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Clima East Pilot Project "Sustainable management of pastures and forest in Armenia to demonstrate climate change mitigation and adaptation benefits and dividends for local communities" UNDP/EU

Guideline for conducting vulnerability assessment of mountain rangeland and forest ecosystems in Vardenis sub-region of Gegharkunik Marz in Armenia

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Content

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1. Purpose of the guideline

This guideline has been developed under the UNDP / EU Clima East Pilot Project "Sustainable management of pastures and forest in Armenia to demonstrate climate change mitigation and adaptation benefits and dividents for local communities" as a part of a task regarding the identification and development of a suitable vulnerability assessment approach for the target mountain rangeland and forest ecosystems in Vardenis sub-region of Gegharkunik Marz in Armenia to be later implemented under the Project. The scope of the task included the following activities:

1. Undertake the initial research and accurate analysis of existing approaches related to mountain ecosystem vulnerability assessment to ensure proper advice for the project implementation with specific focus on the project's first component on stocktaking and vulnerability assessment of project target area;
2. Define the approach/methodology best applicable for the country based on the desk review of existing approaches/methodologies for vulnerability assessment of mountain ecosystems, particularly considering current climate conditions and natural hazards, future climate change risks and expected/potential impacts;
3. Develop detailed scope of work (including required input and outputs) for conducting vulnerability assessment of mountain rangeland and forest ecosystems to support in reaching the project objective;
4. Provide substantial input in development of respective term of reference for conducting vulnerability assessment of selected sites in mountain rangeland and forest in Vardenis sub-region of Gegharkunik Marz in Armenia;
5. Develop detailed guideline for conducting vulnerability assessment of mountain rangeland and forest ecosystems in Vardenis sub-region of Gegharkunik Marz in Armenia considering climate change risks and taking into account that the assessment results will serve as a basis for future development of pasture and forest rehabilitation pilots.

The results of the other activities are summarized here in the guideline for conducting vulnerability assessment of mountain rangeland and forest ecosystems in Vardenis sub-region of Gegharkunik Marz in Armenia.

As the selected approaches for the vulnerability assessment are based on an assessment of the specific needs of the Project, previous and upcoming tasks of the Project as well as of the specificities of the Project's target region, the guidelines provided here serve primarily the vulnerability assessment to be undertaken under the Project. The general principles are, however, applicable also in other regions and can be adapted for other purposes as well. As such, however, these guidelines are not meant as a general manual for vulnerability assessment, which affects the structure and detail of the report.

The target of the vulnerability assessment to be conducted under the Project is to guide the development of pasture and forest rehabilitation pilot projects as well as provide understanding for the development of the management of rangelands and forests in the target region. Respectively, the focus of the vulnerability assessment is on the condition and integrity of the target ecosystems, on the current and expected development of these resources under climate change and considering also other pressures affecting the ecosystems as well as on the current and expected socio-economic conditions in the target communities directly affecting and relying on the condition and productivity of the natural resources and the ecosystem services provided by the natural resources. A thorough understanding of the current situation in the target areas serves as a basis for understanding and assessment of potential impacts caused by the exposure to changing climate conditions.

2. Theoretical background for the vulnerability assessment – From a static baseline to a moving baseline

Current ecosystem conditions and integrity revealing ecosystem sensitivity

The utilization and management of ecosystems has been and still is largely based on past experiences and observations of management impacts on the productivity and yield of the natural ecosystems. Utilization of ecosystems based on past observations relies on an assumption of static environmental conditions. However, the underlying assumptions guiding management decision might not hold in the future under climate change. Respectively, to ensure sustainable utilization of natural resources, the management decisions have to be based on a thorough analysis of potential future ecosystem conditions and changes in the ecosystem under the changing climate. Thus, an analysis of the vulnerability of the target ecosystems under climate change is required to guide ecosystem management.

The assessment of vulnerability, however, has to be based on sound knowledge of the current ecosystem conditions. An inventory of the target ecosystems, conducted using well-established inventory methods, traditional site indices as well as growth and yield tables based on past empirical experience, is thus required to reveal information about the current condition and integrity of the ecosystems. **Up-to-date inventory data serves as a starting point for the assessment of potential ecosystem impacts under changing climate conditions and respectively, as a starting point for the ecosystem vulnerability assessment.**

With a specific focus on enabling a vulnerability assessment and assessment of potential future ecosystem conditions, an inventory of an target area should include an assessment of ecosystem composition, biodiversity and integrity, assessment of the productive capacity and yield, evaluation of soil conditions and factors such as erosion and degradation, and based on the aforementioned factors, assessment of the current carbon sequestration potential of the target ecosystems. Importantly, a thorough inventory of the target ecosystems and their use is necessary to determine the sustainability of the current level of utilization of the target ecosystems. Based on an inventory of the target areas and in combination with methods for assessing the development of the target ecosystems, a baseline trajectory of the ecosystems may be developed. Detailed inventory data enables also the utilization of e.g. modeling approaches in this exercise.

Climatological factors as well as biotic factors, such as pests and weeds, play a great role in the development of ecosystems also under current climate conditions. Thus, a stock taking of the target ecosystems has to include assessment of factors such as frequency of wildfires and pest outbreaks. Furthermore, an inventory is necessary to evaluate processes such as erosion and land degradation taking place already under current conditions.

The target ecosystems are greatly affected not only by climatological factors and biotic pressures, but also by anthropogenic pressures. Thus the stocktaking of the target ecosystems has to include an assessment of factors such as grazing pressure, utilisation of wood and timber as well as utilisation of non-wood forest products. The lack of up-to-date management plans for the target ecosystems suggests that qualitative methods are most appropriate for the assessment of these factors. To further assess the utilisation and value of the target ecosystems to the nearby communities as well as in order to identify the adaptive capacity of the communities dependent on pastures and forests in the target area, an assessment of the socio-economic conditions of the adjacent communities is necessary. The socio-economic data complements the ecosystem inventory data in the analyses of ecosystem vulnerability to climate change.

Identifying the impacts of changing climate conditions

Instead of working with expectedly static environmental conditions in natural ecosystems like was described above, climate change forces users of natural ecosystems to consider the potential changes that the changing climate conditions might induce in the target ecosystems in order to ensure sustainability of natural resource utilization in the future. Ecosystem management under climate change entails acknowledging the potential changes in natural ecosystems induced by changes in the climatic conditions as well as the respective effects of these changes on the delivery of the desirable goods and services by the ecosystems. For sustainable management of natural ecosystem, it is thus necessary to identify potential changes in the climatic conditions going beyond the inter-annual and inter-decadal variability present under static conditions. Accordingly, it is necessary to identify potential changes in natural ecosystems caused by the changes in the climatic factors.

Respectively, assessment of the vulnerability of an ecosystem to climate change begins with the identification of expected changes in the climatic conditions and consequent changes in both abiotic and biotic impact factors affecting the ecosystem. When the impact factors have been identified it is possible to analyse the potential impacts in the ecosystems. Understanding how and to what extent the different impact factors induced, strengthened or altered by climate change affect the target ecosystem – or in other words how vulnerable the ecosystem is to climate change – requires knowledge and assessment of the sensitivity of the ecosystems to climatological conditions as well as assessment of its ability to respond to the changes in the environment, or its adaptive capacity. Also the adaptive capacity of ecosystem utilizers and communities reliant on the natural resources should be considered so as to identify their capacity to reduce the sensitivity of ecosystems as well as their own sensitivity under climate change.

These components – **exposure** to climate change and different climatic, abiotic and biotic impact factors, **sensitivity** of the system as well as its **adaptive capacity** – define according to the widely adopted definition of IPCC the vulnerability of a system to climate change. It is also **the theoretical and conceptual framework on which the vulnerability assessment of mountain ecosystems to climate change is built in this guideline**. A short description of this theoretical framework is provided below.

Conceptualization of vulnerability - Components of ecosystem vulnerability to climate change

According to the definitions given in the IPCC Fourth Assessment Report, the vulnerability of a system to climate change is a function of its exposure to changing climate variables and impact factors influenced by climate change as well as the sensitivity of the system to the impact factors and its adaptive capacity or resilience. Exposure is an external factor posed on the system, while sensitivity and adaptive capacity are internal factors of the system. Following definitions given e.g. in the IPCC Fourth Assessment Report and other scientific reports, the different components of vulnerability can be defined in the following manner:

Impact factors can be climatic, physical or biological variables that are influenced by the changing climate conditions. These include factors such as mean climate characteristics (temperature, precipitation), climate variability, abiotic disturbances (including occurrence, frequency and magnitude of e.g. storms and wildfires) and biotic disturbances (e.g. pests and pathogens). **Exposure** is defined as the projection of climate change affecting the system, its degree, duration, and extent of deviation in climate to which a system is exposed.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate change or variability. The **impacts of climate change** in a system are defined as a function of exposure and sensitivity. The effects of climate change can be either direct or indirect, including for example effects of changing temperature or effects of increased disturbances. Many climatic factors such as changes in **temperature** and **precipitation** or more frequent **heat waves** and **droughts**, as

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well as the **rising atmospheric CO_2 concentration** itself, will directly affect eco-physiology in mountainous pastures and forests under climate change. **Wind storms, wildfires** and **mass movements** are examples of indirect abiotic factors, which can become more frequent and intense under changing climate conditions with consequent significant effects on mountain ecosystems. Additionally, **biotic factors**, such as pests, will also be affected by the new conditions. Pest species may benefit from both the new climate as well as the weakened condition of plant species following direct and indirect climatic stresses, which can lead to more frequent pest outbreaks. Weed and other less desired plant species may expand their ranges in pastures and forests under the changing conditions. The complex interplay of the direct and indirect stress factors can make the impacts of climate change on mountain ecosystems both more severe as well as more difficult to predict. The ecological characteristics of an ecosystem affect the sensitivity of the ecosystem to the different impact factors posed by climate change. The sensitivity of a natural ecosystem respectively affects the extent to which mechanisms, such as plant growth and mortality, are affected by the different impact factors.

A risk is the potential adverse outcome of a particular impact. Respectively, **an opportunity** is the potential beneficial outcome of a particular impact.

Adaptive capacity of a system is the ability to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. In the context of vulnerability of natural ecosystems, the adaptive capacity can be further divided into the inherent adaptive capacity of an ecosystem as well as the socio-economic adaptive capacity of the natural resource users. The **inherent adaptive capacity** consists of the evolutionary mechanisms and processes, which enable ecosystems to adjust to changing environmental conditions. Adaptation in natural ecosystems is thus an autonomous reactive process, which happens through biological responses to climate stimuli. These include acclimation through phenotypic plasticity or genetic changes within a population due to natural selection. In natural ecosystems, the ability to adapt to climate change and variability is influenced by characteristics such as existing **biodiversity** in the system, the **successional ecosystem state**, strength of selection, **fecundity of the species present**, **fragmentation of the landscape** as well as site **characteristics such as topography**. Generally species with a very narrow range of suitable conditions (specialist species) might be less able to adapt compared to generalist species able to occupy a wider variety of locations and conditions. The ability of specific species to respond to climate change by migrating to new locations depends among others on the **seed dispersal ability of the species, availability of seed sources, sexual maturity age of the species, soil conditions** as well as **biotic interactions**. Species with short seed dispersal distances, low seed production and complex breeding systems are at greater risk under climate change. Importantly, land-use, landscape connectivity and existence of built environment affect greatly the ability of species to disperse and migrate to new habitats. E.g. in the case of forests, the long life-span of trees might hamper their ability to sufficiently adapt to climate change impacts *in situ*, and it is unclear whether migration rates of trees are sufficient to allow for adaptation in the face of rapid climatic changes. Furthermore, migration and seedling recruitment in new locations are hampered e.g. by habitat fragmentation. In pastures, less desirable species from the perspective of cattle grazing might survive better and expand their range under climate change. As the ability of different species to migrate to suitable conditions varies from each other, it is likely that climate change will induce opening of gaps within current vegetation zones and cause fragmentation in species distribution rather than lead to uniform zonal shifts. This can be especially significant in mountainous environments, which are characterised by variable microclimates and deep environmental gradients.

When **assessing adaptation in the entire ecosystem** as opposed to the adaptation of individual species, the focus is on the functionality of the system: **on the ability of the system to maintain its main functions and provision of ecosystem services under climate change.** In natural ecosystems, the inherent adaptive capacity depends on the levels of **genetic variability within but also among populations** as well as on **the species richness within functional groups**. This functional group diversity provides material for natural selection and enables continued provision of the ecosystem services by the ecosystem, the functionality of which is ultimately maintained despite changes in the environmental conditions and consequent changes in e.g. species composition.

The **socio-economic adaptive capacity** consists of the social and financial capacities of the natural resource users defining the ability to alter the utilization and management of the resources or reduce the pressure on the sensitive ecosystems. In human systems adaptation can be an autonomous process, where the system adapts when it is forced to, as well as a planned process. Planned adaptation to climate change means reducing the vulnerability of a system through specific measures, which aim to reduce the sensitive and enhance the adaptive capacity of the target system. The capacity of natural resource users to identify and to implement specific planned adaptation measures depends on their human and social capital. This includes e.g. **the level of education and training** as well as the **capacity of the users to understand and predict potential changes** in the target ecosystems under climate change and to design options to manage the risks or take advantage of opportunities related to climate change. In addition to the human capital, the ability to implement adaptation options is also highly dependent on **the economic setting** and **the financial capital available**. **The wider socio-economic** and **institutional system for natural resource management and utilisation** also affects adaptive capacity. Furthermore, the intensity of ecosystem management and the general level of activity in the natural resource management sector, which often affect also for example the level of technological development and the availability of technical capital in the sector, as well as the market conditions and demand for ecosystem products and services can affect the adaptive capacity of resource users. Also factors such as land ownership structure can affect the adaptive capacity.

As a function of all of the above mentioned, **vulnerability** is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.

The vulnerability to climate change in natural ecosystems can be exacerbated by **other (anthropogenic) stresses**. Thus it is very necessary to take also the wider context into consideration when evaluating the vulnerability of a system to climate.

The vulnerability of a system can vary at different spatial and temporal scales. Thus, it is highly important to consider the impacts of scale on the assessment of vulnerability and especially on **the uncertainty related to climate change projections and ecosystem responses**.

The assessment of vulnerability starting from the different components described above will help to understand which systems and species are likely to be most strongly affected and why they are most vulnerable to climate change. A thorough and rigorous assessment of vulnerability will provide also a sound basis for designing natural resource management options under climate change. The assessment of vulnerability will provide natural resource users information about which ecosystems and locations are most sensitive to climate risks, where the risks are already evident or most urgent, and where are climate change effects expected to be highly damaging. Likewise, a vulnerability assessment might indicate that the risks are lower in some places or that adaptation in a specific location would be very costly.

3. Review of methodologies for vulnerability assessment and approaches selected for the target region

Many assessments of the vulnerability of natural ecosystems under climate change, like assessments of ecosystem development under static conditions, are conducted today with the assistance of model simulations. Models can be used to simulate potential future ecosystem conditions and expected provision of ecosystem goods and services under a projected future climate. Furthermore, models can be used to assess the consequences of alternative management scenarios in terms of their potential to alter ecosystem vulnerability and to mitigate climate change impacts. Several different types of modelling approaches have been developed to serve different purposes and different aspects of vulnerability assessments in natural ecosystems. As an example, the vulnerability of specific species can be assessed based on estimations of the shifts in the suitable range of the species using bioclimatic envelope models built on geo-referenced empirical observations. Or for instance potential changes in ecosystems, such as pastures and forests, at managerial levels (forest plot level, field level) can be assessed using biophysical process based models. Many models are readily available with full instructions for model parameterization to new conditions. Reviews and comparisons of different models and modelling approaches can be found elsewhere.

All model simulations contain inherent uncertainty, but at the same time they are able to model the complex relations present in natural ecosystems. Respectively, an assessment of uncertainty related to the simulation exercise has to be an integral part of model simulations. Additionally, as a part of appropriate use of models in any application, model simulations have to be assessed always also qualitatively and in terms of their biological realism. Due to remaining uncertainties in both predictions of future climate conditions and underlying mechanism of ecosystem responses, the results of model simulations should not be seen as predictions, but rather as representation of the potential direction, magnitude and range of change. Importantly, to assess and reduce the uncertainty related to model projections, it is recommendable to use multiple models, or ensemble modelling, to enable comparison of modelling results and assessment of potential range of change.

Using modelling approaches sets requirements in terms of input data. Data is required for the parameterization of models for the target region as well as for model runs. The level of uncertainty in model predictions is greatly affected by the quality of input data and the assigned parameters. Regardless, modelling tools can be helpful in the identification of the most critical factors affecting vulnerability and in the assessment of the potential range of change. Thus, it is recommended in this guideline that some modelling approaches both for the assessment of the vulnerability of pastures as well as the vulnerability of forests be tested also under the current project. Furthermore so, as the initial model simulations are highly useful in the identification of future research needs. It is suggested that model simulations in the current context are used for an investigation of a smaller, exemplary area, where input data and parameters could be obtained through the field assessments conducted under the Project as well as through consultations of Project experts.

As was described above, regardless of the use of model simulations, a qualitative assessment is required to evaluate the overall vulnerability under changing climate conditions as well as to assess the validity of modelling results. Thus, it is recommended in this report that a qualitative expert assessment based on best available scientific knowledge of the most important indicators for exposure, sensitivity of the target ecosystems and communities as well as adaptive capacity of the said ecosystems and communities is conducted. Based on the expert assessment, further science-based assessment of climatological threshold levels or appropriate ranges and the available ecosystem and community stocktaking data, the identified indicators can be translated into indices of vulnerability to climate change of the target ecosystem. Through appropriate weighing and aggregation of the different indices, the overall vulnerability of the target ecosystems and communities can be assessed and projected also visually through mapping tools. Calculation of vulnerability indices based on indicators of exposure, sensitivity and adaptive capacity is also, like modelling approaches in ecosystems, a typically applied method to assess a system's vulnerability to climate change. **It is envisioned in these guidelines that the qualitative-quantitative, science-based assessment of vulnerability indicators and the respective calculation of vulnerability indices forms the main part of the vulnerability assessment of mountain rangelands and forests. Model simulations may support this approach.**

In addition to the two approaches described above, considering past trends and observed impacts in forest ecosystems through the assessment of observational data and consultation of local stakeholders are important aspects in understanding potential climate change induced impacts in natural ecosystems. Furthermore, analysis of past climatic variability and consequent ecosystem responses can cast light on the adaptive capacity and vulnerability of the target ecosystem and might assist in identifying most vulnerable areas. Local knowledge is also highly valuable in validation and verification of model simulation results. Furthermore, past observations should be utilised to assess model suitability to local conditions by comparing observations to model runs for the same period.

The development of both quantitative and qualitative vulnerability assessments requires the best available quantitative data of expected climate conditions at scientifically sound geographical and temporal scales. Furthermore, due to the uncertainties in climate change projections especially at finer geographical scales, it is recommended that a range of climate change scenarios is considered in the process of vulnerability assessment. This is a prerequisite for a rigorous assessment of vulnerability. Projections of climate data are required at different altitudes and time steps. Seasonal climatological data is important for the assessment of vulnerability due to respective changes in e.g. regeneration and growing season. Furthermore assessment of the occurrence and frequency of extreme weather events and climatological hazards is required. Like above, also the climate projections especially at finer scales need to be qualitatively assessed and an assessment of what is unknown and uncertain about climatic responses has to be conducted. This is especially important in the targeted mountainous terrain, where high variability in climatic conditions is experienced at the fine scales.

Summarizing what is stated above, the three approaches for the assessment of mountain ecosystem and socio-economic vulnerability in the target region to be applied include **i) qualitative assessment of past observations of ecological changes and their respective impacts on the target communities in the context of historical climate records and climate variability, ii) quantitative index-based assessment of the most significant indicators of impact factors and exposure, sensitivity and adaptive capacity as well as iii) quantitative assessment of the potential range and direction of climate change impacts using modeling approaches for selected exemplary ecosystems and land management units to enable identification of most significant factors altering the vulnerability and adaptive capacity of the target ecosystems.** Prior to conducting the assessment of vulnerability, **a thorough assessment of the current ecosystem and socio-economic conditions in the target communities** will be undertaken, as described above in chapter 2. The main sources of information for this are a field inventory of pastures to be conducted together with the vulnerability assessment as well as the information collected during previous activities undertaken under the Clima East Pilot Project.

4. Vulnerability assessment – Scope of work

The following table lists the components of the vulnerability assessment of the target mountain rangelands and forests in the Varderis sub-region of Gegharkunik Marz in Armenia. The table is divided into sections according to the three selected approaches for vulnerability assessment. Additionally, the first three activities listed in the table concern the establishment of the current ecosystem and socio-economic conditions to serve as the baseline for the vulnerability assessment against which the impacts of the exposure to changing climate conditions are measured. A detailed pasture inventory is included in the first activity. In addition to the detailed scope of work, approaches and expected outputs, the following table lists sources of information and specific methods for obtaining relevant additional information. More specific approaches and methods are identified in chapter 5.

Scope of work	Approach	Output information
1. Stocktaking of current pasture conditions and socio-economic setting		
Stocktaking of pastures in the target region (community level)	Performing a rigorous and detailed field inventory of pastures in the target region Gathering of relevant information from previous outputs of the Project, other existing data, maps etc. Collection of supplementary data (official sources, interviews) Mapping (generation of digital maps of different indicators)	Area and location of pastures, Topographic and altitudinal description of pastures (slope, aspect, altitude) Description of infrastructure - Access to pastures - Water points - Shelter, lodgings Description of pasture areas actually used (used/un-used, reasons) Description of site indices, soil types, bedrock Description of pasture vegetation - Vegetation cover, species composition, biodiversity, species richness, richness of plant species used by grazing animals - Estimation of naturalness of the vegetation - Observed changes in vegetation due to grazing (or other pressures) - Nutritional content of vegetation, pasture quality from the perspective of grazing Productivity and carrying capacity - Amount of vegetation (dry mass) - Amount of fodder (dry mass) (plants suitable for grazing)

		- Productivity per hectare, yield (currently used pasture areas, all pasture areas) (considering only plant matter suitable for grazing) - Number of livestock units supported (allowable grazing pressure, fodder yield per management unit divided by fodder requirements of one livestock unit over the entire grazing period) Soil conditions - Soil compaction - Current level of erosion - Current level of degradation - Susceptibility to erosion and degradation Carbon sequestration potential, size of carbon pools
Assessment of anthropogenic pressures on pastures, organization of grazing	Gathering of relevant information from previous outputs of the Project and other existing data Collection of supplementary data (official sources, interviews)	Grazing pressure, organisation of grazing - Number of animals (expressed in livestock units) - Fodder requirements - Extent of grazing period / pen period, winter fodder requirements - Pasture area required to satisfy fodder requirements (fodder

		requirements divided by the productivity of pasture areas per hectare, kg/(kg/ha)=ha - Grazing areas, seasonality - Organisation of grazing in communities - Who are grazers (e.g. are children involved) - Areas for harvesting winter fodder, productivity - Winter fodder requirements Animal health Other anthropogenic pressures - Utilisation of vegetation, species and amount collected Other land use pressures - On-going and planned activities Identification of current methods for the management of the pasture areas Institutional setting for pasture utilisation and management
Assessment of biotic and abiotic pressures on pastures	Interviews, stakeholder consultation Official records	Frequency and extent of wildfires Frequency and impact of droughts and other extreme weather events Frequency and impact of landslides, mud flows and other mass movements
2. Stocktaking of current forest conditions and socio-economic setting		
Stocktaking of forests in the target region	Gathering of relevant information from previous	Forest cover and location of forests

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	outputs of the Project, other existing data, maps etc. Collection of supplementary data (official sources, interviews) Mapping (generation of digital maps)	Topographic and altitudinal description of forests (altitude, slope, aspect) Description of site indices (bonitet), tree species composition, stocking density, stand structure and age, growth rates, biomass, forest biodiversity and species richness, ecosystem integrity - Estimation of naturalness of the vegetation Regeneration Estimation of degradation/erosion Soil conditions - Soil types - Soil depth Susceptibility to disturbances - Biotic - Abiotic Signs of anthropogenic pressures Carbon sequestration potential, size of carbon pools
Assessment of anthropogenic pressures on forests	Gathering of relevant information from previous outputs of the Project and other existing data Collection of supplementary data (official sources, interviews)	Other anthropogenic pressures - Utilisation of vegetation, species and amount collected - Managed timber harvesting, wood collection - Unmanaged wood collection - Grazing (at forest border) Other land use pressures - On-going and planned activities Identification of current methods for the management of the forest areas

		Ownership structure, institutional setting
Assessment of biotic pressures on forests	Interviews, stakeholder consultations Official records	Pest and pathogen outbreaks (frequency, extent)
Assessment of abiotic pressures on forests	Interviews, stakeholder consultations Official records	Frequency and extent of forest fires and wildfires Frequency and impact of landslides, mud flows and other mass movements Frequency and impact of wind storms Frequency and impact of droughts and other extreme weather events
3. Assessment of socio-economic conditions		
Stocktaking of the target communities	Gathering of relevant information from previous outputs of the Project and other existing data Collection of supplementary data (official sources, interviews)	Socio-economic conditions - Population, demographic - Literacy, level of education - Level of education of ecosystem managers / users - Income level - Income sources, livelihood diversification - Climate sensitivity of main livelihoods - Institutional set-up for ecosystem management
4. Assessment of future climatological conditions		
Analyses of future climate conditions and projections at suitable spatial and temporal scales	Obtain climate projections from relevant sources (to be confirmed by the Project)	Projections of the climatological conditions at suitable spatial and temporal scales (e.g. mid-century, end of century) - Assessment of different climatological trajectories

		- Assessment of uncertainty of local scale projections, uncertainty of different trajectories Ecosystem and community (livelihood) exposure to different climatological impact factors - Long-term trends - Variability and climatological hazards and extreme events - Projections of seasonal climate conditions and variability - Climatological impact factors relevant for biophysical processes Projections of climatological conditions at different altitudes
5. Evaluation of observed ecosystem and climatological changes		
Stocktaking of past ecosystem changes	Interviews and stakeholder consultations Review of past climatological records and statistical data	Identification of past changes related to climatic conditions Identification of historical fodder production levels, causes for variability Assessment of critical factors of ecosystem sensitivity and vulnerability
6. Assessment of vulnerability of pastures		
Assessment of vulnerability of pastures	Science based assessment of most important climatological impact factors - Identification of appropriate indicators - Calculation of indicators relevant for pasture ecosystems (e.g.	Identification of most critical climatological factors Identification of most vulnerable ecosystem types and pasture areas

	growing degree days, soil water availability / evapotranspiration, frost events) (Utilisation of e.g. FAO CropWat model to assess water requirements) Science based assessment of climate change sensitivity of biophysical processes and adaptive capacity (in situ, ex situ) of target ecosystems using indicator species as proxies for habitats/areas and considering the information collected about the target ecosystems under activities 1 and 3 - Identification of appropriate indicators for sensitivity and adaptive capacity - Identification of climatological threshold levels for the indicators of sensitivity to enable normalization of data Assessment of sensitivity to biotic and abiotic impact factors Development of quantitative vulnerability indices based on the science-based analyses, assignment of indicator values to management level plots - Verification of indices through	Identification of areas most vulnerable to climatological hazards and biotic pressures, erosion and degradation, risk of mass movements Identification of potential impacts of climate change on ecosystems and ecosystem services - Numerical estimates of grazing potential and winter fodder production - Numerical estimates of carbon sequestration potential

	stakeholder consultations Mapping exercise, projection of vulnerability indices, vulnerability at different temporal scales Qualitative, science based assessment of potential climate change impacts as a function of sensitivity and exposure considering also adaptive capacity - Potential impacts on ecosystem conditions - Potential impacts on critical outcome variables of concern (ecosystem function, fodder production)	
7. Assessment of vulnerability of forests		
Assessment of vulnerability of forests	Science based assessment of most important climatological impact factors - Identification of appropriate indicators - Calculation of indicators relevant for forest ecosystems (e.g. growing degree days, soil water availability / evapotranspiration, frost events) Science based assessment of climate change sensitivity of biophysical processes and adaptive capacity (in situ, ability to move) using indicator species as proxies for habitats/areas and considering the information	Identification of most critical climatological factors Identification of most vulnerable ecosystem types and forest areas Identification of areas most vulnerable to climatological hazards and biotic pressures Identification of potential impacts of climate change on ecosystems and ecosystem services, including e.g. timber production, biodiversity, water retention, soil protection, protection from mass movements - Numerical estimates of carbon

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	collected about the target ecosystems under activities 2 and 3 - Identification of appropriate indicators for sensitivity and adaptive capacity - Identification of climatological threshold levels for the indicators of sensitivity to enable normalization of data Assessment of sensitivity to biotic and abiotic impact factors Development of quantitative vulnerability indices based on the science-based analyses - Verification of indices through stakeholder consultations Mapping exercise, projection of vulnerability indices, vulnerability at different temporal scales Qualitative, science based assessment of potential climate change impacts as a function of sensitivity and exposure considering also adaptive capacity - Potential impacts on ecosystem conditions - Potential impacts on critical outcome variables of concern (ecosystem function and	sequestration potential

	ecosystem services, timber production, biodiversity)	
8. Assessment of socio-economic vulnerability		
Assessment of socio-economic vulnerability	Assessment of socio-economic sensitivity and adaptive capacity - Identification of indicators for sensitivity and adaptive capacity based on the stocktaking conducted previously Assessment of most important climatological impact factors affecting community livelihoods - Identification of appropriate indicators Development of quantitative vulnerability indices based on the science-based analyses - Verification of indices through stakeholder consultations Qualitative, science based assessment of potential climate change impacts as a function of sensitivity and exposure considering also adaptive capacity	Assessment of overall vulnerability of the target ecosystems and target communities
9. Assessment of future ecosystem conditions and adaptive capacity		
Assessment of future ecosystem conditions and adaptive capacity	Model simulations (e.g. CENTURY ECOSYSTEM MODEL, GOTILWA+ MODEL, 3-PG MODEL) - Model parameterization	Potential future ecosystem conditions under different climate change trajectories Evaluation of potential changes in:

	based on expert assessments and available data - Model validation using past data - Model simulations - Verification of biological realism of modelling results	- Forest composition, growth rates and yield - Pasture vegetation - Pasture productivity and carrying capacity - Carbon sequestration potential Assessment of different management pathways and their impacts
10. Development of detailed analytical report on the vulnerability of the target mountain ecosystems in the Project's target areas to climate change		

5. Detailed approaches and methods

5.1. Approaches for each activity

Stocktaking of current pasture conditions and socio-economic setting

- According to the expected outputs listed in the table above (chapter 4), design and conduction of a detailed field inventory of the pastures to gather required information about
  - Pasture characteristics
  - Pasture soil conditions
  - Pasture vegetation conditions
  - Pasture productivity and carrying capacity
- According to the expected outputs listed in the table above (chapter 4), collection of relevant information from
  - The soil study conducted under the Project
  - The pasture vegetation study conducted under the Project
  - The Rapid Rural Assessment conducted under the Project
  - Land cadastre
  - Existing maps
  - Statistical service (also pest and pathogen outbreaks, wildfires)
- Assessment of additionally required data (<u>note also data requirements in other activities</u>)
  - Preparation of questionnaires combining structured and open-ended questions
  - Selection of appropriate interviewees
  - Conducting interviews and data compilation
- Calculation of relevant indicators based on the field inventory and desk-based review of existing data
  - Biodiversity (see chapter 5.2. below)
  - Species composition and richness (see chapter 5.2. below)
  - Composition and richness of plant species used by grazing animals (see chapter 5.2. below)

  - o Number of livestock units supported by different management units (allowable grazing pressure) (see chapter 5.2. below)
    - ▪ Productivity of pasture areas and allowable grazing pressure divided by i) currently used areas, ii) pasture areas currently not utilised
  - o Susceptibility to erosion (see chapter 5.2. below)
  - o Susceptibility to degradation (see chapter 5.2. below)
  - o Number of animals (in livestock units) (see chapter 5.2. below)
  - o Actual stocking rate (see chapter 5.2. below)
  - o Fodder requirements, required pasture area (see chapter 5.2. below)
  - o Winter fodder requirements, required area for harvesting (see chapter 5.2. below)
- Numerical and visual description of the different aspects of pasture conditions

Stocktaking of current forest conditions and socio-economic setting

- According to the expected outputs listed in the table above (chapter 4), collection of relevant information from
  - o The soil study conducted under the Project
  - o The forest inventory and carbon assessment conducted under the Project
  - o The Rapid Rural Assessment conducted under the Project
  - o Land cadastre
  - o Existing maps
  - o Statistical service (also pest and pathogen outbreaks, wildfires)
- Assessment of additionally required data (<u>note also data requirements in other activities</u>)
  - o Preparation of questionnaires combining structured and open-ended questions
  - o Selection of appropriate interviewees
  - o Conducting interviews and data compilation
- Calculation of relevant indicators
  - o Biodiversity (see chapter 5.2. below)
  - o Species composition and richness (see chapter 5.2. below)
  - o Susceptibility to erosion (see chapter 5.2. below)
  - o Susceptibility to degradation (see chapter 5.2. below)
- Numerical and visual description of the different aspects of pasture conditions

Assessment of socio-economic conditions

- According to the expected outputs listed in the table above (chapter 4), collection of relevant information from
  - o The Rapid Rural Assessment conducted under the Project
  - o Statistical service
  - o Other Project data sources
- Assessment of additionally required data (<u>note also data requirements in other activities</u>)
  - o Preparation of questionnaires combining structured and open-ended questions
  - o Selection of appropriate interviewees
  - o Conducting interviews and data compilation

Assessment of future climatological conditions

- Assessment of requirements for future climate predictions and projections
  - o Activities 6, 7, 8 and 9 in the table above (chapter 4)
- Assessment of requirements of past climate records

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    - Activities 5 and 9 in the table above (chapter 4)
- Assessment of required spatial and temporal scales
- Conducting analyses of future climate conditions and climate projections for the target region
- Numerical and visual description of ecosystem and community exposure to different climatological impact factors
    - Trends of temperature and precipitation
    - Hazards, extreme events
    - Seasonal conditions
    - Altitudinal projections

Evaluation of observed ecosystem and climatological changes

- Preparation of questionnaires combining structured and open-ended questions (<u>note also data requirements in other activities</u>)
    - Selection of appropriate interviewees
    - Conducting interviews and data compilation
- Collection of data from other relevant sources
    - Hydro-Met
    - Statistical Service
    - National Communications to the UNFCCC

Assessment of vulnerability of pastures

- Assessment of most important climatological impact factors
    - Identification of appropriate indicators (e.g. temperature, precipitation, drought events, snowfall)
    - Calculation of indicators relevant for pasture ecosystems
        - Growing degree days, soil water availability etc.
- Assessment of the sensitivity of key biophysical processes and adaptive capacity of pasture ecosystems
    - Identification of indicator species and their biophysical requirements
    - Identification of appropriate indicators and respective climatological threshold levels for sensitivity
        - Ranges of species, regeneration requirements, water requirements, sensitivity to extreme events, seasonal weather requirements etc.
    - Identification of other relevant factors affecting sensitivity
        - Current levels of erosion and degradation, erosion and degradation processes and expected exposure to relevant climatological factors
        - Productivity/Current grazing pressure (calculations for both pasture areas currently used and pasture areas that could be used with adequate infrastructural improvements)
            - Amount of potentially overgrazed pasturelands, sustainability of current management practices
    - Identification of appropriate indicators for adaptive capacity
        - Species range, biodiversity, functional group species richness (material for selection under climate change) etc.
- Development of quantitative vulnerability indices (see chapter 5.2. below)
    - Normalization of data using expert assessment to define threshold levels
    - Calculation of vulnerability indices

- Weighing and aggregation of relevant vulnerability indices to assess pasture vulnerability (see chapter 5.2. below)
- Visual representation of vulnerability indices

Assessment of vulnerability of forests

- Assessment of most important climatological impact factors
  - Identification of appropriate indicators (e.g. temperature, precipitation, drought events)
  - Calculation of indicators relevant for forest ecosystems
    - Growing degree days, soil water availability etc.
- Assessment of the sensitivity of key biophysical processes and adaptive capacity of forest ecosystems
  - Identification of indicator species and their biophysical requirements
  - Identification of appropriate indicators and respective climatological threshold levels for sensitivity
    - Ranges of the dominant species, regeneration requirements, water requirements, erosion and degradation processes, sensitivity to extreme events, seasonal climatological requirements etc.
  - Identification of appropriate indicators for adaptive capacity
    - Species range, biodiversity, functional group species richness (material for selection under climate change), etc.
- Assessment of susceptibility of abiotic and biotic hazards
  - Identification of indicators for biotic pressures
    - Biodiversity, ranges of most common pests and pathogens etc.
  - Identification of indicators for abiotic pressures
    - Stand density, fire risk of species etc.
- Development of quantitative vulnerability indices (see chapter 5.2. below)
  - Normalization of data using expert assessment to define threshold levels
  - Calculation of vulnerability indices
- Weighing and aggregation of relevant vulnerability indices to assess forest vulnerability (see chapter 5.2. below)
- Visual representation of vulnerability indices

Assessment of socio-economic vulnerability

- Identification of indicators for sensitivity and adaptive capacity
  - E.g. vulnerability of livelihood sectors, socio-economic and demographic factors
    - Adaptive capacity of natural resource users
  - Expected changes in pasture productivity, fodder demands
    - Current level of pasture productivity compared to livestock fodder requirements
    - Overgrazing
- Development of quantitative vulnerability indices (see chapter 5.2. below)
  - Normalization of data
  - Calculation of vulnerability indices
- Visual representation of vulnerability indices

Assessment of overall vulnerability of target communities and ecosystems

- Weighing and aggregation of relevant vulnerability indices (pastures, forests, socio-economic) to represent overall vulnerability

Assessment of future ecosystem conditions and adaptive capacity

- Obtaining models
  - CENTRY ECOSYSTEM MODEL
  - GOTILWA + MODEL
  - 3-PG MODEL
- Based on available data (inventories conducted under the Project, expert assessment, science based knowledge), assessment of the ability to parameterize models, selection of appropriate models
- Based on provided tutorials, conduct model parameterization using expert assessment and available data sources
- Conduct model runs
  - Model validation and verification
  - Assessment of uncertainty

5.2. Methodologies

Calculation of biodiversity – Simpson's Diversity Index

A diversity index is a quantitative measure that reflects how many different types (such as species) there are in a dataset, and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types. The value of a diversity index increases both when the number of types increases and when evenness increases. For a given number of types, the value of a diversity index is maximized when all types are equally abundant.

Simpson's Index (D):

$$D = \frac{\Sigma n(n-1)}{N(N-1)}$$

Where

n= the total number of organisms of a particular species,

N= the total number of organisms of all species.

The value for D ranges between 0 and 1. The value zero for the Simpson's index indicates maximum diversity; value 1 indicates minimum diversity (a single species).

Simpson's Index of Diversity:

$$1 - D$$

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The value ranges between 0 and 1. The value zero indicates minimum diversity and value 1 indicates maximum diversity.

Species composition and evenness

The relative abundance (%) of the different species making up the richness of an area.

Species richness

Species richness (usually notated S) of a dataset is the number of different species in the area. The more species present in a sample, the 'richer' the sample.

Richness of plant species used by grazing animals

As above, but excluding the number of species not valuable for livestock.

Allowable grazing pressure

The sustainable number of cattle units supported by one hectare of pastureland without causing overgrazing. Expressed as livestock units.

$$Allowable\ grazing\ pressure = \frac{fodder\ yied\ per\ hectare\ (kg)}{daily\ fodder\ requirement\ per\ livestock\ unit\ \left(\frac{kg}{d}\right) \times duration\ of\ grazing\ period\ (d)}$$

Susceptibility to erosion

For full instruction, see GIZ “Sustainable Management of Biodiversity, South Caucasus”, Manual for Monitoring of Summer Pastures in Greater Caucasus, Armenia.

Susceptibility to degradation

For full instruction, see GIZ “Sustainable Management of Biodiversity, South Caucasus”, Manual for Monitoring of Summer Pastures in Greater Caucasus, Armenia.

Conversion of cattle numbers to livestock units

For the conversion of animals to livestock units, the following conversion factors are to be used[1]:

Type	**Factor**
Cows	1
Cattle of any age	0.75
Sheep, goats	0.16

[1] Adopted from GIZ “Sustainable Management of Biodiversity, South Caucasus”,

Manual for Monitoring of Summer Pastures in Greater Caucasus, Armenia

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Calculation of actual stocking rate[2]

$$Actual\ stocking\ rate\ = \frac{sum\ of\ actual\ livestock\ units}{pasture\ area\ (ha)}$$

Fodder requirements, required pasture area

Calculation based on daily fodder requirements of the grazing animals multiplied by the outdoors grazing period. Required pasture area calculated by dividing fodder requirements with pasture productivity.

$$Fodder\ requirement = number\ of\ livestock\ units\ \times\ daily\ fodder\ requirements\ (kg/(livestock\ unit\ per\ day)))\times grazing\ period\ (d)$$

$$Required\ pasture\ area = \frac{number\ of\ livestock\ units\ \times\ daily fodder\ requirements\ \left(\frac{kg}{livestock\ unit\ per\ day}\right)\times grazing\ period\ (d)}{yield\ of\ fodder\ per\ hectare\ (\frac{kg}{ha})}$$

Winter fodder requirement, area required for harvesting

As above, but using the length of the pen feeding period.

Development of vulnerability indices

Normalization of data

The assessment of vulnerability requires that the different indicators selected to represent exposure, sensitivity and adaptive capacity of the target ecosystems and communities are presented as comparable values using a common scale. To this end, the indicators have to be normalized and expressed as unit-less values ranging between 0 and 1. Value 0 represents no vulnerability and value 1 represents maximum vulnerability (note the correct direction of change in the calculation of indices from different datasets!). Normalization of data representing the various indicators enables also the aggregation of the different values.[3]

For datasets measured on metric scale, the following equation is used to normalize a specific value:

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[2] Adopted from GIZ "Sustainable Management of Biodiversity, South Caucasus",

Manual for Monitoring of Summer Pastures in Greater Caucasus, Armenia

[3] For a good description of data normalization, see for example "The Vulnerability Sourcebook Concept and guidelines for standardized vulnerability assessments" published by GIZ in co-operation with Adelphi and Eurac Research.

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$$X = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where

X_i = the value to be normalized (from the dataset)

X_{min} = the lowest value for the indicator

X_{max} = the highest value for the indicator

X = the normalized value within the range 0 to 1.

If for a specific dataset the vulnerability "increases in the wrong direction" (e.g. high economic resources of natural resource users represent high adaptive capacity and thus should result in a lower value for vulnerability), subtract the obtained normalized value from value 1.

Calculation of vulnerability indices

For some of the chosen indicators of sensitivity, exposure and adaptive capacity it is appropriate to use the minimum and maximum values extracted from the datasets of this vulnerability assessment. The values calculated in this manner represent the relative vulnerability of the ecosystems and communities within the target area.

However, especially for many of the biological and climatological indicators, it is more appropriate to identify minimum and maximum threshold levels that more accurately describe the biological / physiological process or e.g. limits of species range or climatological requirements for successful regeneration. Using the threshold levels identified from scientific literature and the expert consultation process, the normalization of the dataset value is calculated using the same equation as before but replacing the minimum and maximum values with the identified threshold levels:

$$X = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where

X_i = the value to be normalized

X_{min} = the lower threshold level

X_{max} = the higher threshold level

X = the value within the range 0 to 1.

The vulnerability values calculated in this manner can yield a more realistic picture of the vulnerability of the system. However, the values obtained in this manner are as good as the estimates for the threshold levels. The uncertainty should be treated in an appropriate manner and indicated appropriately in the final reporting.

Data measured on other scales than metric scales (e.g. categorical scales) can be translated into normalised values by assigning each category a range of values within the target metric range 0-1. E.g. for a five-point scale:

Class	Range	Metric normalized value
1	0-0.2	0.1
2	0.2-0.4	0.3
3	0.4-0.6	0.5
4	0.6-0.8	0.7
5	0.8-1	0.9

Weighing

If some of the identified indicators of sensitivity, exposure or adaptive capacity are assessed in the expert consultation as more important than some other indicators, they can be considered "heavier" than the other indicators and accordingly assigned a weighing factor for the aggregation process. The assigned weighing factors should, however, be based on sound knowledge and should thus be assigned carefully.

Aggregation

Once the indicator values are transformed into indices of vulnerability on a common scale, the overall vulnerability can be obtained by aggregating the values.

If equal weights are used for each indicator, the aggregate value can be obtained by summing the indicator values and dividing them by the number of indicators:

$$X = \frac{\sum_i^n X_i}{n}$$

Where

X = the aggregate value

X_i = value of each indicator

n = number of indicators.

If varying weights are used for the indicators, the aggregate value can be obtained by summing the weighed indicator values and dividing them by the sum of the weights:

$$X = \frac{\sum_i^n (X_i \times w_i)}{\sum_i^n w_n}$$

Where

X = the aggregate value

X_i = value of each indicator

W_i = weighing factor for indicator i

n = number of indicators.

Aggregation is meaningful only if the indicator values are calculated correctly and the vulnerability increases in the right direction.

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