



# Grassland Carbon Stock Calculation and Preparation of Water Balance Model for Vashlovani Protected Areas

## Final Report 2014

The survey „Grassland Carbon Stock Calculation and Preparation of Water Balance Model for Vashlovani Protected Areas“ was carried out under the framework of the project: “Sustainable Management of Pastures in Georgia to Demonstrate Climate Change Mitigation and Adaptation Benefits and Dividends for Local Communities”. The project is funded by EU and implemented by UNDP Georgia. The survey was implemented by GIS-lab in collaboration with in Ecological Agriculture and Nature Conservation Laboratory of Agricultural University of Georgia. Since the aim of the project is the rehabilitation of pasturelands and the introduction of sustainable grazing practices in Georgia on the basis of Vashlovani Protected Areas (VPAs) example, activities implemented during the survey aimed at carbon stock inventory, general soil fertility assessment and water balance modelling of VPAs pastures. Information derived from the survey is of great importance for future management planning and outlining rehabilitation areas and measures. Based on data, maps and GIS models of survey soil fertility, carbon stocks for present time were evaluated and overgrazing regions outlined. Also water balance distribution was determined for current and future business as usual scenarios (2014 and 2070 years).

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## Introduction

Vashlovani protected area is located in eastern part of Georgia. The area is characterized by its dry climate sitting only 150-50 meters above sea level with desert and semi-desert steppe vegetation and arid and deciduous forests. Semi-desert part of VPAs is intensively used as pastures and overgrazing became main problem for local ecosystem as well as for farmers.

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Carbon assessment is estimation of CO<sub>2</sub> emissions avoided by stopping deforestation process and fossil fuel substitution or, alternatively, estimation carbon sequestered in biomass and soil as a result of enhancement of sinks of carbons through afforestation, reforestation and grassland rehabilitation activities. Carbon inventory involves estimation of stocks and fluxes of carbon from different land-use systems in a given area over a given period and under a given management system [1].

Since project aims rehabilitation of pastures of VPAs, general soil fertility assessment is also one of scopes. Therefore general fertility study was conducted to evaluate general nutritional condition for particular vegetation important for pastures in VPAs. VPAs soil (stratified by vegetation types) condition was evaluated in terms of available nitrogen content, soil organic matter and soil pH.

For more information on soil fertility accurate estimation of available water capacity (AWC) and water balance modeling was conducted. Survey named Grassland Carbon Stock Calculation and Preparation of Water Balance Model for Vashlovani Protected Areas was performed by GIS-lab in collaboration with in Ecological Agriculture and Nature Conservation Laboratory of Agricultural University of Georgia. Water balance modeling was performed by experience GIS specialist using modern GIS technologies. Field works were carried out by qualified team and laboratory analysis was performed by soil experts in

Ecological Agriculture and Nature Conservation Laboratory of Agricultural University of Georgia.  
Following activities were carried out during the survey:

1. Carbon stock inventory
2. General soil fertility assessment
3. Water balance modeling

## **Short Physical and Geographical Overview of Vashlovani National Park**

### ***Geographic Location***

Vashlovani protected territories are located in the farthest east part of Georgia (Map 1). This research is focused on Vashlovani National Park. The Park mainly covers Khumro, Bughamoedani, Lekistskali Gorge, Alazani-heading ravines (Sarkaliskhure, Arphadara, Chaibulakhi) and plains located in the narrow gorge of the Alazani River, Shavimta massive, ChighoelTkhevi, Eshmakiskhevi. Hypsometrically the research territory is located at 150 to 845 meters above sea level (Shavimta Mountain).

### ***Relief and Geology***

Vashlovani National Park has complex and non-homogeneous relief. It is characterized with complex interchanges of various anticline mountain ridges and hills and depressed plains.

The southern part of the National Park has the roughest terrain (elevation - 200-600 meters). Here the complex interchanges of monoclinial asymmetric hills and depressed and peneplenized plains (Khumro, Bughamoedani, Lekistskali, etc.), located between them, is witnessed. Characteristic for monoclinial hillocks are southern steep, sometimes vertical-denuded slopes and relatively less inclined northern slopes. The series of such asymmetric cuerdas rotate from west to east. The terrain is roughened by numerous dry, narrow and deep erosive ravines and precipices (Eshmakiskhevi, Mamachai, Pantishari, Kumro, Mijnskikhure, etc.), which cross moniclinial ridges and divide them into small sections. The past and current endogenic and exogenic factors (inclination and direction of layers, intensity of physical and chemical weathering processes, unequal density of rocks, destruction, erosion and denudation processes) triggered the formation of weird terrain shapes (towers, pillars and other sculptural form); these processes resulted in narrow piercing ravines, eroded slopes ('badlands') and vertical walls ('sharps'); numerous pseudo-karsts have been formed in gypsum containing marine clays, mostly on Khumro, Usakhelo Mountain and Mijnskikhuri massifs. This territory is formed by sandstones, clays and conglomerates of Absheron and Akchagil age (centuries).

The Alazani River-heading dry ravines (Sarkliskhure, Ghoristskali, Arphadara, Chaibulakhi and other nameless ravines) located in the middle part of the research territory (between Vashlovani structural basin and Mijnskikhure massive on the one side and Shavimta Mountain on the other side) have similar, but less fractional and less furrowed and erosive topography. This territory is gradually elevating and passes to Shavimta massive. ChighoelTkhevi is also marked with relatively mild undulating land.

The highest part of the National park is Shavimta section (elevation - 848 meters), which is characterized with asymmetric topography – relatively less inclined, plane, hilly undulating southern and western side-hills and Alazani valley-heading relatively steep, more or less furrowed northern and eastern slopes. A number of permanently full-flowing and dry ravines start from northern slope, which ravines furrow the

slopes and head down to Alazani valley. Geologically here are the continental deposits of Alazani series of Absheron and Akchagil age [27, 32, 31, 42, 41].

### *Climate*

On the research territory is marked with zonal change of climate from south northwards.

The southern and south-eastern parts (Eshmakiskhevi, Khaladara, “Didi Chrdili” (Big Shadow), “Patara Chrdili” (Small Shadow), Duzdahgi, Mijnskuri and Usakhelo Mountain massifs, etc.) and depressed valleys located between them (Khumro, Bughamoedani, Lekistskali, etc.) are influenced by Iran-Turan dry climate and belong to semi-arid zone. Typical for this zone is dry subtropical climate with relatively cold winter and long hot summer. The sum total of average annual temperature is 13°C. The average annual precipitation is within 350-400 mm; is characterized with two maximums (spring and autumn) and two minimums (summer and winter). Evaporation is 900-1000 mm and humidity rate – 0,4-0,6.

The middle part of the research territory is characterized with moderately humid subtropical climate. Winter is moderately cold and summer is relatively hot and long. The average annual temperature is 10,3-12°C. The sum total of average annual precipitation is within 500 mm; is characterized with two maximums (spring and autumn) and two minimums (summer and winter). Evaporation is 800-900 mm and humidity rate – 0,5-0,6.

The climate of Shavimta Massive is moderately humid with moderate winter and long warm summer. The average annual temperature is 10,5°C. The sum total of average annual precipitation is over 600 mm. Most of total precipitation accounts for May and June and minimum – for July and August. Evaporation is 700-800 mm and humidity rate – 0,5-1,0 [22, 33, 34, 35, 41].

### *Hydrographic Network*

Vashlovani National Park is very poor in hydrographic Network. On the east the research territory is abutted by the transit river Alazani, which influences only the narrow strip of the riverside. Another full-flowing stream is the River Lekistskali (Mtsaretskali), where the water is permanently flowing for a certain distance. It joins the Alazani River on the territory of Azerbaijan. Subject to its influence is also only a narrow strip of the gorge. On the other hand, the research territory is very rich in dry and periodically water-flowing ravines, with water flowing through them only during heavy rains [27].

### *Soils*

The soil distribution pattern on the territory of Vashlovani National Park is mainly of zonal nature; however there are intrazonal soils as well. Specifically the spatial distribution of soils from south to north is as follows: there is brown earth of arid forest on northern slopes of monoclinal hills, Lekistskali, Ghoristskali and Arphadara ravines, Mijnskuri and Usakhelo Mountain Massifs, considered as chestnut soils by some scholars. These soils are characterized with high content of gypsum (in the form of crystals), profile sealing and poor content of organic substances. In this zone, loam and grey desert and semi-desert soils of mechanical clay composition of different level of salinity are distributed interzonally on depressed valleys of Bugha-Moedani, Khumro and Lekistskali ravine middle and lower reaches. In the southern and partially in the middle part of the territory and in Eshmakiskhevi various modifications of stony grey-brown soils are distributed on the slopes and hillocks. Apart from them there are black and brownish soils in the middle part of the territory. Shavimta is characterized with forest brown and brown soils. There are alluvial soils along the River Lekistskali.

Particular mention should be made of southern steep slopes of monoclinal hills and Mijnskuri and Usakhelo Mountain Massifs which are mainly devoid of real soil. Here are saline loams, clay and clay-

sand badlands on the one part and cemented conglomerates on the other. There are also bedrock outcrops, sandstones and clastic-bulks [28, 29, 40, 27].

## Overview of the Flora of Vashlovani Protected Territories

Vashlovani National Park is characterized with biome diversity and contrast. Dominating are the biomes of deserts (plain and foothill deserts), xerophilic forests (arid thin forests), phrygana vegetation, steppes, hemixerophilic summer-green shrubbery (Shibljak shrubs) and foothill deciduous forests with characteristic for them vegetation. Apart from them there are phytocenosis of grove forests, hydrophilic vegetation, Tugai-type shrubs and meadow-steppes, also clastic-gravel xerophilic complexes [24]. The distribution of these biomes is subject to certain zonal regularity, what is mainly triggered by zonal change of edaphic and climatic condition from south northward, also by different topography patterns and geological origin. The formation of contemporary vegetation of Vashlovani protected territories and the regularity of its distribution was greatly influenced by human economic activities. Contemporary zoning of vegetation from south northward is of the following pattern: arid forests, steppes and foothill deciduous forests. Intrazonal types of vegetation are: desert vegetation, phrygana vegetation, hemixerophilic summer-green shrubbery (Shibljak shrubs), grove forests, meadow-steppes, various xerophilic complexes. Their formation and distribution is related to specific relief-edaphic conditions. Particular mention should be made of the distribution of Shibljak type vegetation (specifically, of thorn-bushes). In historical past they would create subzones (micro zones) between arid forest and steppes on the one part and steppes and foothill deciduous forests – on the other. As of to date this regularity is upset due to the impact of anthropogenic factors; geomorphologic processes also contributed to this process. Below is offered the short overview of the vegetation.

Desert vegetation is represented in two different ecological variations: (1) plane and (2) foothill deserts. Plane deserts are of both primary and secondary origin (formed as a result of *Pistacieta* degradation), whilst foothill deserts are of primary origin. The plain deserts are common for Khumro, Bugha-Moedani, and the plains and hillocks of Lekistskali gorge middle and lower reaches. They also penetrate into lower reaches of Alazani gorge (Mijniskhure, Sarkliskhure) as small fragments. The most common is *Artemisieta lerchianae* formation, within which formation different plant communities have been formed (Pic.1). Rather rare are phytocenosis of *Salsoleta ericoidis* and *Salsoleta dendroidis* formations, which are common for the middle reaches of Lekistskali gorge. There are small sections of *Salsoletum nodulosae* on diluvial plains of Khumro, Bugha-Moedani, Lekistskali gorge and Mijniskhure. Communities of *Nitraria schoberi* were common for Alazani gorge (Mijniskhure, Sarkliskhure). Foothill deserts include anticline hills located in south-east part of Iori upland, loams and loamy badlands of Mijniskhure and Usakhelo Mountain massifs; dominating are *Artemisietum lerchianae*, *Salsoletum nodulosae* and *Gamantheta pilosae* phytocenosis. There are *Atriplexetum canae* groupings in Vashlovani structural basin. The elements of *phrygana* vegetation are present in florist composition of foothill desert. Due to the foregoing rather frequent are the transitional between them groupings. Respectively *phrygana* vegetation and foothill deserts create single ecosystem on loams and loamy badland slopes and massifs, which system is one of the most xerophilic on Vashlovani protected territories.

*Phrygana* vegetation is common for anticline hills, Mijniskhure and Usakhelo Mountain massifs. Together with foothill desert vegetation it creates an intrazone in arid forest areas, it is present on loams, loamy and loan-sandy badlands and hillock of different exposition; can be found on grey-brown, loamy and loam-containing stone-gravel soils as well. Predominating are *Reaumurieta alternifoliae* and *Caraganeta grandiflorae* formations. Very rare phytocenosis of *Atraphaxieta spinosae* formations can also be found.

Apart from the foregoing small phytocenosis of tragacanthic plants [*Astragalus microcephalus*, *A. caucasica*, *Acantholimon fominii*] and tomiliar-type groupings (*Ziziphora serpyllacea*, *Teucrium nuchense*, *T. polium*, *Scutellaria orientalis*, *Thymus tiflisiensis*, *Th. karjaginii*) are also present. They dominating mainly on cemented conglomerates, stone-gravel and limestone rocks.



Picture. 1. Fragments of *Artemisieta lerchianae* & Foothill Desert & Pryganoid Vegetation - D1-1 & Ph-Fd. Kumuro.

Xerophilous forests are the most common type of vegetation of Vashlovani protected territories, dominating at 100-600 m above sea level under different topographic (slopes, plains, hillocks, alluvial cones, ravines, etc.) and edaphic (brown, loamy, slightly saline grey and grey-brown soils, shingles, etc. of arid forest) conditions. Prevailing for Vashlovani protected territories are *Pistacieta* (*P. muticae*) and *Junipereta* (*J. foetidissima*, *J. polycarpus*) formations. *Juniperetas* are mainly found in the middle and upper parts of the slopes and *Pistacietas* – on the lower parts of the slopes and mild forms of the terrain (wave-like hillocks, plains, alluvial cones, ravine edges). These formations are of diverse typological composition. They are fully deforested on quite large areas of the region and are substituted by secondary desert, semi-desert, steppe and Shibliak phytocenosis. Apart from them there also rare *Aceretum* (*A. iberica*), *Celtisetum* (*C. caucasica*) and *Pyretum* (*P. salicifolia*) phytocenosis.

Steppe area on Vashlovani protected territories mainly covers Bugha-Moedani, Khumro, Lekistskali gorge, Jeirani valley (Zilicha), Chighoeltkhevi, Eshmakiskhevi and Shavimta slopes (Pic.2). Its small phytocenosis are scattered almost all over the whole territory. They are mainly dominating on hillocks and slopes, rarely – on the plains. They are of both primary and secondary origin – created as a result of cutting down of primary hemixerophilic shrubs (mainly of thorn bushes) on the one part and of foothill deciduous forests (mainly of oaks). Dominating are *Bothriochloeta* (*B. ischaemum*) and *Stipeta* (*S. lessigiana*, *S. capillata*) formations. *Bothriochloeta* cover almost the whole area of the steppes of Vashlovani protected territories and create zonal type of vegetation. They grow at 200-850 m above sea level on various soils and hillocks, slopes and plains of different exposition. Respectively, both xerophilic



and more or less mezophilic variations have been developed and they are very in rich typological composition. *Stipeta* are fragmentarily represented on ridge plains and slopes of hills at 400-840 m above sea level; are formed on brown and brown-carbonate soils. Can be found also on black and blackish soils.



Picture 2. *Stipeta* - S2. Shavi Mta.

*Cleistogenetum bulgarici* communities can also be conditionally attributed to steppe vegetation. They are of secondary origin and fragmentarily incorporated into various sections of the territory.

Shibljak-type hemixerophilic shrubs are fragmentarily represented at 200-1000 m above sea level. They are of both primary and secondary origin. Dominating is thorn-bush (*Paliureta spina-christi*), formation, its phytocenosis being scattered all over the whole area of Vashlovani protected territories. Apart from them widely represented are polidominant shrubs of various modifications.

Foothill deciduous forests are common for Savmta, shadowy slopes of Artsiviskhevi and ravines heading from Shavmta to Alazani (Arphadara, Chaibulakh). Dominating are oak stands (*Querceta ibericae*), ash stands (*Fraxineta excelsior*) and Oak-Oriental hornbeam (*Carpineta caucasici*) formations.

The largest stands of bottomland forests are maintained in Jumaskhuri (Alazani gorge); smaller sections can be found in the vicinity of the village Sabatlo, Arphadara and Mijnskikhuri ravine debouchments. There can be found the communities of *Populeta* (*P. hybrida*, *P. nigra*) and *Querceta* (*Q. pedunculiflora*) formations.

There is a small stand of *Desert Poplar* (*Populus euphratica*), nowhere else found in Georgia.

Tugai-type shrubs, created by *Tamarixetum* (*T. ramosissima*, *T. smyrnensis*) groupings are fragmentarily represented on the water edges and humid plains of Lekistskali gorge.



Meadow-steppe Polidominant *Gramineto-varioherbetum* phytocenosis of various modifications are prevailing on Shavmta. Their floristic composition is complex, consisting of the steppe, meadow and bush species.

The fragments of hydrophilic vegetation can be found on Alazani banks and Lekistskali gorge, where the ground waters come out on the surface. Prevailing are reed (*Phragmites australis*) and partially Giant Cane (*Arundo donax*) phytocenosis [23-26, 36, 43].

## Survey Design

Carbon inventory category for national greenhouse gas inventory according to IPCC(1996) and IPCC (2006) for this particular survey is grassland remaining grassland (GG). This category was used with some country-defined methodological specifications.

Carbon cycle is one of the biogeochemical cycles of the earth, which describes flows of carbon between biosphere, atmosphere, oceans and geosphere. Two main anthropogenic impacts on carbon flax into the atmosphere are burning fossils and changes in land use. Human activities like livestock grazing lead to grassland soil degradation and emission of carbon contained in biomass and in soil to the atmosphere [3,5, 7].

Carbon inventory is estimation of carbon stocks and flaxes from different land use systems in a given area over a given time period and under a given management system. According to IPCC (International Panel in Climate Change) (2006) [12] carbon in land area is accumulated in five main pools (table 1.1):

1. Above-ground biomass (living biomass);
2. Below-ground biomass (Living biomass);
3. Deadwood (Dead organic matter);
4. Litter (Dead organic matter);
5. Soil organic carbon (soil).

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Pool		Description
Living biomass	<b>Above-ground biomass</b>	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage.
	<b>Below-ground biomass</b>	All biomass of live roots. Fine roots of less than 2 mm diameter (the suggested minimum) are often excluded because these often cannot be distinguished empirically from soil organic matter
Dead organic matter	<b>Deadwood</b>	All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter.
	<b>Litter</b>	All non-living biomass with a size greater than the limit for soil organic matter (the suggested minimum is 2 mm) and less than the minimum diameter chosen for deadwood (e.g. 10 cm) lying dead and in various states of decomposition above or within the mineral organic soil. This includes the litter layer as usually defined in soil typologies.  Live fine roots above the mineral or organic soil (of less than the suggested minimum for below-ground biomass) are included whenever they cannot be empirically distinguished from the litter.
Soil	<b>Soil organic matter</b>	Organic carbon in mineral soils to a specified depth chosen and applied consistently through a time series. Live and dead fine roots within the soil (of less than the suggested minimum for belowground biomass) are included wherever they cannot be empirically

Table 1.1 Definition of carbon pools according to IPCC (2006) [N.H. Ravindranath, M. Ostwald. 2008]

Annual change in carbon stock is a sum of annual changes in different carbon pools. Distribution of carbon in different carbon pools varies in different land use category. For savanna, grasslands, pastures and cropland soil is dominant over vegetation in storing carbon. Therefore estimation of soil carbon is

critical for given land-use category. Nevertheless, since given project aims reclamation of certain part of VPAs (migratory routs) and increase in grass productivity is expected, we strongly believe that living biomass (above-ground and below-ground) was also target pool of our investigation. Even though living biomass in grasslands is part of annual cycle; assessment of living biomass carbon may characterize distribution/overgrazing of biomass across the pilot area comparing biomasses of similar vegetation communities of different areas. According to IPCC dead organic matter (Deadwood and litter) are not priority pools for grassland land-use category since accumulation of carbon there is negligible [1, 10-12].

Summarizing above described, we outline three carbon pools for carbon inventory for a given project area: 1. Above-ground biomass, 2. Below-ground biomass and 3. Soil organic carbon.

Preparing carbon inventory for a given land-use category two approaches for carbon stock estimation are involved: 1. Carbon “Stock–Difference” method, which requires estimation of stocks of different carbon pools over two periods and 2. Carbon “Gain–Loss” method, which requires estimation of annual gains and losses in carbon stocks.

Since “Gain-loss” method estimates gains in carbon stock of the pools due to grows and transfer of carbon from one pool to another, this method doesn’t seems to be relevant for our project, because fluxes between pools are not much expected in grassland-remaining grassland category.

“Stock-Difference” method is more appropriated since increase in carbon stocks are expected after implementation of grassland reclamation activities. The carbon stocks are estimated twice for each pool at two points in time and are given by:

$$\Delta C = (C_{t_2} - C_{t_1}) / (t_2 - t_1)$$

$\Delta C$  is the annual carbon stock change in the pool,  $C_{t_1}$  the carbon stock in the pool at time  $t_1$ , and  $C_{t_2}$  the carbon stock in the same pool at time  $t_2$ .

Recommended frequency of measurement is 3-5 years depending on project purposes. In our case it’s two years, because on-going UNDP/EU project ends up in 2016. In this particular survey data for time  $t_1$  was obtained only.

Estimation using “Stock Difference” method will be done in two years according to following steps:

- Estimation of the stock of a pool at time  $t_1$  and repeat the measurement to estimate the stock at time  $t_2$ .
- Estimation of the change in the stock of selected carbon pool by deducting the stock at time  $t_1$  from that at  $t_2$ .
- Obtaining the annual change in stock, divide the difference in stocks by the duration ( $t_2 - t_1$ ) in years.
- If the estimates are made for sample plots, extrapolation to per hectare basis.



- Obtaining the total for the project area, extrapolate the per hectare estimate to the total project or land-use category area.

Carbon pools in the survey were estimated using “Plot method” which is most suitable, cost-effective and commonly adopted and is described in reports, manuals and books Special Report of Intergovernmental Panel on Climate Change on Land Use Land-Use Change and Forestry [18], Winrock Carbon Monitoring Guideline [15], FAO [6], Revised IPCC 1996 Guidelines [11], IPCC Good Practice Guidance [9], USEPA and LBNL [19], CIFOR Methods [8], GHG Inventory Guidelines 2006 [10] etc.

In order to estimate above-ground biomass, following steps were undertaken:

- All background information was collected, like: Projection of location maps showing latitude and longitude, topographic sheets, forest map and soil maps; names for land-use systems and their location and area, Elevation, topography and broad soil type; proximity to human settlements, roads, urban centers, markets; Land tenure or ownership etc.
- Project area was stratified according to two principles: 1. vegetation types and 2. Condition of grassland. Stratification according to grassland conditions will be carried out using visual observation during the fieldworks. The condition of sampling plots was divided into following categories: good, moderate and bad. Stratification according to vegetation types was carried out using map of vegetation types for Vashlovani Protected Area developed during previous UNDP, NACRES and GIS-Lab project. Analysis from previous botanical survey of VPAs showed that there were approximately 26 polygons on the map with homogenous, dominant vegetation communities.
- Two stratification layers will be overlapped in a way, that 3 plots was placed on each polygon (when possible) of vegetation type (dominant community) where grassland conditions were –good, moderate and bad. Therefore 68 plots will be laid on a map including migratory routes. Three plots (sometimes more, sometimes less, depending on accessibility of area) on each stratum were placed on bad, moderate and good places, where grass density was compact, moderate and not compact. The “shrub plot” size of the plot will be 5X5m<sup>2</sup> and the shape square, which is most suitable for grassland carbon inventory [15]. Type of plots is “temporary plots”, since they are appropriate for annual vegetation. From each plot all three carbon pools were investigated.
- The “stratified systemized sampling” sampling type was chosen. In this technique, the project or activity area is stratified based on key features which are vegetation status and vegetation density in our case.
- Following parameters was recorded during field works: name of species; density (number/plot); fresh weight of herb layer biomass (g/m<sup>2</sup>) and dry weight of herb layer biomass (g/m<sup>2</sup>).

Tier 2 allows for estimation of changes in biomass due to management practices. Method was derived from empirical country-specific data, taking into account grassland type, vegetation inventories, rate of biomass utilization, soil and climate specifications. Two kinds of data were collected: quantitative and

qualitative. Quantitative includes carbon stock and other values estimated and calculated as a result of field works and laboratory analysis. Quantitative data was derived from fieldwork as an analysis and evaluation of site, like visual evaluation of land, soil and vegetation condition, site specifications etc.

### Methodology for Above-ground biomass estimation

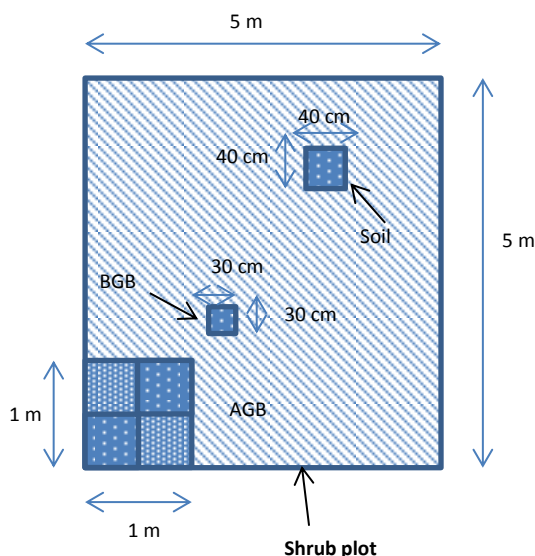
Following steps for above ground estimation was performed:

1. Stratification according to vegetation types and land condition.
2. Planning sampling points and field work routs (see map.2). 68 plots were identified for sampling and two expeditions planned.
3. Timeline was defined for field fork and amount of sampling plots per day (see map.2). Different color dots represent different sampling plots. Each color corresponded to the sampling day, so main sampling area was covered during 7 days (each expedition).
4. "Plot No X" was defined on the map using GPS coordinates.
5. Undisturbed soil was with " good, bad or average vegetation cover" was chosen and corners of 5 m<sup>2</sup> "shrub plot" were marked. See Fig. 1.
6. Wooden sampling frame was placed to mark 1m<sup>2</sup> square within "shrub plot" for above ground biomass harvesting (Pic. 3).



*Picture. 3. Wooden frame.*

1. The mass of herbal samples were approximately 100 g. When grass biomass density was high, it was enough to harvest just 0.5m<sup>2</sup> or 0.25 m<sup>2</sup> area.



**Fig. 1.** Shrub plot with AGB, BGB and soil plots within.

2. Harvested biomass was separated from soil and roots and placed in paper bag.
3. Number of samples was written on the bag.
4. The field data were recorded on Worksheet #1.

#### *Laboratory Procedure Protocol and Calculations for AGB*

1. Weigh plant biomass directly to get fresh weight (FW) and record the value.
2. Chop all samples and mix them well before taking subsamples.
3. Weight about 100 g as a subsample.
4. Place subsample in the oven at 85 oC for 48 hours, weigh its dry weight (DW). Record the value.

Total dry weight ( $\text{kg m}^{-2}$ ) = Total fresh weight (kg) x Subsample dry weight (g) x Sample area ( $\text{m}^2$ ) / Subsample fresh weight (g)

$C_{\text{AGB}} = \text{Total dry weight} \times 0.47$

Multiply biomass by the carbon content of dry biomass. The default value is 0.47 tonne of C per tonne of biomass (DW). This default value differs from one in the GPG-LULUCF (IPCC, 2003), but it's more realistic for herbaceous biomass (IPCC 2006).

The highest value among the monthly values is considered as the grass or herb productivity for that area expressed as dry tonnes per hectare per year.



## Methodology for Below-ground Biomass Estimation

For estimation of below-ground biomass expansion factors from above-ground biomass (root-to-shoot ratio) are often used. Root-to-shoot ratios show wide ranges in values at both individual species [9, 1, 4, 16] and community scales, therefore to reduce uncertainty level, IPCC recommends to acquire, as far as possible, empirically-derived root-to-shoot ratios specific to a region or vegetation type. Since there is no available empirically-derived ratio on target region, neither on particular vegetation types, we conducted below-ground survey based on vegetation type stratification. Acquired empirical expansion factors can be used lately (for next measurement time) and no more below-ground measurements need to be conducted for this region and other regions with similar vegetation.

Even though methods for below-ground biomass estimation for different land-use categories are not standardized by IPCC, we chose method of “soil core or pit for non-tree vegetation”, since we found it most appropriate for grassland vegetation. Carbon content was recalculated but multiplying biomass by the carbon content of dry biomass.

Steps in estimating the below-ground biomass as follows:

1. Sampling plot of 30cmX30cm within the shrub plot was selected (see pic.4)



*Picture 4. Root sampling.*

2. 20 cm deep pit was dig out.

3. Different vegetation and soil type determines different length of root system. According to our observation main mass of root was located within 0-20 cm depth, although for some species roots were going sometimes deeper than 1-2 m that made excavation of full length root almost impossible in condition of semi-desert zone and lack of water. Nevertheless the main mass of roots was collected from 0-20 cm depth.
4. Since there was no possibility to wash the samples, roots were carefully separated from excessive soil and stones by hands.
5. Samples were placed in plastic bags with the names of samples on it and fieldwork sheet #2 was filled in.

### ***Laboratory Procedure Protocol and Calculations for BGB***

1. Separate the roots from soil by placing the soil samples on a sieve (mesh size of 2.5 or 5 mm) and wash the roots under running water.
2. Collect all the roots and weigh them.
3. Estimate the dry weight by oven-drying a sample of roots at 70°C to a constant weight (for at least 8 h).
4. Estimate the dry weight of the roots for the volume of sample cube (calculated from its height, width, depth) for all the sample plots.
5. Extrapolate the root biomass to per plot and hectare, using dry weight of the root samples collected to the depth of sample cube.
6. Adopt the method of calculation from AGB (see above) with an exception that extrapolation should be done for the root biomass from the volume of the soil on per hectare basis for the depth, usually 20 cm depth (where 20 cm depth = 2,000 m<sup>3</sup>) of soil per hectare. Extrapolating data per hectare to data per given area.

### **Methodology of Soil Analysis**

Soil analysis was conducted from one sample for following analysis: 1. Soil organic matter (SOM) and soil organic carbon (SOC) for carbon stock inventory and 2. Soil hydrolysable nitrogen (N), soil pH and available water capacity (AWC) for water balance modelling.

Several methods are available for SOC (soil organic carbon) estimation. Among six most widely used methods we chose direct estimation of organic matter and SOC consequently by loss-on-ignition (LOI) method. After consultancy with soil experts regarding accuracy and cost of various methods, this method was found to be most appropriate for soil types of VPAs.

1. Sampling plot of 40cmX40cm within the shrub plot was selected (see fig.3)
2. 30-40 cm deep pit was dig out.
3. The vertical wall of pit was marked with knife at two places: 1-15 and 15-30 (A) or 1-20 and 20-40 (B).

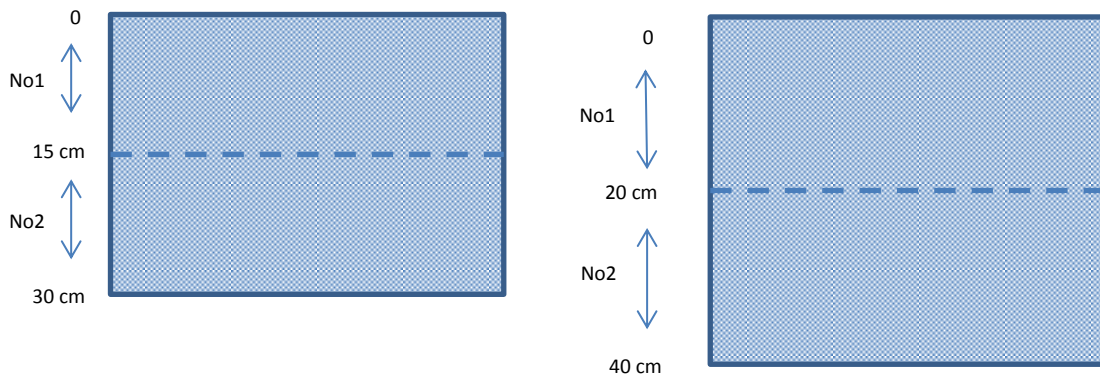


Fig. 2. Vertical slice of pit for soil sampling. Two possible variations of sampling sites.

4. Metallic cup with known volume was pressed against vertical wall of pit at depth No1 using mallet. Cup filled with soil was removed (pic.5).



Picture. 5. Soil Sampling

5. Sample was transferred to the plastic bag.
6. Procedure was repeated for depth N2.
7. Knowing volume of box will enable us to calculate bulk density.
8. For soil sampling Worksheet #3 was used.



### *Laboratory Procedure Protocol and Calculations for SOM and SOC*

1. Weight the fresh weight of sample to calculate bulk density.
2. Use Loss-on-ignition method for SOM analysis.

#### Weight Loss-on-Ignition (LOI 360°C) overview:

- A sample of soil is dried at 105° C to remove moisture. The sample is weighed, heated at 360° C for 2 hours and weighed again after the temperature drops below 150° C.
- Any material that losses moisture below 360° C is a potential source of error. Therefore, soil moisture must be removed before the base weight of the sample is taken. Also, ignited samples must not be allowed to re-absorb moisture from the air before they are weighed. Gypsum loses water of hydration gradually. Soils containing gypsum should be heated initially at 150° C instead of 105° C. Some hydrated clays may also lose water below 360° C. It is important that the results of this method be calibrated against organic carbon, preferably using a carbon analyzer, on soils from the area for which the test will be used.

#### Procedure

- Place a 5 g scoop of soil into a tared 20-ml beaker
- Dry for 2 hours or longer at 105° C
- Record weight to  $\pm 0.001$  g
- Bring oven to 360° C. Samples must then remain at 360° C for two hours.
- Cool to  $< 150^{\circ}$  C
- Weigh to  $\pm 0.001$  g, in a draft-free environment

#### Calculations

- Calculate percent weight loss-on- ignition (LOI)

$$\text{LOI} = (\text{wt. at } 105^{\circ}\text{C}) - (\text{wt. at } 360^{\circ}\text{C}) \times 100$$

Wt. at 105° C

- Estimate % organic matter. Organic matter is estimated from LOI using regression analysis. Select soils covering the range in organic matter expected in the area serviced by the lab. Determine % organic matter using a carbon analyzer or by the Walkley-Black procedure for organic carbon. Regress OM on LOI.
- Estimating soil carbon density (tC/ha). SOC is calculated from SOM by multiplying by the carbon content of SOM. The content of organic carbon in soil estimated in percentage terms needs to be converted to tonnes per hectare using bulk density, depth of the soil and area (10,000 m<sup>2</sup>).

$$\text{SOC (t/ha)} = [\text{soil mass in 0-30 cm layer SOC concentration (\%)}] / 100$$

$$\text{Soil mass (t/ha)} = [\text{area (10,000 m}^2\text{/ha)} \times \text{depth (0.3 m)} \\ \times \text{bulk density (t/m}^3\text{ )}]$$

#### Quality Control

- At least one standard soil of known LOI value should be run with each batch of samples. If the result is not within the known standard deviation, corrective action is required.
- All beakers should be re-tared monthly. Two beakers from each batch of 50 should be re-tared weekly. If the results are not within  $\pm 0.002$  g of the previous tared weight; re-tare all beakers in the batch.

#### Reporting

- Data are reported as % LOI or as estimated % O.M.
- SOC is calculated from SOM by multiplying by the carbon content of SOM.

### *Laboratory Procedure Protocol and Calculations for Soil Hydrolysable Nitrogen*

#### Protocol for spectrophotometer based on photolorimetric method to measure soil organic nitrogen

- Nitrate and Nitrite:
- Nitrate and nitrite are extracted by shaking 2 g of air dried soil in 30 mL 0.01 M CaSO<sub>4</sub> for 15 minutes followed by filtration. The nitrate in the filtrate is measured on a Lachat Quikchem 8500 Flow Injection Analyzer. In this method, the nitrate is reduced to nitrite in a copperized cadmium column. The nitrite then reacts with sulfanilamide under acidic conditions to form a diazo compound. This in turn couples with N-1-Naphthylethylenediamine dihydrochloride to form a reddish purple azo dye, which is measured colorimetrically at 520 nm. Nitrite is determined by the same process but without using the copperized cadmium column.
- Ammonium:
- Ammonium is extracted by shaking 2 g of moist soil with 30 mL of 2 M KCl for 30 min. The extract is analyzed on a Lachat QuikChem 8500 Flow Injectin Analyzer. In this method, the ammonium reacts with salicylate in the presence of nitroprusside (catalyst) to form an emerald green complex, which is measured colorimetrically at 660 nm. [Nitrate and nitrite can also be determined from the 2 M KCl extract.]

#### Protocol for pH-meter potentiometric method to measure soil pH values:

- Weigh 20 g of soil sample into a 100 mL beaker.
- Add 20 mL of deionized (DI) water and place on a stirrer to mix for 30 minutes.
- Cover and let stand for an hour.

- For the most accurate measurements, allow the buffers and the soil sample both to come to room temperature. (A difference in temperature will add error to your measurement.)
- 2-point calibration is recommended with a pH 7 and a pH 10 buffer solution. The electrode slope should be between 92 and 102%.
- Rinse electrode and ATC with DI water and blot dry. Place probes in soil sample and measure pH and record measurement.

1. AWC was calculated based on organic matter content and soil texture class.

## Mapping Methodology and Basic Principles

Software for the procession of both geoinformation systems and remote sensing data was used for mapping purposes and, prima facie, it is quite difficult to manage the process and it requires highly-qualified specialists. However it should as well be mentioned, that necessary softwares, as well as most satellite data, are often free. Hence, following certain training, it is possible this methodology to be automated and disseminated between various institutions. However it should necessarily be mentioned, that due to the lack of time the mapping methodology, as well as modeling of certain ecological processes, require more profound thinking, technological improvement and more thorough development of accuracy checking mechanisms.

Mapping methodology included following processes:

- Using Remote Sensing Data (Landsat 8,Rapideye )
- Finding Relationships Between ecological Factors
- Vegetation Index Calculation
- CoKriging and Geostatistical Analysis
- Interpolated Surfaces

## Methodology for Water Balance Modeling

Data needed for performing a water balance is following: a digital elevation model (DEM), soil available water capacity (AWC), and monthly temperature, precipitation, and solar radiation. Soil water-holding capacity is available from digitized soil surveys and gridded data are available for monthly climate, elevation and solar radiation. The resolution and spatial extent of these data sets means that the analysis was performed at a very fine spatial scale.

The average difference in slope was computed from the DEMs for each study area; Available water capacity in the top 30-40 cm of soil was obtained for each site from VPA. In semiarid grassland main root

system is expected to occur within the top 30-40 cm; soil probes were installed at the approximate midpoint of this depth.

A key component of a water balance approach is the calculation of potential evapotranspiration (PET) at each site. There are approximately 50 different methods of computing potential evapotranspiration, although for this application it is essential to select a method that provided monthly estimates of PET using readily available data. Calculation of monthly Potential Evapotranspiration according to Turc (1961) is following:

$$PET = 0.013 \times \left[ \frac{T}{(T + 15)} \right] \times (R + 50)$$

where PET is potential evapotranspiration (mm), T is temperature (°C), and R is radiation (Wh/m<sup>2</sup>).

ArcGIS (v. 9.2) software includes a “Solar Radiation” toolset which estimates global solar radiation at any time of year for either a point or for an entire DEM, based on its latitude (ESRI 2006). The only atmospheric parameters required for Solar Radiation are the diffuse proportion, and atmospheric transmittivity (the proportion of solar radiation outside the atmosphere that reaches the surface).

Once monthly radiation is computed, water balance models are performed to estimate PET, soil moisture storage, AET, soil moisture deficit, and soil moisture surplus for every grid cell within the DEM.

To evaluate this possibility, stepwise regression was used to uncover any relationships between the differences in sites’ measured versus modeled soil moisture, and GIS-derived variables describing the sites’ topographic setting. These variables included slope, aspect, curvature, profile curvature, plan curvature, upslope area, topographic wetness index, distance to divide, elevation difference to divide, distance to peak, elevation difference to peak, and landform category (e.g., ridge, valley, slope).

## Survey implementation steps

Present survey considered following milestones:

- Detailed schedule of activities with methodology
- Fieldwork in VPAs
- Monthly reports
- Lab work and tests
- GIS analysis and modelling
- Other reports and presentations

Duration of survey was 4.5 months and was consisted from following stages:



- *Preparation of detailed methodology and timeframe*  
Detailed methodology was prepared and introduced to the team. Methodology included fieldwork procedures, lab analysis protocols, worksheet and maps. Total grassland area of VPAs was disaggregated into stratas according to vegetation types. 68 stratas were outlined and sample plots determined on the map. Maps were prepared to plan sampling plot location, sequence of sampling and routes respectively.
- *Preparation for the expedition and fieldwork*  
Expedition member meeting was organized. All equipment and various material needed for the fieldwork was acquired prepared. Fieldwork procedure and worksheets was given to expedition members.
- *Implementation of fieldwork*  
Two expeditions were launched to VPAs. Field work was conducted to collect three types of samples: Above ground biomass (AGB), below ground biomass (BGB) and soil samples (SS) for the fertility assessment.
- *Laboratory analysis*  
612 samples (table.2) were sent to the laboratory for the following analysis: 1. AGB carbon stock, 2. BGB carbon stock, 3. soil carbon stock, 4. Soil nitrogen, 5 Soil moisture content and 6 soil pH.

No	Analysis	No of samples
1	pH	136
2	Available water capacity	136
3	Nitrogen	68
4	Living biomass carbon	136
5	Soil organic matter/carbon	136
<b>Sum:</b>		<b>612</b>

*Table.2. Amount of samples for laboratory analysis*

- *Data proceeding*
- *Data analysis, GIS modelling and interpretation*  
Data was analyzed and graphs, maps and diagrams created.
- *Presentation of survey.*  
The meeting was held on October 31, 2014. Survey developers introduced their results. During the meeting, relevant issues will be discussed among Georgian and foreign colleagues.
- *Preparation of publication*  
Publication with most relevant results was prepared to publish.

## Results and Discussions

Ecological Agriculture and Nature Conservation Laboratory of Agricultural University of Georgia has conducted laboratory study and delivered their results to GIS-lab for farther interpretation. Results received from laboratory consisted of data integrated into six following tables:

- Soil Analysis Results #1, which consists of following data: name of sample, soil depth, available nitrogen content, category and range.
- Soil Analysis Results #2, which consists of following data: name of sample, soil depth, pH, category and range.
- Soil Analysis Results #3, which consists of following data: name of sample, soil depth, Soil organic matter, category and range.
- Soil Analysis Results #4, which consists of following data: name of sample, soil depth, hygroscopic water, soil organic carbon %, soil organic carbon t/ha and available water capacity.
- Below-Ground Biomass Carbon Stock analysis #5- name of sample, sampling volume, total fresh weight of sample, fresh weight of sub-sample, dry weight of sub-sample, total dry weight of sample, organic carbon content in subsample, organic carbon content in sample.
- Above-Ground Biomass Carbon Stock analysis #6- name of sample, sampling volume, total fresh weight of sample, fresh weight of sub-sample, dry weight of sub-sample, total dry weight of sample, organic carbon content in subsample, organic carbon content in sample.

VPAs soil (stratified by vegetation types) fertility condition was evaluated in terms of available nitrogen content, soil organic matter and soil pH. Carbon stock was calculated for three different pools: Above Ground Biomass (AGB), Below Ground Biomass (BGB) and Soil carbon (SOC). All data was evaluated for “grassland” category (table.3; map.1)

Areas of VPAs	
Name	ha
Protected Area	34665
Nature Reserve	10372
Grasslands	16192
Out Of Nature Reserve	24293
Migratory Rout	988

*Table.3 Areas of VPAs of different landuse categories.*

### Mapping Approech

Total area of Vashlovani Protected Territory grasslands makes 16190 hectares, where the samples were taken from 68 different places, what is not sufficient for making reliable thematic maps as quite often various types of herbage and local ecosystems with differing soil, physical, terrain and climatic specificities are stretched between field data. Hence the mere interpolation of fieldwork data and

making averaged from different points spatial surface is not reasonable as in this case some important territories would have been lost on the map.

### Establishing Correlative Links

In the context of the aforementioned challenge, we tried to establish correlative links between our data and other existing variables in order to further use these links to make more accurate maps. IBM SPSS Statistics 20 bivariate correlation function was used to make the table of correlative links, where the stars denote the correlation importance level. See Table 4.

	C_BG B t/ha	C_AG B t/ha	C Bio t/ha	C_SO C t/ha	C total	Fapar	N mg/k g	PH_2 0	PH_4 0	MSAV I	SOM_2 0	L-8 TIRS
C_BGB t/ha	1	.016	.502**	.007	-.111	-.001	.132	.007	-.066	-.024	.033	.067
		.896	.000	.957	.367	.995	.285	.955	.590	.844	.790	.588
C_AGB t/ha	.016	1	.715**	.163	.289*	.525**	-.145	-.246*	-.213	.557**	.305*	-.509**
	.896		.000	.184	.017	.000	.238	.043	.081	.000	.011	.000
C Bio t/ha	.502**	.715**	1	.192	.243*	.489**	.040	-.152	-.158	.517**	.332**	-.384**
	.000	.000		.116	.046	.000	.748	.217	.197	.000	.006	.001
C_SOC t/ha	.007	.163	.192	1	.740**	.567**	-.025	-.114	-.017	.562**	.862**	-.339**
	.957	.184	.116		.000	.000	.837	.354	.892	.000	.000	.005
C total	-.111	.289*	.243*	.740**	1	.647**	-.028	-.241*	-.143	.664**	.688**	-.479**
	.367	.017	.046	.000		.000	.822	.048	.245	.000	.000	.000
Fapar	-.001	.525**	.489**	.567**	.647**	1	.020	-.392**	-.297*	.989**	.572**	-.653**
	.995	.000	.000	.000	.000		.870	.001	.014	.000	.000	.000
N mg/kg	.132	-.145	.040	-.025	-.028	.020	1	.043	.112	-.018	-.010	.107
	.285	.238	.748	.837	.822	.870		.730	.363	.884	.932	.387
PH_20	.007	-.246*	-.152	-.114	-.241*	-.392**	.043	1	.591**	-.388**	-.124	.435**
	.955	.043	.217	.354	.048	.001	.730		.000	.001	.314	.000
PH_40	-.066	-.213	-.158	-.017	-.143	-.297*	.112	.591**	1	-.288*	.044	.513**
	.590	.081	.197	.892	.245	.014	.363	.000		.017	.722	.000
MSAVI	-.024	.557**	.517**	.562**	.664**	.989**	-.018	-.388**	-.288*	1	.583**	-.651**
	.844	.000	.000	.000	.000	.000	.884	.001	.017		.000	.000
SOM_0_2 0	.033	.305*	.332**	.862**	.688**	.572**	-.010	-.124	.044	.583**	1	-.310*
	.790	.011	.006	.000	.000	.000	.932	.314	.722	.000		.010
L-8 TIRS	.067	-.509**	-.384**	-.339**	-.479**	-.653**	.107	.435**	.513**	-.651**	-.310*	1
	.588	.000	.001	.005	.000	.000	.387	.000	.000	.000	.010	

\*\* . Correlation is significant at the 0.01 level (2-tailed). \* . Correlation is significant at the 0.05 level (2-tailed). c. Listwise N=68

Table. 4. Correlation between data obtained from fieldworks.

## Carbon Inventory

As was expected soil organic carbon was significantly higher than corresponding values of above-ground biomass and below-ground biomass carbons (table 5). Percentage difference of carbon stocks of different pools are presented on fig. 1. As seen from the table 4 and fig. 1, AGB slightly exceeds BGB carbon values. Despite this overall pattern, on migratory route, where sheep are regularly transferred from pastures to watering and back, BGB exceeds AGB because of overgrazing in this area (table 6). The same is for Kumro and Bugha moedani where intensive grazing and desert type vegetation result in bigger BGB/AGB ratio.

Average Value of Carbon in Different Pools of VPAs		
C BGB t/ha	C AGB t/ha	C SOC t/ha
1.23	1.49	33.27

Table. 5. Average values of carbon in different pools of VPAs.

Carbon of all three pools will be measured again in two years using same sampling technologies and carbon stock difference will be calculated using “stock difference method” described above. Especially interesting will be migratory route area, since this area is target for reclamation work.

Area	Total AGB carbon / t	Total BGB carbon /t	Total SOC /t	C total/t	AGB Average t/ha	BGB Average t/ha	SOC Average t/ha	C Average t/ha	BGB/AGB	Grasslands/ha
Total VPAs grassland	20454,57	19488	509576.7	549519.3	1.49	1.23	33.27	35.99	0.82	16190
Migratory rout	990.9	1216	28656.54	30863.44	1.1	1.37	32.4	34.9	1.23	885
Buhga Moedani	565	752	16986	18303	1.1	1.53	34.7	37.4	1.33	489
Kumuro	891	1447	30141	32479	0.8	1.38	28.7	30.9	1.62	1051

Table. 6. Carbon stocks of different pools calculated as a tonnes of carbon per hectare for different areas of Vashloani grasslands.

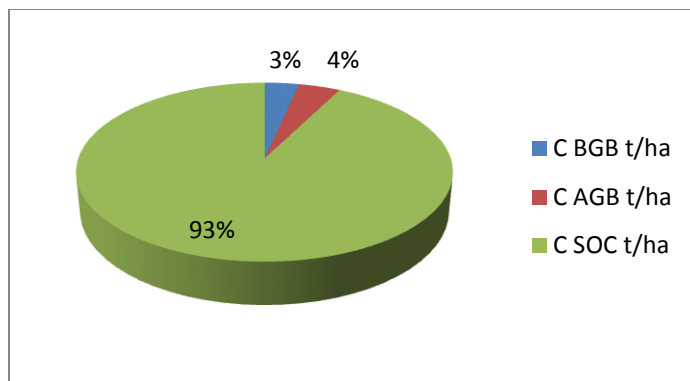


Fig.1 Percentage difference of carbon stocks of different pools.

### Above-Ground Biomass (AGB)

As evidenced by figure 2 the aboveground biomass in plant communities of desert ecosystem is low and is noticeably far behind the respective figures of steppe ecosystem plant communities. Such figures are consistent with the regularity of distribution of communities in vegetation cover, which, in its turn is conditioned by zonal changes of climate and topography. Specifically in parallel to reduction of aridization from south northwards the aboveground biomass increases, i.e. the aboveground biomass of desert – semi-desert vegetation, growing in more extreme conditions, is considerably far behind similar showings of steppe. This regularity is maintained within main steppe formation – aboveground biomass of *Bothriochloeta* communities, growing in relatively arid conditions (*Bothriochloeta* with *Artemisieta lerchiana* – S1-1 and *Bothriochloeta* with xerophilous motley grass (*mixtoherbosa*) and ephemers – S1-2) are considerably far behind the aboveground biomass of the other communities of the same formation.

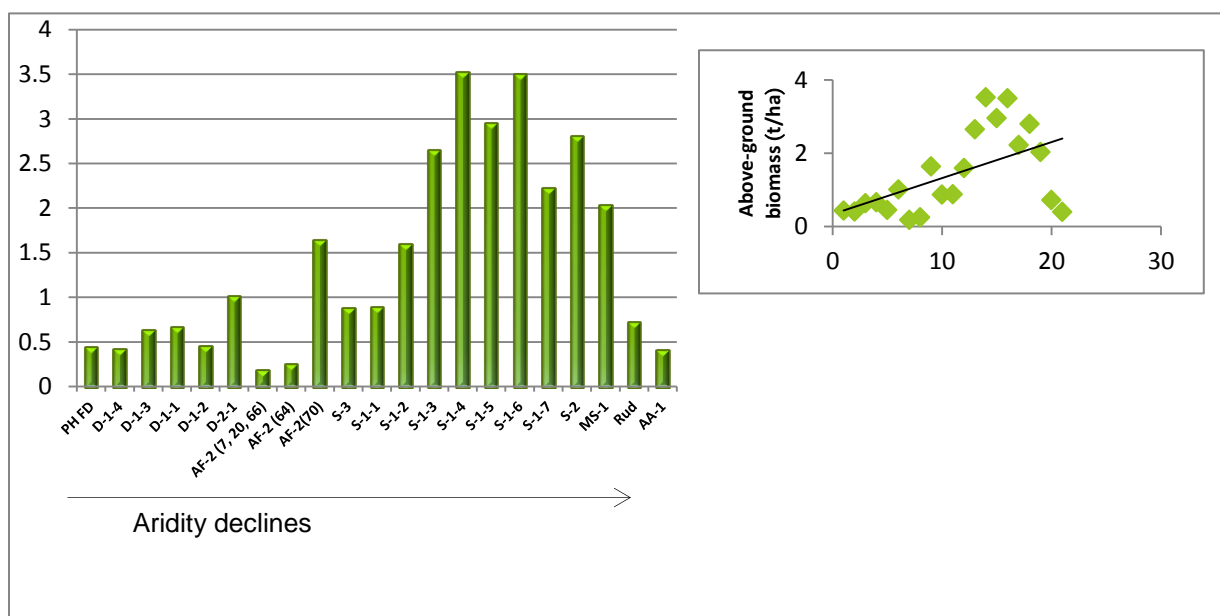


Figure.2 Above-Ground Biomass Carbon (t/ha) Variations According to Plant Communities



In this context it is also important to make comparison between various communities of *Pistacieta*. The biomass of grass cover of *Pistacieta* communities (*Pistacieta* with *Artemisieta lerchianae* and *Bothriochloeta* – AF2-64 and *Pistacieta* with *Bothriochloeta* – AF2-7, AF2-20, AF2-66), prevailing in relatively more extreme conditions in Lekistskali gorge is significantly smaller as compared with the aboveground biomass of *Pistacieta Stipa* (AF2-70) community, prevailing in the upper part of Chighoeltkhevi slopes.

Special mention should be made of *Cleistogenata bulgarici* formation – S3, which we have conditionally included in steppe vegetation. It is presented in small amounts on the research territory and is not neither characteristic nor typical vegetation. Its communities are of secondary origin and are incorporated in the area of various types of vegetation. We have conducted cuts in the southern part of the research territory (Mijniskhure ravine) in the most arid climatic conditions. Hence, it can be said that its biomass is consistent with the showings of *Artemisieta lerchianae* and *Bothriochloeta* formation communities growing in similar conditions.

Unfortunately we did not have chance to study the biomass of ruderal vegetation under different climatic conditions. The researches were conducted only in the southern part of the research territory – in the middle reaches of Lekistskali gorge. The obtained showings are compatible with general trends. But the correlation of aboveground biomass of ruderal vegetation with aridization it is not established. Furthermore, we would like to add that the study of ruderal vegetation for the establishment of nutrition value of pastures is useless, as such communities are colonizing permanent sheep pastures and nearest adjoining land plots and they cannot be substituted by some other plants.

To make the aboveground biomass carbon distribution maps we used the data of remote sensing, specifically Landsat 8 spectral channels, which are available at USGA website <http://glovis.usgs.gov/> for free. Using space data the vegetation indexes within Vashlovani Protected Territory were created, specifically vegetation period averaged MSAVI (Modified Soil-adjusted Vegetation Index), which demonstrates chlorophyll concentration at particular places for a specific period and is used for arid and desert-type terrains. MSAVI is calculated as follows:

$$MSAVI = (nir - red) * (1 + L) / (nir + red + L)$$

where: “nir” – is near-infrared channel, “red” – is red channel and “L” – is soil-brightness correction factor, which in our case is 0.5.

After the creation of MSAVI model as a result of procession of space image, we used it in the course of interpolation as trend estimation variable. ESRI GeoStatistical Analyst software was used for interpolation purposes and the interpolation method employed was CoKriging. Furthermore, the regressive links of variables were estimated using geostatistical module, the variable value was determined as p-value < 0.05. Apart from this it should necessarily be mentioned that calculations were made only on herbage and this does not include the valuation of wood or underwood type vegetation cover, which are partially depicted on the map (see map.3). The map shows that southern part of Vashlovani has less above-ground biomass. The reason is desert type vegetation and overgrazing.

### ***Below-Ground Biomass (BGB)***

The diagram (Fig.2) shows that in the case of below-ground biomass the aboveground biomass correlation trend with relation to aridization is more or less maintained. However, in certain cases there are major deviations. In our opinion such deviations can be explained by methodological and technical imperfection of the process of collection of below-ground biomass.

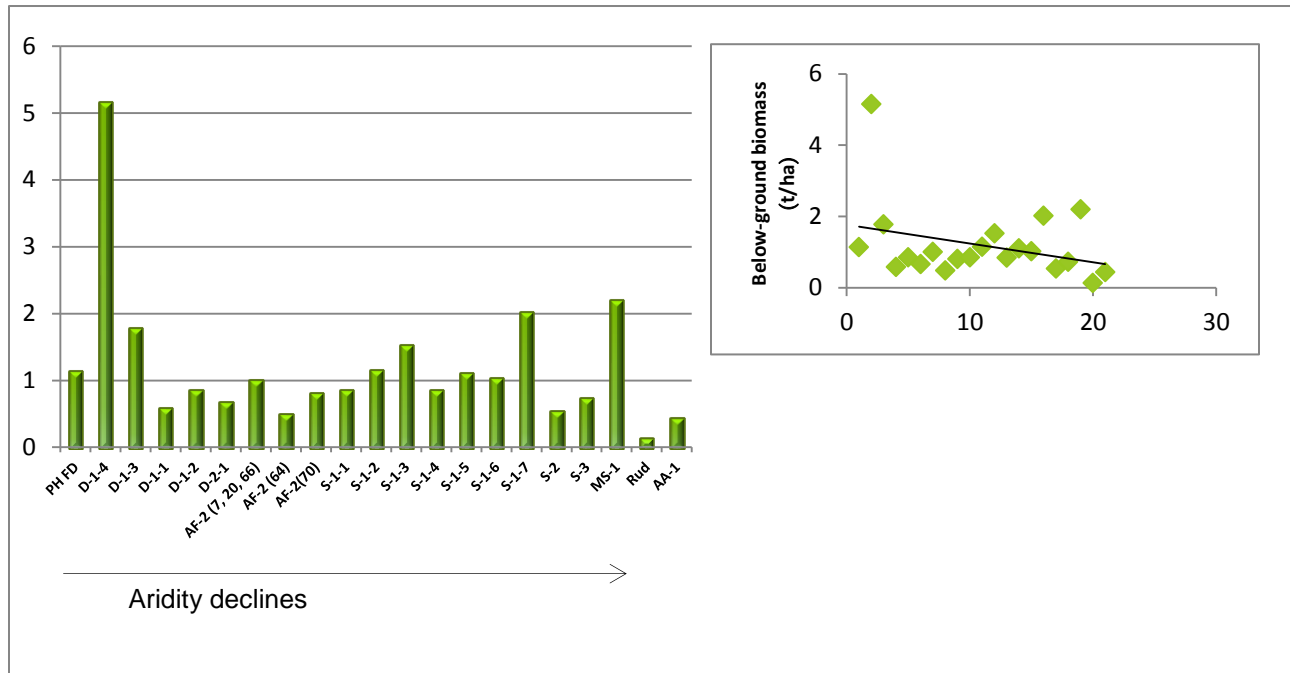


Fig.2 Below-Ground Biomass Carbon (t/ha) Variations According to Plant Communities

### ***Correlation between above-ground and below-ground biomasses***

The diagram (fig. 3) evidences that in plant communities of desert – semi-desert ecosystems below-ground biomass considerably exceeds the above-ground one. In steppes this correlation is favouring aboveground biomass. Such a trend is in correlation with aridization and is quite natural. This trend is mostly maintained within certain formations as well.

According to evidence in literature (Sokhadze, 1977), it is a well-known fact that in Shiraki *Bothriochloeta* steppes the aboveground biomass is less than the underground one. In our opinion the difference between data, obtained by us and those contained in literature can be explained by methodological and technical imperfection of the process of collection of underground biomass (following the methodology, over 1mm thick roots were collected from upper 0-20 cm layer of the soil on 20X20 squares).

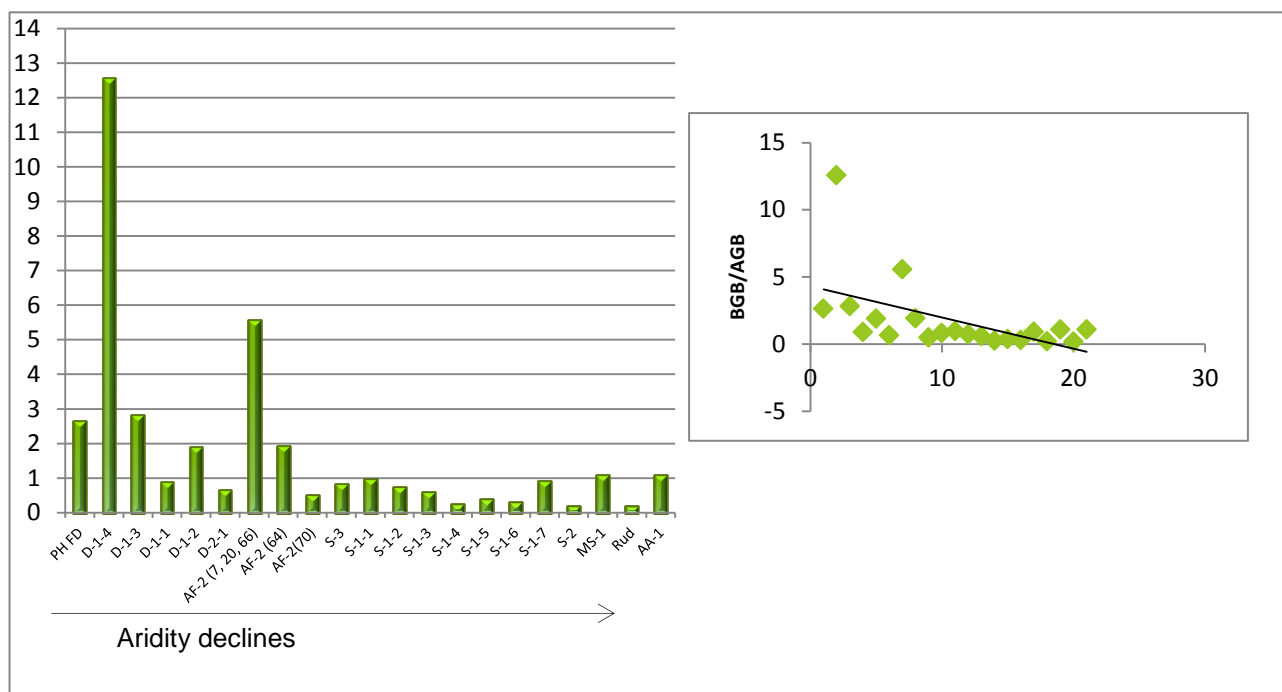


Figure 3. Root-to-shoot ratio (BGB/AGB) of living biomass carbons.

If similar studies are conducted in future as well, it is necessary to follow the same method). However, it should be mentioned that our results are fully compatible with general trends – in parallel to the reduction of aridization the aboveground biomass is increasing from desert – semi-desert ecosystems to steppe ecosystem and the difference between underground and aboveground biomasses is reducing.

### Soil Organic Carbon (SOC)

Unlike distribution of aboveground biomass, soil organic carbon does not always describe the aboveground state of vegetation, as carbon is being accumulated in soil for decades and, in fact, is the kind of stock, which reflects historical processes. E.g. as evidenced by laboratory surveys, the woods used to cover larger areas in the vicinity of Shavimta mountain of Vashlovani Protected Territory. High carbon concentration is anomalous on grasslands located nearby woods, meaning that once this territory was woodland, but later the area was deforested owing to human intervention. Based on the foregoing the interpolation method is less accurate in this case as it is with regard to aboveground biomass (See Map 4). However it is worth mentioning that the main principles and trends of soil organic carbon distribution are maintained and clearly visible both in herbage and wood and under-wood vegetation. ESRI GeoStatistical Analyst software was used for interpolation purposes and the interpolation method employed was CoKriging.

Results show that soil organic matter (SOM) as well as soil organic carbon (SOC) is higher in topsoil than in lower layer. During formation of soil the accumulation of byproducts of animal and plant organic tissue mineralization was more intense in upper layer than in lower resulting in humus formation as a most fertile layer of soil

## VPAs grassland fertility study

### Soil pH

One of the key factor determining soil fertility is soil pH. The soil pH is a measure of the acidity or alkalinity in soils. Soil pH determines types and density of vegetation being important variable in soils as it controls many chemical processes that take place like plant nutrient availability by controlling the chemical forms of the nutrient. According to data presented in this survey, dominant pH values in VPA soil are alkaline. Such high alkaline values are quite extreme for most of plants. This might be the reason of less biodiversity within vegetation of a given area. The reason is that soil in this particular area was developed on bed rocks and soils containing alkali chemical compounds (including high content of carbonates). High level of transpiration of Arid climate zone induce high accumulation of soluble chemicals in soil determining pH values.

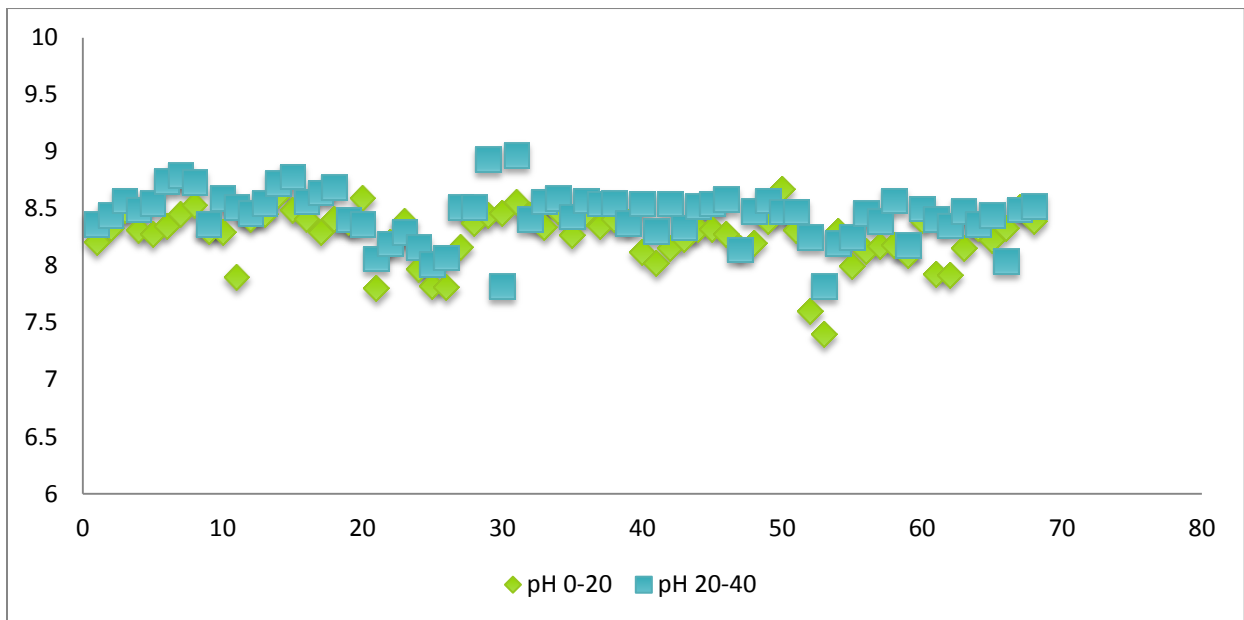


Figure 4. Comparison of pH Values of Soil at Two Different Depth.

Analysis of pH at two depth shows that the deeper is soil the more alkali it is (fig.4). In our opinion this might be related to salt content in various depths of the soil. In semi-arid regions the soil content in lower layers is higher than in other ones. Correlating soil pH data with elevation revealed moderate negative correlation (CC -0.42), which means that as higher as less alkali is soil pH. The reasons of particular phenomena may be different like different soil composition or soluble alkali chemical accumulation at lower attitudes. As seen from fig.5 the regularity of spread of plant communities demonstrates that alkalinity is decreasing from desert – semi-desert ecosystems towards steppe ecosystem. This trend is essentially maintained within individual formations as well. Average negative correlation was revealed between pH data and hypsometrical showings (correlation ratio -0,427), meaning that the alkalinity decreases as the elevation increases.

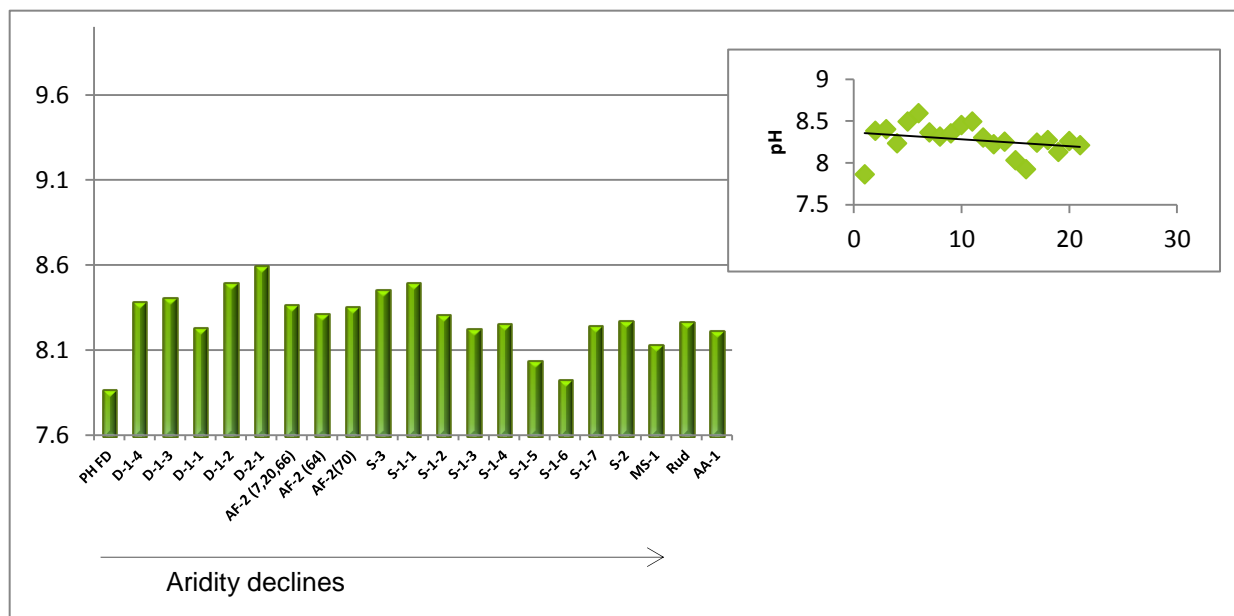


Figure 5. Soil pH Variations According to Plant Communities.

This trend evidences that aridization on the research territory is directly related to the increase of elevation relative to sea level. Respectively the revealed outcomes demonstrate that alkalinity decreases in parallel to the decrease of aridization. Important are the topography patterns as well – in the case of sloping terrain the salts migrate towards plains, what decreases salinity level and respectively that of the alkalinity. In our opinion this trend of alkalinity decrease is quite natural and is conditioned by the whole complex of soil formation factors and is compatible with the regularity of distribution of vegetation cover. Since soil respiration is higher at the bear soil places, areas with overgrazed vegetation cover are more subjected to capillary infiltration. Therefore extreme pH values as well as high difference between two layer pH were outlined during the survey.

As demonstrated by correlation table hydrogen ion concentration (pH) is highly correlated with surface temperature, specifically with Landsat 8 satellite thermal channels, which portray earth surface temperature. The surveys evidence (reference), that hydrogen ions move from the depth (producing rocks) to soil surface as the soil temperature increases, resulting in soil salinization. The maps were made based on this theory and high correlative links (pH), using Landsat 8 thermal channels along with field data. As a result the maps were made, which depict not only the distribution of hydrogen ion concentration (pH) in soil but also clearly demonstrate areas degraded due to overgrazing and anthropogenic intervention.

Maps 5 and 6 show spatial distribution of pH values within 0-20 cm and 20-40 cm layers correspondingly. According to our believe percentage difference between two layer pH values detected areas of overgrazing what is information of great interest. As seen from map 7, red values with big difference between pH values correspond to location of farms (black dots) and intensively managed pastures in Kumro and Bugha Moedani.



### *Soil Hygroscopic Nitrogen N*

In most grasslands the two factors that most limit plant growth are moisture (rain) and nitrogen. Important processes in the nitrogen cycle include fixation, ammonification, nitrification, and denitrification. In grazing systems, the majority (70% or more) of the ingested nutrients is returned to the pasture via excreta (dung and urine). Nevertheless, low level of nitrogen in soil may be associated with overgrazing factor. Carbon to nitrogen level in soil is one of key factor for soil fertility assessment.

For the present time, according to our results, the soil available nitrogen content varies between ranges “low” and “very low”\*, what indicates that soil in VPA is depleted from such forms of nitrogen compounds which are crucial for plant nutrition. Consequently effective soil fertility which determines formation of green biomass is low. Low nitrogen content is mainly caused by low precipitation and therefore low activity of soil micro biome involved in nitrogen fixation and inorganic nitrogen containing compound formations. The correlation between available nitrogen content and above-ground biomass within plant communities is presented in table 7.

### *Correlation of aboveground biomass with soil fertility parameters*

One of the important parameters of soil fertility is the content of soil carbon. The researches demonstrated that the trend of decrease of its content is notable from plan communities of desert ecosystem towards steppe ecosystems (fig.6). The content of soil carbon and organic substances is not a result of their one or two year accumulation. It is being formed during a long period of time. Respectively, it can be concluded, that the process of its accumulation in desert ecosystems is retarded.

We believe, that of paramount importance is the correlation between the aboveground biomass and soil carbon content on the one part and the correlation between aboveground biomass and nitrogen content in soil on the other. The presented data (Pic.6) evidence, that the content of nitrogen is much higher than aboveground biomass in desert ecosystem plant plantations than in steppe ecosystems. Even more apparent is the difference between soil carbon and aboveground biomass. These trends make us believe, that in relatively extreme conditions (arid climate, soil salinity, etc.) the plants are not able to consume them. In desert ecosystems the increase of nitrogen content is promoted by certain plants as well (e.g. *Salsola dendroides*) (author). We do not exclude grazing factor – in places of intensive grazing sheep fertilize the soil with large amounts of urea-ammonia liquor.

It should as well be mentioned that the determination of the consumption of nitrogen and organic substances by plants in various climatic conditions require ecophysiological studies and is beyond the terms of reference of this Project.

Plant communities	Nitrogen mg/kg	Above ground biomass t/ha	Correlation coefficient (CC)	Degree of correlation
PH FD	48.34	0.43		
D-1-1	53.49	0.66	0.83301178	High positive correlation
D-1-2	46.07	0.45		
D-1-3	48.51	0.63		
D-1-4	59.8	0.41		
D-2-1	43.13	1.01		
S-1-1	39.05	0.88	0.706493238	High positive correlation
S-1-2	44.42	1.76		
S-1-3	43.06	2.65		
S-1-4	45.89	3.52		
S-1-5	43.95	2.49		
S-1-6	42.56	3.49		
S-1-7	44.19	2.22		
S-2	44.9	2.8		
S-3	41.115	0.87		
MS-1	53.02	2.37		
AF-2 (7,20,66)	44.43	0.18	0.577153062	Moderate positive correlation
AF-2 (64)	48.88	0.25		
AF-2 (70)	49.14	1.64		
Rud	52.115	0.72		
AA-1	48.94	0.4		

Table 7. Correlation between available nitrogen content and above-ground biomass within plant communities.

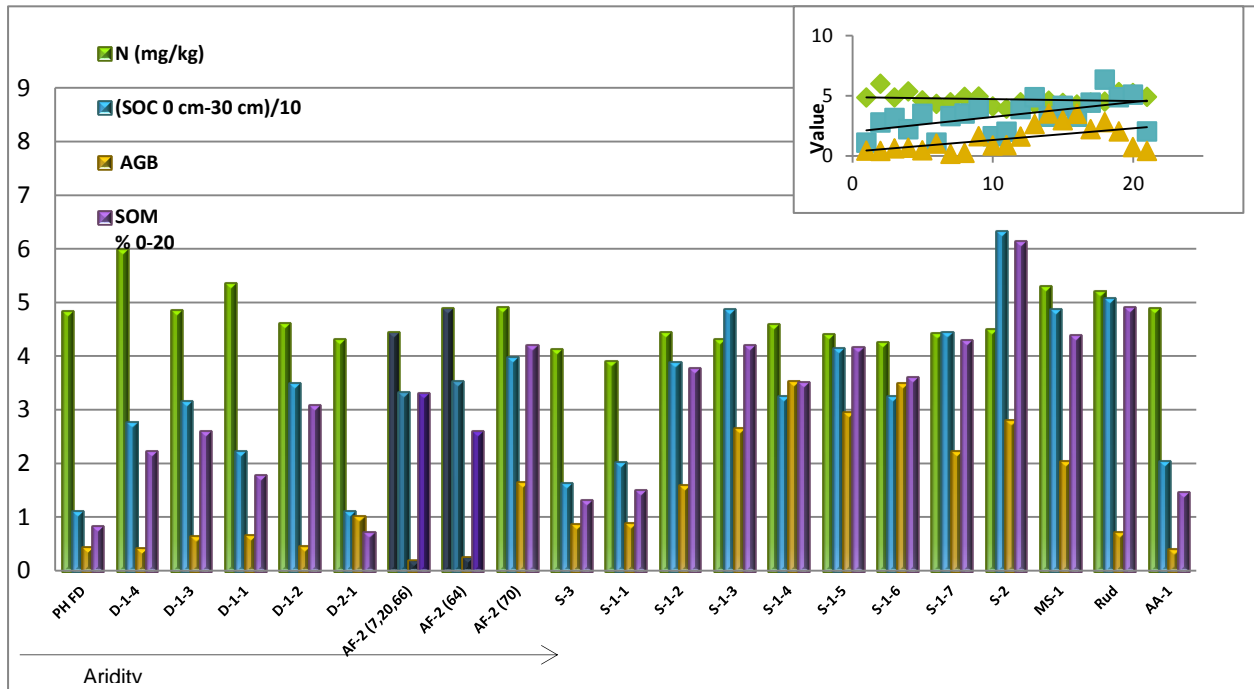
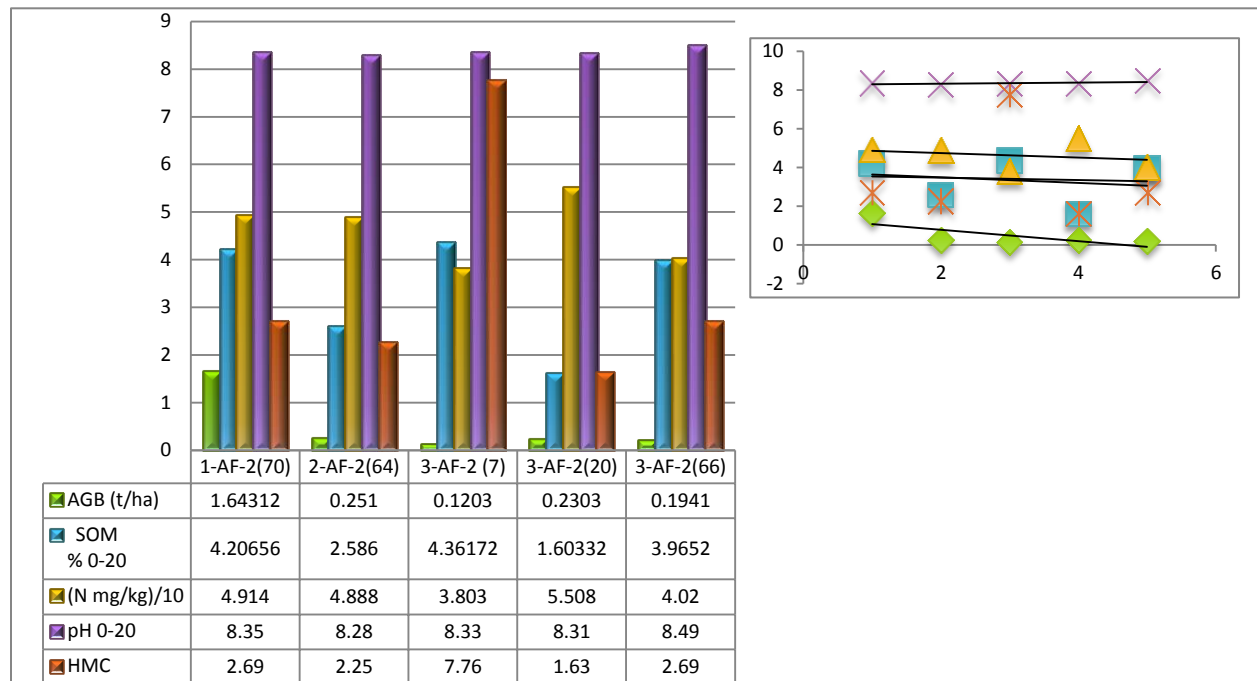


Fig. 6. Correlation Between Biomass Carbon Values and Soil Fertility Parameters According to Plant Communities.

### *Mutual comparison of vegetation cover degradation and various parameters*

One of the important factors for the study of pastures is mutual comparison the state of vegetation cover and its various biological parameters. In this respect the test results of samples collected on various lands within *Pistacieta* formation. The data on diagrams (Fig.7,8) are arranged according to the level of degradation of vegetation cover. The degradation was evaluated visually (1 – good state, 2 – average, 3 – degraded). The diagram data evidence, that aboveground biomass is abnormally low as compared to soil fertility and soil carbon content. Such correlation means that the small amount of aboveground biomass is triggered by over-pasturing and not soil fertility. The degraded lands are located on sheep transfer routs and have been under serious anthropogenic pressure for a long period of time, what had its impact on research outcomes. However it should be mentioned that: most probably the degradation of vegetation cover under excessive pasturing started long time ago and is not a result of the nearest past. Hence it is not excluded that high soil carbon content under *Pistacia* crone can be conditioned by decomposition of fallen leaves of *Pistacia* tree and high concentration of nitrogen – fertilization of soil by sheep with urea-ammonia liquor. In this context it is noteworthy, that the biomass of *Bothriochloeta* communities under *Pistacia* crones and adjacent strip will be small, but even visual inspection demonstrated that the structure of the lands was apparently degraded (floristic composition, cenotic role of certain species and other geo-botanical characteristics evidence the foregoing).



*Figure 7. Relationship Between Above-Ground Biomass and Soil Fertility Data in Pistachio Communities (AF-2)*

High aboveground biomass of Section AF 2(70) on the diagram is not triggered only by less anthropogenic load. Physical and geographical conditions also contribute to this situation (relatively high

hypsometric locations as compared with other sections, less arodization of the climate, fertile soil, higher content of humidity in soil, etc.) Degradation of vegetation cover due to excessive pasturing was recorded in the data of *Bothriochloeta* xerophilic motley grass and ephemers communities (S-1-2) (Fig.9).

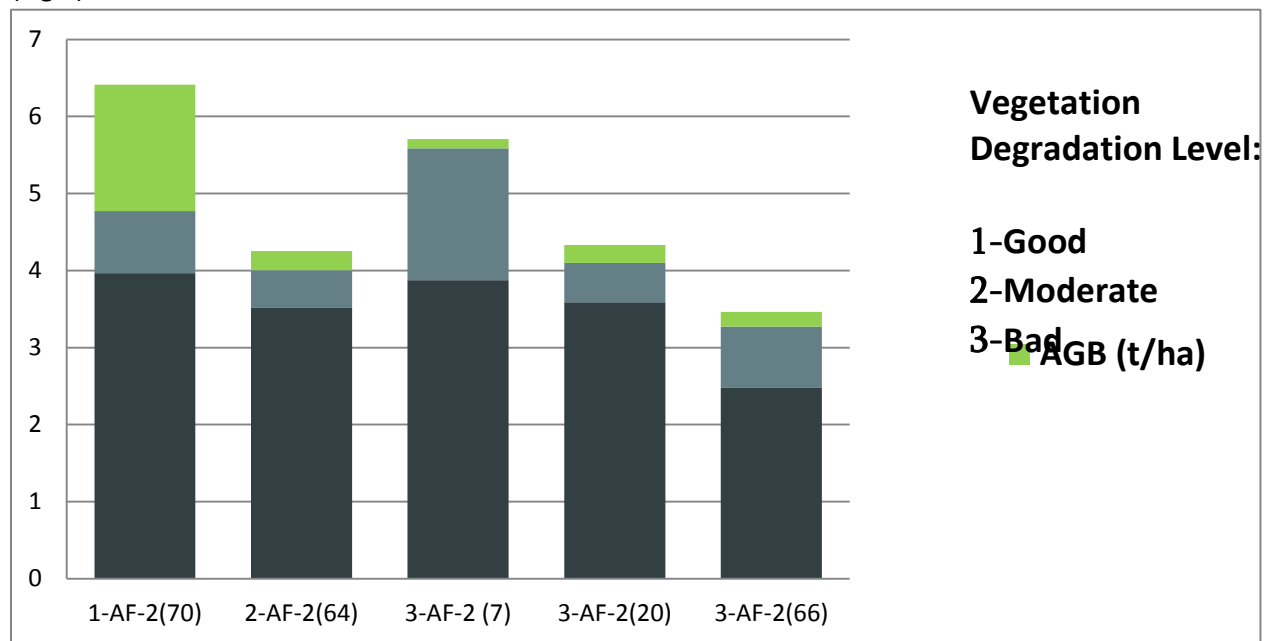


Figure 8. Above-Ground, Below-Ground and Soil Carbon Values in Pistachio Communities (AF-2)

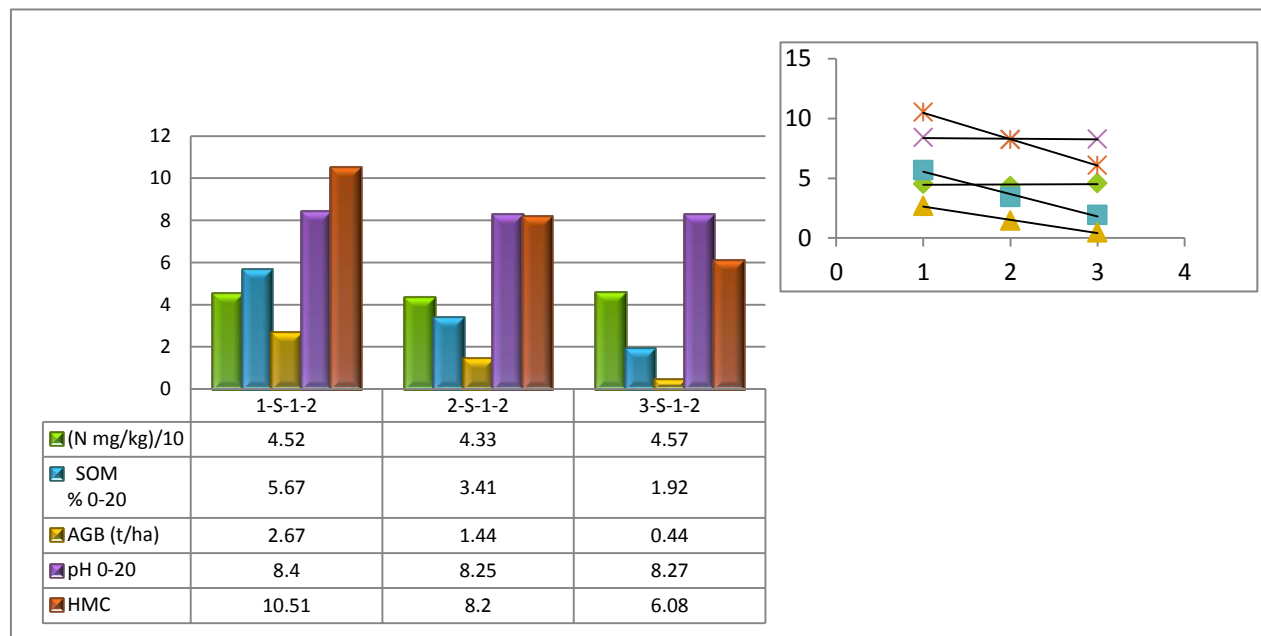


Figure. 9. Relationship Between Above-Ground Biomass and Soil Fertility Data in Steppe Communities (S-1-2)



The diagram evidences, that the soil fertility and aboveground mass are decreasing in parallel to degradation of vegetation cover. At the same time the nitrogen composition in soil and its pH is all types of land-plots (1 – good, 2 – average, 3 – degraded) are almost identical. In our opinion the reduction of organic substances of soil on degraded sections demonstrates that vegetation cover on these lands has been relatively thin for decades.

However worth mentioning is the correlation of degradation and the content of hygroscopic humidity in the soil – the level of degradation is increasing in parallel to the reduction of the latter. Such correlation makes us believe, that the reduction of aboveground biomass may be triggered by microstructural changes of soil, which provide for less retention of hygroscopic humidity.

### ***Soil Organic Matter SOM***

Soil organic matter is the fraction of the soil that includes: plant and animal residues at various stages of decomposition; plant roots; cells and tissues of soil organisms; and substances synthesised by the soil population. SOM is one of key indicator of soil fertility. Table 8 shows levels of soil organic matter. SOM in VPAs are mostly varying between low and very low, indicating low level of soil fertility.

Distribution of organic matter in soil is closely related to soil organic carbon, being highly correlated. Due to this reason we used soil organic carbon data along with field points when making that type of map. As in the aforementioned methodology the ESRI GeoStatistical Analyst software was again used for interpolation purposes and the interpolation method employed was CoKriging.

Spatial distribution of SOM is depicted on the map 8. Similarly to soil organic carbon map 8 indicates that soil is depleted from organic compounds in southern part of Fashlovani.

Level	Total SOM %
<b>Very low</b>	<b>≤2</b>
<b>Low</b>	<b>2-4</b>
<b>Medium</b>	<b>4-6</b>
<b>High</b>	<b>6-8</b>
<b>Very high</b>	<b>≥8</b>

*Table. 8 Levels of soil organic matter.*

## Water Balance Modelling

All living organisms need water and energy. Water balance shows connections between energy and precipitation. Water balance is the quantitative expression of the evaporation-condensation cycle on earth.

A general water balance equation is:

$$P=Q+E+\Delta S$$

Where:

P is precipitation

Q is runoff

E is evapotranspiration

$\Delta S$  is the change in storage (in soil or the bedrock)

Microclimate developed under topographic influence impacts biodiversity, plant productivity, cycle of nutrition and pedogenesis. Knowing water demand and water storage makes possible of better understanding ecosystems, spatial processes in ecosystems and their sensitivity to climate change. Water balance approach used in this survey accounts evaporative demand and moisture availability for broad-range vegetation types across all geographic scales. A water balance approach offers numerous advantages over traditional moisture indices. It assesses moisture availability and utilization in absolute terms, using readily available data and widely used GIS software. Results are directly comparable across sites, and although output is created at a fine-scale, the method is applicable for larger geographic areas. Since it incorporates topography, available water capacity, and climatic variables, the model is able to directly assess the potential response of vegetation to climate change.

Water balance outlines species-environment relationship. Factors that may influence this relationship include latitude, aspect, topographic position and slope configuration.

In the water balance modelling ArcGIS software and spatial analysis module were used. To prepare water balances following criteria were used:

- Digital Elevation Model-DEM
- Available water capacity –AWC
- Monthly Temperature
- Monthly Precipitation
- Solar Radiation

Water balance models were developed for current and future scenarios (2014-2070). Existing monthly climate data were used according to VERY HIGH RESOLUTION INTERPOLATED CLIMATE SURFACES FOR GLOBAL LAND AREAS (Ave. 1950-2000) [Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005] and for future scenario according to GISS-E2-R AIM RCP6.0 ( Ave. 2061-2080) [Goddard Institute for Space Studies (<http://data.giss.nasa.gov/modelE/ar5/>)]. Relief and its derivatives - Digital Elevation Model and Derivatives: Topo 10m/Pixel. AIM RCP 6.0 intermediate Representative Concentration Pathways (RCPs) of greenhouse gas concentration trajectories (adopted by the IPCC\*) was chosen. As results four types of models were created:

- Potential evapotranspiration

Map 9 shows potential evapotranspiration (PET) in VPAs. A measure of moisture demand, which is the amount of water that can be evaporated and transpired from a vegetated surface if water is not a limiting factor. When PET exceeds precipitation, water demand is met in part through soil moisture utilization (drawing from soil storage). The maximum amount of water that can be held in storage is dependent on the site's available water capacity (AWC), which in turn is dependent on soil depth and texture. Precipitation in excess of PET results in soil moisture recharge, and any remaining excess becomes surplus, lost from the site by subsurface drainage.

Methods of modeling PET include surface-dependent approaches, which generally include vegetation and soil characteristics, and reference-surface methods, which model PET for a "reference crop" (such as grass or alfalfa) but do not directly include vegetation parameters (Fisher et al. 2005); these reference-surface methods are typically either temperature-or radiation-based. In the present study, a reference-surface approach was adopted for a number of reasons.

Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Evaporation shows the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. Evapotranspiration is an important part of the water cycle. As seen from map 9, for 2070 average increase in evapotranspiration is 100 mm/y.

- Actual evapotranspiration

Map.10 describes actual evapotranspiration in VPAs for current and future scenarios. Actual evapotranspiration (AET) accounts for water availability, and the difference between PET and AET is deficit. Potential evapotranspiration (PET) is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile. Actual evapotranspiration is said to equal potential evapotranspiration when there is ample water.

- Deficit

Map 11 shows annual deficit of water in soil for current and future scenarios. As outlined from the map moisture deficit will be more extreme in southern part of Vashlovani (Kumuro and Bugha Moedani).

- Moisture “supply – demand.”

Map 12 indicates moisture “supply-demand” for current and future scenarios. Positive values indicate that plants are able to meet moisture needs through precipitation, negative values indicate that plants must turn to soil moisture storage to attempt to meet their moisture needs. Model indicates that area of Vashlovani (Shavi Mta) where plants meet moisture needs (blue color) today, will suffer from moisture deficit in the future. We strongly believe that overall trend of desertification will cause invasion of xerophilic vegetation in more areas of Vashlovani (Pic. 1 and pic.2).

#### Accuracy Assessment

Accuracy of spatial topographic data was 10 m/pixel. Climate data was depended on the observation accuracy. Precision of water model is determined by balance. If water budget is in “balance”, then:

$$PET = AET + \text{deficit}$$

$$\text{Precipitation} = AET + \text{surplus}.$$

## Conclusions

Correlation between surface temperature and overgrazing was detected and Map showing pH influence on pastures was developed. Spatial distribution of above-ground, soil organic carbon and soil fertility parameters like pH and soil organic matter determined that most depleted areas are southern pastures and migratory routes where hot climate, overgrazing and moisture deficit altogether cause lack of fertility and subsequently less biomass production. Summarizing all above described and based on above-mentioned criteria, we outlined three areas in Vashlovani - Bugha Moedani, Kumuro and migratory route, for which carbon stocks of different pools were calculated and reclamation works will be considered.

Since vegetation types and species are important for pastures as they have different nutritional value for sheep, species-environment relationship is information of great interest. Knowledge in variations in moisture demand and availability within pilot area gives us better understanding of various processes in ecosystems and ecosystem dependence on climate change as well as of species-environmental relationship. According to our results, global warming and consequent change in climate will lead to desertification to most territories which are currently used as a pastures, what will cause expansion of desert vegetation species to the higher zones, whereas overall trend will be change of mesophilic vegetation to xerophilic one, which is information of great interest for management policy of pastures.

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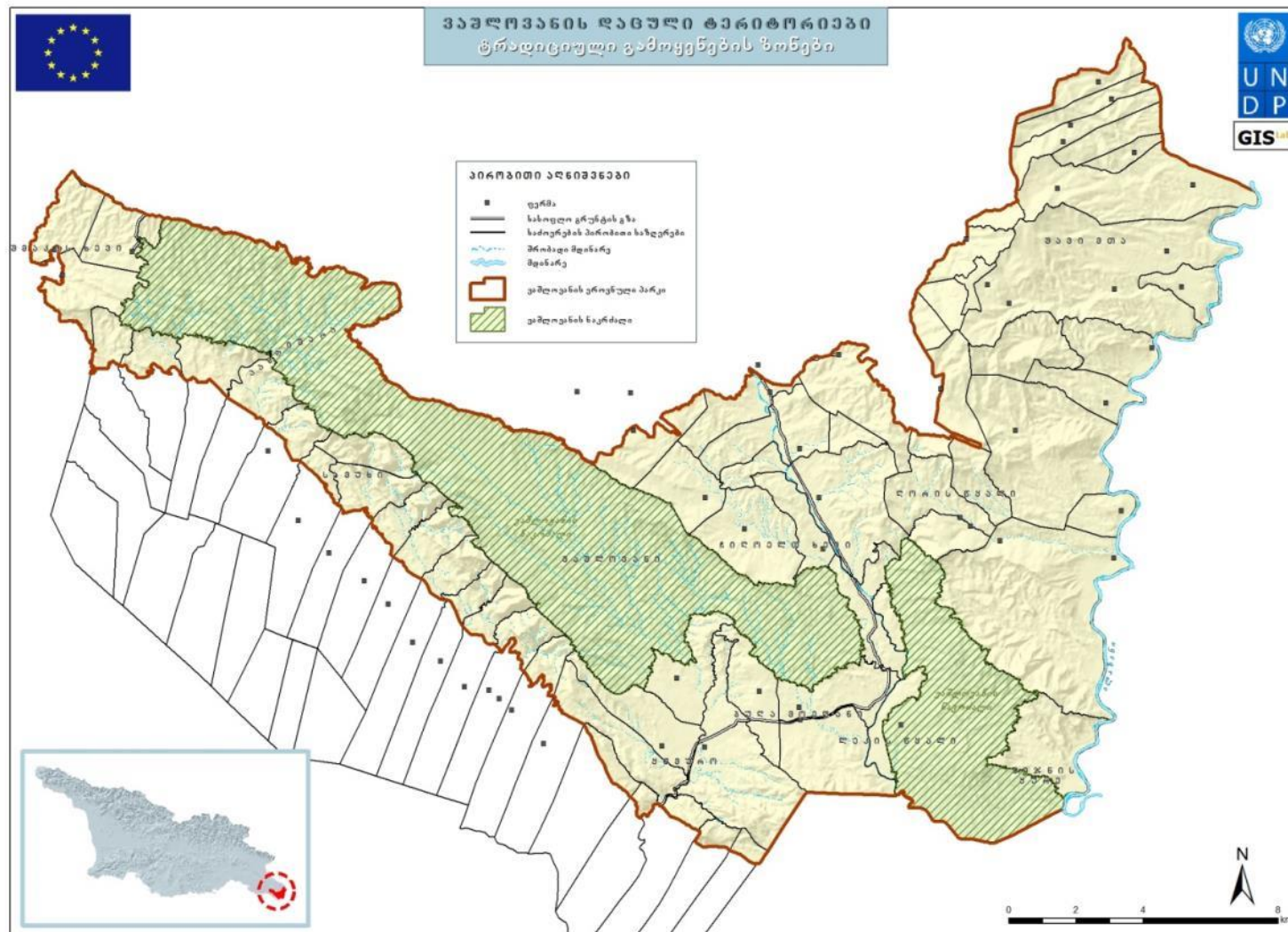
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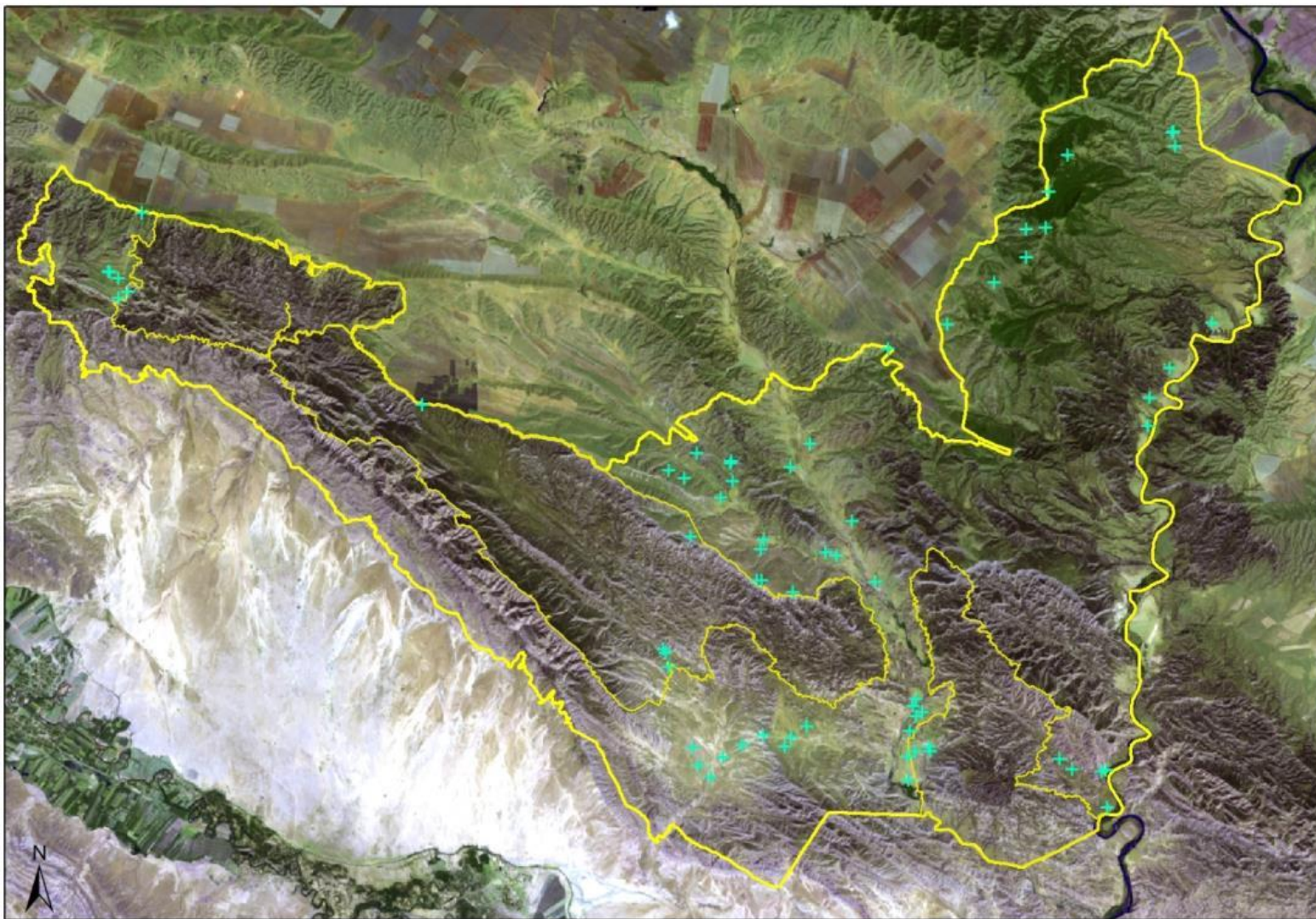
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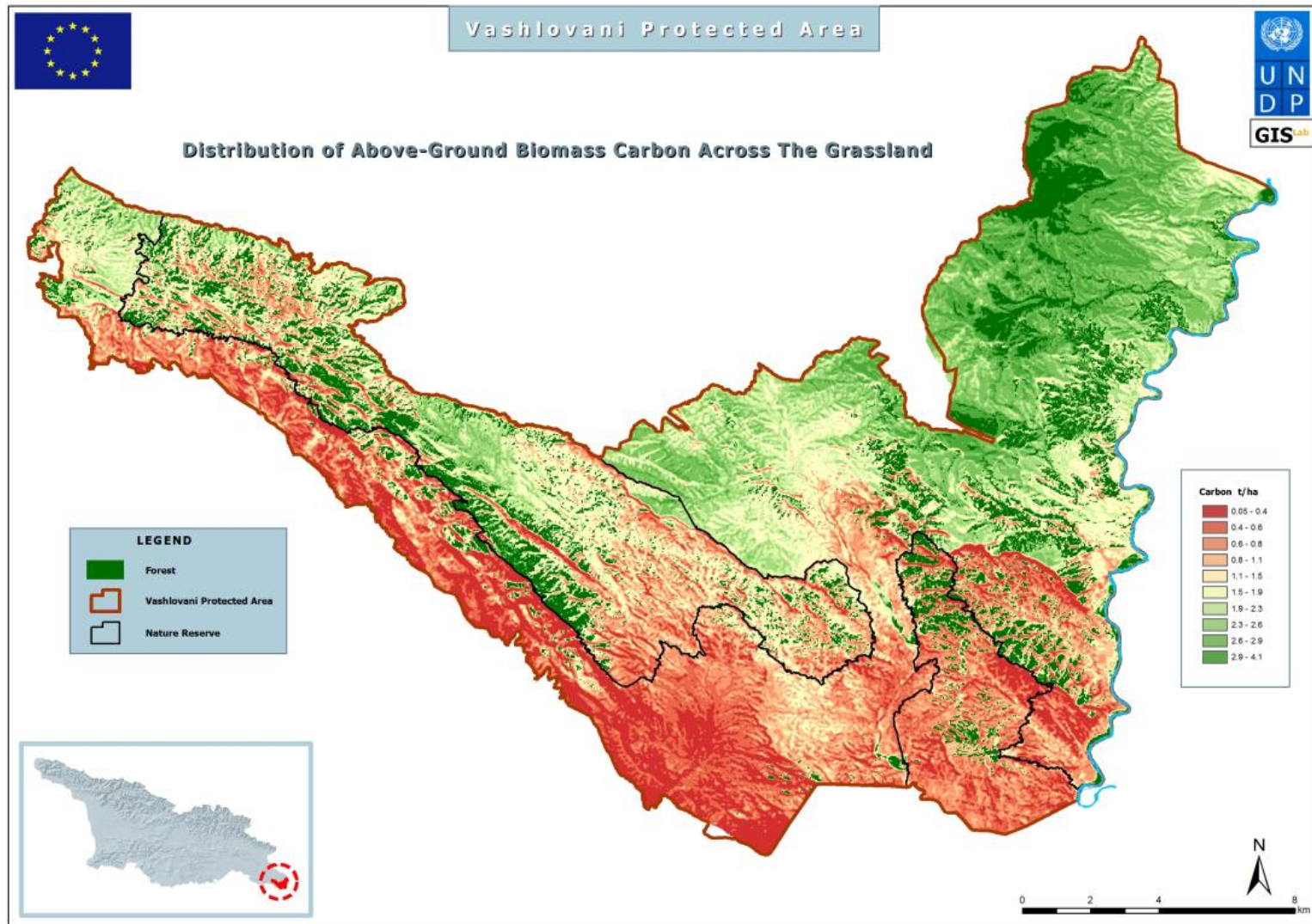
## Annexes. Maps.



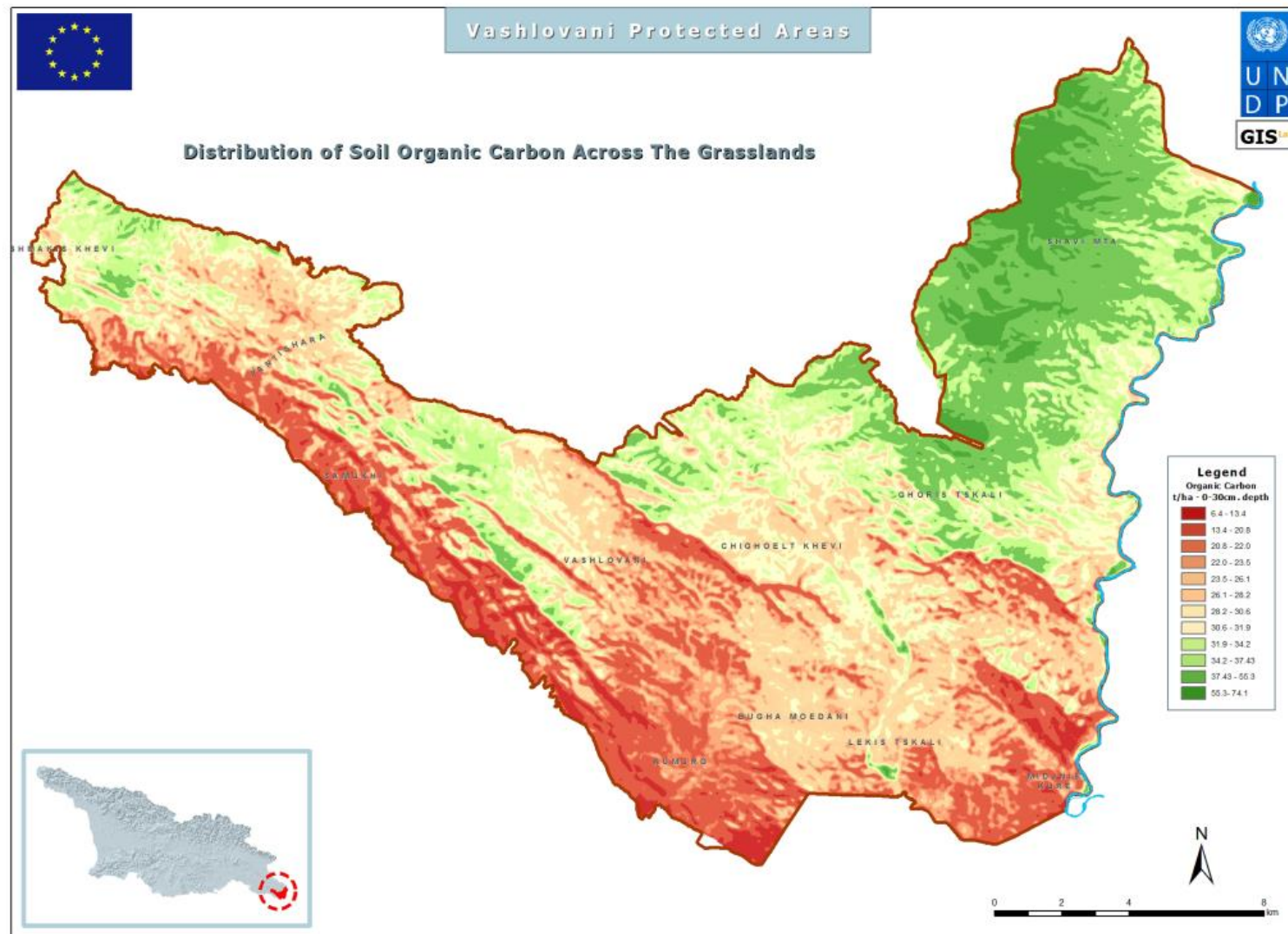


Map. 2. Sampling points across the VPAA.

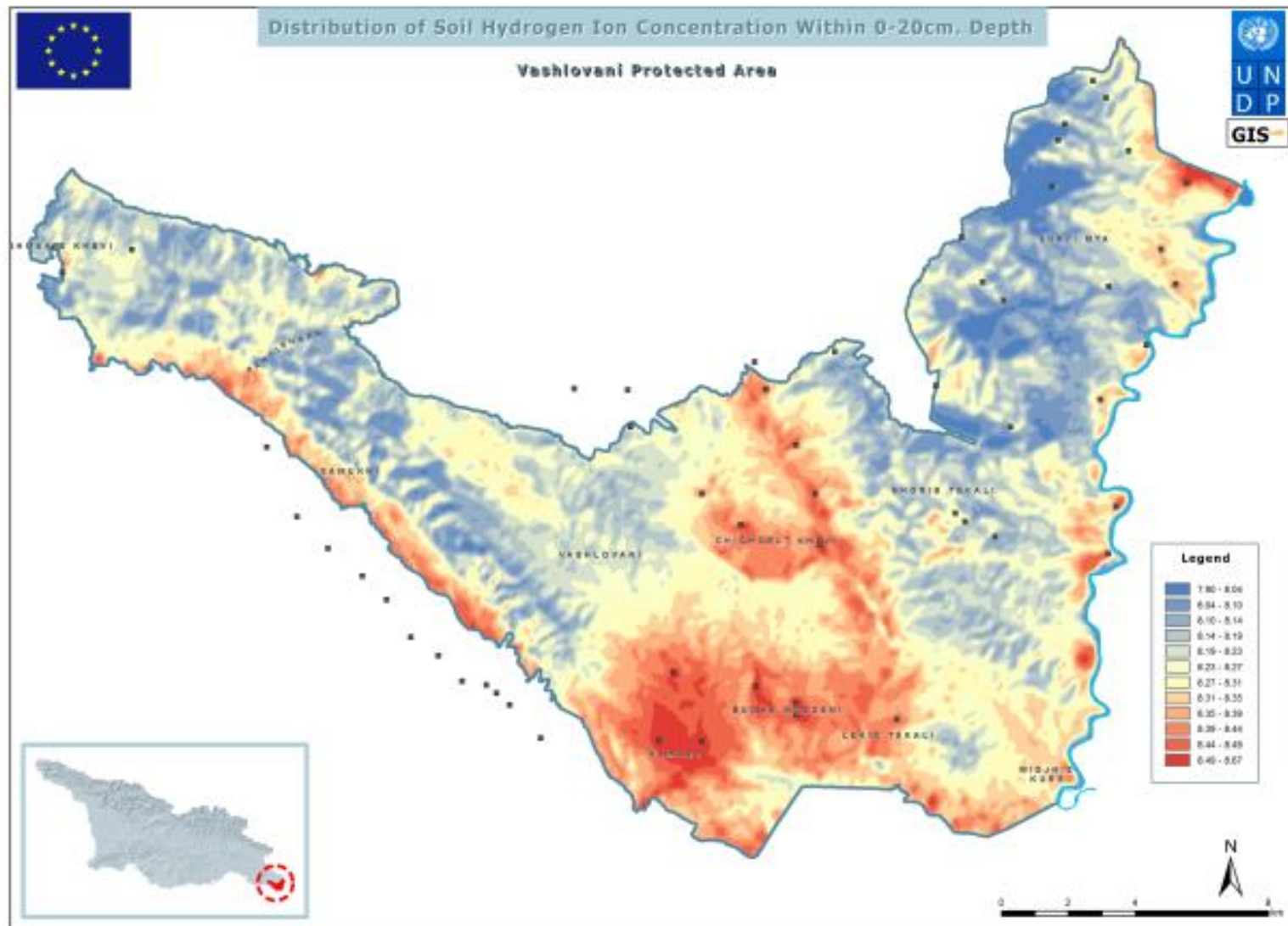




Map.3 Distribution of Above-Ground Biomass Carbon across the Grassland

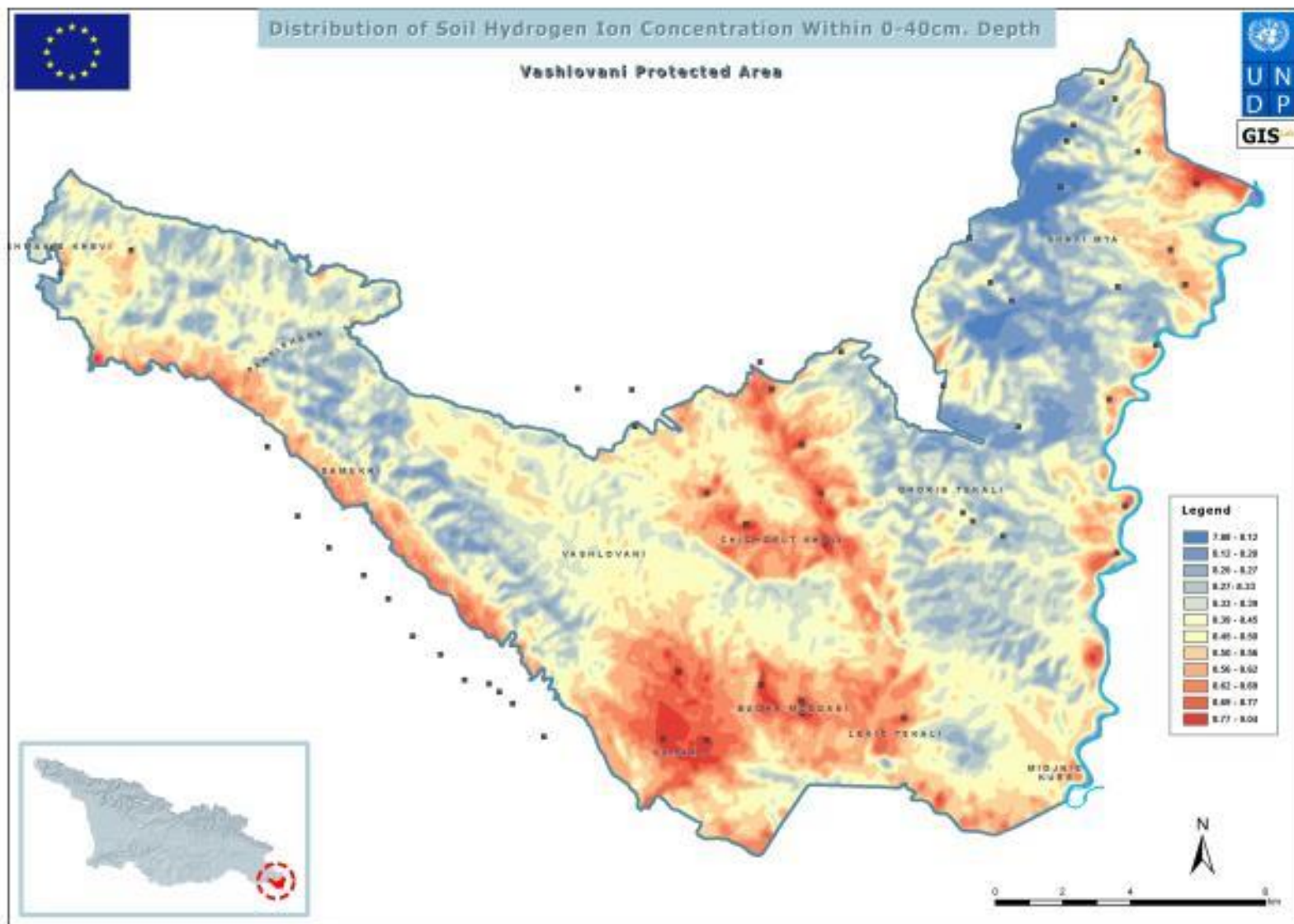


Map.4 Distribution of Soil Organic Carbon across the Grasslands.



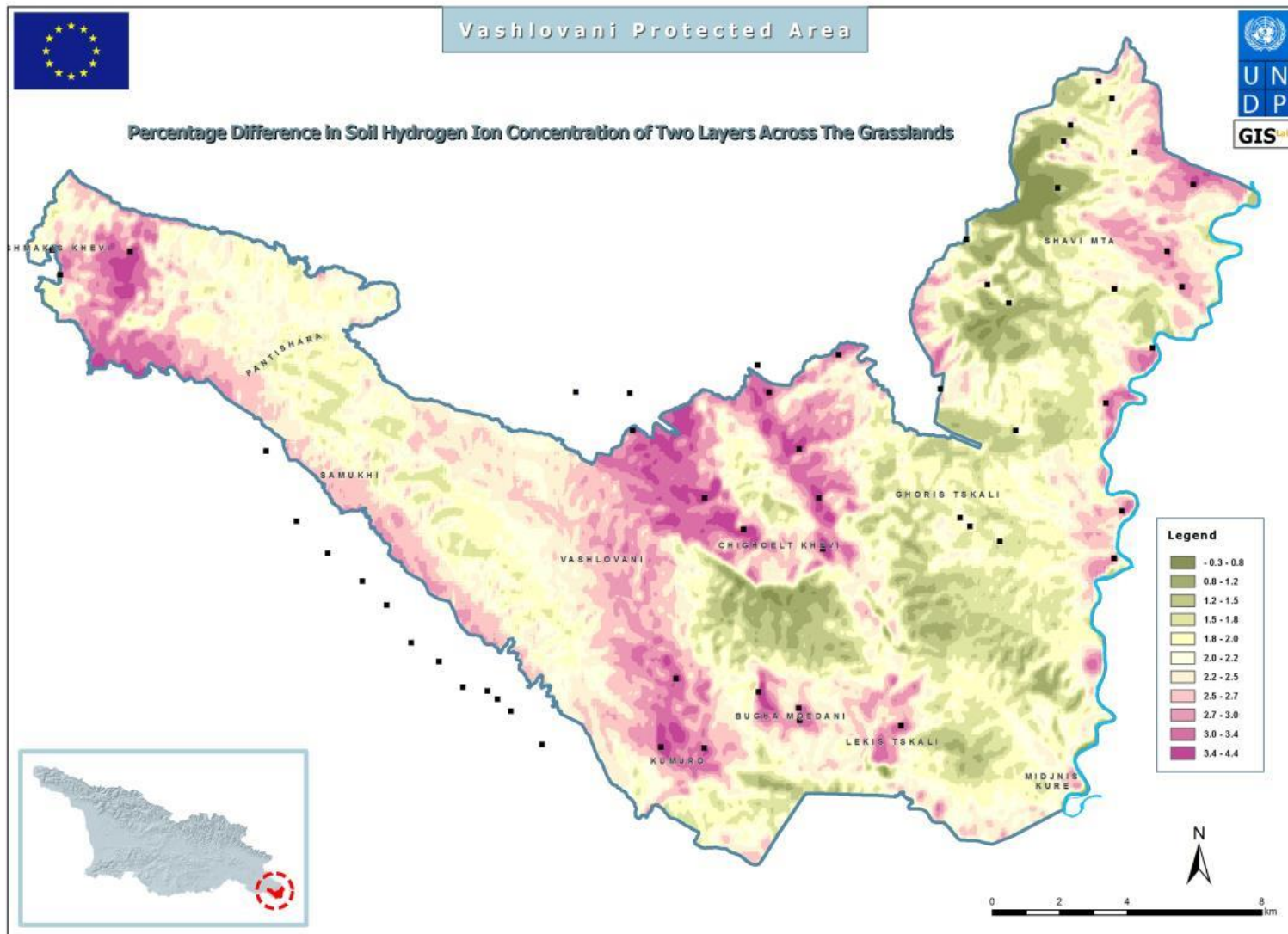
Map. 5 Distribution of Soil Hydrogen Ion Concentration within 0-20 cm layer.



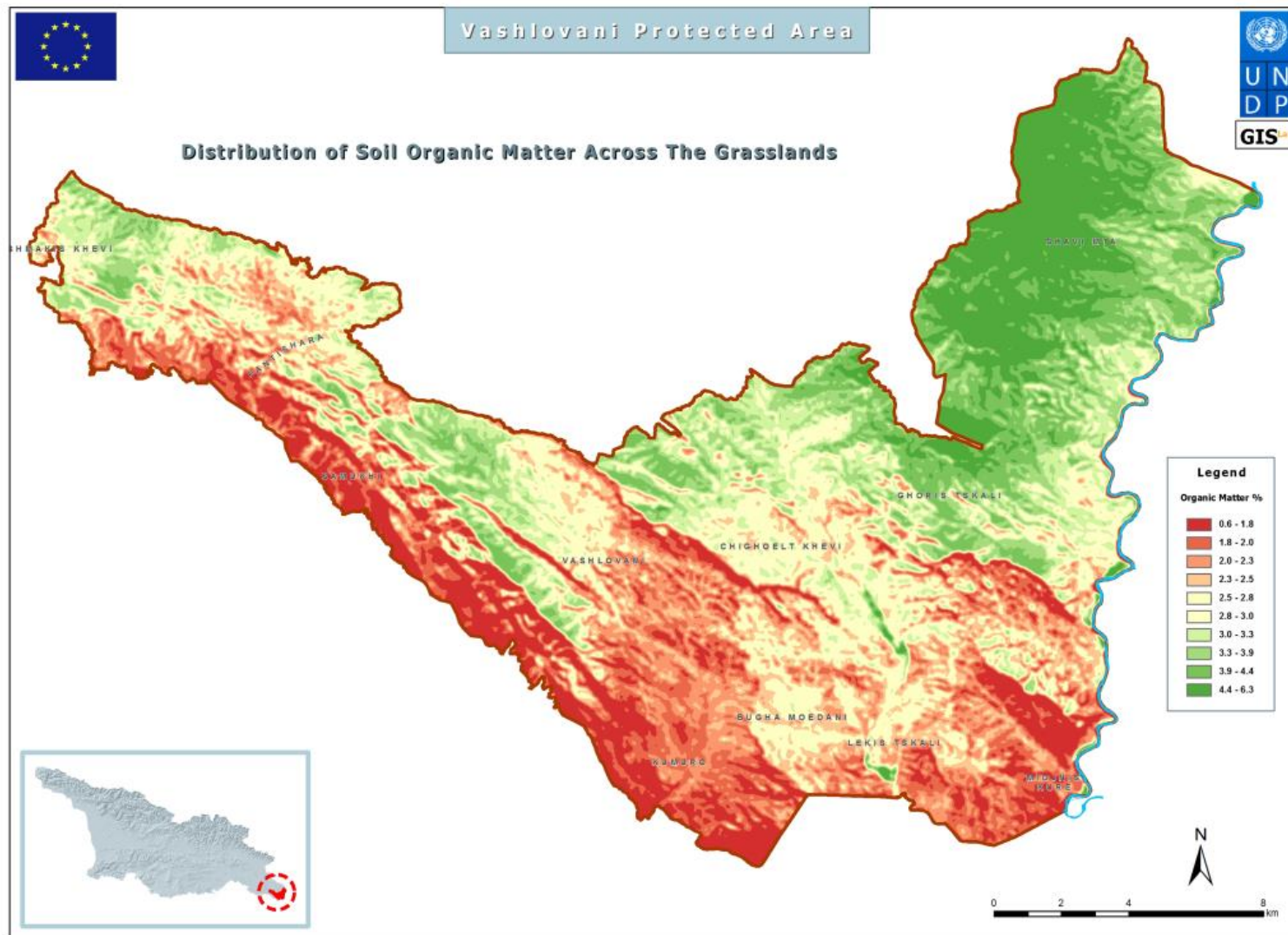


Map. 6 Distribution of Soil Hydrogen Ion Concentration within 20-40 cm Layer.

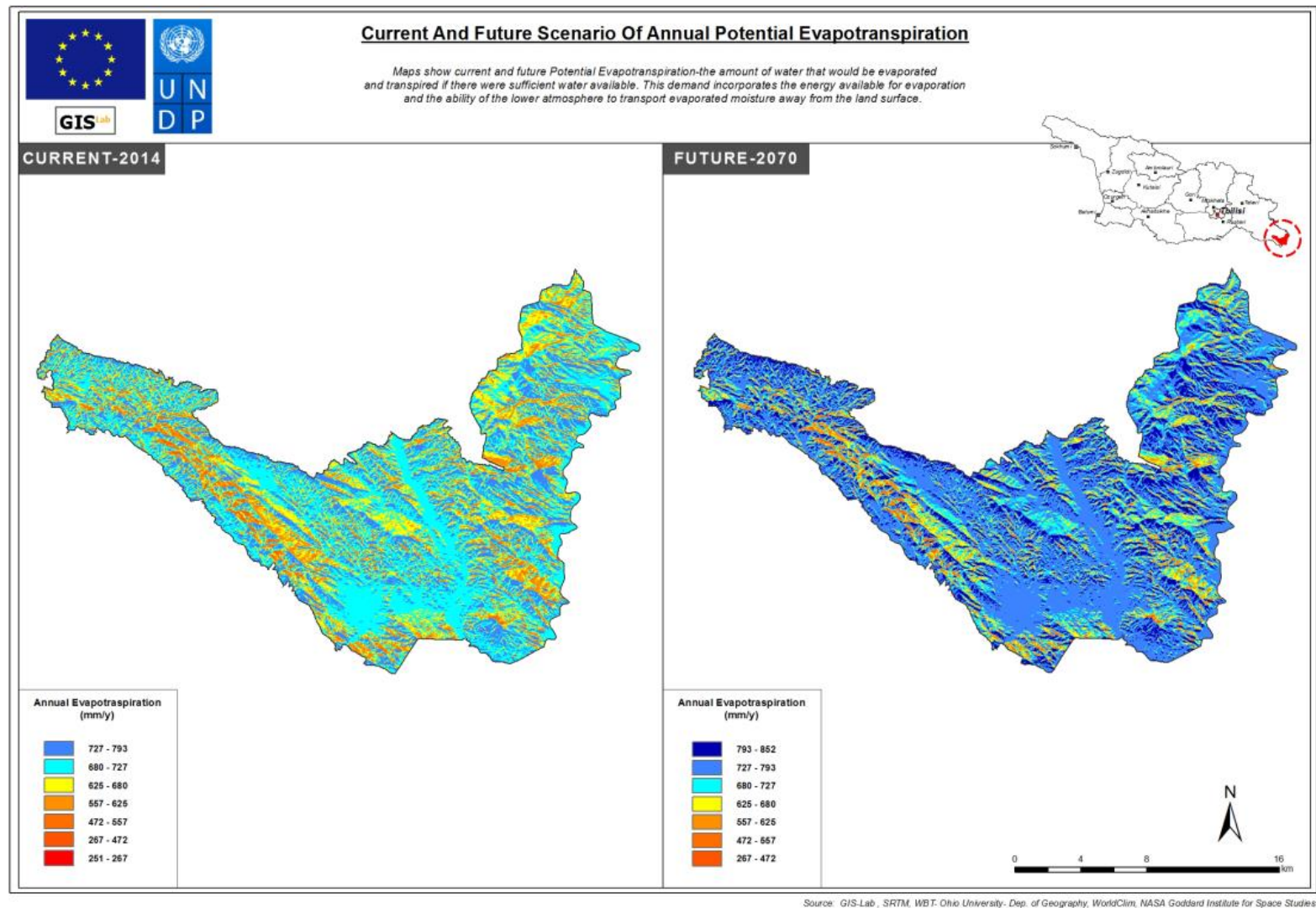




Map.7 Percentage Difference in Soil Hydrogen Ion Concentration of two layers Across the Grasslands

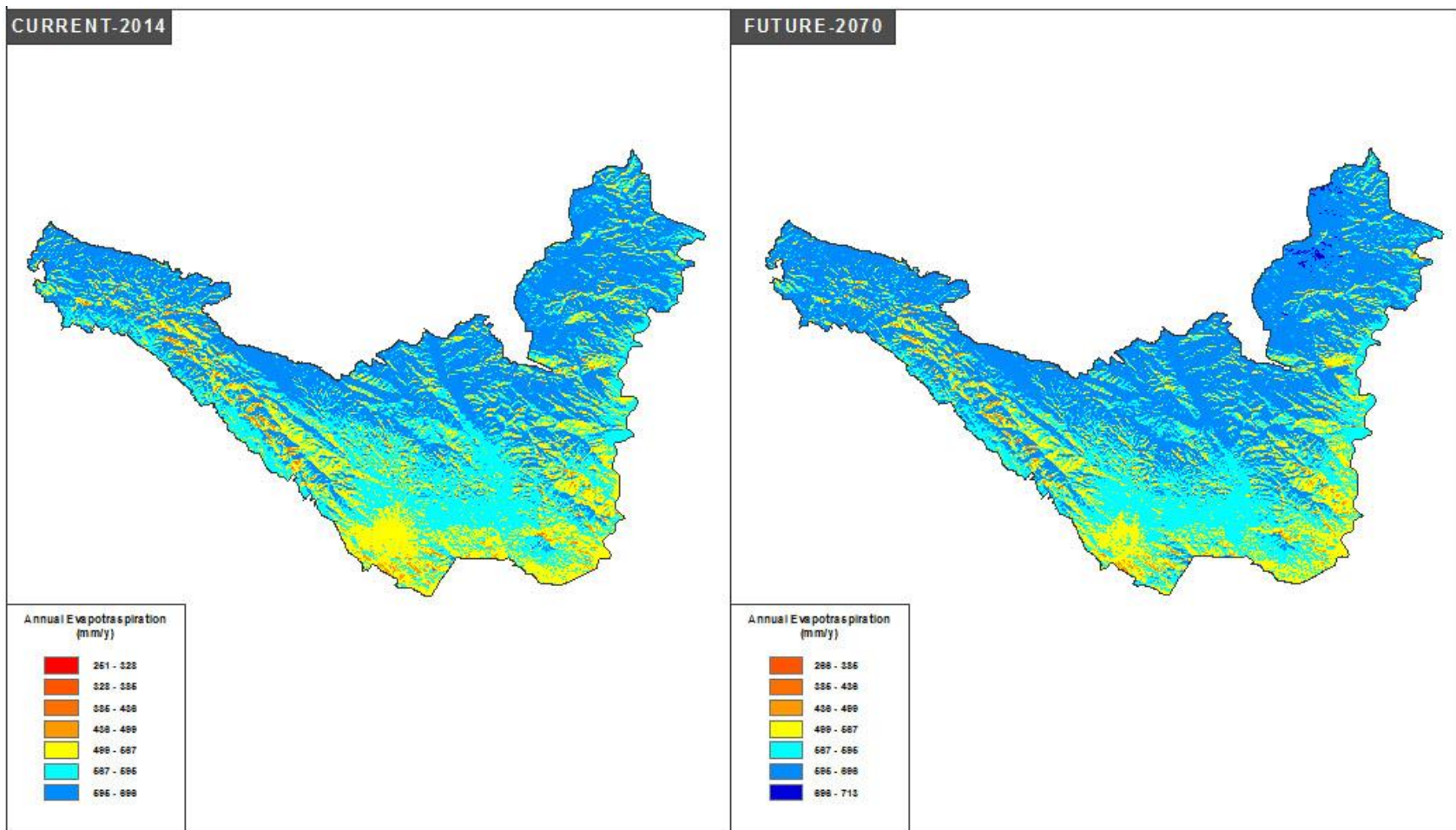


Map .8. Distribution of Soil Organic Matter across the Grasslands.

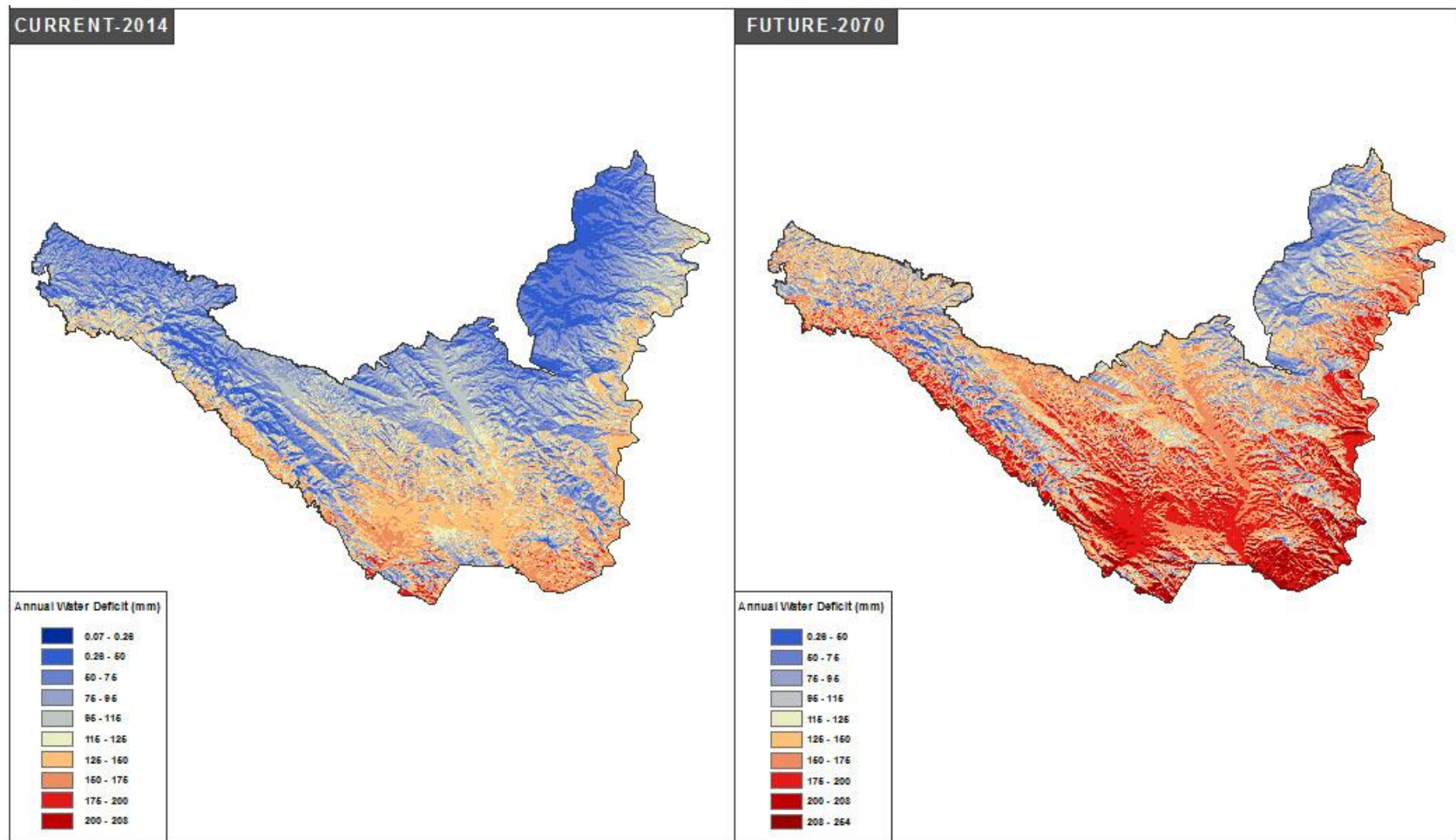


Map. 9 Current and future scenario of potential evapotranspiration in VPAs

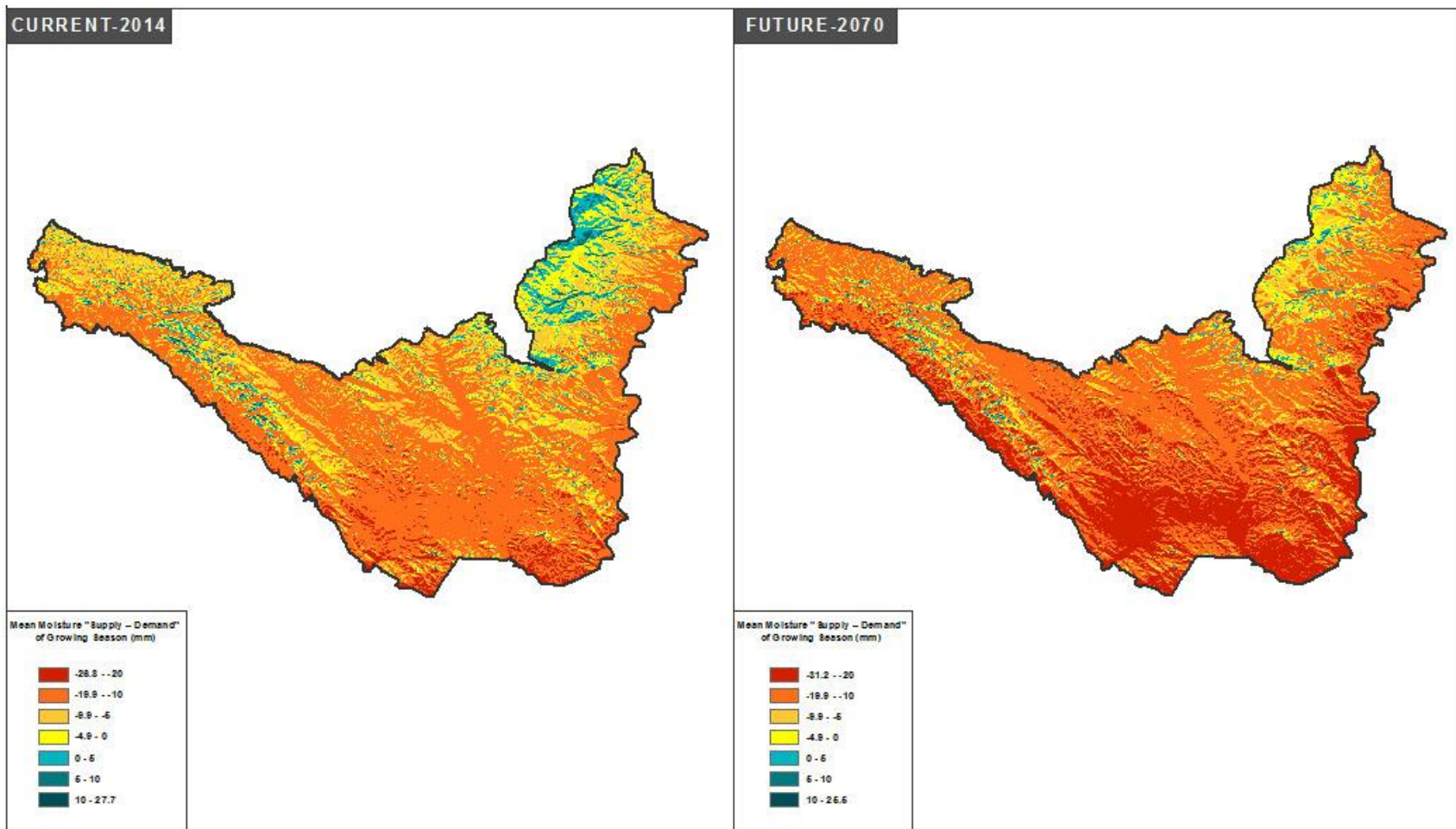




Map. 10 Actual evapotranspiration in VPAs



Map.11 Annual moisture deficit in VPAs.



Map.12 Moisture "supply - demand" in VPAs