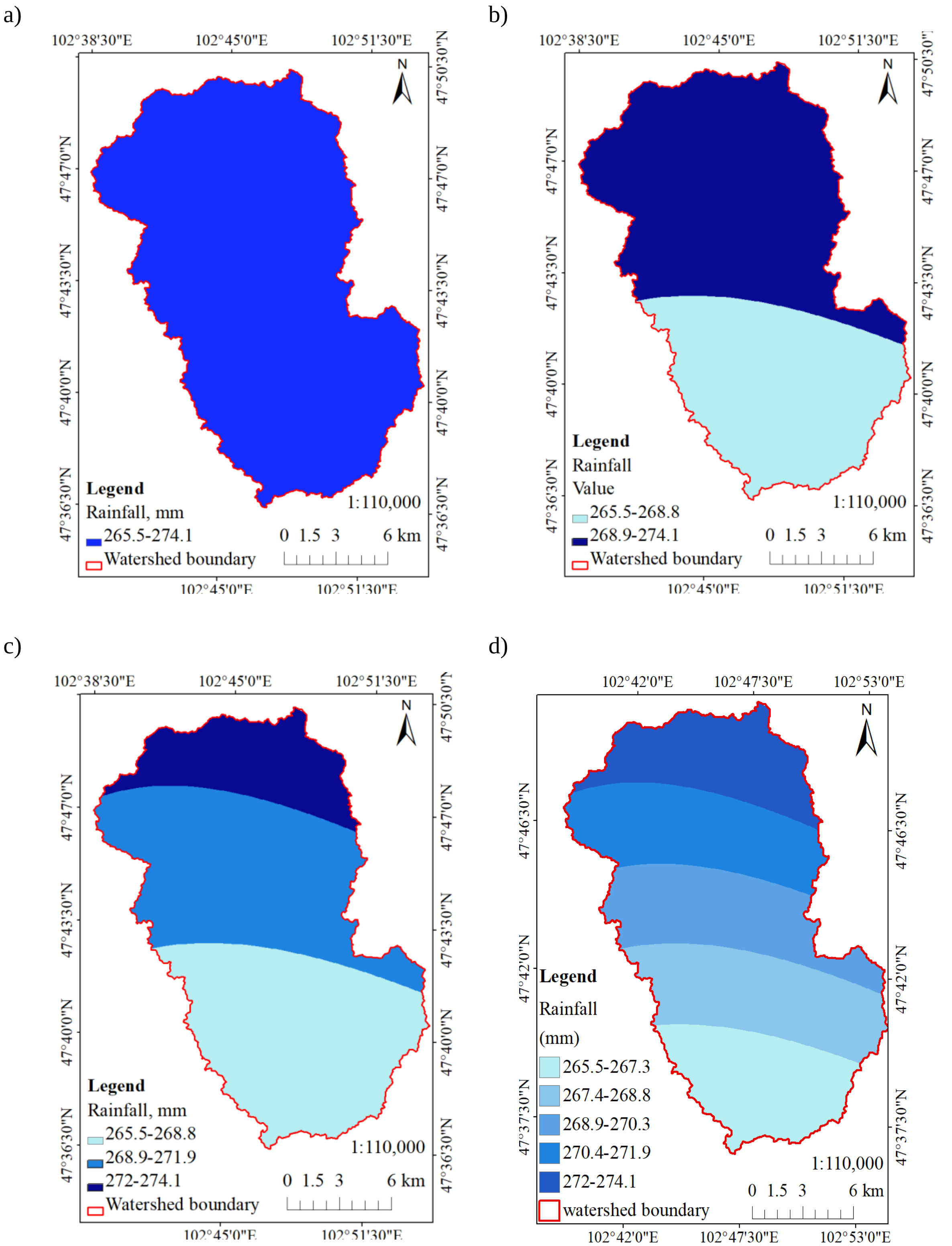


Fig. A. 1 Different classes of rainfall in 2019 a) 1 classes, b) 2 classes, c) 3 classes, and d) 5 classes

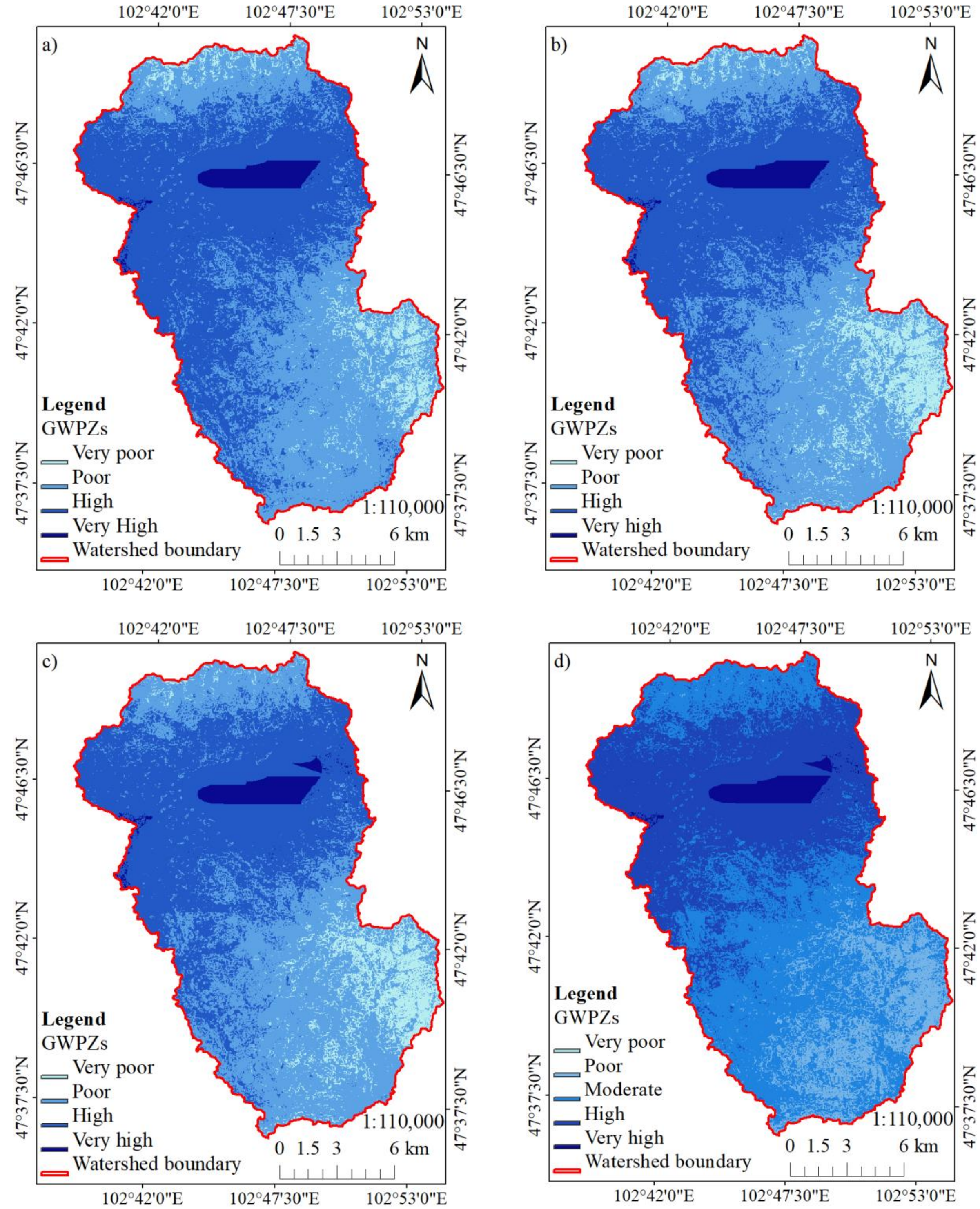


Fig. A.2 GWPZs of the Ogii Lake Basin in 2019 based on the different classes
a) 1 classes, b) 2 classes, c) 3 classes, and d) 5 classes

Research achievements

Peer reviewed journal papers

1. **M. Amgalan**, O. Enkhtsolmon Toru Matsumoto, and T. Ulaanbaatar **"**Estimation of livestock waste generation and its potential non-point pollution source for water quality degradation: Case study of Ogii Lake, Mongolia", Journal of Applied Science and Engineering A, Vol I, Issue 1, 2019 ISBN: 2664-2026.
2. **M. Amgalan**, O. Enkhtsolmon Toru Matsumoto, T. Ulaanbaatar, and Hidenari Yasui "Changes and causes of environmental characteristics of Ogii Lake and Orkhon Valley, Mongolia" Journal of Water and Environment Technology, 2020 Volume 18 Issue 4 Pages 199-211 Online ISSN: 1348-2165.
3. **M. Amgalan**, Toru Matsumoto, T. Ulaanbaatar, N. Nandintsetseg, S. Erdenesukh, D. Sandelger, and E. Altanbold "Estimation of evaporation from Ogii Lake using the energy budget method" Journal of Japan Society of Civil Engineering, Ser. G (Environmental Research) Vol.76, No.5, 2020. Online ISSN: 2185-6648.
4. **M. Amgalan,** Toru Matsumoto, T. Ulaanbaatar, O. Enkhtsolmon "Mapping of groundwater potential zone using GIS and remote sensing on Ogii Lake Basin, Mongolia" Journal of the Remote Sensing Society of Japan, Revised version has submitted on Feb 11, 2021

Participation on the international and national conferences

1. **M. Amgalan**, Toru Matsumoto, Hidenari Yasui, Bing Liu, T. Ulaanbaatar, and O. Enkhtsolmon "Assessment of surface water quality in Orkhon Valley, Mongolia" A conference of science application and development solution of Mongolia, 22-23 November 2017.
2. **M. Amgalan**, Toru Matsumoto, and T. Ulaanbaatar "Assessment of climate change impact on surface water quality and quantity and its mitigation management: Orkhon Valley, Mongolia" The 13the Biennial International Conference on Eco Balance, 9-12 October 2018.
3. **M. Amgalan**, O. Enkhtsolmon, Toru Matsumoto, and T. Ulaanbaatar "Climate change impact on livestock growth and its non-point pollution source for water quality degradation around Ogii Lake County, Mongolia" 8th IWA-ASPIRE Conference e-proceeding (Extended abstract), November, 2019
4. **M. Amgalan**, Toru Matsumoto, T. Ulaanbaatar, N. Nandintsetseg, S. Erdenesukh, D. Sandelger, and E. Altanbold "Estimation of evaporation from Ogii Lake using the energy budget method" JSCE 28th International Summer Symposium, 23-25 September 2020.