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Complex evaluation of climate change - an example from Georgia's landscapes

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Abstract

The purpose of this study was to develop spatial-temporal model of Georgia's landscapes, which gives a chance to determine the current tendencies of landscape changes in different landscapes, such as humidity/aridity, increase/decrease of bio-productivity, etc. The model used gives possibility to reveal causes of mosaic changes, associated with global climate change. The study was based on the conception of spatial-temporal analysis and synthesis of landscapes. It was carried out in different landscapes across Georgia. The daily geo-conditions and annual dynamics of landscapes was determined by analyzing some long-term data collected from meteorological stations. As a complex value, daily geo-conditions of landscapes were analyzed. On the bases of inventory of landscapes, GIS-technology and thematic mapping, main tendencies in the landscapes were developed. Arid, Semi-arid, Semi-humid landscapes occupied a great area, which formed approximately 1/3 part of the whole territory of Georgia. These include 8 types, 11 sub-types of landscapes and 24 genera. The main share of these landscapes was concentrated in East Georgia, but some semi-humid areas were spread in West Georgia. The influence of climate change was evaluated considering several parameters, such as change of forest area, share of agricultural land in the total area of landscape, degree of fragmentation of landscapes and productivity of vegetation.

Key words

Climate change, Georgia, Landscape approach, Landscape changes,

Introduction

The landscape change is one of the most important problems for geographical, agricultural and environmental studies. The studies on this topic give an opportunity to create united scientific basis for sustainable use of natural resources, as well as landscape planning and environmental protection. Among the world's ecological problems,an upcoming one is global climate change. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years (Anonymous, 2013). It's important to find the ways to decrease the threats of global climate change, avoid expected social-economical destabilization and food supply reduction as a result of environmental degradation. From this point of view, the aim of scientific studies is to develop methodology of evaluation of landscape changes and current trends (Wobus *et al*., 2010).

Climate change is occurring in South Caucasus. In all three countries there is strong evidence of increased warming over the last century.The geo-conditions of Georgia's landscapes have been studied by many researchers notable among these being; Djibladze (1984), Tediashvili (1984) and Beruchashvili

(1989). No detailed study has been conducted on the analysis of whole Georgian territory, where choosing of separate meteorological stations or posts for each genus of landscape is required. However, there is one important problem which relates to the lack of data, not all landscapes are provided equally with the network of meteorological stations. This is why the use of extrapolation is a must in such studies.

Georgia shows statistically increasing trend in mean annual temperature, mean daily minimum temperature and mean daily maximum temperature, though there are no trends in mean annual precipitation nor the number of wet days per year (Anonymous, 2011).

It is important that not only the estimation of geo-conditions of the average multi-annual landscapes, but also the dynamics on yearly basis should be considered. This gives us an opportunity to determine what trends developed in the landscapes and to answer all the questions that have a constructional meaning. For example; activation of which natural or natural-anthropogenic processes (the warming of climate, desertification, humidity, aridity, etc.) does it point out? In which landscapes are these processes revealed more clearly and which one is threatened by radical changes? How much are the states of NTCs' latest years dynamics near to or its deviation from the average multi-annual? As a result (according to the concept method), it is possible to estimate what changes are to be expected according to the landscape-geophysical features (amounts of geo-masses, the width and complexity of the vertical structure of NTCs). It is also possible to estimate the trend of changes in landscape resource potential and make a prognosis.

This issue is pressing and of utmost importance for Georgia, connected with its environmental problems like activation of natural disasters (flooding, avalanches, mudflows, etc.), increase of soil erosion and degradation, deforestation and desertification, raising risk of extinction of relict and endemic species, decrease in biodiversity, fragmentation and degradation of landscapes, reduction in the sustainable and nature-protection functions of landscapes and decrease in agricultural productivity and many others.

Many studies were conducted on the influence of global climate change all over the world, but its influence in terms of different landscape units has not been studied in depth (Anonymous, 1983). Methodological basis which can enable us to explain mosaic nature of climate change has not been fully developed. The landscape approach just gives possibility to investigate natural components in mutual relationship and to reveal causes and reasons of the mosaic changes (Anonymous, 1996; Anonymous, 2001; Nikolaishvili and Tskhvaradze, 2013).

The question of the dynamics of the geo-conditions of landscapes for the whole of Caucasia have been reviewed earlier (Beruchashvili, 1995), where on the bases of computer modeling, the scenarios for the development of landscape-ethological situations under the influence of different conditions have been developed. The review presents dynamics of geo-conditions of landscapes from a different perspective, with the help of which we will determine not estimated, but real ongoing changes in the landscapes. These include three most important stages: the earlier state; the present state and the expected results. In the expected results, those processes would be required which have been presented as factors in the general model of scenarios of landscape-ethological situations developed by Beruchashvili (1995).

Georgia has many perspectives in different fields like development of national tourism- recreation, trans-boundary tourism, development of trans-boundary protected areas etc. Agriculture is well-developed sector and agricultural lands make up more than 2/3 of all plain landscapes in the country; major part of local population is involved in agriculture (Anonymous, 2012). So, climate change consequences can cause a vast negative influence on socio-economic structure of the country. Main problem is connected with the absence of complex evaluation of landscapes due to climate change and also absence of integrated scheme of landscape planning, based on the committed and science-based methodology. Therefore, special attention needs to be directed to the consequences impacts of climate change and involvement of research findings in the territorial planning, as well as determination of natural resource potential of landscapes and current trends which is one of the most important problem in Georgia.

Materials and Methods

Georgia is characterized with various natural features and resources, several recreational ecosystems, virgin landscapes, mineral water resources with high discharge, wind and solar energy, agrilands, various minerals, etc. A greater part (58 %) of the country has relatively high percentage of pristine or little changed ecosystems (Nikolaishvili *et al.,* 2010). These natural peculiarities have not been investigated at length and no interpretation has been given for the ecological functions which Georgians can play. We come across arid, semiarid, semi-humid, transitional semi-humid, humid and extra-humid landscapes with steppes, thorny plants, deciduous and coniferous forests, swampy habitats, sub-alpine and alpine meadows. Almost every climatic zone is represented here, except for savannas, tropical forests and deserts. In all, there are 14 types, 21 subtypes of landscapes and 71 genera and more than 150 species (Beruchashvili, 1995; Beruchashvili and Nikolaishvili, 2012).

Great Caucasus protects Georgia from the direct penetration of northern cold air masses. Lesser Caucasus and High plateau of South Georgia have the same function as these defend the territory of Georgia from the penetration of hot and arid air masses. Amount of precipitation decreases from west to east and middle and mountain forest landscapes of Great and Lesser Caucasus generally receive higher amount than lowlands and plains. The maximum precipitation more than 4,000 mm, is recorded in West Georgia (Mtirala, Adjara), while in southern-eastern part it is - 400 mm and lesser per year.

The present investigation was based on the concept of spatial-temporal analysis and synthesis of natural territorial complexes (Beruchashvili, 1995; Anonymous, 1983). This approach gives possibility to study the components of nature with common methodological bases, structural peculiarities and functions, also spatial-temporal features of landscapes due to climate change.

The present work aimed to study the so-called geo-conditions of landscapes, which included set of structures and functionality parameters during a certain period of time, when concrete influence (radiation, precipitation) was transformed into concrete function (water yield, increase of phytomass, etc.).

Several factors determine these differences, grouping of which was possible according to certain indicators. To analyse these factors database of GIS was created, which consisted of 23 indicators, grouped according to 5 main factors *i.e.*, geological and geo-morphological (4 indicators), climatological and hydrological (6), soil and vegetation (3), dynamic (6) and socio-economical (4) factors. In particular, geological and geo-morphological indicators were: steepness of slope, type of migration regime, exposition of slope and density of rocks. The degree of sensitivity of each indicator was determined according to different landscapes. Each landscape was evaluated by rating method by assigning a particular grade. For example, high sensitivity at 30-35° sloped plateau was determined with 3 grades, while 10-200 sloped plateau with 2. By summing up all the grades of the indicators, the sensitivity of landscapes related to each factor was determined, also in total. On the basis of method of normalized value ;which allows "redistribution" of equal data in correspondence with equal numerical intervals, in particular within 0-10 or 0-100; which was determined comprehensively the degree of sensitivity of landscapes was obtained. The method defined the integrated parameters as well as share of each variable in it. This approach gave opportunity to determine the quality of sensitivity of Georgian landscapes in the era of climate change.

The study included correlating the data amassed in climate reference books and other statistical issues with landscapes of Georgia; creating the database of GIS, which describes 71 units of landscapes with 23 attributes; determining long-term geo-conditions of landscapes, based on 3 main meteorological parameters (daily air temperatures, precipitation and snow cover) and pre-configured logical function; revealing the duration and occurrence of geo-conditions of landscapes; defining annual dynamics and trends of landscapes (humidity, aridity, changes in the amount of phytomass (Efe, 2010).

Long-term meteorological data was used. In addition, data for different landscapes of Georgia collected from field work, carried out during 1980-2005 by the LAB for Environmental Studies by Aero-space Method (Tbilisi State University) was also used. Cartographical bases of study were 2 landscape maps of Georgia; the smallest unit was landscape genera (scale 1: 1,000,000), and Map of Natural-territorial complexes (NTCs) - the smallest unit was types of NTCs (scale 1:500,000) (Beruchashvili, 1993; Beruchashvili and Nikolaishvili, 2012). GIS-technology was used for the processing of all data.

Results and Discussion

Air Temperature : Dynamics of the annual average air temperature has very complex and diverse character. This complexity is connected with inequalities according to different landscapes and different periods of time. For subtropical humid landscapes, spread on the Colchic lowland and foothill areas were covered by expansive forests in the past and characterized by warm winters and hot and humid summers. The annual average temperature was 14-15ºC, with extreme changes between -15+45^{0}C. During 1955 -2008, Georgia experienced an increase in the annual average air temperature by 0.2-0.6ºC (Anonymous, 2009; Mumlazde, 1991; Tavartkiladze *et al*., 2011).. In fact this increasing trend was evident from 1906 to 1995, both in East (by 0.1 to 0.5ºC) and West Georgia (by 0.1 to 0.3ºC) (Anonymous, 1999). This was only a general trend. Data analysis showed various trends in different landscapes. The increasing trend was especially a characteristic for the plain landscapes of East Georgia, in particular, for plain and hilly semiarid landscapes with open woodland, steppe and poly-desert vegetation. This trend was dramatically revealed in transitional to moderate-thermophic semi-humid landscapes. Comparing different time spans with each other, it was observed that increase in average temperature of the month was characteristic mostly for the cold period of the year and it reached climax in January. On the contrary, during warm period of the year, either there was a slight decrease in the temperature or no change at all. This means, that the annual temperature amplitude decreased more and more and the climate became more continental (Anonymous, 1999).

A similar trend was observed in plain landscapes of West Georgia, but here, it showed less intensity. In plain subtropical humid landscapes, located in the central parts of Colchic lowland, average annual temperature had slightly increased in recent years. Analysis of data from 1936 to 2012 revealed that within 10-year-long interval, a quite difficult situation was observed. Compared to present conditions, during 1933-1942, the average temperature of air was higher by 0.4°C. After this, excluding 1973-1982 and 1983-1992 periods, a small tendency of increase was seen. Also, during the last 20-years, there has been no increase in the average temperature of air and it was equal to the 1993-2011 average norm of the decade. A different situation was observed in foothill subtropical humid landscapes, which are bounded by Colchic lowland, Great Caucasus and Lesser Caucasus, going up to an altitude of 500-600 m asl. In recent years, average annual temperature increased by 0.2-0.3ºC.

One of the most sensitive regions to climate change in Georgia is Black Sea coastal zone represented by landscapes of beach and coastal dune and were affected by a variety of physiographic processes, such as tectonic reduction and rising sea level (the mean rate of eustasy is roughly 2.5-2.6 mm yr^{-1}), increase in frequency of powerful storms (force 5 to 7), decreasing width of beach zone, floods and flash floods, river sedimentation, etc., some of which were being intensified by climate change. The average annual temperature here was 14-15°C, average temperature of coldest month (January) was +5.9-6.9°C, and warmest month (July) +22.1ºC and 22.9ºC; with extremes ranging between +45ºC to -15°C (Anonymous, 2004). During the year 1924-1996, the sea surface temperature decreased by 1.0°C, but in 1990-2006 it increased by 1.3ºC, resulting in the warming of the sea surface temperature by 0.3ºC (Anonymous, 2009).

On high mountain landscapes with alpine and sub-alpine meadows, above 2,000-2,500 m the average annual temperature was below zero. The summer was temperate and humid; in July the average temperature was about 16.7 ºC, with an absolute minimum between -30ºC and -35ºC. In recent years, the average annual air temperature in this landscape has increased by 0.4 ºC. A tendency in the increase of absolute temperatures was noted here.

Precipitation : While in the Georgian mountainous landscapes air temperature is an important landscape-forming factor, in the valley landscapes, this role is taken by humidity. In particular, from west to east (with a few exceptions), a gradual decrease of atmospheric precipitations and humidity take place. Accordingly, deficiency of humidity takes a sharper character parallel to the distance from Black Sea coast. So, depending on the altitude and remoteness from the coast, types of climate in Georgia varied from humid subtropical in the Colchic lowland to temperate humid subtropical and semi-arid climate zones, also to cold and humid climate zone at high mountains. On high plateau of South Georgia, the sum of annual precipitation fluctuated between 450-700 mm.

In almost every landscape of Georgia, the change of atmospheric precipitation was observed, which was pronounced very unevenly. The differences were connected not only to the distances form the sea, but also to the increase in altitude, which pushed some territory under rain shadow, etc. Even though the tendency of increase of atmospheric precipitation took place, but the average of several years highlighted an increase in the atmospheric precipitations. This increase was more clearly expressed in west Georgia, especially on the coastline, but less in eastern Georgian valley zone. On plain, subtropical humid landscapes of Colchic lowland made up 150-250 mm.

Numerous situations were also observed on mountainous landscapes. Recently, in the lower and mid part of western Georgian mountainous forest landscapes, a slight increase in atmospheric precipitation took place, which was far less than in the Colchis valley. As for the east Georgian lower and mid mountainous forest landscapes, mostly there was a tendency towards decrease in the atmospheric precipitation (Nikolaishvili, 2009).

A bigger difference was observed on comparing the landscapes on the basis of separate monthly average indicators. The tendency of increase of atmospheric precipitation was not characteristic for every month of the year. In most cases, tendency towards a decrease was observed, but even in this case, the picture was not uniform.

Important changes were observed at the arrival time of atmospheric precipitation. After 1970's, the occurrence of abundant precipitation in small time spans had taken place, the number of days with short and abundant precipitation had increased. This regime of precipitation took place in both east and west Georgia, in valley and mountainous landscapes, which increased the chances of occurrence of natural catastrophes (mudflows, landslides, debris flows).

Drought : One of the parameters is duration and intensity of drought. This frequently appears in the plain landscapes of East Georgia, which has negative effect on the productivity of agricultural lands and pastures (Gorgisheli, 2009; Kvachakidze, 2006). It is also reflected by a decrease of water resources and

Table 1 : Average monthly temperature during different periods of time in transitional to moderate-thermophic semi-humid landscapes of Georgia

Months / Periods of times		1	2	3	4	5	6	7	8	9	10	11	12
1886-1905	1	0.1	2.2	6.7	11.6	17.1	21.3	24.2	24.2	19.4	14.0	7.0	3.0
1961-1992	2	1.8	3.2	7,4	13.0	17.8	21.6	24.8	24.4	20.0	13.9	8.0	3.8
1880-1992	3	1.2	2.8	6.8	12.3	17.4	21.3	24.5	24.2	19.7	13.8	7.8	3.2
1880-2008	4	1.8	2.8	6.8	12.7	17.3	21.1	24.3	23.6	19.5	13.4	8.0	3.7
Difference (1-4)		1.7	0.6	0.1	1.1	0.2	-0.2	0.1	-0.6	0.1	-0.6	1.0	0.7
Difference (2-3)		0.6	0.4	0.6	0.7	0.4	0.3	0.3	0.2	0.3	0.1	0.2	0.6

degradation of soil; especially in semi-arid and arid landscapes with open woodlands, shrubs, and steppe vegetation, partly with halophytic deserts and semi-deserts, stretching in East Georgia and occupying more than 6.7 % of whole area of Georgia. During 1952-2011, the duration of droughts has increased. From the 1969-75 to the 1998-2011 the number of draught days has almost doubled (Fig. 1). This is especially dangerous for agriculture, because a large part of these landscapes is covered by summer pastures. Due to intensive grazing at certain places these landscapes have been degraded and soils erodible. An additional factor is that, windshields and irrigational systems are deranged (Anonymous, 2012).

These landscapes also differed by duration and repeatability of this geo-condition. But there were many other conditions, common for different landscapes. The landscapes of Georgia are characterized by quite a diversified set of geo-conditions. In the middle mountain forest landscapes, the longest (42% of the year) were the geo-conditions of winter structure stabilization, while geo-conditions of summer phytogenic structure stabilization occupied only 24%. As compared to low mountain forest landscapes, the middle mountain landscapes with prevalence of beech forests showed less geo-conditions of summer phytogenic structure stabilization, because as the absolute altitude increased, the duration of warmth and summer decreased. The shortest were the geo-conditions of complication

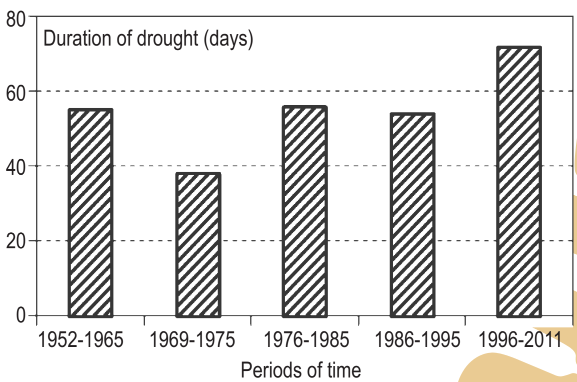

Fig. 1 : Duration of drought of semi-arid and arid landscapes of East Georgia

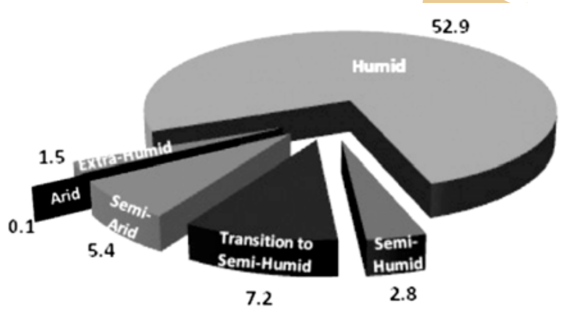

Fig. 2 : Area of landscapes of Georgia on the basis of humidity (%)

and simplification of spring and autumn phytogenic structures (5% each). As for pluvial geo-conditions, these were 24% of all year length (Nikolaishvili, 2009).

Geo-conditions : Every landscape is characterized by a set of certain geo-conditions.Depending on the dynamics of geo-conditions there were number of landscape-physical indicators which too change. In humid landscapes, the dynamics of soil humidity reached its maximum during spring and autumn (May and October) and was minimal during summer months. The average soil humidity in the western part of the distribution area of the said landscapes was more (5-15%) than in the eastern part. However, this was hardly true for the month of May. Same was true with other landscapes, making it clear that there was no direct relation between soil humidity and geo-conditions, but the duration of some or other geo-conditions, by a concrete moment of time and number of days ago the pluvial geo-conditions occurred, needed to be considered (Nikolaishvili and Demetrashvili, 2011).

The interval of soil productive moisture variation is quite important and such a variation was observed even in the course of same geo-condition. This depends on the duration of the current geo-condition, or more precisely, how long ago the said geo-condition occurred. For instance, if in the middle mountain forest landscapes, summer geo-condition with stability of phytogenic structure had occurred only recently, the amount of productive moisture was quite high, but if the given geo-condition lasted for 1 to 1.5 month, the productive moisture was quite low and reached its minimum from August 15 to September 5. From IInd week of October, as the frequency of occurrence of pluvial geo-conditions increased, the indicator of productive geo-condition also increases, and in 0-20-cm-thick soil layer it reached 1000-1100 %. Even less is the soil productive moisture during the geo-conditions of winter nival structure stabilization, when it was only 50-10%.

The vertical structure of NTC varied during the year, in particular, the strength and size of geo-horizons changes. As for the width of vertical NTC structure, it changed significantly in some landscapes and only slightly in others depending on the phytogenic structure, i.e. whether forest or forest-free area are dominant. In forest NTCs, this change was minimal (approximately up to 1 m) and occurred as a result of the changes following the frondescence and defoliation of trees. In treeless NTCs (over the secondary grasslands), the strength may decrease by 2- or 3-fold or even more.

The width of NTCs vertical structure was particularly diminished in the landscapes of high mountain subalpine meadow, with a degree of reduction reaching 10 or more. The width of forest-free NTCs was characterized by least change in the landscapes (except high mountain sub-nival and nival landscapes) with dominating semi-desert vegetation.

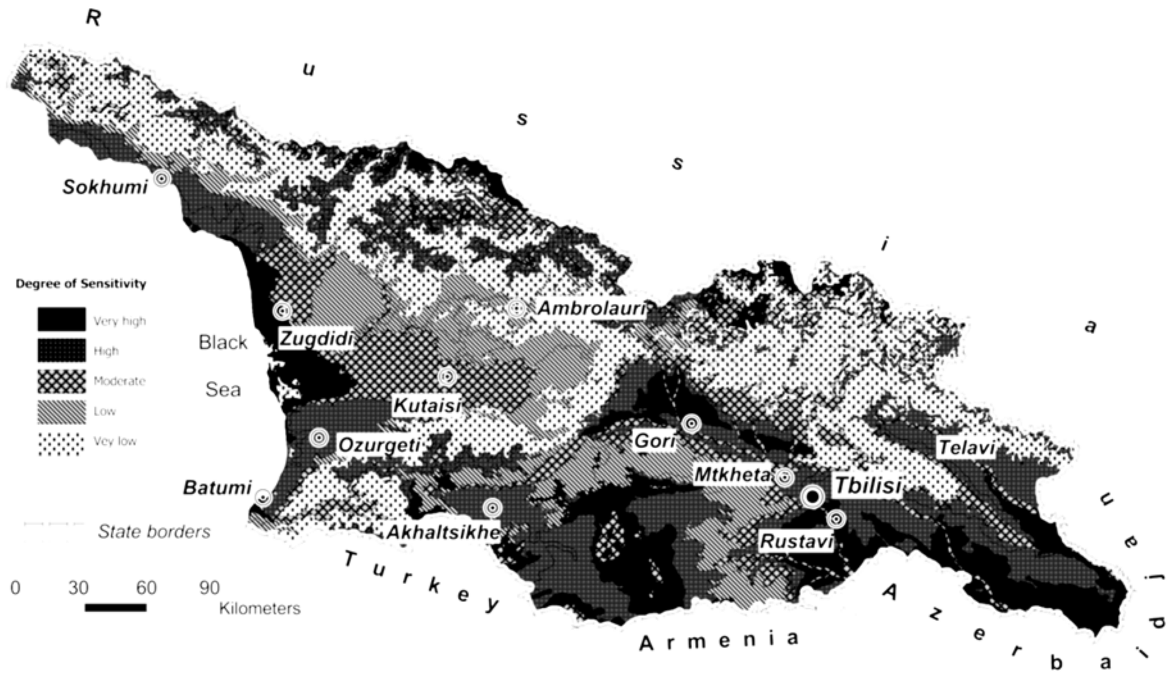

Fig. 3 : Degree of sensitivity of Georgia's landscapes on the background of climate change.

The complexity of NTCs vertical structure in the average mountain forest landscapes of Georgia was also maximum during summer and minimum during winter. The complexity was particularly simplified in forest-free NTCs, where only 2 or 3 geo-horizons survived out of 4-7 occurring in summer season. As for forest NTCs, the diminution was particularly of different nature. The change was significant in the lower and upper mountain forest landscapes, while was less evident in the middle zone of the hypsometric distribution of the middle mountain forest landscapes. The types of NTCs dominating the area (whether forest or forest-free) mattered much in this connection. The least change was fixed with forest NTCs with mat, or Colchic forest, while the greatest change was fixed in forest NTCs with grassy or deciduous bush cover.

As for the changes in the structure and complexity of the NTC; vertical structure within the limits of the same type or sub-type of landscape seasonally; was less evident. It may be said that in fact there was no difference. This was true not only with the average mountain forest, but also with almost any landscape of Georgia. Exception were the landscapes under strong anthropogenic influence and because of their significant diversification, the difference could be seen even in the dynamics of the structure and complexity of the NTC vertical structure at the level of landscapes sub-types and types.

Depending on the season of the year, the duration of geo-conditions was quite irregular. In most landscapes, prevalued mostly summer and winter geo-conditions, while the duration of spring and autumn geo-conditions was less. It was clear that the duration of winter geo-conditions increased as the absolute altitude increased, and the duration of pluvial geo-conditions increased from east to west.

It is known that the seasons of the year do not coincide with the calendar seasons. Their duration, onset and endings differ. The duration of winter in the middle mountain forest landscape was 5.5 months, while the duration of summer was 3.5 months and the duration of spring and autumn was 1.5 months each. In the western part of the distribution area of the middle mountain forest landscapes, the duration of spring and autumn were same, while in the eastern part, spring was longer than autumn. Establishment of the "warm" geo-conditions of NTCs is a longer process than the "cold" states which can be explained by the continentality of the climate. The difference between the east and west parts of the middle mountain forest landscapes of Georgia in respect of continentality was little, but perhaps certain impact was seen during different durations of the seasons.

In the landscape ethology, it is considered that changing one season with another one is not defined by the establishment of a state typical to another season, as the change may be temporal or short. Only stable establishment of certain states means end of the season and onset of the seasonal changes of the vertical structures of NTCs.

Degree of sensitivity of Georgia's landscapes : Using the method of normalized value, the degree of sensitivity of Georgia's landscapes was evaluated. In all 5 levels of sensitivity were determined: Very high, high, moderate, low and very low sensitivity (Fig. 3). Very high sensitive landscapes were located mainly along the Black Sea coastal zone, eastern extreme part of Georgia, high plateau of South Georgia and high mountain glacial-nival landscapes of Great Caucasus. These landscapes were rarely inhabited, with the exception of cities and resorts of Black Sea coastal zone. High sensitive landscapes were adjoining the above-mentioned categories. These landscapes were more settled and a great number of industrial enterprises and also agricultural lands were located here. Most part of moderate sensitive landscapes were located in the central part of Colchic lowland, also in semi-humid foothills of Eastern Georgia. Only middle mountain forest and few other landscapes existed with low and very low sensitivity. But it should be mentioned that if these landscapes underwent great anthropogenic influence, the negative processes could stir these up into a different category, such as moderate or high sensitive landscapes.

These studies have enlightened the fact that for a real picture of the impact of climate change, the analysis of meteorological parameters alone is not sufficient. Such an approach often leads us to unwanted results. Evaluation of such complex characteristics is also needed such as, the daily geo-conditions of the landscape. This approach exactly gives us an opportunity to investigate not only the annual dynamics, but also rare, non-typical and critical geo-conditions, the existence of which points to the existence of the changes in the structure and functioning of a landscape, the bias of the average multiannual from the norm, which indicates the existence of certain trends. It can be said that for a possible evaluation of the risk quality of landscapes towards the climate change and revealing current basic trends, only way is to follow the complex approach. This approach will reveal the clear image of the mosaic impact of climate change on one hand on the territory.

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