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MODERN STATE AND FORECAST OF WATER RESOURCES OF MONGOLIA IN THE LIGHT OF CLIMATE CHANGES

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Surface and groundwater resources play vital roles in the economy of Mongolia. Due to changes in water resources and regime, there is a decline, as well as the complete disappearance of certain types of vegetation and wildlife. An important task is to study the current state of the water resources of Mongolia and their forecast in the face of climate change. The article summarizes the changes in the surface waters in Mongolia. There is a decrease in surface runoff, the area of lakes and glaciers in the XX century. According to RegCM4-ECHAM5 and RegCM4-HadGEM2 models, precipitation and respectively runoff is projected to increase and simultaneously, evaporation from water surface and evapotranspiration are expected drastically increase, that will lead to imbalance of water, drying effect will be prevailing in a river basins. It is urgent issue to take adaptive measures against negative impacts of climate changes.
Keywords: climate change, evaporation, evapotranspiration, glaciers, lakes, Mongolia, precipitation, RegCM4-ECHAM5, RegCM4-HadGEM2, surface runoff, surface waters, temperature, water resources.

Introduction

The total surface water resource of Mongolia is estimated as 599 km^3/year, and is composed mainly from water stored in lakes (500 km^3/year) and glaciers (62,9 km^3/year). Only 5,8% of the total surface water resources, i.e., 34,6 km^3/year, are in rivers, with 2,1% in base flow and 3,7% in direct runoff of rainfall and from snow melting as determined from a flow separation analysis. Despite their small size, the surface and groundwater resources play vital roles in the country's economy, especially in agriculture, livestock production, industry and domestic water supply. The purpose of this article is to assess the current state and future changes in the water resources of Mongolia.

Current changes in surface waters. The annual, total river flow since 1978 varies, gradually increasing and reaches its maximum value of 78,4 km^3 in 1993. Long lasting low flow period steadily continues since 1996 and reaches its minimum of 16,7 km^3 in 2002. 22,7 km^3 of annual, total river flow was formed in 2015, that is lower than its long-term mean by 11,9 km^3.

There were 4296 lakes, covering total water surface area of 15514,7 km^2, acquired from a topographic map scaled as 1:100000, compiled, based on air photos taken in the 1940th. The lake area data, retrieved from LANDSAT satellite images show that there were 4069 lakes with total surface area of 15384,3 km^2 in 2000, 3825 lakes with total surface area of 14696,6 km^2 in 2006, 3699 lakes with total surface area of 14393,2 km^2 in 2010, 3727 lakes with total surface area of 14305,6 km^2 in 2014 and 3464 lakes with total surface area of 14312,6 km^2 in 2015, respectively. Accordantly, total lake area reduced by 0,8% or 130,3 km^2 and 227 lakes were dried out in 2000, by 5,3% or 818,1 km^2 and 471 lakes were dried out in 2006, by 7,2% or 1121,5 km^2 and 597 lakes were dried out in 2010, by 7,8% or 1209,1 km^2 and 569 lakes were dried out in 2014 and by 7,8% or 1201,9 km^2 and 832 lakes were dried out in 2015, respectively, in comparisons with data of 1940th (fig. 1).

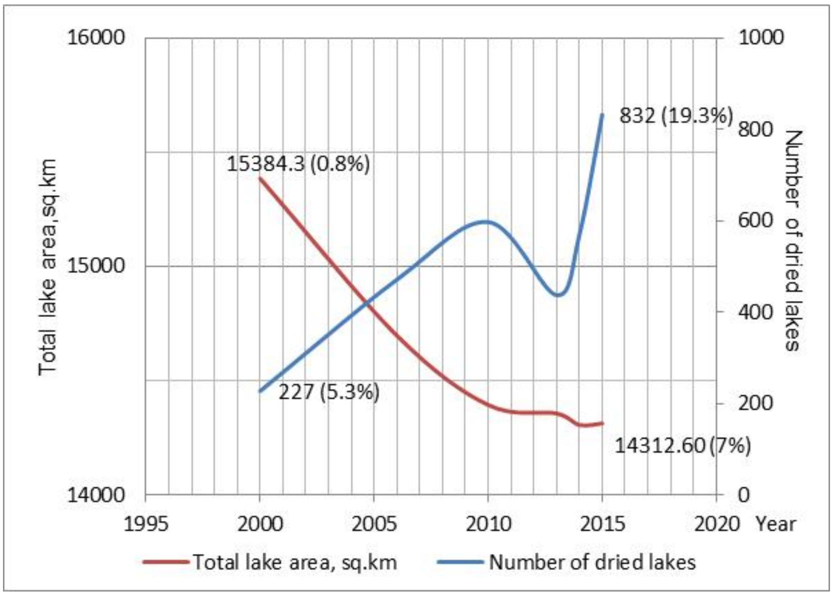


Fig. 1. Changes in total lake areas and number of dried lakes

Water level of large, big and bigger lakes tends to decrease in last 20 years. Water level of lakes and natural lagoons, located in floodplain, watered once during high flood event, remains low. Water level of lakes and natural lagoons, located in desert steppe and Gobi desert, such as Khyargas, Boontsagaan, Orog lake and etc. steadily decreases. Note that there are problems with the level regime of Lake Baikal — the main receiving reservoir of the surface waters of Mongolia (Гармаев и др., 2017).

Detailed comparisons of areas of individual glacier massifs derived from different sources of data shows that areas of glacier massifs tend to be overestimated with topographic map compiled in 1940th. Total glacier area, distributed in 42 mountain massifs, derived from topographic map, scaled as 1:100000, was 535,0 km^2 in 1940th. Glacier areas, retrieved from LANDSAT satellite data, were 470 km^2 in 1990, 451 km^2 in 2000, 389 km^2 in 2011. Accordantly, glacier areas retreated by 12,1% in the period of 1940th till 1990, by 4% in 1990-2000, and by 13,75 in 2000-2011 periods. Totally glaciers retreated by 29,9 in last 70 years. Glacier retreat and shrinkage intensified after 1990th and most intensive ablation occurred in last 10 years (Даваа, 2015).

Dynamics of glacier massif areas show that more intensive retreating occurs in flat top glaciers in the Tsambagarav, less retreating occurs in Corrie glacier dominated massif in the Munkhhairkhan, average retreating rate is observed in glacier complexes of the Tavanbogd, Kharkhiraa and Turgen Mts due to climate warming.

First evidence on the glaciers on Mongolian Altay was reported in the literature in connection with Potanin's expeditions to northwestern Mongolia (1877-1879) and later, with the expedition of Polish geologists (Rutkowski and Slowanski, 1970). The observations made by those expeditions contained first, very general, descriptions of separate glaciers in the immediate vicinity of the expedition's routes.

One hundred years later, in summer 2010, a US–Mongolian expedition retraced portions of the 1910 expedition. Analyses of field data, repeated photographs from 1910 and 2010, topographic maps from 1970, and satellite imagery from 1992 and 2010 were used to describe the changes in the glacial system. The results suggest that while the snow and ice volume on the summits appears to be intact, lower elevation glaciers show significant recession and ablation. From 1910 to 2010, West Turgen Glacier receded by 600 km^3 and down-wasted by 70 km^3 (Kamp et al, 2013).

Cumulative ablation rates decreasing upwards along the Potanin glacier in 2004-2015 period were 41,15-48,65 m at the altitude of 2977-2998 m, 33,85-40,63m at 3033-3057 m, 31,15-36,76 m at 3116-3123 m, 27,33-33,04 m at 3234-3247 m and 19,18-27,57m at 3339-3366 m.

The same cumulative ablations of Soutern Ulaan-Am flat top glacier at the Tsambagarav Mts. in 2004-2014 period were 13,56 m at the altitude of 3607 m, 11,18 m at the altitude of 3621 m, 10,88 m at the altitude of 3700 m, 8,59 m at the altitude of 3732 m, 5,93 m at the altitude of 3771 m, 5,70 m at the altitude of 3814 m.

US NASA (National Aeronautics and Space Agency) and German space agency, DLR (Deutsches Zentrum für Luft- und Raumfahrt) jointly launched a pair of the satellite units as GRACE (Gravity Recovery and Climate Experiment) on the same orbit. Detailed estimation of changes in Earth's gravity field is made through precise measurements of the distance between the units. Since the measured gravity field, at monthly timescales, is the integration of that from the atmosphere, the ocean, the solid earth and the terrestrial water storage (TWS), the terrestrial water storage change (TWSC) can be derived through the independent estimation of the others. It is derived that TWSC having a horizontal resolution of approximately 300-400km, and a temporal resolution of about a month for the period of 2005-2011 (Kobayashi and Asanuma, 2013). TWSC from GRACE is the sum of changes in vertically integrated water mass, such as ground water, soil moisture, snow accumulation and so on. They used Level-3, gridded 0.5^o data set, including Northen part of China (fig. 2). There are remarkable temporal changes of TWS in each region. In the region "a", including some part of the Altay Mts., Great Lake hollow and Northern part of China, continuous decrease in TWS can be found, which can be attributed to the glacier retreat, lowering water level of lakes and ground water. TWS continuously decreases in the area “c” covering Central Mongolian Economy region, centered by Ulaanbaatar. These are in marked contrast with the area “d” where TWS shows fairly constant. It is also noted that these 4 areas show seasonal change of TWS. Among these, the area “a” exhibits the largest seasonal change in TWS and decrease in 30 mm. This can be partly consistent with seasonal snowfall, its melted water and decrease in groundwater level.

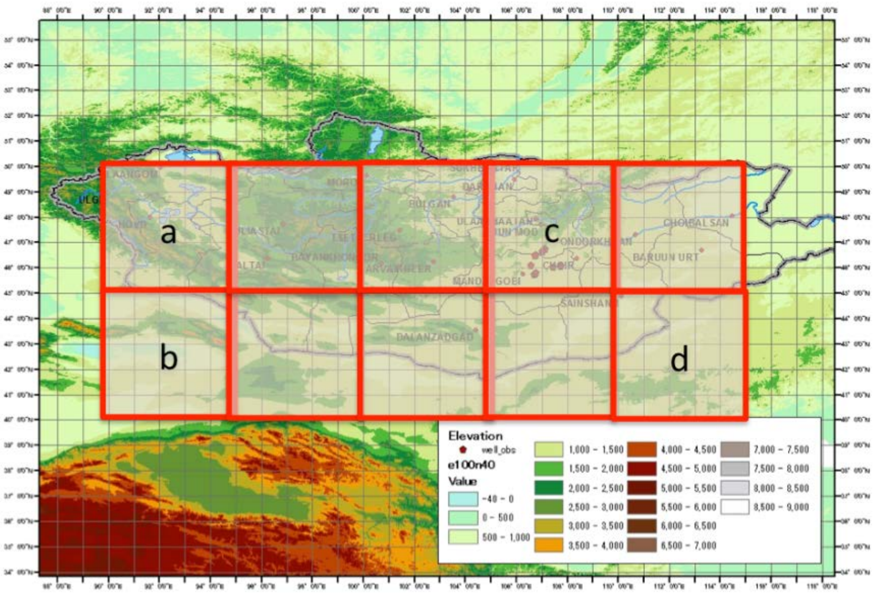


Fig. 2. Target region and the subareas subject to the analyses

Future climate change impact on water. NCEP reanalysis climate data have been used for initial and boundary conditions of RegCM4 climate model. Past climate data have been simulated with RegCM4 climate model in the period of 1986-2005. Using climate data simulated with RegCM4, have been estimated water balance elements such as precipitation, runoff, evaporation from open water surface, evapotranspiration and etc for the period of 1986-2005. Estimated and gridded runoff depth has been compared with observed runoff depth, derived from its map. Correlation coefficient between observed and simulated runoff depth is 0,74 and mean absolute error was 0,51 mm.

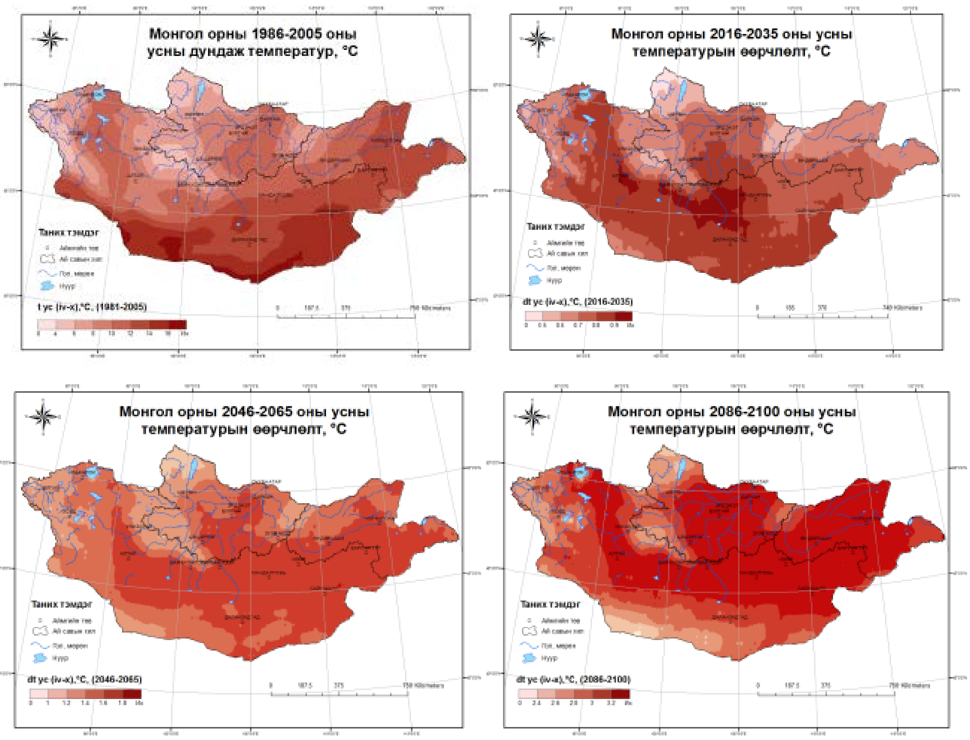
Hydrological network comparably well-developed and pleasant natural conditions are in the Arctic Ocean basin (AOB), Mongolia. Therefore, basin average precipitation in the basin is higher by 27% than that in the Pacific Ocean basin (POB) and much higher by 80% than that in Asian Internal Drainage basin (AIDB), Mongolia. Hence, average runoff depth is 1,95 times higher and evapotranspiration is also higher by 11% in the AOB than that is in POB. Runoff depth 4,7 times higher and evapotranspiration is also much higher by 44% in the AOB than that is in AIDB. Average water temperature for the period of April to October in the AOB is less by 3,1-3,3 °C and evaporation from open water surface is also less by 30-39% than these are in the POB and AIDB (table 1).

Table 1

Average values of water balance elements, mm and average water temperature, 1986–2005

Regional river basins	**Precipi tation**	**Runoff depth**	**Evapotran spiration**	**Evaporation from open water surface**	**Average water temperature (Apr.-Oct.),°C**
Arctic Ocean basin	246,3	70,9	175,4	517,0	8,4
Pacific Ocean basin	194,1	36,3	157,8	851,9	11,7
Asian Internal Drainage basin	137,0	15,0	122,0	738,5	11,5

Average water temperature for the period of Apr.-Oct. has been estimated with air and soil surface temperatures, projected by RegCM4-ECHAM5 and RegCM4-HadGEM2 models and regression equations expressing the dependency between water and soil, air temperatures in accordance to RCP8.5 GHG scenarios. Average water temperature, projected by RegCM4-ECHAM5 model output results will increase by 0,7 °C, 1,5 °C and 3,2 °C in periods of 2016-2035, 2046-2065 and 2080-2099 in the AOB and by 1,5 °C, 1,6 °C, 3,3 °C in the POB and by 0,8 °C, 1,6 °C, 3,1 °C in the AIDB in comparisons with water temperature of 1986-2005 period.



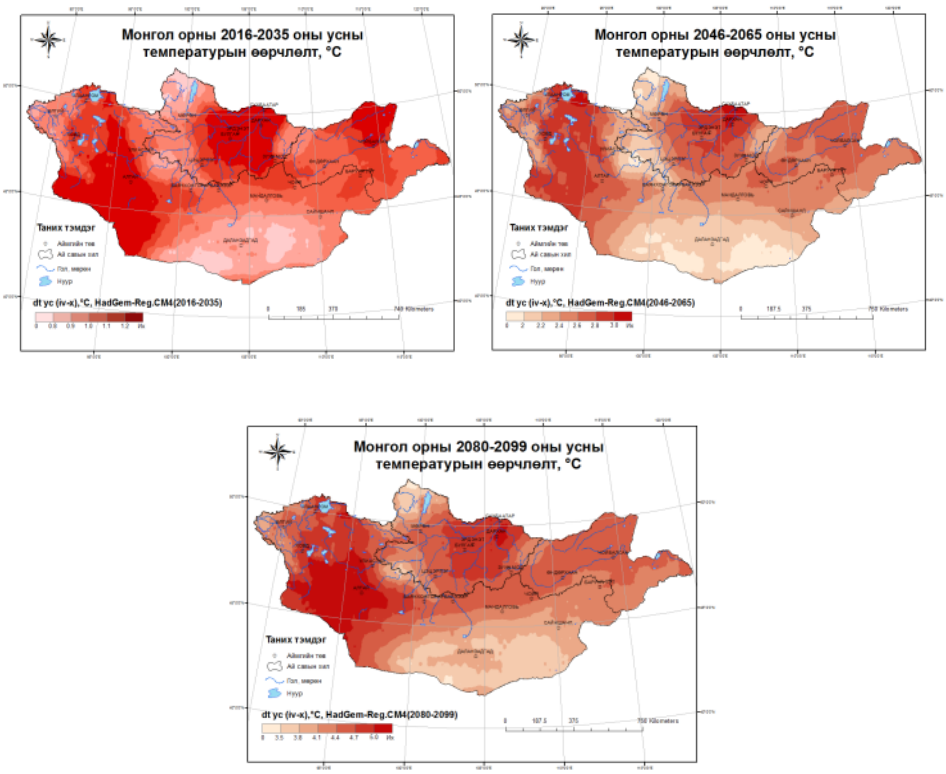


Fig. 3. Spatial distribution of current average (Apr.-Oct.) water temperature and its changes, projected by RegCM4-ECHAM5 and RegCM4-HadGEM2 models

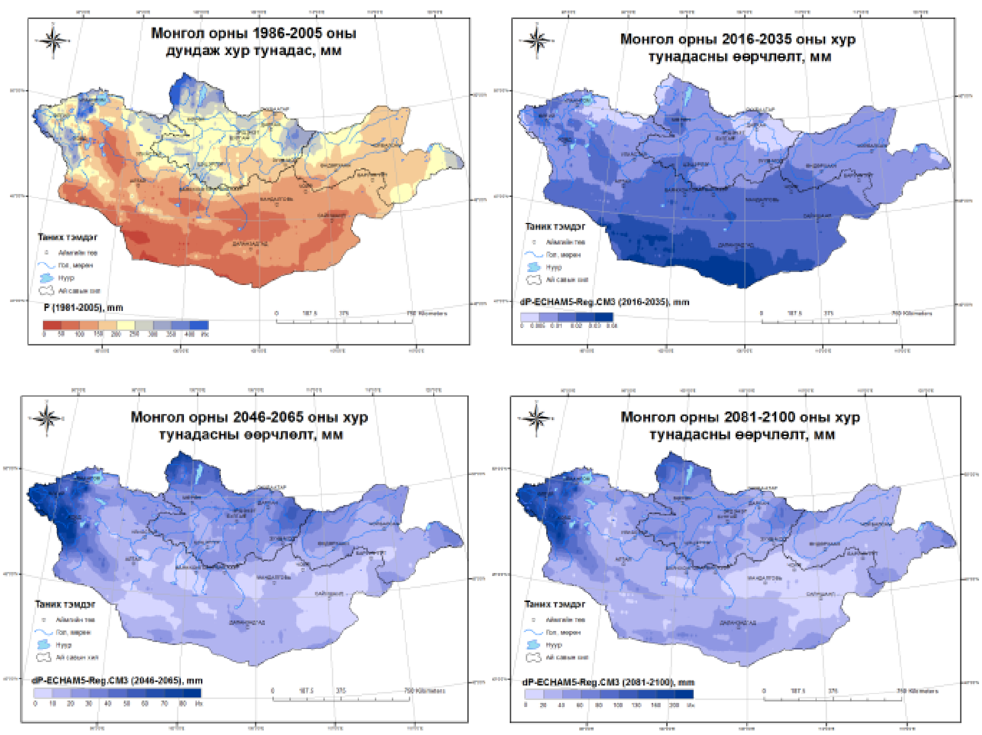
Projected average water temperature by RegCM4-HadGEM2 is expected even higher than that projected by RegCM4-ECHAM5 model. These projected by RegCM4-HadGEM2 values will be higher in 2016-2035, 2046-2065, 2080-2099 periods by 0,4 °C, 1,1 °C, 1,3 °C in the AOB, by 0,4 °C, 1,0 °C, 1,2 °C in the POB and by 0,2 °C, 0,9 °C, 1,3 °C in the AIDB than that projected with RegCM4-ECHAM5 model, respectively (Fig. 3 and Table 2).

Annual mean precipitation, projected by RegCM4-ECHAM5 is expected to increase in 2016-2035, 2046-2065 and 2080-2099 periods by 0,01 mm, 30,6 mm, 53,7 mm in the AOB, by 0,01 mm, 20,6 mm, 32,9 mm in the POB and by 0,02 mm, 19,9 mm, 41,4 mm in the AIDB, respectively comparisons with the annual mean precipitation observed in 1986-2005 period. Annual mean precipitation, projected by RegCM4-HadGEM2 model results is higher than that projected by the RegCM4-ECHAM5. That will be higher in 2016-2035 period by 20,1 mm in the AOB, by 14,8 mm in the POB and by 18,9 mm in the AIDB and changes in the precipitation will be nearly the same as projected by RegCM4-HadGEM2 and RegCM4-ECHAM5 models in 2046-2065 and 2080-2099 periods (Fig. 4 and Table 2).

Table 2

Projected future changes in water balance elements and temperature

Regional basins		**AOB**	**POB**	**AIDB**	**AOB**	**POB**	**AIDB**
Models used		**RegCM4-ECHAM5**			**RegCM4-HadGEM2**		
Changes in annual mean precipitation, mm	2020	0,01	0	0,02	20,1	14,8	18,9
	2050	30,6	20,6	19,9	31,1	23,7	27,7
	2080	53,7	32,9	41,4	54,7	59,8	51,4
Changes in annual evaporation from open surface of water, mm	2020	143,5	164,7	106,8	26,8	38,6	34,3
	2050	162,3	364,5	96,1	70,1	106,4	108,4
	2080	221,6	370,2	150,2	106,3	155,7	175,2
Changes in runoff depth (May-October), mm	2020	0	0	0	6	2,7	1,8
	2050	8,9	4	2,1	9,2	4,4	2,5
	2080	15,6	6,2	4,3	16,1	10,8	4,5
Changes in average water temperature (Apr.-Oct.), °C	2020	0,7	0,7	0,8	1,1	1,1	1
	2050	1,5	1,6	1,6	2,5	2,6	2,4
	2080	3,2	3,3	3,1	4,5	4,4	4,4
Changes in annual evapotranspiration, mm	2020	0	0	0	14,1	12,1	17,1
	2050	21,7	16,6	17,8	21,9	19,3	25,2
	2080	38,1	26,7	37,1	38,6	49	46,9



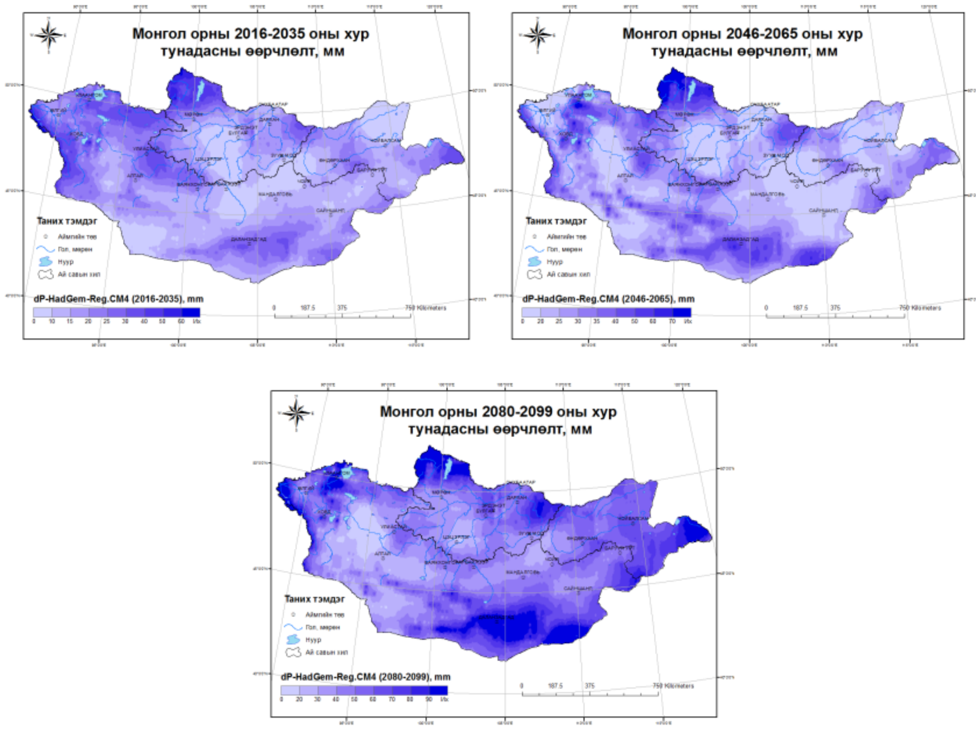


Fig. 4. Spatial distribution of current annual precipitation and its changes, projected by RegCM4-ECHAM5 and RegCM4-HadGEM2 models

Annual mean (Apr.-Oct.) evaporation from open surface of water, projected by RegCM4-ECHAM5 is expected to drastically increase in 2016-2035, 2046-2065 and 2080-2099 periods by 143,5 mm, 162,3 mm, 221,6 mm in the AOB, by 164,7 mm, 364,5 mm, 370,2 mm in the POB and by 106,8 mm, 96,1 mm, 150,2 mm in the AIDB, respectively comparisons with the annual mean evaporation from open surface of water, observed in 1986-2005 period. The evaporation, projected by RegCM4-HadGEM2 model results is less than that projected by the RegCM4-ECHAM5. That will be 2,08-5,35 times less in the AOB and POB in all future periods and by 3,11 times less in the period 2016-2035 and by 11-14% in AIDB in the periods of 2046-2065 and 2080-2099 periods than that projected by RegCM4-ECHAM5 model (Table 2).

Annual mean runoff depth, projected by RegCM4-ECHAM5 is expected to increase in 2016-2035, 2046-2065 and 2080-2099 periods by 0,0 mm, 8,9 mm, 15,6 mm in the AOB, by 0,0 mm, 4,0 mm, 6,2 mm in the POB and by 0,0 mm, 2,1 mm, 4,3 mm in the AIDB, respectively comparisons with the annual mean runoff depth, observed in 1986-2005 period. The runoff, projected by RegCM4-HadGEM2 model results is less than that projected by the RegCM4-ECHAM5. That will be less in the period of 2016-2035 by 6,0 mm in the AOB, by 2,7 mm in the POB and by 1,8 mm in the AIDB and changes in the runoff will be nearly the same as projected by RegCM4-HadGEM2 and RegCM4-ECHAM5 models in 2046-2065 and 2080-2099 periods (Fig. 5 and Table 2).

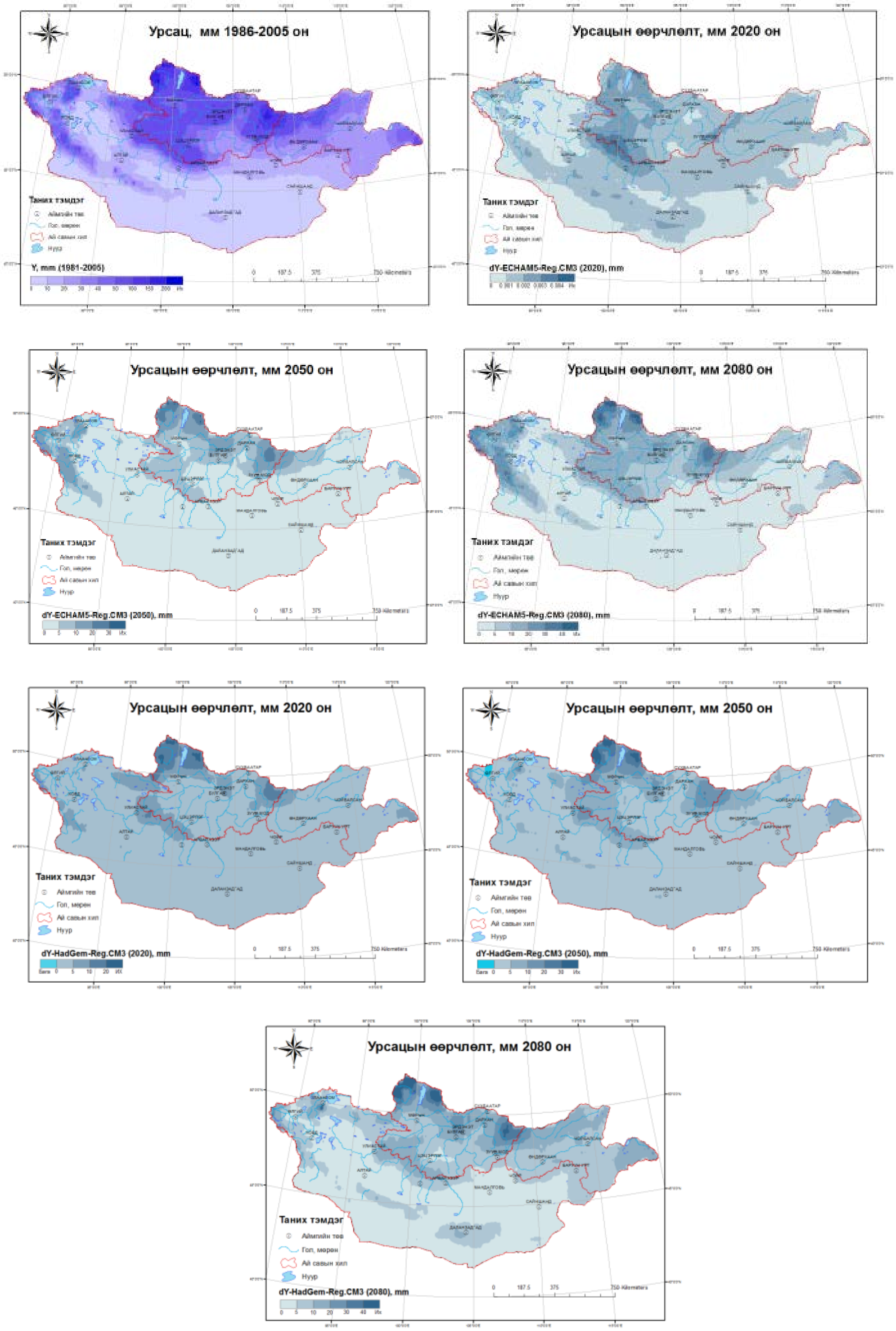


Fig. 5. Spatial distribution of current annual runoff depth and its changes, projected by RegCM4-ECHAM5 and RegCM4-HadGEM2 models

Changes in water balance elements, projected by RegCM4-ECHAM5 model are basin specific. Almost no changes in precipitation and accordantly no changes in runoff are expected in the period of 2016-2035. However, annual mean (Apr.-Oct.) evaporation from open surface of water is projected to increase by 128 in the Tuul, by 71 in the Kharaa, by 52 in the Eroo, by 115 in the middle reach of the Selenge and Orkhon rivers, by 60-174 in their upper reaches, respectively mm/year, in the AOB. Changes in this evaporation are expected to increase by 95 in the Kherlen, by 88 in the Onon, by 52 in the Ulz, by 67 in the Galyin, and by 41 in the Khalkh river basins, respectively mm/year in the POB and by 74 in the Khovd, by 138 in the Zavkhan, by 107 in the Khungui, by 85 in the Baruunturuun, by 45 in the Turgen, by 130 in the Tes, by 20-30 in the river basins draining from southern slope of Altay Mts., by 182-313 in the river basins draining from southern slope of Khangai Mts., by 299 in the river basins draining from southern slope of Gobi-Altay Mts., by 160-295 in the Galba-Oush-Dolood Gobi basins, respectively mm/year, in the AIDB. However, precipitation and respectively runoff is projected to increase and simultaneously, evaporation from water surface and evapotranspiration are expected drastically increase, that will lead to imbalance of water, drying effect will be prevailing in a river basins.

These changes will lead to changes in water balance elements of lakes. Water level of the Khuvsugul and Uvs lakes are expected to increase, while, water level of the Khyargas and Khar-Us lakes is expected to remain as it is at the present. However, water levels of lakes located in steppe, dry steppe, desert steppe and Gobi deserts are expected to decrease and lead to water imbalance and drying processes will be intensified.

Mean annual ablation rate has been estimated as 3,11, 3,21, 4,04, 5,19 m/year in the period of 1982-2010, 1911-2030, 2046-2065 and 2080-2099, respectively. Annual ablation rate in the period of 2011-2030 is projected to slightly increase by 3 percent that will increase by 29,9 percent in 2046-2065 and 67,0 percent in 2080-2099 periods in comparisons with the current.

Accordantly, mean annual mass balance has been estimated as -1,68, -1,76, -2,40, -3,63 m/year in the period of 1982-2010, 1911-2030, 2046-2065 and 2080-2099, respectively. Its mean annual value in the period of 2011-2030 is projected to decrease by 5 percent that will decrease by 43,3 percent in 2046-2065 and 116 percent in 2080-2099 year's period in comparisons with the current. Total glacier in the Kharkhiraa river basin is projected to decrease till 13,7 km^2 by 2030 and will be significantly decreasing by 2049 (Davaa et al., 2014).

Conclusions

Based on the foregoing, the community and the environment should adapt to changes in climate, for which it is necessary to reduce the negative effects and use them effectively to develop concrete solutions.

Adaptation to climate change in the livestock pastoralists implies a change in lifestyle, nature and way of life. The negative effects of climate change include depletion of fields, drought, lack of water for human and livestock needs, impoverishment, deterioration of social and cultural conditions, loss of traditions, etc., unfortunately, there is almost nothing to be said about positive moments of climate change. For pastoralists, the adaptation process is a change in consciousness and approach in the area of using fields for grazing, the number of livestock, and the use of water reserves.

Any reserve with unreasonable use will come to an end. Rarely, when a reserve is gradually used, the reserve is gradually replenished, because direct use disrupts the natural balance of nature, as a result of which it must be used very carefully. Since the process of melting the ice sheet, dehydrating the soil and turning it into a desert place, evaporation of surface water is an irreversible process, in those places where these processes are the lowest indicators, in Mongolia it is a region of the Altai Range, Khangai, Khentii, the organization of new protected water basins and regulation of water regime. There is no need to organize water basins in the desert zone, where evaporations have the highest rates. To overcome the negative effects of climate change, it is necessary to combine government policies and the national project "water" in order to accumulate and economically use water resources in the desert and steppe zones, to organize closed protection basins.

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СОВРЕМЕННОЕ СОСТОЯНИЕ И ПРОГНОЗНАЯ ОЦЕНКА ВОДНЫХ РЕСУРСОВ МОНГОЛИИ В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА

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Ресурсы поверхностных и подземных вод играют жизненно важную роль в экономике Монголии. Из-за изменений в водном режиме наблюдается снижение, а также полное исчезновение определенных видов растительности и животных. Важной задачей является изучение текущего состояния водных ресурсов Монголии и их прогноза в свете изменения климата. В статье приведен анализ изменений ресурсов поверхностных вод Монголии. Установлено, что в XX веке происходит снижение поверхностного стока, площади озер и ледников. Согласно расчетам по моделям RegCM4-ECHAM5 и RegCM4-HadGEM2 ожидается, что осадки и сток будут увеличиваться, и одновременно ожидается значительное увеличение испарения и эвапотранспирации, что приведет к дисбалансу водных ресурсов в речных бассейнах. Актуальной проблемой является принятие адаптивных мер против негативных последствий изменения климата.
Ключевые слова: изменение климата, испарение, эвапотранспирация, ледники, озера, Монголия, осадки, RegCM4-ECHAM5, RegCM4-HadGEM2, поверхностный сток, поверхностные воды, температура, водные ресурсы