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Assessment of High Mountain Lakes Vulnerability to Climate Change: A case Study from Seven Rila Lakes, Bulgaria

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INTRODUCTION

Systematic hydro-meteorological observations on Bulgarian high mountain lakes haven't been conducted in recent decades. Hydro-climatic observations in the Seven Rila Lakes area had been made by Vulkanov (1938) Paounov (1940), Ivanov (1964, 1959) Vodenitcharov (1960) and Tsankov (1985). Some recent publications from Grunewald (2008) for Pirin Mountain and Nozharov (2009, 2013) for peak Musala in Rila show that in these high mountain areas the average air temperature and length of growing season increased, as well as the cases of sporadic droughts. There is strong positive correlation between the air temperature and glacial lake's surface water temperature, which is an important indicator for climate change impact on lake's ecosystems.

Since 2012 in the area of Seven Rila Lakes operates a new monitoring system, created by the National Institute of Geophysics, Geodesy and Geography at Bulgarian Academy of Sciences in frames of a project, funded by National Science Fund. It provides information about air temperature, humidity, atmospheric pressure, water temperature, lake's levels change and water quality. First results from these observations were published in November 2012 (Nikolova et al., 2013a; Nikolova et al., 2013b, Nozharov, 2013). However the data range is not long enough yet for climate analysis. That is way the role of spatial climate information for high mountain areas, provided by different regional climate models is a possible way to fill the gap due to the luck of regular long term observations.

The aim of this paper is to assess the high mountain lakes vulnerability to climate change which may be applied for management of different adaptation measures.

Materials and Data

Since 2012 in the area of Seven Rila Lakes operates a new monitoring system, created by the National Institute of Geophysics, Geodesy and Geography at Bulgarian Academy of Sciences in frames of a project, funded by National Science Fund. It provides information about air temperature, humidity, atmospheric pressure, water temperature, lake's levels change and water quality. First results from these observations were published in November 2012 (Nikolova et al., 2013a; Nikolova et al., 2013b, Nozharov, 2013).

The main data sources in this investigation are public, but also we use some results from our field observations in the area of the Seven Rila Lakes, as well as spatial climate information for high mountain areas in Bulgaria, provided by regional climate models. An analysis on the climate change projections for the territory of Southwest Bulgaria is made on the base of the Fifth Assessment Report (AR 5), (IPCC, 2013) as well as the tools provided by KNMI Climate Change Atlas. The KNMI Climate Explorer is a web application to analysis climate data statistically. It is now part of the WMO Regional Climate Centre at KNMI, together with ECA&D (http://Climate Change Atlas.htm).

The measurements of air temperature, precipitations and atmospheric pressure are collected by data logger at Ribnoto Lake for the period June 2012 – November 2014 and Salzata Lake for the period July 2012 – November 2012. In addition are collected data from field observations about the lakes water temperature and changes in the water levels from June to October for the period from June 2012 to November 2014.

Study area

The system of the Seven Rila Lakes is located in the circus complex within the north-western part of Rila Mountain, in frames of Rila National Park. This part of the mountain has a typical alpine landscape with the relevant glacial forms formed in the Pleistocene. The lakes system decreased stepwise to the Dzherman River Valley from an elevation of 2535 m at Salzata Lake to 2095 m at Dolnoto Lake. The catchment area is 236,7 ha. The biggest lake is Bliznaka (16,8 ha) and the deepest one is Okoto (38 m). The mmorphometric data for all lakes are provided by Paunov on the base of measurements conducted in the period 13-15.08.1932 г. (IMH, 1964), (Table 1).

Table 1. Morphometric characteristics of the Seven Rila Lakes (after Paunov, 1940)

	Salzata	Okoto	Babreka	Bliznaka	Trilistnika	Ribnoto	Dolnoto
Elevation (m)	2535	2440	2282	2243	2216	2184	2095
Area (ha)	7,8	5	4,1	16,8	2,5	1,3	5,3
Depth (m)	4,8	38	29	26	5,5	2	10,5
Catchments area (ha)	18	24,0	21,84	128,7	138,4	165,3	236,7

METHODS

Climate change vulnerability assessment

The assessment of high mountain lakes vulnerability to climate change is based on an assessment of climate change impact and systems sensitivity. A Vulnerability Index is proposed to estimate lake's vulnerability to climate change (Nikolova, 2014).

Hazard of climate change stems from the uncertainty of the realization of one or another scenario for climate change and is defined as the likelihood that a particular outcome and impact against sensitive systems. This approach was adopted by IPCC in AR5 (AR5 Technical Summary, 2013), which distinguishes between 7 plus 3 additional likelihood of the realization of one or another scenario for climate change.

Exposure depends on which systems are exposed to the particular influence.
Sensitivity depends on the combination of the likely outcome, A, B or C, of the realization of a given scenario for climate change and the expected *impact* of climate change on the system. The impact can be positive (+), negative (-) or neutral (0).

Sensitivity is determined for each system and each climate scenario individually by scoring: 1 - low, 2- moderate, 3- high.

Vulnerability in the context of the impact of climate change is measured by ratio between the sensitivity and adaptive capacity of the exposed systems.

Adaptive capacity measure the potential of the system to adapt to changes (Brooks, 2003). Here it is measured using a simplified scheme in three scores:

1 - Insufficient adaptive capacity - no action is taken to address the risk of climate change;
2 - Sufficient adaptive capacity - partly implemented directives, strategies and programs for adaptation and mitigation of climate change;
3 - High adaptive capacity - executed directives, strategies and programs for adaptation and mitigation of climate change.

Vulnerability Index (VI) is calculated by dividing sensitivity scores on adaptive capacity cores:

$$VI = S/Ac$$

Where:
S – Sensitivity
Ac– Adaptive capacity

$$S = \sum (\sum Sn \text{ max scores} / \sum Sn \text{ scores}) / n$$

Where:
Sn – Sensitivity to each climate change indicator
n – Number of climate change indicators

The level of vulnerability is estimated according the modified scale proposed from Garcia et al., (2012), (Table 2).

Table 2. Vulnerability Index Scale (after Garcia et al., 2012).

Vulnerability Index Value	Vulnerability
0,80 – 1,00	Extremely vulnerable
0,50 – 0,79	Very vulnerable
0,20 – 0,49	Moderately vulnerable
0,01 – 0,19	Vulnerable

To implement the proposed approach we use as indicators for climate change impact and sensitivity, projected changes in *air temperature* (^{0}C), *precipitation* (%) and *number of dry spill days*, from full CMIP5 ensemble for scenarios RCP 2.6, RCP 4., RCP 6 and RCP 8.5 for 2081-2100 periods, compared to mean values for 1961-1990 period. Proposed are three indicators for lakes vulnerability: *lake's surface water temperature, lakes water level* and *ecosystem services*.

RESULTS

Climate change impact and vulnerability indicators

Water temperature is an important indicator for climate change because there is a strong positive correlation between both air and surface water temperature. On table 3 are represented data collected from Regional Inspectorate on Environment and Water (RIEW) in Blagoevgrad for the lakes Salzata, Ribnoto and Dolnoto. These measurements had been made every month from June to October in the period 2004 – 2012 in an interval of about 2 hours around 14:00h. The data range is extended with data from our field observations from the same months in 2013 and 2014. Results show a trend of increase of air and water temperature (Figure 1, Figure 2).

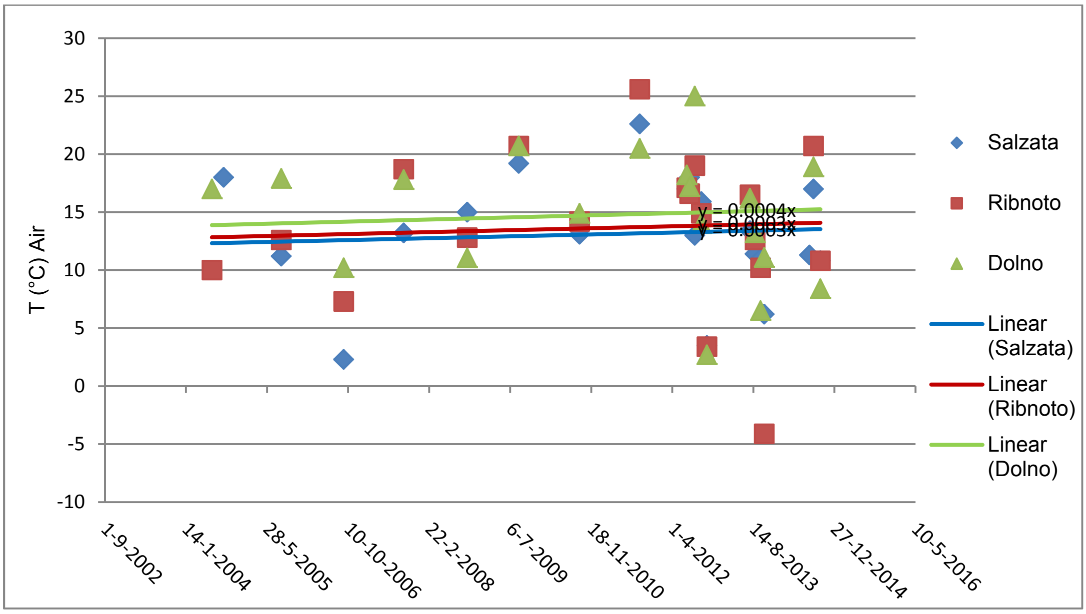

Figure 1. Air temperature June – October (2004 – 2014)

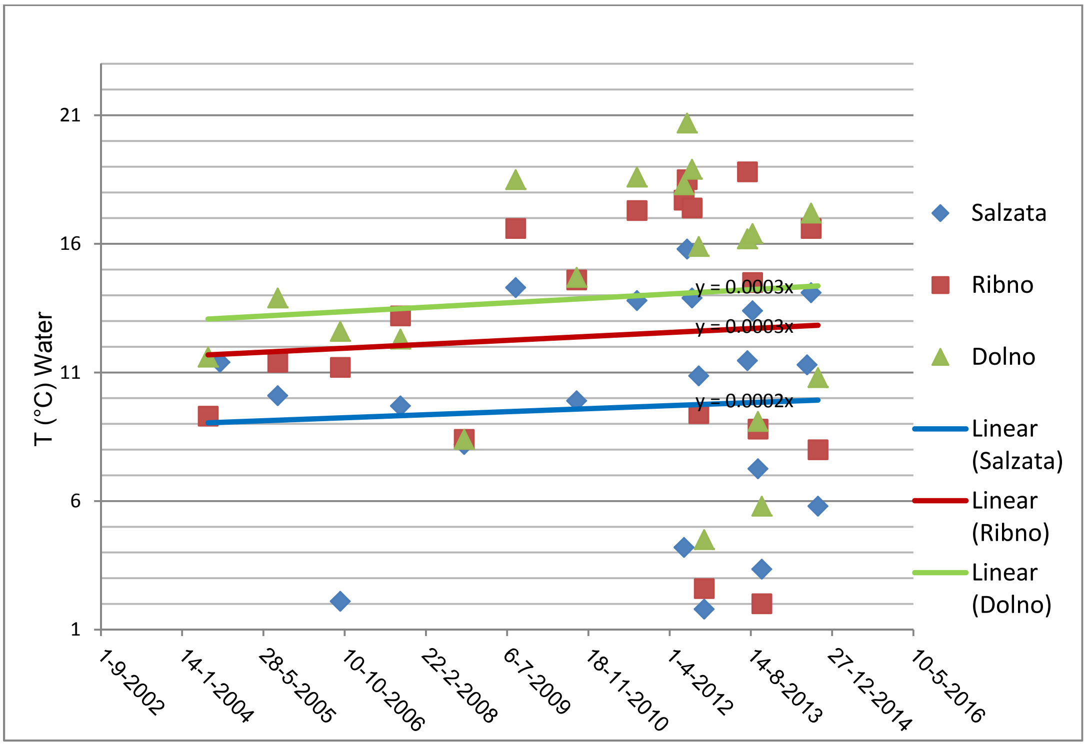

Figure 2. Lake's water temperature June – October (2004 – 2014)

The obtained information is valuable because the measurements of the water and air temperature were made simultaneously and we can calculate the correlation between them. The correlation coefficient values for air and water temperature are high, between 0,77 for Salzata lake and 0,85 for Ribnoto Lake (Table 3).

Table 3. Average temperature of air and lakes water and correlation coefficient for the period June – August (2004-2014)

Lake	Mean Air Temperature (°C)	Mean Water Temperature (°C)	Correlation coefficient (R)
Salzata	12,7	9,3	0,77
Ribnoto	13,7	12,4	0,85
Dolnoto	14,8	13,9	0,80

These results can be taken as an indication that if the temperature increases by the way described in the Global Climate Models (GCM) and Regional Climate Models (RCM), it will lead to rise of lake's water temperature and greater evaporation coupled with decrease in rainfall and increase of number of days with dry spills. Under these conditions is very likely to observe deterioration of the lakes ecosystems in terms of biodiversity, increased eutrophication and environmental state in the lakes system in the future.

Lakes water level is the second important indicator. It depends mainly from the air temperature and precipitations in the study area of the Seven Rila Lakes, which have no underground feeding. The correlation coefficient between air temperature and water levels is negative and very high: Dolnoto (-0,99), Ribnoto (-0,96), Trilistnika (-0,95), Bliznaka (-0,98), Babreka (-0,96), Okoto (-0,77) and Salzata (-0,98), where the values only for Trilistnika and Okoto are not statistically significant (Nozharov, 2013).
The data for lakes water level dynamics for the period June-October (2012-2014) clearly shows that the decrease of the lakes levels is observed from June to September and it is

highest in August and September with maximum decrease 25 -30 cm. Raising of the lakes levels is registered only in June and October due to heavy precipitations (Fig. 3). It is important to draw attention on the fact that the data from summer in year 2012 are representative for one of the warmest and drier summer in the country records. The air temperature in the region of the Seven Rila Lakes is about 4 ° C above norm and monthly rainfall is about 50% of normal in July and August, when the temperature deviation is about 3.5 - 4 ° C from the norm, and the monthly amount of precipitations is 20 to 50% of normal. In September and October temperature in the region remains about 5 ° C above the norm (Bulletin of NIMH, July 2012). These data show that the lakes water levels are very sensitive to the changes in precipitations and temperature and in this case, because of lack of underground feeding, it may be reliable indicator for the changes in climate conditions.

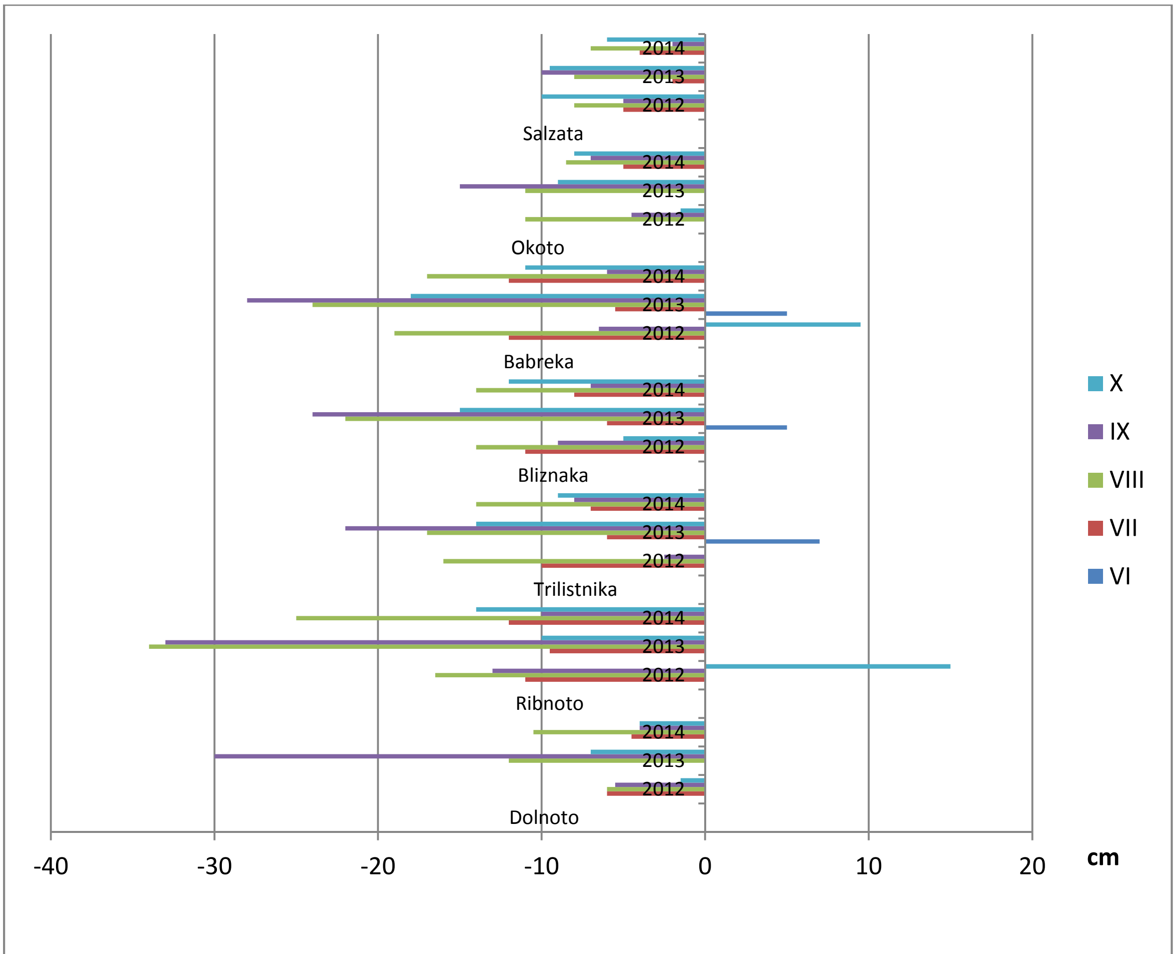

Figure 3. The Seven Rila Lakes water levels change from June to October (2012-2014)

Ecosystem services (ES) in the catchment area are an integrative indicator for the environmental state and change. The results of a previous investigation published by Nedkov et al. (2014) find that "*the ecosystems in the area of Seven Rila Lakes provide various services with focus on the cultural and regulating. The supply capacity of the cultural services is the highest which is due to the exceptional recreational, aesthetical and spiritual potential of the area. The supply capacity of regulating ecosystem services is predominantly high while provisioning services have relatively low supply capacity*." The ES supply capacity depends mainly on ecological integrity of the system (Burkhard, 2013) but it means that we have to evaluate extend of change in ecosystem structure and processes which would decrease the system supply capacity and increase its vulnerability. In addition, our ability to do this depends on the scale which we use for this aim. Particular supply of goods and services delivered in the local area is influenced very often from regional or global scale processes and we observed a cross scale effect of this interaction (Zurliny et al., 2010). Because of the high level of uncertainty of the climate change projections and their impact on each class of ES (Regulating services (RS), Provisioning services (PS) and Cultural services (CS) we implement a qualitative assessment of the impact, sensitivity and adaptive capacity of the ES in the lakes system in respect of each RCP scenario (Table 3).

Climate Change Vulnerability Index
The analysis of the temperature and precipitation data for four thirty years periods, provided by the World Bank Climate Change Portal, shows a stable trend of increase of the temperature and decrease of the precipitations in high mountain areas of the Seven Rila Lakes, where the average temperature for the period 1991-2009 is with 1,74°C higher than the average temperature for the period 1901-1930. The decrease of average precipitations sum between the same periods is 144 mm according the same data base (Nikolova, 2014). We have to keep in mind that these data are extrapolated for a well-expressed mountain territory and they most probably do not provide precise values of the observed changes. However they show clear trends of the observed changes in the study area, which are most significant between the last two thirty years periods 1961-1990 and 1991-2009. The average temperature for the last period increase with 1,66°C in Seven Rila Lakes area and decrease in average precipitations sum is 70,3 mm (Nikolova, 2014).

Regional climate projections (RCP) for all RCP's scenarios also show an increase of average temperature and number of dry spill days for territory of Southwest Bulgaria of 1,5-2,0°C (RCP2.6), 2,0-3,0°C (RCP4.5), 3,0-4,0°C (RCP6), 4,0-5,0°C (RCP 8.5) and decrease of precipitations sum from 10% (RCP2.6, RCP4.5, RCP6) to 20% (RCP8.5) for the time horizon 2081- 2100 (Table 4).

Following the proposed methodological approach we assessed the possible impact and sensitivity of these changes for each RCP scenario for each particular vulnerability indicator (Culmon1 in Table 4). We assigned 1 score, relevant to "insufficient adaptive capacity" in respect of all indicators because at this moment there are no any actions taken to address the risk of climate change for Bulgarian high mountain lakes in spite that they are in protected areas. Appropriate adaptation measures in this case relate to better management of ecosystem goods and services and reduction of anthropogenic (tourism) pressure in the lakes systems.

Table 4. Climate change impact and sensitivity assessment

Indica-tor	IPCC AR5	RCP (2081 – 2100)			Impact Positive (+), Neutral (0) or Negative (-)			Sensitivity (S) Low – 1, Moderate – 2, High - 3			Ac 1-Low 2-Mediu m 3-High
1	2	3			4			5			6
	RCP Scenari o	ΔT ↑ (°C)	ΔP ↑↓ (%)	ΔEx* ↑	ΔT ↑ (°C)	ΔP ↑↓ (%)	ΔEx ↑	ΔT ↑ (°C)	ΔP ↑↓ (%)	ΔEx ↑	
Water temper ature	RCP 2.6	1.5-2.0	0.0-10↓	2-4	-	0	0	3	1	1	1
	RCP 4.5	2.0-3.0	0.0-10↓	2-8	-	-	-	3	1	3	1
	RCP6	3.0-	0.0-	2-8	-	-	-	3	1	3	1

		4.0	10↓								
	RCP8.5	4.0-5.0	10-20↓	8-10	-	-	-	3	3	3	1
Lakes Water Level	RCP 2.6	1.5-2.0	0.0-10↓	2-4	-	0	0	1	1	1	1
	RCP 4.5	2.0-3.0	0.0-10↓	2-8	-	-	-	2	1	3	1
	RCP6	3.0-4.0	0.0-10↓	2-8	-	-	-	3	1	3	1
	RCP8.5	4.0-5.0	10-20↓	8-10	-	-	-	3	2	3	1
Ecosystems services	RCP 2.6	1.5-2.0	0.0-10↓	2-4	-	0	-	2	1	1	1
	RCP 4.5	2.0-3.0	0.0-10↓	2-8	-	-	-	3	1	3	1
	RCP6	3.0-4.0	0.0-10↓	2-8	-	-	-	3	1	3	1
	RCP8.5	4.0-5.0	10-20↓	8-10	-	-	-	3	2	3	1

Ex - Number of dry spills days*

The results from sensitivity assessment and values for the Vulnerability Index are represented in Table 5. According them the Seven Rila Lakes are “extremely vulnerable” in respect of water temperature rise and “very vulnerable” in respect of changes in lakes water levels and supply of ecosystems services and goods.

Table 5. Climate change vulnerability assessment

Indicator	Sensitivity scores	∆T (°C)	∆P (%)	∆Ex*	n	S	Ac	Vulnerability Index
Water temperature	S max	12	3	9				
	S sum	12	6	10				
	S n	1	0.5	0.9	3	0.8	1	0.8 - Extremely vulnerable
Lakes Water Level	S max	6	2	9				
	S sum	9	5	10				
	S n	0.6	0.4	0.9	3	0.65	1	0.65 – Very vulnerable
Ecosystems services	S max	9	2	9				
	S sum	11	3	10				
	S n	0.81	0.66	0.9	3	0.79	1	0.79 – Very vulnerable

Ex* - No. of dry spills days

CONCLUSIONS

Observed and projected changes show trends of increasing temperature and decreasing precipitation in the area of Seven Rila Lakes. According the results from climate change vulnerability assessment the projected changes may lead to high risk for lakes ecosystems and theirs water regulating, provisional and cultural services. Being extremely valuable part of the countries' natural capital, high mountain glacier lakes need implementation of special measures for adaptation to climate change through better management of ecosystems goods and services and reduction of anthropogenic pressure in the lakes systems.

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