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Recent Changes of Water Regime and Resource of the Ganga Lake and Related Some Socio-Economic Aspects

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Abstract: The Lake Ganga is located in the Sukhbaatar provincein Eastern Mongola and in terms of wetland service and local natural beauty the lake is very important water bodies. In this paper, lake morphometry, water level fluctuation and water balance of the Ganga Lake have been analyzed to reveal the coupling effects of climate change and human impacts.

It's water regime and morphometric changes serve as indicator of climate change in the steppe and Gobi region. The lake is very vulnerable for the climate warming and human impacts. In recent years, water level of the lake much dropped and continued its shrinkage of water surface area, especially dramatic lake depletion was observed in summer of 2016. The cause of such changes is mainly climate warming. Summer of 2016 was hottest summer since mid-1940th when started permanent and systematic observation for regional climate, around Ganga lake. Rainless days continued from end of July till early September, covering nearly whole August month of this year and at same time, during this period also observed longest consecutive extreme hot days which exceeds 30°C in the region. As consequences of such extreme weather condition, water surface area reduced till 0.29 km^2 which several times smaller than normal lake condition. Water level of the Ganga lake has dropped by 1.5 m since late 1990th where the lake was full and in last 3-4 year lake water level dropped by 50-60 cm.

Recent years, due to drying out of several open water sources, which serve for livestock watering, serious pasture degradation took place around lake area. For instance, additionally 16 herders family moved to Ganga lake site from surrounding area and in summer of 2016 about 31000 of livestock concentrated in the lake area. Such huge concentration of animals in the small lake water also seriously affected to lake water quality and lakebed sediment situation.

Key words: Ganga lake, climate change, water level decline, lake morphometry changes

1. Introduction

The Ganga lake is located in Eastern steppe of Mongolia, near Daryganga village at 12 km in the east-south direction from the village. The lake is formed in small hollow induced by blockage of sand dune named "Moltsog els" at elevation of 1294 m. The basin of the area around the lake is very distinctive in terms of natural composition and combined by wetlands, sand dune and dry steppe.

The lake basin area generally composed by the plateau with mean elevation of 1300 and highest point is "Gangyn tsagaan ovoo" hill with top elevation of 1530 m a.s.l. According to the natural zoning and belt classification, the lake basin area located in margin of dry and desert (fady) steppe [1]. The lake is registered in the list of Wetlands of International Importance (Ramsar convention) in 22nd March of 2004 which include 3.28 hectare area. The lake site is locally attractive for tourist with its state sacrificed hill named Altan ovoo, Lake Duut, Orgikh and Gashin springs and sand dunes as Kholboo and Moltsog and have high spiritual value with legends and divinities attached to the lake. Therefore, by resolution of the Mongolian parliament under No.22 dated on 2004, the lake area covering 62860 hectaretook under protectionas National Conservation Park classification.

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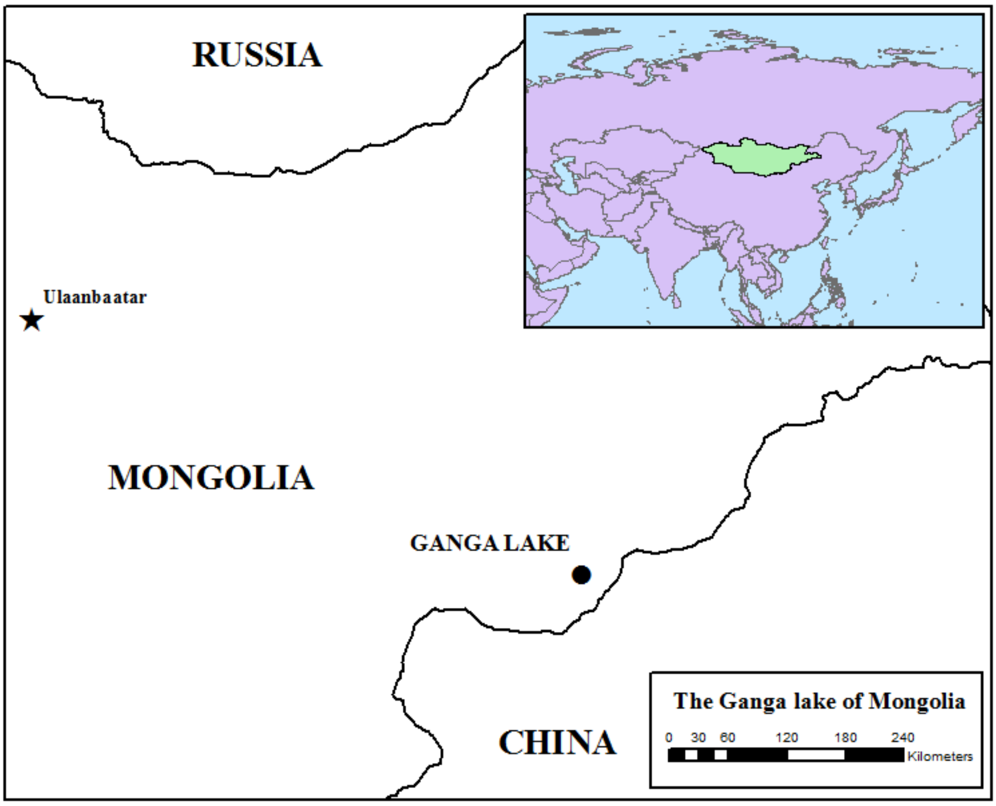

Fig. 1 Location of the Ganga lake, Daryganga, Eastern Mongolia.

In the northern shore of the lake edged by sand dune while around the lake grow bushes and shrubs, willow and several springs drain into lake including Orgikh and Bayan etc.. The Ganga lakebed composed by glay, rich with hydrobiological resources and very important point for migrating birds. The Ganga is very famous among Mongolian with "Fall Swan's Ensemble" where nearly whole water surface area of the lakes covered by white swans and other migrating birds in early October. Recreational capability of the lake is high. The lake is also vital important drinking water source for animals and local herders and very vulnerable water body to the climate change and human's influences.

Table 1 Morphometric parameters of some lakes in the Ganga lake basin [2].

Lakes	Lake water level elevation, m	Water surface area, km^2	Length, km	Width, km	Length of lake shore line, km	Maximum depth, m	Volume, km^3
Ganga lake	1294	2.2	2.1	1.5	6.2	2.6	0.0044
Duut lake	1288	0.5	1.1	1.5	2.8	1.1	

2. Materials and Methods

In this study have been used long term monitoring data of the Ganga-Daryganga hydrological station (1998-2016), water balance study data from local Science-Technological project of RIIMHE which carried out in 2013-2015 and field trip measurement results from 2016 in the Ganga lake site. Climate data were obtained from the Daryganga meteorological stations and also nearest meteorological station at Bayandelger.

Lake surface area changes are estimated using topographic map with scale of 1:100000 and Landsat satellite data from 1999, 2001, 2006, 2011 and 2013-2016. Socio-economic data around lake area and village Daryganga is provided from locals and Ministry of Environment and Tourism.

Two raingauges with tipping bucket principle (DAVIS-II, USA) have been installed at Ganga lake and Daryganga meteorological station sites during the period of 2014-2016. Surface inflow or springs yields were measured by current meter and calculated by the velocity-area method. An open water evaporation rate was calculated from climate data of surrounding meteorological stations using empirical equation derived for Mongolian condition [3]. Finally, lake water balance is estimated using the following water balance equation. Any water balance of the lake can be expressed through the following water balance equation [4].

$$Q_o(t) + P(t) - Q_r(t) - E(t) = dV/dt \qquad (1)$$

Where: $Q_o(t)$:total surface inflow to the lake, $P(t)$:rainfall, $Q_r(t)$:outflow form the lake, $E(t)$:evaporation from the lake, dV/dt:lake volume change for Δt;

Basic lake morphometry such as water depth, surface area, shoreline length and volume are estimated by direct boat measurements, hand GPS and differential GPS (Trimble, USA) and analyzed and processed with ARCGIS 9.3 software.

3. Results

3.1 *Review on Study of Ganga Lake*

The basic morphometry, water quality, lake origin and water level fluctuation of Ganga Lake have been studied by different research organizations in different periods. For example, one of first research outputs on Ganga Lake have produced by Institute of Geography and permafrost pf Mongolian Academy of Sciences [5].

Systematic observation for lake regime started from August of 1987, when have been installed first hydrological gauging station at the lake site by Institute of Hydrology and Meteorology [6]. This gauging station was operated till 1992 and then closed due to lack of financing. Later, in July of 1997, the hydrological gauging station at Ganga lake site re-opened [7] and up to now is operating within official state hydrometerological observational network of Mongolia.

According to historical narrative, during period of 1860-1870s, the Ganga Lake was dried out for three consecutive years and in the middle appeared island of the lake (Locals elders interview, by P. Nyamjav, 1987). Also, locals and elders suspected that lake water level decline and drying out phenomena is due to sand dune shift or sand storm which filled up the lake bottom.

The Research and Information Institute of Meteorology, Hydrology and Environment (RIIMHE) have been carried out Science-Technological project named as “Hydrological cycle and water balance of Mongolia” in 2013-2015 [8] and in this project included studies on climate around Ganga Lake area, lake morpohmetry, tributaries into lake (several springs) and further lake water balance etc. The lake water balance study also continued in 2016. At present days, in the Ganga Lake basin is operating quite dense hydrometeorological monitoring network. Additionally installed raingauges, groundwater table and spring runoff measurement sites to the existing hydrological stations at Ganga and Duut lakes and meteorological stations in Daryganga village. Hydrochemical and biological sampling also included in the program of the hydrological gauging stations at lakes.

The main goal of the research was to document vulnerability of the lake to climate change and human influences by analyzing long term hydro-climatic data around the lake, estimating lake morphometry changes and developing water balance of the lake.

3.2 *Regional Climate Background and Weather Condition of 2016*

Regional climate and its change are certainly key factors which define water regime and resource of the Ganga Lake. Recent sharp temperature increase,

increase of number of hot days, and decrease of rainfall amount in the region are main reasons of drying out water bodies, including small lakes and springs and desertification in the Ganga lake basin. Climate warming is much intensifying in the Eastern Mongolia. Annual mean air temperature have been increased by 2.03°C in last 70 years in this region and intensity of warming was 0.020°C/year for period of 1961-1990 while it have increased till 0.050°C/year in1991-2009 [9].

Evaporation rate from water surface is crucial loss from open water bodies such as Ganga lake. Since 1961, potential evaporation have been increased by 110 mm (within 50 years) in eastern part of Mongolia while sum of precipitation already reduced by 34 mm in same period [10].

Generally, the lake area in Mongolia decreased by -9.3% at an annual rate of -53.7 km^2 yr^{-1} during 2000 to 2011 for the 73 lakes. However, considerable spatial variations, such as slight-to-moderate lake area reductions in semi-arid regions and rapid lake area reductions in arid regions, were also detected [11].

In the eastern steppe of Mongolia soil degradation and desertification take place in recent years and occurrence of dust storms is becoming more frequent. For instance, dust storm occurs about 10 days on average within a year in period of 1960-1969 and then its occurrence significantly increased in 2000-2007, reaching 33 dust storm cases within a year [12]. Another important factor which seriously affect Ganga Lake decline is extreme hot days occurrence. Number of hot days where air temperature exceed 30.0°C generally counts about 20 cases within a year in 1961-1990. However, from 1991 to 2007, number hotdays increased till 24 days a year.

Generally, annual precipitation has strong seasonal pattern with predominant amount occurrence in the summer season (up to 80 percent within V-IX months) in Mongolia as well as in the eastern region where locate the Lake Ganga. Long term series of annual sum of precipitation in the Eastern region of Mongolia shows that year 1965, 1978, 1986, 1995, especially since 2000, 2001, 2005-2007, 2009-2010 year were relatively dry years with annual sum of precipitation which range from 90 to 140 mm (with regional mean of 196 mm) [13]. In case of monthly sum of precipitation, monthly sum of rainfall may reach 100-230 mm in July and August in wet years while in dry years, accounts only less than 10 mm within given months.

Rainfall analysis of summer of 2016 shows that May and June's rainfall in the Daryganga region was higher than regional long term mean amounts.But, July and August of 2016, where normally expect higher amount rainfall, were extreme dry months. For example, rainfall amount in July of 2016 was 17.3 mm in the Ganga lake site which is 3 times less than regional mean of the month and August month was even more dry, basically with only 2.2 mm of rain (with regional mean of August of 41.8 mm).

Not only Ganga lake site was dry in July and August of 2016, but also nearest meteorological stations show similar dry situations. For example, Bayandelger station was completely dry in August which is unprecedent in systematical observational history of this station.

One of clear indicator of increase of climate warming intensity is increase of number of hot days in the region. As mentioned earlier, mean number of hot days was about 20 days a year while in summer of 2016, totally 41 hot days have been recorded around Ganga lake area. Number of hot days of 2016 also break whole long term from 1961 to 2016. In other words, in 2016 have observed maximum number hot days since beginning of systematic observation for climate in the region.

From 18th of July till 12th of August of 2016, observed 23 consecutive hot days where air temperature exceed 30°C in Ganga lake area and another 14 hot days cases observed in July and August of 2016 and maximum air temperature reached 39.4°C in this period. If consider monthly mean air temperature in the region, monthly mean air temperature of August month of 2016 was 21.4 and 22.8°C in Erdenetsagaan and Bayandelger stations, respectively.These values indicate that August of 2016 was hottest months in last 75 years in the region.

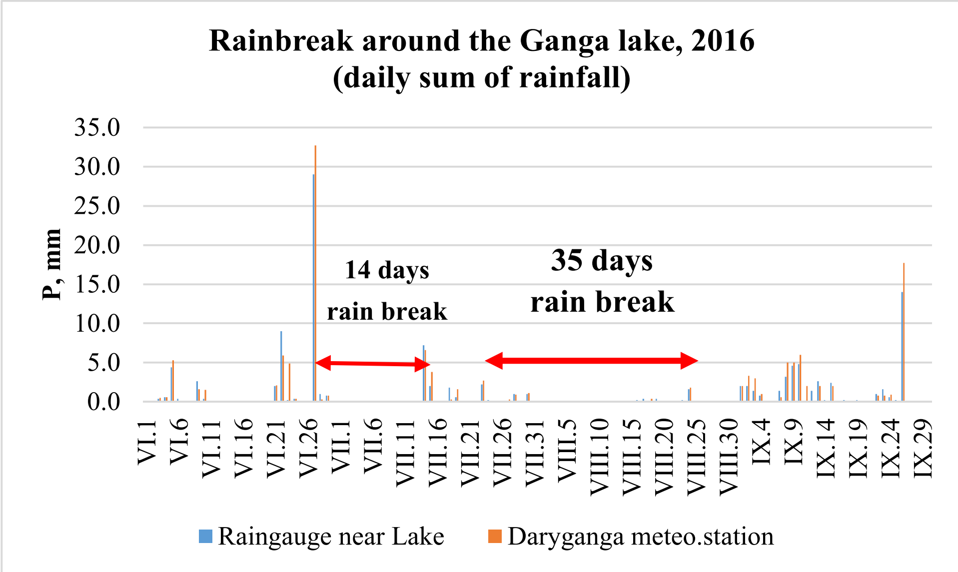

Fig. 2 Daily rainfall and rainbreaks in the Ganga Lake basin in 2016.

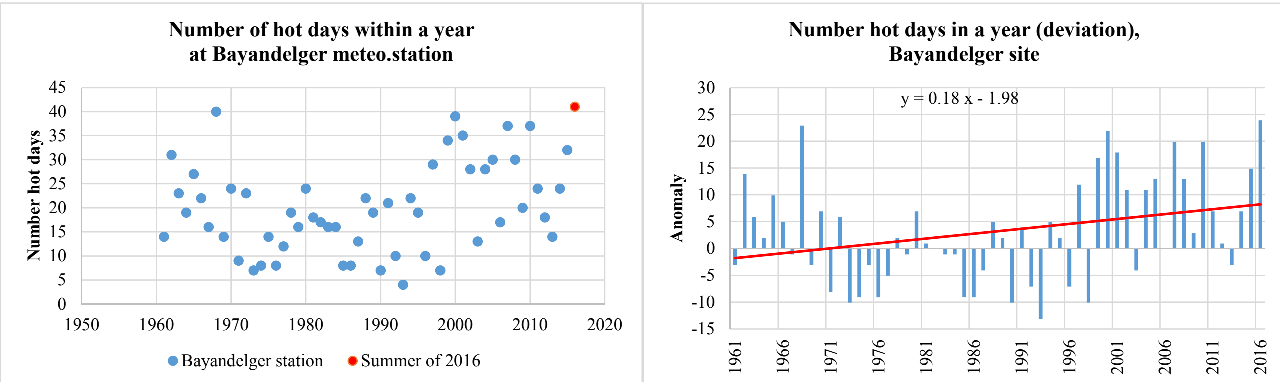

Fig. 3 Long term changes of number of extreme hot days in the Ganga Lake region.

Two more automatic raingauges have been installed in the Ganga lake site within the mentioned Science-Technological project in 2013. Records of raingauges compared with official meteorological station data and found quite sufficient confident with official meteostation data in terms of timing and amount.

In last 3-4 years where carried out water balance study of the Ganga Lake also have observed significant change of regional climate. For example, mean temperature for warm season have increased by 1.0°C in last 3 years. At same time, sum of warm period rainfall have decreased by 15-40 percent in the Ganga lake site.

Table 2 Monthly sum of rainfall in the Ganga lake basin, 2016.

Raingauge sites	VI	V	VI	VII	VIII	IX	X	IV-X
Daryganga raingauge	1.2	41.5	56.6	17.3	2.2	52.1	*23.4*	194.3
Daryganga meteo. station	*1.2*	*41.5*	51.2	16.0	2.8	44.6	*23.4*	180.7
Lake site raingauge	*1.2*	*41.5*	46.0	43.4	8.2	61.6	*23.4*	225.3
Mean of 2016	*1.2*	*41.5*	51.3	25.6	4.4	52.8	*23.4*	200.1
Regional long term mean	**8.4**	**16.5**	**48.1**	**56.7**	**41.8**	**18.3**	**6.1**	195.9

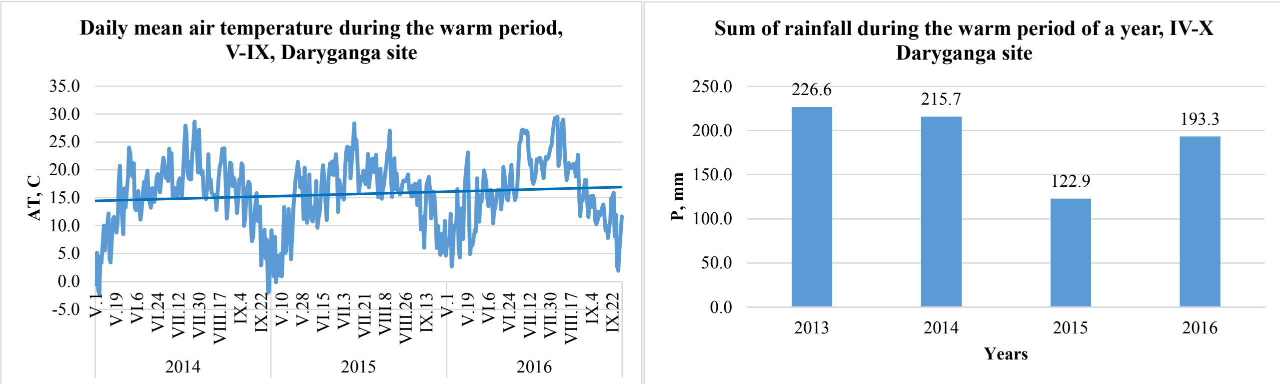

Fig. 4 Recent climate changes in the Ganga Lake area.

3.3 Lake Water Level Fluctuation and Variation

Inflow or main water sources of Ganga Lake are rainfall at water surface of the lake, spring's yield which drains into lake, temporary direct surface runoff from surrounding catchments of few dry beds and groundwater inflow through the lakebed with distant recharge area. Water level fluctuation of the Ganga Lake has general pattern with gradually decreasing behavior from Spring to Autumn. Except some wet years with extreme high events, response of the Ganga Lake to rainfall amount is not much clear.

Mean amplitude of water level fluctuation of the Ganga Lake is 25-30 cm and in some rainy years may approach up to 1.0 m while in dry years amplitude water level fluctuation is just around 10 cm. In July of 1998, lake site has received exceptional rainfall of 100 mm which is about 60 percent of annual sum of precipitation of the region and such big rainfall amount produced 60-100 cm rise of water level at Ganga Lake in few days.

Long term variation of water level of the Ganga Lake shows that the mean water level has increased by 100 cm from 1987 to 2000. Then followed about 10 years low flow period (2001-2011) in the region with annual rainfall of 110-202 mm and water level of the Ganga lake much dropped. Year 2012 was wet year with 346 mm of annual sum of rainfall and since has observed some short rising tendency in the water level of the lake (year 2013 and 2014).

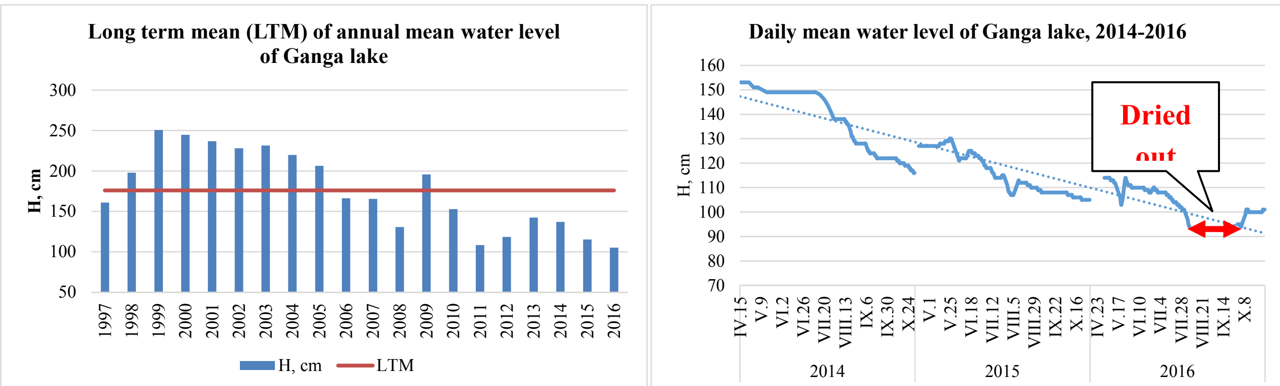

Fig. 5 Annual mean water level (long term mean) and daily water level (2014-2016) variation.

Although immediate response of rainfall in the Ganga Lake basin to the lake water level is not clear, summer rainfall certainly recharges the groundwater, namely springs around the lake. Therefore, there is some assumption that accumulated groundwater from summer rainfall have effect on water level increase of the lake with some lack period, for example, in the following next year's spring season.

Response of the lake water level to rainfall or rainfall-water level relationship mostly defined by pattern of very local spatial distribution of rainfall in the Ganga lake area, antecedent soil moisture condition in the lake basin and other related factors. For instance, excessive rainfall has occurred at lake water surface or mostly in the recharge area of the springs etc.

Long rainbreak and continuous long hot days occurred in July and August of 2016 was main reasons of drying out of Ganga Lake and made social, public noises in the local and country scale. Many disputes and debates began in different media on how to recover and save the lake involving popular public figures, politician and researcher. At the end of August remains only very thin mixture of water and sand with area of 0.29 km^2 which is 7-8 times less than normal size of the lake. Generally, in last 3 years, from 2014 to 2016, the water level of the Ganga Lake has dropped by 60 cm.

3.4 Changes of Basic Morphometry of the Lake

The basic morphometric parameters of the Ganga Lake such as water surface area, shoreline length, depth and volume are measured by direct boat measurement, hand GPS and differential GPS and their changes are defined with use of topographic map and satellite images of different time and period. As noted in the Catalogue of Mongolian lakes [1] water surface area of the Ganga lake was 2.2 km^2 and then during the estimation in 2011-2012, the size of the lake has reduced till 1.6 km^2. Later, the water surface of the area sligthly expanded in 2013-2014,reaching1.8 km^2 . In recent years, the water surface area of the lake has clear shrinking tendency and since 2000 water surface area reduced by 60-70 percent [14].

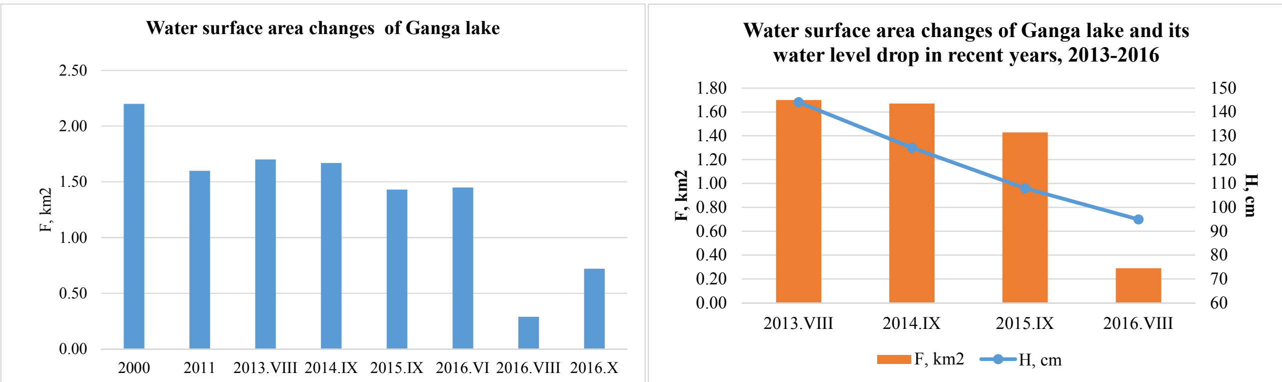

Fig. 6 Recent changes of water surface area of the Ganga Lake and related mean water level.

3.5 Some Estimation Results of Main Components of the Lake Water Balance

Water regime and water balance of the Ganga lake mainly defined by evaporation from open water surface, rainfall at water surface of the lake as well as in the lake basin and inflow from the springs. Among these factors, especially in dry climate, evaporation is an essential part of the lake water balance.

In this study, evaporation is estimated by following empirical equation derived for the local condition (G. Davaa, 1996).

$$E = 0.29\cdot(1.0 + 0.32\cdot V_{200})\cdot(e_o - e_{200}) \quad (2)$$

where: V_{200} — wind speed at 2.0 m level above ground, m/sec, e_o — water vapour calculated from water temperature, hPa, e_{200} — absolute air humidity 2.0 m level, hPa.

Results of estimation show that during warm period of year from May to September, about 630-900 mm of water may evaporate from the Ganga lake. Evaporation rate also has increasing tendency and in last 3-4 years, sum of warm period evaporation is increased by 250 mm.

According to the local legend and folk, there are 21 springs feed the Ganga lake. However, at present days, depending on flow condition of a year, there are only 2-3 springs constantly drain into the Ganga lake. In 2016, only Orgikh and Bayan springs drain into the lake. Besides, spring's flow measurement is not regular and a few flow measurements have done in different seasons in different years. Particularly, the study team from Institute of Meteorology and Hydrology (RIIMHE) have conducted flow of mentioned springs in 1987, 2000, 2012, 2014-2016. These sparse measurements of spring's yield somehow indicate that yield of the Orgikh spring varies around 6-8 l/sec while yield of the Bayan spring is about 10-12 l/sec.

During the morphometric measurement and analysis, depth of the lake were linked to a lake water level (datum) and established water level — elevation or surface area relationships were established.

$$H = 128.2 \cdot F^{0.76} \quad (3)$$

Where: H- lake water level, m, F- lake water surface area, km^2.

Mentioned relationships allow us to estimate volume of the lake and consequently water balance of the Ganga lake. The volume of the Ganga lake ranges around 2060000-3140000 m^3 within the estimation period, 2009-2016.

Table 3 Mean water balance of the Ganga lake.

Estimation period	Evaporation		Rainfall		Changes of volume		Total runoff	
	km^3	mm	km^3	mm	km^3	mm	km^3	mm
2009-2016	0.001	1110	0.0002	197	-0.00011	-716	0.0010	1653

Our estimation shows that 18.6 percent of inflow of the Ganga lake water balance is due to rainfall and 81.4 percent of inflow belongs to total surface and groundwater inflows. Due to its small catchment of surface runoff, no regularly flowing spring's tributaries, runoff and direct rainfall on the lake surface cannot compensate for evaporation losses and mostly water balance of the Ganga lake is therefore negative.

Concerning groundwater component of the water balance, we select 2 dug wells near to the lake (within 2-10 km from the lake) and compared water table location in the wells with lake surface elevation and it shows that selected well tables always below the lake surface elevation by several meters. In fact, groundwater component of the water balance of the lake is very uncertain and its needed more detailed and complex research and data to understand interconnection to the lake.

3.6 Socio-environmental Issues around Lake Area and Lake Basin

As mentioned before, data and research results on interaction between groundwater and lake water, location and condition of recharge area of groundwater and springs are very much limited and no any monitoring activities for groundwater and this situation is main lack of understanding functioning of the lake and values of climate change impacts.

Local people herders and even some researchers stated that one of cause of lake drying out is livestock concentration related consequences such as livestock manure into lake water, land degradation around lake and recharge area of groundwater, livestock drinking and as a results occur water pollution, eutrophication due to increased nutrients. However, still do not have data and research results which scientifically explain influences of such processes on lake shrinkage and water level decline.

Another concern about lake shrinkage is sand dune shift and increasing frequency and intensity of dust storm in the region (local people suspected that dust storm and sand dune shift fills up the lake and then water surface area reduces and water level drops). Also impacting mechanisms of such phenomena still is not clear in relation to the lake changes.

Total population of Daryganag village is about 2900 with 798 families. Total number of livestock is 62896 including mainly sheeps and goats, also some horses and cattle. Total area 64710.8 he and 95 percent of them is considered to be pasture. Recent land inventory is reported that "…40 percent of pasture of the Daryganga region is degraded and pasture capacity around lake already exceeded and plant species changed to weed…” (Management plan of the Daryganga National Conservation park, 2014).

During the hot and rainless months of 2016, many small lakes, ponds, springs are dried out in the Ganga lake basin limiting drinking and livestock watering sources of herders and animals and forced to move herders to the Ganga lake area. Surface water inventory carried out in 2014, counts 33 springs and 22 small lakes and ponds with water in the Daryganga region while similar inventory which conducted in 2016 reported drying out of 12 ponds, lakes and another springs cutted down in the region.

Local people, local government and central organizations such as Ministry of Environment and Tourism, some research institutions are quite actively involved in research study funding, some concrete measures to recover and protect the Ganga lake. In accordance with “Plan of measures on protection and recovery of Ganga lake ecosystem” approved by State secretary of Ministry of Environment and Tourism already taken some practical measures and activities including sand and wind protecting blocks, planting of shrubs and willow around the lake, improving water supply for livestock watering by drilling new wells in the lake basin, design and construction of accumulations ponds from snow melting and intense rain. The Ministry also plan to carry out complex research studies on interaction between groundwater and lake water, groundwater recharging possibility using geophysical survey methods and to point groundwater borehole sites for wells and groundwater monitoring.

Generally, water resource reductions were closely linked with an exacerbation of desertification and deterioration of local socio-economic systems in arid and semi-arid regions of Mongolia. At same time, climate projections showed evapotranspiration increase is expected to be 6-10 times greater than some small increase of rainfall that means drying and desertification will be intensifying in the region.

4. Conclusions and Recommendations

Water regime and morphometric changes of small lakes serve as indicator of climate change in the steppe and Gobi region and the lake is very vulnerable for the climate warming and human impacts.

Under intensifying climate warming trend in the Eastern Mongolia, climate extremes such as consecutive hot days, long rainbreak and frequent dust storm are key reasons of drying of Ganga lake.

Groundwater recharge mechanism and interaction between groundwater through the lakebed of the Ganga lake are main uncertainties of the water balance of the Ganga lake and therefore it is needed to extend hydrometeorological network of the Ganga lake basin with following observation and monitoring, pan evaporation, groundwater table measurement, permanent measurement for spring yields at required frequency similar to climate and lake water level.

Impact of livestock concentration, land degradation, sand dune, dust storm to the lake depletion also is needed to clarify and continue to support any local and national activities on lake protection and recovery.

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