Features of the natural environment of the Tea Road corridor in the context of the climate change

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Abstract. Low-water period in the basin of Lake Baikal began in the middle 90s of the 20 century. A statistically significant trend in temperature increase and decrease in precipitation is established. The analysis of water inflow in Lake Baikal is performed. It is established that the Baikal level practically directly depends on the water content of the Selenga river. Dendrochronological reconstruction of the Selenga river run-off was carried out. In recent decades, a statistically significant trend towards the descent of the river run-off with the analysis of air temperature and atmospheric precipitation in the whole basin in the Russian part of the basin has been identified. The meridional transect (E 105-107, N 51-44) is chosen for the investigation, covering all arid climatic zones. A set of methods for remote sensing, geoinformation technologies and in-situ surveys of geosystems with the implementation of landscape, geobotanical and soil studies, mapping of vegetation of model polygons and key sites were used. A spatio-temporal assessment of the state of natural-anthropogenic geosystemsis carried out, criteria, indicators and tendencies of their dynamics are determined in connection with the processes of land degradation and desertification.

1. Introduction

Lake Baikal is the largest freshwater lake by volume in the world, containing roughly 20 % of the world's unfrozen surface fresh water. Lake Baikal together with the adjacent territories in 1996 was included in the UNESCO World Heritage List. In connection with this, the problem of the protection and conservation of lake water resources is acquired exclusively acute [1].

The Baikal Lake basin is located almost in the center of the vast Asian continent and covers an area of 545 km^2 (excluding water area of Lake Baikal), 45 % of which lies within the Russian Federation, the rest is on the territory of Mongolia. About 73 % of river waters are formed on the territory of Russia, 27 % – Mongolia [1].

Because of the global warming in Transbaikalia the temperature of air limit layer increases, precipitation decreases [2]. All this has led to the low water content of the rivers flowing into the Baikal. There has been steady declining trend of the main flow of the Baikal tributary – the Selenga river – due to the lack of rainfall [3, 4].

Land degradation in arid, semi-arid, and dry sub-humid areas – also referred to as dry lands – may result from various factors, including climatic variations and human activities [5]. It includes diverse processes, ranging from changes in plant species composition to soil erosion, and reduces the land's productive potential [6]. Land degradation may diminish the land's resilience, making it more vulnerable and reducing its capacity to recover from disturbances. Furthermore, land degradation can have negative effects on other resources, such as water, soil, flora, and fauna [7].

Causes of land degradation can be natural or man-made. Natural causes include periodic stress from extreme and persistent climatic events, aridity, and droughts. Man-made causes include unsustainable human land use – for example, overgrazing, deforestation, and over-cultivation – as well as indirect socio-economic drivers, such as unstable food market prices and political instability or changes [8].

Land degradation and desertification processes are widespread in Russia and Mongolia. Over 85% of the Mongolian territory is located in dry climate zones: dry sub-humid, semiarid, arid, and extra-arid.

The vegetation is the first experience the impact of desertification [9], and that is why investigation of its changes have a particular importance.

Our research deals with vegetation dynamics of dry climatic zones of Mongolia from NDVI time series analysis and field investigations. The tasks of this study included: 1) field geobotanical studies on testing ranges and classification of vegetation; 2) analysis of the dynamics of the NDVI vegetation index according to satellite data; 3) analysis of the spatial structure of phytocenosis. A number of model monitoring polygons and key sites of contact monitoring has been established in different latitudinal zones according to the longitudinal transect (105-107° E, 51-44°N). These polygons include a wide range of territories with dry climate conditions. This work revealed the main factors, agents, and trends of development for desertification processes in different climate zones.

Two model polygons were considered in Central Mongolia: 1) the Kharaa river downstream basin and the Orkhon river right feeder; 2) the central part of Dundgoviaimag (Middle Gobi). The first polygon is situated in a semiarid climate zone with grassland and bunchgrass steppes. The second is located in an arid climate zone; from botanical and geographical points of view, its main feature is the prevalence of desertified steppes.

2. Materials and methods

An analysis of the meteorological series of air temperature and precipitation was held along the whole basin of Lake Baikal based on the initial data of weather stations and a global database of geospatial meteorological parameters Climate Research Unit – CRU (spatial resolution of 0.5×0.5 of angular degree) [10].

The analysis of the hydrometeorological information was held on the basis of historical data and weather gauging stations of the Republic of Buryatia, Transbaikalia region and Mongolia.

According to gauging stations and dendroclimatic stations, a spatio-temporal reconstruction of river flow parameters in the Selenga river basin was conducted [11]. As a result, water flow model reconstruction of the Selenga river and its tributaries – rivers Uda, Khilok, Chikoy, Dzida, Orkhon and Kharaa was obtained. For individual watercourses the time-series until 1666 have been restored. This allowed us to reveal regularities of moisture fluctuations in Baikal Asia in retrospective.

Remote sensing methods, especially satellites, have provided opportunities to organize immediate vegetation monitoring.

Of particular importance in the establishment of a system of remote sensing monitoring is the possibility of organizing completely automated satellite data processing. Over the last years, such technologies were actively being established and developed in the Russian Space Research Institute, Russian Academy of Sciences (IKI RAS). They allowed the creation and actualization of the archive of constant satellite observations on the territory of Russia and adjoining states for the period from 2000 until the present. The basis of automatized technologies established by the IKI RAS is the analysis of NDVI values and comparison with the index variation of the previous years [12].

The temporal dynamics of the vegetation was estimated using archive geoportal data of the IKI RAS for the period of 2001-2017.

To conduct relief morphometric analysis, a number of the corresponding morphometric maps were established and analyzed (along with the data of field observations) on the basis of the Digital Elevation Model SRTM: hypsometry, slopes, and aspects [13].

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While identifying vegetation species, Mongolian [14] and Buryatia [15] keys to identification of plants were used.

3. Climate change in the Baikal region

On the basis of the annual CRU data a statistically significant trend of increasing temperature and decreasing rainfall in the basin of Lake Baikal was found.

Two humidification periods were allocated: 1980-1998 years – wet period; 1999-2017 years – dry period. The wet period is characterized by positive trends of precipitation totals for almost the entire basin of Lake Baikal, with the highest growth rate observed for Khamar-Daban ridge – 14 mm, and for the area of the Middle Baikal – 10 mm for the period under review.

During the dry season in 1999-2017years there is a negative trend in the amount of precipitation for the basin of Lake Baikal. Extreme reduction in moisture for the dry period under review is marked for Khamar-Daban ridge and amounts to -30 mm. In the Upper Angara and the Barguzin river basins the rate of decreasing reaches -18 mm. Atmospheric precipitation effects the long-term fluctuations in river flow to a greater extent than other elements of the water balance.

From 1885 to 2012 years the average annual air temperature in the Trans-Baikal region increased by 2.0 °C [4] (note that at the same time, the annual average temperature around the globe increased by 0.85 °C) [16]. The temperature increase is observed for the entire catchment area of Lake Baikal, while the areas with low growth rates of surface temperature are interspersed with areas with high growth rates, both in latitudinal and longitudinal directions.

4. Peculiarities of Lake Baikal water level regime

It should be noted that since 1996 Lake Baikal is UNESCO World Natural Heritage site. Due to the fact that the Baikal is an artificial reservoir (after the construction of the Irkutsk hydroelectric station in 1956), it can lose this honorary status, which may lead to the risk of inclusion of Lake Baikal to the list of World Heritage in Danger.

The actual water levels of Lake Baikal in vivo (1900-1956 years) ranged from 454.93 m (historical minimum was recorded in 1904) to 457.10 m (maximum was recorded in 1869). In regulated conditions (1960-2015 years) the minimum mark was registered in 1982 – 455.27 m, the maximum in 1988 – 457.42 m (hereinafter used Pacific Heights system).

Average annual useful inflow into the lake during the observation period (1900-2015) is 1872 m^3/s, in vivo – 1916 m^3/s, minimum average annual inflow into the lake was observed in 1903 – 1106 m^3/s, the maximum was in 1932 – 3251 m^3/s; over-regulated in the period – 1824 m^3/s, the minimum inflow was recorded in 1979 – 1244 m^3/s, the maximum – in 1973 – 2848 m^3/s [17].

If the outflow of Lake Baikal will be controlled, it may gradually lose its uniqueness and over the time this can lead to the loss of biodiversity up to the complete disappearance of many species. When the level exceeded 457.0 m, during the high-water years in the middle of the 90-ies of the last century, low-lying coastlines of the east coast were destroyed (coastal forests, recreation zones, beaches and coastal constructions). It caused environmental damage throughout the natural and biological complex of lake system [18].

If the level of Lake Baikal is extremely low, we can observe changes in the groundwater regime and groundwater lowering; violation of the existing mechanisms of Baikal water purification; reduction in water exchange of the sor system with open Baikal, the increase in average temperatures and heavy overgrowth of shallow water; the death of aquatic organisms on the shore of the lake and the coastal system as a result of drying and freezing of the habitats, which are responsible for the processing of organic matter; peat fires in the Selenga river delta [19].

The spring-and-summer period in 2015 was characterized by great losses of forests from fires in the Republic of Buryatia. The dynamics of forest fires on the lands of the State Forest Fund of the Republic for the period from 1936 to 2015 was analyzed. According to the Federal Forestry Agency of the Republic of Buryatia from April to October of 2015 Forest fires caught the area of 750,500 hectares, that exceeds the long-term annual average by 12 times.

Before the construction of the Irkutsk hydroelectric complex (in natural conditions) the level of the lake varied in the range up to 2.17 m. During the period of operation of the Irkutsk hydroelectric station until 2001 the level of the Baikal was 17 times higher than the mark of 457.0 m and 18 times it fell below 456.0 m [20]. After acceptance in March 26, 2001 of the Russian Federation Government Decree № 234 "On the limit values of the water level in Lake Baikal in the implementation of economic and other operations" the level fluctuated in the meter range (456.0-457.0 m), but on 25.02.2015, for the first time since 2001, it fell below the mark of 456.0 m. This is primarily the result of the low water period, which was established in the middle of the 90-ies of the last century and was the highest rate ever recorded. The situation with the low-water level of Lake Baikal basin continues in 2016-2017 years.

Due to the anomalously high air temperatures and almost complete absence of rainfall, inflow of water into the lake in 2015-2017 years was extremely low. The minimum level mark 455.71 m was detected on April 28 to May 06, 2016. The maximum level of Lake Baikal water (after 2014) was 456.27 m (September 7, 2017), which is the lowest value since 2001.

An analysis of the inflow of water into Lake Baikal was carried out. The minimum and maximum water flow, volume of the flow of the major rivers of Lake Baikal basin were studied. It was found that the run-off of the Upper Angara and the Barguzin rivers in the last 20 years has remained within the long-term average rate, the Selenga river run-off was reduced and now stands at 65 % of the normal value. Together these three rivers provide 70 % of the annual inflow of water into Lake Baikal. The level of the lake almost depends on the water content of the Selenga river [21]. A good alignment between the inflow fluctuations in Lake Baikal and the Selenga river run-off was determined, which was confirmed by the high values of correlation of the coefficients between these variables: for the observation period (1934-2014) – 0.85, during the dry periods (1954-1958, 1976-1982, 1996-2014) – 0.68 [17].

The formation of water resources in the catchment area of Mongolia which accounts 67 % of the watershed district of the Selenga river was studied. The dynamics of the Selenga and the Orkhon rivers flow, its main tributary, was studied. High-water period of the Selenga river was observed from 1979 to 1995. In recent years low-water period in the Selenga river basin is observed. The minimum flow during the dry periods, as well as the annual flow, tends to decrease. It is a continuous period of low flow which provided a negative trend of the minimum flow. Thus, the inflow of water into Lake Baikal in recent years is the record-breaking minimum for the whole period of instrumental observations.

5. Reconstruction of the water flow of the Selenga river basin

Unfortunately, for a full analysis of the history of the Baikal fluctuations, we have a too short period of instrumental observations – only 115 years. Considering that our object under study is Lake Baikal, which is the oldest lake in the world (20-35 Million years), this short period of observation data does not allow us to get a more or less objective picture of the changes in its level for a longer time. In this regard, only long-term series of observations allow to define changes in moisture regime correctly. An analysis of annual tree rings allows to essentially extend climatic characteristics [22]. For example, the reconstruction of the Baikal level on dendrochronological data is presented in the article of Andreev S.G. [23].

According to gauging and dendroclimatic stations' data, a spatio-temporal reconstruction of river flow parameters in the Selenga river basin was conducted [11]. As a result, water flow model reconstruction of the Selenga river and its tributaries – the rivers Uda, Khilok, Chikoy, Dzida, Orkhon and Kharaa was obtained.

For each river the time-series until 1666 were restored. This allowed us to reveal regularities of moisture fluctuations in Baikal Asia in retrospective.

There is a spatial and temporal coherence of tree growth with water flow dynamics of the Selenga river and its tributaries. This is particularly evident in the low and high water periods. The correlation values for individual tributary basins are analyzed. The maximum value of 0.66 is a generalized chronology obtained through 8 local chronologies and "responsible" for the valley of the Dzida river. The Dzida river valley is an isolated area, surrounded by high mountain ridges. Here, the run-off is formed within the valley. This explains the close relationship between water consumption and growth of trees, depending at some extent on the incoming water from the atmosphere. High correlation can be observed in the small rivers in the steppe and forest steppe zones.

For the Chikoy river connection with tree rings is smaller (R = 0.47). This value can be explained by the fact that the formation of the Chikoy river flow is under the influence of the Pacific air masses coming in the second half of the summer on the east and affecting the upper catchment area. This explains weakening of the connection of dendrochronological series of the stations located in middle and lower parts of the valley.

It should be noted that the reconstruction of the Kharaa river water flow, built on the same stations as for the Chikoy river, shows a similar picture while taking into account that Kharaa basin is located 300 km to the south. This fact is determined by the general laws of the Chikoy and Kharaa rivers run-off formation.

Annual fluctuations in water of the Orkhon river flow showed a close relationship (R = 0.53) with stations located in the Dzida river basin. The values obtained for the correlation between the indices of growth of annual rings and instrumental measurements of river flows on Mongolian part of the Selenga river basin (for the Kharaa river R = 0.47, for the Orkhon river R = 0.53) allow us to expand our network of stations in the basins of these rivers and get more reliable model reconstruction.

20 century in comparison with the previous centuries was provided with water resources. The general trend of the 20 century has the following character: until mid-century water content has increased, reaching a peak in the mid-1940s, and then began to slowly decrease. The modern period, starting in 1950s is characterized by an increase in water content.

6. Desertification processes

6.1. Semiarid climate zone

Among the desertification types discovered by FAO-UNEP [24], on the greater part of the Selenga River basin, especially in its Mongolian part, the vegetation cover degradation is the most widely spread.

It is revealed in structural changes of the steppe, forest steppe, and pasture phytocenosis, the successions of their species by synanthropic ones, and decreased projective cover and grass height. In places with the highest development of degradation and land desertification processes caused by a high density of grazing animals on easily deflated sand and sabuloussoils, digression processes of steppes and forest steppe geosystems are increased even more. As a result, soilcover is being destroyed, affected by trampling and subsequent deflation, while the existing types of microrelief are being reformed. We noticed an especially strong manifestation of these processes in the poorly populated pine *Pinussylvestris L.* and drought resistant elms *Ulmuspumila L.* in the Kharaagol sandy area (absolute height values are 735-815 m).

According to the scheme of the landscape and the ecological district division located in the central part of the Selenga River basin, the Kharaagol model polygon is situated in an area of high ecological intensity, caused by both natural and anthropogenic factors. Let us consider the key site of 19.2 km^2 situated in the northern part of the Kharaagol polygon, 3 km southeast of the Darkhan city. The biggest part of this site, located on the separated slopes of low hill terrain of the Orkhon-Kharaagol interfluve (maximal height marks are 810-870 m), has steppe caragana-cereal-fringed sagebrush (*Artemisia frigida – Leymus chinesis – Caragana microphylla*) vegetation. As geobotanical studies have shown, the small-leaved *Caragana microphylla (Pall.) Lam.* dominates in the projective vegetation cover (17-20 %). Fringed sagebrush, *Artemisia frigidaWilld* .is also widely spread, as well as Chinese wild rye *Leymus chinensis (Trin.) Tzvelev*, etc. Most of the land is used as pasture.

Using access to the satellite monitoring service "Vega" to monitor the vegetation condition[12], average NDVI curves were built for the Kharaagol key site for the first 17 years of the twenty-first century. Some nonuniformity of the NDVI distribution was observed throughout the years, caused by different climate conditions. It should be pointed out that in 2007, 2008 and 2012 the NDVI values were rather high 0.6, which is related to the higher values of temperature and moisture regime during the summer months of these years. The important feature of the system "Vega" is a possibility of the research with meteorological information. It gives the chance to receive spatial distribution of meteorological parameters for any date of the vegetation period. The average summer value of the NDVI in 2011 was 0.45 for this site, which proves sparse vegetation during this year.

According to the Mongolian State National Statistics Committee [25], a tendency to increase the number of farm animals was observed on the territories of Selenge and Darkhan-Uulaimags in 2000s. Express surveys conducted for arats having a household within the territories of the Kharaagol model polygon showed that nearly half of them immigrated here (to be closer to main market of animal products) with their herds in the 2000s from other periphery Mongolian aimags, the western (mostly) and Gobi.

6.2. Arid climate zone

On the territory of Dundgovi aimag (Middle Gobi), moving from north to south, there is a gradual landscape substitute: desertified steppes of semi-deserts are changed for deserts with saxaul (*Haloxylon sp.*).

Studies showed that in conditions of insufficient moisture (an annual sum of atmospheric condensation less than 100 mm on the territory of Ulziitsomon of the southern part of Dundgoviaimag, a maximal value of 150 mm in the north, or a complete absence of fresh surface water), Gobi landscapes are affected by degradation processes easily, especially by the physical weathering, deflation, and degradation of vegetation. Even though the general pasture load is low on the territory of Dundgoviaimag because of the rather low density of the animal base, the soil surface is trodden around bases within a 0.5-0.7 km radius, and there is hardly any vegetation cover (projective cover from 0 to 1 %).

Up north from the aimag center Mandalgovi, southern dry steppe landscapes dominate. They are located on 70-80 % of the territory. Desertified steppes take up 10-20 %, while saline and alkali saline soil comprise under 8 %. South from Mandalgovi, within the limits of the Middle Gobi model polygon, desertified steppe landscapes prevail (65-75 %). The southern steppes take up 20-30 %, and the saline ones comprise less than 9 % of the territory.

The average NDVI value for the last 17 years aggregated for the Middle Gobi model polygon is 0.12, which proves poor vegetation. NDVI values are slightly higher in 2012 and 2013.

Comparison of natural geobotanical studies conducted in 2011-2017 and the results for ecological groups of the Gobi areas of 2010 proves this conclusion, representing the increased share of euxerophyte plants in projective cover for different areas at 12-15 %, indicating continuous invasion of euxeropyte desert species of plants in the north. Thus, the share of euxerophytes has increased in the projective cover from 77 % in August 2010 to 96 % in August 2012 on the key site situated in the lowland, stony, desertified steppes 20 km south of Mandalgovi.

Meteorological data analysis proved that in the 2000s there was more severe drought during the summer periods than in the previous century, which, in our opinion, is the main factor for the digression tendency in the Gobi vegetation.

7. Conclusion

Statistically significant trend of increasing temperature and decreasing precipitation with the identification of wet and dry periods is established. In recent years, due to abnormally high air temperatures and almost complete absence of atmospheric precipitation, water flow into Lake Baikal has been extremely low during the whole period of instrumental observations. As a result, there were problems with the level regime of Lake Baikal.

There is high year and seasonal growth in response to the current precipitation in the dendrochronological series for specific areas. Spatio-temporal coherence of the tree growth with water flow dynamics of the Selenga river and its tributaries was revealed. So statistical models of reconstruction of water flow show good correlation (r = 0.47 ... 0.66) between the increase in the annual rings of Scots pine and annual consumption of water. On the example of the Mongolian part of the Selenga river basin, it is shown that the spatial relationship between the water run-off and dendroclimatic stations located on the territory of Russia can be traced for hundreds of kilometers.

It was found that for forest-steppe regions of the Baikal Asia a limiting factor for tree growth is the atmospheric precipitation which form the water flow of the Selenga basin rivers. The data flow rates for a large time interval can serve as a basis for the planning of water resources management. This aspect is particularly relevant for the Selenga river, because of its cross-border location.

Climatic zones of the north of Central Asia experience different trends of desertification processes associated with both climatic variability (mainly aridization) and anthropogenic influence. The performed studies for different channels of optical bands using methods based on the consideration of differences in spectral reflection, together with field natural investigations, prove that the degradation of the vegetation cover has been increasing for the last 25 years.

Cattle overgrazing is observed on the studied areas. It conditions overload for pastures and leads to the digression of their vegetation cover. Therefore, livestock farmers and other land users need to use pasture rationally, changing grazing areas from time to time and thus regulating the grazing rotation.

Remote sensing methods, based on the analysis of spatial and temporal variability of biophysical vegetation parameters, allow quick determination of areas of ecological intensity conditioned by the degradation of vegetation cover and desertification.

Thus, a significant transformation of the natural environment is currently observed in the Tea Road corridor.

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References
[1] Afanasev A N 1976 *Water Resources and Water Balance of the Baikal Lake Basin* (Novosibirsk: Nauka) p 239 (in Russian)
[2] Budyko M I and Izrael Y A 1987 *Antropogenic Variations in Climate* (Leningrad: Gidrometeoizdat) p 406 (in Russian)
[3] Garmaev Y Z 2010 *River Flow of Baikal Lake Basin* (Ulan-Ude: Buryat State University Press) p 272 (in Russian)
[4] Obyazov V A 2013 *Russia. J. Proceedings of the RAS* **450**(6) 713–6 (in Russian)
[5] UNCCD 1994 *United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought And/or Desertification, Particularly in Africa* (Paris: A/AC.241/27)
UNCCD 2018 *Achieving Land Degradation Neutrality* Income accessed online on 12th August 2018 via http://www.unccd.int
[6] Hill J, Megier J and Mehl W 1995 *Rem. Sen. Rev.* **12**(1-2) 107–30.
Reynolds J F 2001 Desertification *Encyclopedia of Biodiversity*, vol 2, ed S Levin (San Diego: Academic Press) 61–8
Reynolds J F et al 2007 *Science* **5826**(316) 847–51
[7] Hennemann R 2001 *Elective on Land Degradation, Assessment, Monitoring and Modelling. Soil Science Division* (The Netherlands: ITC, Enschede)
Hennemann R 2001 *Some Notes About Soil and Land Degradation in the Naivasha Range land Zone. Soil Science Division* (The Netherelands: ITC, Enschede) p 3
[8] NPACD 1997 *National Plan of Action to Combat Desertification in Mongolia* (Ulaanbaatar: Government of Mongolia, Ministry of Nature and Environment) Income accessed online on 12th August 2018 via https://knowledge.unccd.int/sites/default/files/naps/mongolia-eng2000.pdf

IOP Conf. Series: Earth and Environmental Science **190** (2018) 012029 doi:10.1088/1755-1315/190/1/012029

UNCCD 2009 *Factsheets aboutthe United Nations Convention to Combat Desertifucation* (Bonn: UNCCD) Income accessed online on 12th August 2018 via http://www.unccd.int/fr/resources/publication/Pages/factsheets.aspx

World Meteorological Organization 2006 *World Day to Combat Desertification, Climate and Land Degradation* (Geneva: WMO) No989

[9] Gunin P D, Miklyaeva I M, Bazha S N, Slemnev N N and Cherdonova V A 2003 *Arid Ecosystems* **9**(19-20) 7–21

[10] Harris I, Jones P, Osborn T and Lister D 2014 *Int. J. Climatol.* **34** 623–42

[11] Garmaev E Z and Andreev S G 2013 *Runoff Reconstruction of Major Rivers of the Selenga River Basin* Certificate of state registration database № 2013621267, Russian Federation. Proposal № 2013620567 Rightholder: Baikal Institute of Nature Management SB RAS; Receipt date: 06.06.2013; Registered in the Registry Database: 26.09.2013 (in Russian)

[12] Lupyan E A, Savin I Y, Bartalev S A, Tolpin V A, Balashov I V and Plotnikov D E 2011 *Russia. J. Modern Problems of Earth's Remote Sensing* **8**(1) 190–8 (in Russian)

[13] Farr T G and Kobrick M 2000 *EOS Trans. AGU* **81** 583–5

[14] Grubov V I 1982 *Key to Identification of Vascular Plants of Mongolia* (Leningrad: Nauka) p 443 (in Russian)

[15] Anenkhonov O A et al 2001 *Key to Identification of the Plants in Buryatia* (Ulan-Ude: Buryat Science Center) p 670 (in Russian)

[16] Kokorin A O 2014 *Climate change: a Review of the Fifth IPCC Assessment Report* (World Wildlife Fund) p 80

[17] Bychkov I V and Nikitin V M 2015 *Russia. J. Geography and Natural Resources* **3** 5–16 (in Russian)

[18] Bezrukov L A and Nikolsky A F 1995 *Russia. J. Geography and Natural Resources* **1** 125–34 (in Russian)

[19] Sinyukovich V N 2016 *Russia. J. Water Sector of Russia: Problems, Technologies, Management* **1** 42–51 (in Russian)

[20] Nikitin V M, Saveliev V A, Berezhnykh T V and Abasov N V 2015 *Russia. J. Region: Economics and Sociology* **3**(87) 273–95 (in Russian)

[21] Garmaev Y Z and Khristophorov A V 2010 *Water Resource of Baikal Lake Basin,* ed A K Tulokhonov (Novosibirsk: Academic Publishing House "Geo") p 231 (in Russian)

[22] Cook E R and Kairiukstis L A 1990 *Methods of Dendrochronology. Applications in the Environmental Sciences* (Dordrecht: Kluwer Academic) p 393

Fritts H C 1991 *Reconstructing Large-Scale Climatic Patterns From Tree-Ring Data* (Tucson: Univ. of Arizona Press) p 286

Shashkin A V and Vaganov E A 1993 *Russia. J. of Ecology* **5** 3–10 (in Russian)

Schweingruber F H 1996 *Tree Rings and Environment: Dendroecology* (Berne: Haupt Publ) p 609

Vaganov E A and Shiyatov S G 1999 *Russia. J.Siberian Journal of Ecology* **2** 111–6 (in Russian)

[23] Andreev S G, Vaganov E A, Naurzbaev M M and Tulokhonov A K 1999 *Russia. J. Proceedings of the RAS* **368**(3) 400–3 (in Russian)

[24] FAO/UNEP 1984 *Provisional Methodology for Assessment and Mapping of Desertification* (Rome: FAO) p 83

[25] Mongolian National Statistical Office 2010 *Mongolian Statistical Yearbook 2009* (Ulaanbaatar) p 448