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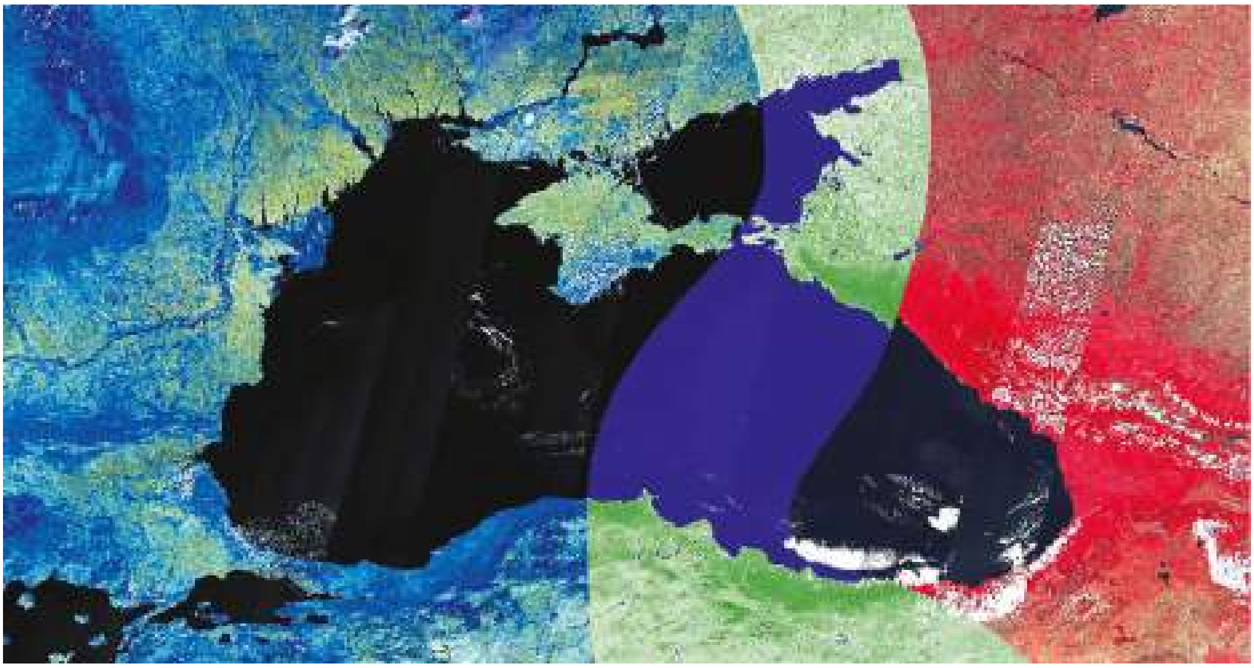

AGRICULTURAL WATER BALANCE, WATER PRODUCTIVITY, AND WATER STRESS INDICES

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List of Abbreviations

CBC	Cross-Border Cooperation
CCSM4	The Community Climate System Model
CIA	Central Intelligence Agency
CO_2	Carbon dioxide
CWR	Crop Water Requirements
DSS	Decision Support System
EEA	European Environmental Agency
ENI	European Neighborhood Initiative
EU	European Union
EUWI+	European Water Initiative Plus
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information Systems
HPP	Hydropower Plant
ISO	International Organization for Standardization
IWMI	International Water Management Institute
MSAVI	Modified Soil Adjusted Vegetation Index
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NGO	Non-Governmental Organization
NRW	Non-Revenue Water
RAW	Readily Available Water
RCP	Representative Concentration Pathway
SRES	Special Report on Emissions Scenarios
TAW	Total Available Water
UNCCD	United Nation Convention to Combat Desertification
USA	United States of America
USAID	United States Agency for International Development
USSR	Union of Soviet Socialist Republics
WFN	Water Footprint Network
WP	Water Productivity
WRI	World Resource Institute
WUA	Water User Associations

INTRODUCTION

It is well known that water scarcity stands as one of the most important limiting factors of agricultural sector optimum production (Zamani et al., 2019; Linker et al., 2016). According to the latest reports, irrigation is accountable for the 51.4% and 59% of the total freshwater consumption in USA and EU respectively (EEA, 2019; Maupin et al., 2014), whilst a further increase up to 30% is expected in the water demand on the agriculture sector by 2030 (Beddington, 2009). Additionally, the impact of the ongoing climate change on the rainfall events severity is expected to result in a substantial loss of water through runoff, deteriorating the status of the groundwater resources, with a parallel increase in the irrigation water requirements by up to 70-90% until 2050 (Resende et al., 2019; Li et al., 2018).

Coastal river deltas and the areas in the broader area around them, serve usually as major places of intensive agriculture exploitation, industry, and commerce (Loucks, 2019). Consequently, the pressure that is imposed to these complex and sensitive areas by the daily human socioeconomic activities, resulted in their degradation by e.g., salinity intrusion in coastal areas (Nguyen et al., 2019; Rahman et al. 2019), leaching of nutrients (nitrogen, phosphorus) (Mai et al., 2010), and pesticides and herbicides substances from the agricultural land into the river delta (Papadopoulou-Mourkidou et al., 2003; Vryzas et al., 2009; Vryzas et al., 2011). Moreover, the climate change extremes and the expected sea-level rise, in combination with coastline erosion impose a further threat to these systems (Loucks, 2019).

Recent studies have shown the potential of crop models to be used as irrigation scheduling tools, contributing to the rational use of the available water resources, securing the agricultural sector sustainability and increasing its resilience in the ongoing changes (Tsakmakis et al., 2017; Pereira et al., 2020). However, crop models have an innate certain level of uncertainty, due to the differences among crop cultivars and potential divergence in plants' response to different soils and climate conditions. New generations of low-cost and reliable meteorological stations and soil moisture sensors (that can be monitoring the climate conditions and soil moisture almost in real time), in combination with the advances in satellite remote sensing images in terms of temporal and spatial resolution, promise to ameliorate the crop models uncertainty via an operational in season correction and re-adjustment (Tsakmakis et al., 2021).

However, one of the main drawbacks of the crop models is that most of them perform point-based simulations (Tenreiro et al., 2020). This fact renders their value for region level estimations limited. To bridge this gap some researchers proposed and studied the coupling of crop models with hydrological models (e.g., Hydrus) (Siad et al., 2019). Nevertheless, this approach requires a lot of input data to feed into the hydrological model, making its wide implementation difficult. On the other hand, the contemporary developments in remote sensing imagery, allowed the upscaling from single point modeling into regional scale calculations, by exploiting the spatial distribution of vegetation indices (e.g., Normalized Difference Vegetation Index, NDVI) within the region (Bellón et al., 2017; Han et al., 2020). The acquired remote sensing images in combination with in-situ observations and advanced programming techniques (e.g., deep learning) allow the production of reliable regional crop maps (Frolking et al., 2002; Kussul et al., 2017; Wardlow and Egbert, 2008).

This deliverable of PONTOS project aims to (a) calculate the water use by the agricultural sector in the study area; (b) calculate and propose water productivity benchmark values for most popular and water demanding crops; and (c) estimate the potential annual water stress level that is induced by the farmers to the crops. The ultimate objective of the proposed methodology is to provide a dynamic, functional tool that could contribute to the rational use of the available water resources from field to watershed level.

In this report, the Armenian study area is presented and characterized from an agricultural and water balance perspective, as well as the methodology of the study and the results of its application discussed.

Author of this report would like to thank Valeria Kormysh, an intern who prepared the first chapter summarizing key definitions regarding the agricultural water balance, water productivity, and stress indices.

1. Agricultural Water Balance, Water Productivity, and Water Stress Indices: Key Definitions

Under the European Union's ENI CBC Black Sea Basin Programme "PONTOS", the following work aims to be an introduction of one the most contemporary relevant topics researched in climate change studies: the relationship between water, climate change and crop production. Moreover, this research wants to present to the reader possible methods, models and technologies against climate change, especially related to agriculture and crop production like the *AquaCrop* model developed by FAO. To review all the topics mentioned, this work is characterized by a methodological structure that includes a brief study on water-related terminology (Chapter 1.1) in order to offer to the reader a more accurate understanding of water-related vocabulary and acquire the ability to distinguish the most used terms of water phenomena and climatic situations characterized by limited water availability. In Chapter 1.2 of this research we present a first acquaintance on the relationship between water-issues and their use in the agriculture sector and the impact of climate change on cultivation and productivity. Moreover, modern technological solutions would be analyzed as the *AquaCrop* model from FAO, able to simulate the yield response of herbaceous crops to different weather conditions and is particularly well suited in settings where water is a key limiting factor in crop production. Also, examples of this model application will be provided by analyzing its application in PONTOS countries´ pilot areas (Armenia, Georgia, Greece and Ukraine). In conclusion, Chapter 1.3introduce to the reader the notions of *"mitigation"* and *"adaptation"* related to climate change, actions with the aim to manage climate risks and taking advantage of any positive opportunities that may arise.

1.1 Assessment-related Terminology

In our daily language there are many expressions that want to indicate those phenomena in which there is a negative disproportion between the availability of water for use and the fulfillment of the needs that require a certain amount of it. We read and heard indifferently about drought, water scarcity, water emergency, desertification etc.. However, these expressions in technical language are not all synonyms but refer to phenomena that are different in character and etiology. Distinguishing and defining precisely , as far as possible, these terms is not just a mere linguistic exercise, but represents an important prerequisite in order to identify the necessary measures and actions to be implemented to deal with water-related information in a more accurate manner.

In the past decades, the technical-scientific field has developed many indices, studies and methodologies to effectively evaluate water resources vulnerability but there was not created a univocal, universally accepted definition of water-phenomena. For different experts and organizations (Wang et al., 2021; CEO Water Mandate, 2014; Mariani et al., 2018) in order to be able to create a more cooperative and productive research environment, the scientific community should define an essential terminology in order to monitor and assess water-related challenges. This paragraph will present the main definitions for water availability phenomena by analyzing and selecting the main technical vocabularies from academic and scientific related literature of high cited publications.

One of the main conceptual debates that a great number of experts (White, 2014; Distefano, 2017; Wang 2021) have noted is that there is no widely accepted definition for "water scarcity", "water stress", and "water risk" terms that are regularly used by the media, government reports, NGOs, international organizations as well as in the academic literature, to highlight areas where water resources are under pressure. Comparing different studies and authors like the CEO Water Mandate (2014), Zingaretti (2013) and Mariani (2018) that were specifically analyzing the differences between different water terminology and methodology with the aim of reaching a broad conceptual agreement, this research find that their main definitions of water “scarcity”, “stress” and “risk” seem to converge and offer to the reader a reliable understanding of the phenomena. Moreover, to achieve a more broad understanding of the main terminology of water-vulnerability terms the concepts of “water consumption”, “water withdrawal”, “drought”, “desertification” and “water footprint” will be explained.

- *Water scarcity*

“Water scarcity” is a condition determined by anthropogenic (Mariani, 2018: 12) or human-driven (CEO, 2014: 4) factors and it refers to the volumetric quantity of freshwater resources and to the function of the volume of human water consumption relative to the volume of water resources in a given area. The “scarcity” term wants to indicate the imbalance that arises from an overuse of water resources, caused by consumption being significantly higher than the natural renewable availability (Schmidt, Benítez, 2013). Also, it indicates the physical abundance of fresh water rather than whether that water is suitable for human use (CEO, 2014). As a matter of fact, a territory that may have abundant water resources and thus not be considered water scarce but, at the same time, have such severe pollution that those supplies are unfit for human or ecological uses.

- *Water stress*

By *“Water stress”* refers to a condition of excessive water withdrawal compared to the natural availability of the renewable water resource therefore, it represents the lack of freshwater for the human and ecological demand. Compared to scarcity, “water stress” is a more inclusive and broader concept because it consider several physical aspects related to water resources, like water availability, water quality, and the accessibility of water (i.e., whether people are able to make use of physically-available water supplies), which is often a function of the sufficiency of infrastructure and the affordability of water, among other things. The particular feature of the water stress concept is that it is assessed differently depending on societal values. For example, societies may have different thresholds for what constitutes sufficiently clean drinking water or the appropriate level of environmental water requirements to be afforded to freshwater ecosystems, and thus assess stress differently (CEO, 2014).

In short, water scarcity is considered as a lack of physical abundance of freshwater resources but without considering whether water is suitable for use, and water stress as a lack of ability to meet human and ecological demand for freshwater, in terms of water quantity and quality and accessibility to water.

- *Water risk*

“Water risk” refers to the possibility for a specific entity (ex. business, local community, manufacturing chain, government, etc..) to experience water-related threats (ex.flooding, water scarcity, infrastructure decay, drought). The extent of danger is a function of the likelihood of a specific challenge occurring and the severity of the challenge’s impact. The main characteristic of water risk is that it is defined and interpreted differently by each sector of society and the organizations within them. Thus, is measured at a micro level because its values and characteristics are interpreted differently in every new context it's analyzed. Many water-related conditions, such as water shortage, pollution, bad governance, inadequate infrastructure, climate change and others create risks for many sectors and different organizations simultaneously. This condition is also referred to as “shared water risk” (Baleta & Winter, 2017) that suggests that different sectors of society have a common interest in understanding and addressing

shared water-related challenges. However, some contest the appropriateness of this term on the basis that risk is felt uniquely and separately by individual entities and is typically not shared, per se (CEO, 2014:6).

- *How "water scarcity", "water stress", and "water risk" are related one to another:*

"Water scarcity" is an indicator of a problem with water availability where there is a high ratio of water consumption to water resources in a given area, thus is one aspect of many that contribute to and inform *"water stress."* Water availability, water quality, and water accessibility are the three components that are compromised by water stress. Scarcity and stress both directly inform one's understanding of risks due to basin conditions (Schulte, 2014). Companies and organizations cannot gain robust insight into water risk unless they have a firm understanding of the various components of water stress (i.e., availability, quality, accessibility), as well as governance and other non-water-related-stress factors.

- *Different definitions of water scarcity and water stress*

As this work previously mentioned, different studies and researches used the terms "scarcity" and "stress" interchangeably, and one of the objectives of this work is to distinguish their meaning and use. Also, we stressed that there is not a universally agreed definition of "water stress" and "scarcity". Taking into consideration that, the following paragraph has the objective of showing the most highly cited definition of the notion of water stress and scarcity that are summarized in the *tab. 1* and *tab. 2* of this section. The criteria of selection is based on the most cited definitions in the academic literature of water-vulnerability topics, which reflects how different authors understand the severity of the water challenges[1], the nature of the challenges[2] and their causal relationship[3].

Table 1. Highly quoted definitions and conceptions of "water scarcity"

Who?	Term	Definition	Reference
European Environmental Agency	Water Scarcity	Water scarcity occurs where there are insufficient water resources to satisfy long-term average requirements.	European Environmental Agency

[1] Some existing definitions think of "scarcity" and "stress" as different degrees of the same challenge. For example, under the Falkenmark Indicator, an area is thought to reach water stress when per capita water availability is below 1,700 cubic meters per person per year (based on an estimation of human water requirements), and to have reached scarcity when per capita water availability is below 1,000 cubic meters per person per year (CEO, 2014: 10).

[2] Others think of scarcity and stress as challenges that are distinct in nature (even if slightly) and consider different factors. For example, according to the European Environment Agency, scarcity refers to "long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system", whereas stress occurs when "the demand for water exceeds the available amount during a certain period or when poor quality restricts its use" (CEO, 2014: 10).

[3] Others conceptualize water stress as the effects of water scarcity. For example, FAO AQUASTAT considers water stress to be "the symptoms of water scarcity or shortage, e.g. widespread, frequent and serious restrictions on use, growing conflict between users and competition for water, declining standards of reliability and service, harvest failures and food insecurity." (CEO, 2014: 10).

FAO	Water Scarcity	A shortage of water supply of an acceptable quality; low levels of water supply, at a given place and a given time, relative to design supply levels.	FAO AQUASTAT
Water Footprint Network	Blue Water Scarcity	The ratio of blue water footprint to blue water availability where blue water Link availability is equal to natural flows minus environmental water requirements.	Water footprint Network
Water Footprint Network	Green Water Scarcity	The ratio of green water footprint to green water availability.	Water footprint Network
Falkenmark indicator	Water scarcity	The fraction of the total annual run-off available for human use.	Global Water Forum
CEO Water Mandate	Water scarcity	The volumetric abundance, or lack thereof, of freshwater resources.	CEO Water Mandate
International Organization for Standardization (ISO)	Water scarcity	Extent to which demand for water compares to the replenishment of water in Link an area, e.g. a drainage basin, without taking into account the quality of water.	ISO 14046
International Water Management Institute (IWMI)	Water Scarcity	Approach that includes a critical ratio of countries that are predicted to be unable to meet their water demand without investment in water infrastructure and efficiency as economically water scarce; and countries predicted to be unable to meet their future demand, even with such investment, as physically water scarce.	International Water Management Institute (IWMI)
International Water Management Institute (IWMI)	Water Poverty Index	This approach attempts to take into account the role of income and wealth in determining water scarcity by measuring: the level of access to water; water quantity, quality, and variability; water used for domestic, food, and productive purposes; capacity for water management; and environmental aspects.	Natural Resources Forum (UN)

Table 2. Highly quoted definitions and conceptions of "water stress"

Who?	Term	Definition	Reference
European Environmental Agency	Water Stress	Water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use.	European Environmental Agency
FAO	Water Stress	The symptoms of water scarcity or shortage, e.g. widespread, frequent and serious restrictions on use, growing conflict between users and competition for water, declining standards of reliability and service, harvest failures and food insecurity.	FAO AQUASTAT
Vanham, D., et al. (2018)	Blue water stress	The ratio of total fresh water withdrawn by all sectors to the water availability (total renewable freshwater resources minus environmental flow requirements) in a particular country or región.	Science of the total environment
Pfister's definition	Water Stress	A logistic function of the ratio of total annual freshwater withdrawals to hydrological availability, and water stress ranges from 0 to 1.	Assessing the Environmental Impacts of Freshwater Consumption in LCA
WRI AQUEDUCT	Baseline water stress	The annual water withdrawals divided by the mean of available blue water. Baseline water stress measures the level of competition for available water, and estimates the degree to which freshwater availability is an ongoing concern.	World Resource Institute

- *Water consumption and withdrawal*

Another component that is essential to provide meaningful information on the relative extent of water "stress" is the difference between water consumption and water withdrawal. With the term *"water withdrawals"* we refer to the volume of freshwater extracted from a surface or groundwater source, without accounting for how much is returned to the freshwater source after use (Kohli et al., 2010). Furthermore, it is important to stress that the water withdrawn rarely returns the source in perfect condition after being used by industry, agriculture, as well as by other users, and the change in quality contributes to raising water impact levels.

With *"water consumption"* we refer to the volume of water that is extracted from a freshwater source and not returned to that source after use (CEO, 2014). Water is consumed due to evaporation or being incorporated into a product. Also, water consumption estimates help measure the impact of water use on downstream water availability and are essential for assessing water shortages and shortages at the river basin level, including impacts and on aquatic ecosystems.

Finally, understanding whether the volume of "withdrawals" exceeds available water resources in a given area, sheds light on whether this is enough water to meet human and ecological demand, thus the usefulness of both "consumption" and "withdrawals" is in understanding the total water "stress".

- *Drought and Desertification*

Drought and desertification are global environmental problems affecting developed and developing countries. They are accompanied by the reduction in the natural potential of the land, the depletion of surface and groundwater have negative repercussions on the living conditions and the economic development of the people are impacted by it (Abahussain et al., 2002). Drought and desertification processes integrate climatic elements with human activities in transforming productive land, into an ecological impoverished area generally referred to as desert (Olagunju,2015).

According to the United Nation Convention to Combat Desertification (UNCCD), *"desertification"* is land degradation in arid, semi-arid and humid areas resulting from various factors, including climatic variations and human activities (UNCCD, 2008). The climate affects the chemical and biological deterioration of the soil and conditions water and wind erosion. The state of the soil (texture, structure and chemical and biological properties) is the major vulnerability factor, particularly in the dry sub-humid zones where the influence of climatic factors is less predominant.

With the term "*droughts"* we refer to the natural and temporary meteorological condition in which, for a sufficiently long time and over a large geographical area, a significant reduction in the amount of precipitation happened. This condition determined significant negative effects on the environment and on the economic activities. It is a natural phenomenon linked to the variability of climatic conditions, in particular of precipitation, and can be considered a magnet (Mariani, 2018).

The relations between desertification and drought on the one hand, and human influence on the other, are unknown and complex. Occasional droughts (due to seasonal or inter-year variations in rainfall) and long-term severe droughts can both be caused or aggravated by the influence of man on the environment (the reduction in vegetation cover, the changes in the local climate, the greenhouse effect, etc.). Human activities can, therefore, accelerate desertification and aggravate its negative consequences on people (FAO).

- *Water Footprint: blue, green and gray water*

Other main terms in the quantitative assessment of water security are the concepts of blue, green and gray green water. As noted by different researchers (Wang et al., 2021; Munoz Castillo et al., 2017) still nowadays many studies around water availability don't make any difference if during their analysis they are focusing only on the stress induced by one source of water or they are also considering different forms of water available in that area.

With the term *"blue water"* we refer to water that has been sourced, withdrawn and/or consumed from surface and groundwater resources. Furthermore, blue water is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time (Hoekstra, 2011: 2). Meanwhile, the term *"green water*" refers to water that is stored in the root zone of the soil by precipitation and then evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products (Hoekstra, 2011), is very important for crop production, the ecosystem and grazing lands. Last, we refer as *"gray water"* to the volume of freshwater that is required to assimilate the load of pollutants in order to meet existing ambient water quality standards.

Moreover, blue, green and gray water are of main importance when we use the *“water footprint”* indicator, which can be considered as a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal. Its main purpose is the calculation of the volumetric use of freshwater used for the creation of a product over the full supply chain. It's a multidimensional measurement showing water consumption volumes by source and polluted volumes by type of pollution. All components of a total water footprint are specified geographically and temporally. The water footprint indicator offers a better and wider perspective on how a consumer or producer relates to the use of freshwater systems.

The local environmental impact of a certain amount of water consumption and pollution depends on the vulnerability of the local water system and the number of water consumers and polluters that make use of the same system. Water footprint accounts give spatio-temporally explicit information regarding how water is appropriated for various human purposes. They can feed the discussion about sustainable and equitable water use and allocation and also form a good basis for a local assessment of environmental, social and economic impacts.

In general, blue water resources are generally scarcer and have higher opportunity costs than green water, so that may be a reason to focus on accounting the blue water footprint only. However, green water resources are also limited and thus scarce, which gives an argument to account for the green water footprint as well. Besides, green water can be substituted by blue water – and in agriculture the other way around as well – so that a complete picture can be obtained only by accounting for both. The argument for including green water use is that the historical engineering focus on blue water has led to the undervaluation of green water as an important factor of production (Falkenmark, 2003; Rockström, 2001). The idea of the gray water footprint was introduced in order to express water pollution in terms of a volume polluted, so that it can be compared with water consumption, which is also expressed as a volume (Chapagain et al, 2006b; Hoekstra and Chapagain, 2008). If one is interested in water pollution and in comparing the relative claims of water pollution and water consumption on the available water resources, it is relevant to account the gray in addition to the blue water footprint.

- *The Life Cycle Assessment* (LCA) & *The Water Footprint Assessment* (WFA)

The Life Cycle Assessment is an analytical and systematic methodology that evaluates the environmental footprint of a product or service, along its entire life cycle. The calculation ranges in fact from the phases of extraction of the raw materials constituting the product, to its production, its distribution, use and its final disposal, returning the environmental impact values associated with its life cycle. Similarly, through LCA techniques, the environmental footprint of a service can be calculated, accounting for the footprint of everything needed for the provision of that same service. At the end of the calculations, the environmental footprint value of a product / service is thus returned according to different "impact categories", which represent all the different impacts that this generates in the various environmental sectors (Iyyanki et. al, 2017)

The relevance of LCA techniques lies mainly in their innovative approach, which consists in being able to evaluate all the phases of a production process as related and dependent: among the tools created for the analysis of industrial systems, LCA has therefore taken on an important role in recent years and is growing strongly in terms of national and international technical uses. The water footprint Assessment (WFA) is the fraction of the impacts analyzed in the LCA system which are related to water. They include impacts associated with water use, and the subsequent effect on water availability for humans and ecosystems, as well as direct impacts on the water resource and its users from emissions to air, soil and water. These later are quantified using the traditional LCA impact categories (Hoekstra, 2011).

The Water Footprint is a geographically explicit indicator, which indicates not only the volumes of used or polluted water, but also the place where this occurs. The water footprint is an innovative concept that allows you to analyze the water consumption and the pollution phenomena that develop along the production chains, to evaluate the sustainability of water uses and identify where and how can best be done to reduce the use of water.
On the concept of water footprint and on the calculation methodologies introduced by Professor Arjen Hoekstra builds the Water Footprint Network (WFN) a non-profit foundation, established in 2008. This is basically an international dynamic learning network. The WFN proposes itself as a connecting platform for different actors (private sector, non-governmental sector, governments, the United Nations and dissemination centers of the knowledge) interested in sustainability, equity and efficiency in use of water.
The application of the concept of virtual water allows us to discover that the water we consume is actually much more than what we see flow before our eyes for domestic uses; most of us
it ignores, in fact, that immense volumes of water are involved in our activities daily, primarily in food production.

- *Conclusion*

The terminology used to refer to different aspects of water challenges has evolved over the past decades like the social and economic demands of our world where water started to be a precious resource, and its quantity and quality is disputed between different users. Water challenges like scarcity and stress are relative and dynamic concepts, and can occur at any level of market supply or civil demand, but they are also social constructs: its causes are all related to human interference with the water cycle. For example, nowadays the focus of water-vulnerability studies link the social demand created by the population growth as a way to measure gaps in water availability (Brown, 2011). Actually, the continuous increase of domestic water withdrawals and demands led to the recognition of the importance of water for ecological sustainability.

Water-related challenges can be expected to intensify with most forms of economic development, but, if correctly identified, many of its causes can be predicted, avoided or mitigated. For example, the next paragraph of this work is going to explore how agriculture and the primary sector can impact the water phenomena, especially water stress and scarcity and the scientific developments to control and manage the impact of agriculture on water vulnerability.

1.2 Agricultural Water Stress

Nowadays, agriculture is the sector where water vulnerability has the greatest relevance, since it accounts for 70 percent of global freshwater withdrawals and more than 90 percent of its consumptive use (FAO, 2017). One cause linked to the increasing demand of agricultural products is the fact that in the last decades world's population has grown very fast, in particular in developing countries where people also started to have new demands on their diet including more variability, more meat and dairy products. This situation is putting additional pressure on water resources (Steduto, 2012) and by different studies of FAO (2009; 2017) it is expected that 60 percent more food will be needed between now and 2050 to satisfy the demand of an eventual population of more than 9 billion people.

In general terms, agricultural water use is increasing the severity of water scarcity in many areas of the globe, and causing water scarcity even in geographic spaces that are relatively well endowed with water resources. Agriculture, and in particular irrigated agriculture, is undergoing rapid changes and facing both old and new challenges. Farmers across the world have to adapt to a world where trade and globalization have rapidly increased interconnection and interdependence between people's production and consumption patterns, and where technological progress has boosted agricultural productivity. The green revolution and subsequent progresses in agronomy have helped agricultural production outpace population growth and feed an ever-increasing number of people with ever more diversified food of increasing quality. But it has also come with a large environmental cost (Steduto, 2012).

The current global environmental situation, the diminution of natural water resources, the recent and sudden climate changes are causing an atypical impact on the territory and consequently on the productivity of cultivated plants. The consequence of water vulnerability in agriculture lies in the biological productivity in climatically arid areas that have important consequences like: erosion, soil degradation, salinization, deforestation and loss of biodiversity. Global climate change is a significant factor in the reduction of agricultural productivity causing a decrease in the growth period, extreme meteorological events during the phases of the reproductive cycle, heavy rainfall during planting, heat stress during flowering and long dry periods.

Furthermore, the lack of water can lead to further stress due to the increase in soil salinity which limits the productivity and growth of cultivated plants (Shrivasta, 2015). At a physiological level, plants suffer three main types of damage: osmotic, nutritional and toxic. The first one is linked to the water potential of the soil that causes a reduction in cellular turgor which leads to alteration of metabolic processes and inhibition of growth; The nutritional stress on the other hand, is determined by competition ionic in the processes of absorption at the root level and finally the toxic damage that affects both the functionality of the membrane by altering its permeability and transport; Finally, the enzymatic activities damaging metabolic processes such as photosynthesis and respiration. Therefore, it can be noted that the growth and productivity of crop plants largely depend on their vulnerability to environmental stresses. High salinity, absence of water and high temperatures are the major stressful conditions that limit agricultural production.

Plants respond to these stresses through a set of biochemical and physiological adaptations, involving the functions of many stress-related genes. Any attempt to improve stress tolerance requires a better understanding of fundamental physiological, biochemical and molecular events (Lisar, 2012). In the last decades, various approaches have been tested, for the production of tolerant plants, through the use of classical genetic methods but also by improving cultivation techniques like the AquaCrop Water Productivity Model developed by the Land and Water Division of FAO.

- *Using the AquaCrop for Evaluation of Water Productivity and Stress*

Given the importance of water for agriculture and food production, and the dominant role of agriculture in global water withdrawal, FAO has undertaken a review of its water programme in order to propose a more effective and more strategic response to the growing issue of water scarcity. AquaCrop model simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production (FAO) and provide advanced methodology for calculation the crop water requirements and the irrigation
scheduling. The development of the AquaCrop model has gone through several phases: its conceptual design, its implementation in a software product, the various functional checks, the calibrations and validations in different environments and for different crops, the improvements of the initial algorithms, and the development of a simple and intuitive user interface. The model consists of four modules: climate, soil, crop and management that through an analysis of the AquaCrop software can provide an optimization of the management of the crops, develop an effective irrigation strategy and make comparison and prediction of current and potential yields.

The first module, *climate*, has five input variables: maximum and minimum atmospheric temperature, rainfall, evaporative demand from the atmosphere (ETo), and the average annual concentration of carbon dioxide (CO2) in the atmosphere. The *soil* module, with its water balance, is configured by the user by indicating up to a maximum of five horizons of variable depth, each with its own texture. Also, the soil profile is explored by the roots, the model calculates the soil water and salt balance. The *crop* module, with its development, growth and yield, is represented through its phenology, the growth of the canopy cover (expressed by the percentage of vegetation that cover the soil), the rooting depth, the accumulation of biomass, the harvest index and the final production. Finally, the *management* is expressed through its major agronomic practices such as the control of the field-surface practices (mulching; soil bunds), fertility level, irrigation method and level and fertilization.

AquaCrop separates soil evaporation from transpiration and simulates the accumulation of biomass over time as a function of transpiration water, using the 'water productivity' (WP) parameter. The model is able to show the main components of the soil–plant–atmosphere and the parameters driving phenology, canopy cover, transpiration, biomass production and final yield. The main features that distinguish AquaCrop from other crop models are:

- the emphasis of the crop response to water with crop-specific parameters;

- the relatively small number of parameters and variables;
- is aimed at practical end-users, it gives particular attention to the fundamental processes involved in crop productivity and in the responses to water, from a physiological and agronomic background perspective.
- the use of the ‘water productivity' (WP) values, normalized for atmospheric evaporative demand and of carbon dioxide concentration, that gives to the model a great versatility in being used in different environments and seasons;
- the model is intuitive and maintains an optimal balance between accuracy, simplicity and robustness, and can be used as a planning or management tool;

An important application of AquaCrop is represented by the comparative analysis between obtainable and actual productivity which allows to identify the causes of any difference between the two productivity. Furthermore, the model lends itself very well to prospective studies such as the impact of climate change on crop productivity.

- *AquaCrop and the impact of climate change*

The impact of climate change on crop production consists of different elements. Some of these can be assessed with the AquaCrop model, while other components require other scientific approaches. Regardless, the impact of climate change on crop production that are assessed using the AquaCrop model are:

- Changes in precipitation;
- Changes in crop water demand due to changes in reference evapotranspiration;
- Changes in crop base & upper temperature;
- Changes in irrigation applications.

Other impacts of climate change on crops that require a more details and expert-view approach are:

- Impact on pest and diseases;
- Impact on weeds.

With the objective to provide a more empirical understanding on how AquaCrop model works against water stress issue in crop productivity in the following section this research will provide some examples on how this model was used in different pilot areas of PONTOS partnership countries (Armenia, Georgia, Greece and Ukraine). The objective of showing the AquaCrop model, being able to adapt its functions and data management under distinct weather and soil conditions and for different crop productions.

- *AquaCrop in Armenia*

Armenia is a mountainous, landlocked country in the Caucasus, covering an area of 29 800 km^2 and an estimated population of 2.97 million (2018), The climate is continental with hot summers and cold winters. The country has 2.974 million ha of land, of which 2.043 million ha is considered agricultural land (0.69%). The total area of arable land is 446.0 thousand ha (21.8% of agricultural lands), out of which 68.1 thousand ha is concentrated in Ararat valley (15.2 %). More than 57 percent of agricultural land in Armenia is pastures and meadows (FAO, 2021).

Agriculture is one of the most important sectors of the national economy, representing 11,72 percent of the national GDP (2021) and giving work to approximately 30 percent of the population (US Trade, 2021). Although approximately 70 percent of Armenia's territory is classified as agricultural land, arable land represents only 15 percent of the total territory. Agriculture is carried out mainly in the valleys and mountain sides of Armenia's uneven terrain, with the highest mountain pastures used for livestock grazing. Fertile volcanic soil allows cultivation of wheat and barley as well as pasturage for sheep, goats, and horses. With the help of irrigation, figs, pomegranates, apricots, and olives also are grown in the limited subtropica Aras River valley and in the valleys north of Yerevan, where the richest farmland is found. Irrigation is required by most crops, and the building of canals and a system of irrigation was among the first major state projects of the Soviet republic in the 1920s.

Agricultural production is heavily biased toward crops, which in 2006 accounted for 64% of gross agricultural output. The principal agricultural products are grains (mostly wheat and barley), potatoes, vegetables, grapes (both table and wine), and fruits.

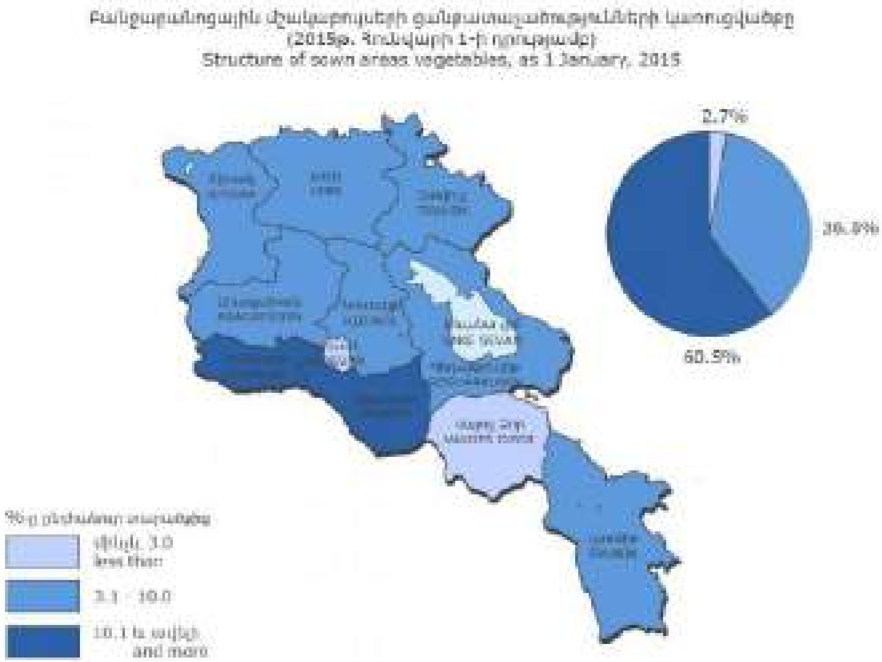

Figure 1. Sown Areas of Armenia, provided by the Ministry of Agriculture of the Republic of Armenia

The AquaCrop model was implemented in selected fields in Ararat Valley with tomato, cucumber, watermelon and table grapes. The climate data were taken from Armavir, Artashat and Ararat Meteorological Stations located inside the area of the Valley. The climatic data received from the stations for each day in the period 1980-2019 was sufficient to calculate the Crop Water Requirements (CWR) and the irrigation scheduling of selected crops fields, using the formulas provided in FAO Irrigation and Drainage Paper 56 and for use in the AquaCrop model. In addition, it was demonstrated that AquaCrop has a capability to estimate the crop yield based on different climate change scenarios and location of crops as latitude and elevation.

In order to calculate the CWR and the Irrigation Scheduling the soil-water characteristics were also needed. In Ararat Valley the soil data used for the AquaCrop model has been supplied in the form of GIS maps which can be opened with QGIS and ArcGIS software applications. There were identified three kinds of soils present in the geographical area: Meadow, Solonchak/Solonetzes and brown podzolic soils.
The crops and yield response as developments and yield depends on the way the soil surface is maintained and on the soil fertility. AquaCrop allows the user to input data, set parameters and view the data.

Figure 2. (AquaCrop - window to set Field management description)

To start the moisture balance in the soil, AquaCrop needed the data of the initial moisture of soil at the start of the growing season of crops. For the case of Ararat Valley, for all soils and locations, it is assumed by the module analysis that the initial moisture of the soil is 73 percent of TAW (Total Available Water = Field Capacity – Permanent Wilting Point)

Calculation of Crop Water Requirements and Irrigation Scheduling in Ararat Valley has been carried out for the pilot crops: Tomato, Cucumber, Watermelon and Table Grapes. For each crop adequate irrigation method has been considered:

- For tomato: furrow, drip and sprinkler methods;

- For cucumber, watermelon and table grapes: furrow and drip methods.

At the end of the simulations, AquaCrop was able to offer the best irrigation options for the selected crops that are recommended to replace the existing outdated norms in the Manual *"Irrigation Norms and Regimes of Agricultural Crops for Irrigated Lands in the Republic of Armenia, 2007"*.
The new suggestion made by the model would reduce the water consumption for agriculture by 1 - 3 norms (doses) representing 10 - 30% of total yearly irrigation requirements without affecting the yield of the valley´s crops by more than 3 - 5 percent (FAO, 2021a). Besides that, AquaCrop takes into consideration more detailed soils and crop characteristics (in comparison with the previously used models) and utilizes the most reliable crop coefficients for calculation of evapotranspiration. The "Updated Irrigation Norms", creade taking into consideration AquaCrop results, should reflect the model´s research in the valley and are expected to better suit crops needs and to allow water saving.

Lastly, the AquaCrop model was able to predict the water requirements in case of Climate Change at the level of year 2050 for the same crops analyzed in Ararat Valley. It was calculated that with the same soil and underground water level the crop water requirements would need at least three or more irrigation applications each year. The good effect related to Climate Change is the increasing of the crop yields by 30 - 40% due to increased content of CO_2 in air. The resulting reduction of water volume consumption, if applied, will substantially reduce the irrigation costs and create important water resources for irrigating adjacent areas and to increase the volume of the yields.

Considering the national case and the previous norms and manuals, they often led to over-watering the yields which resulted in higher irrigation costs and water wasting because it did not consider the crop yield and water productivity. In addition, the "Manual of Irrigation Norms" (2007) presented the irrigation norms only for furrow irrigation and it cannot be used for irrigation scheduling with more advanced irrigation systems, such as drip irrigation systems. Moreover, because of climate change, an update of the data of the irrigation regime is required and needed for long-term benefits. AquaCrop has been demonstrated to be the best methodology so far, provening to be the most advanced methodology for calculation of Crop Water Requirements and offering both manual and automatic irrigation scheduling systems. Also, the proposed reduction of water consumption, if applied, will substantially reduce the irrigation costs and create new available water sources for irrigating adjacent areas and increase the volume of the yields.

- *AquaCrop in Georgia*

Georgia is a very mountainous country located in the Caucasus at the intersection of Eastern Europe and Western Asia. It has a quite varied landscape, western Georgia's landscape ranges from low-land marsh-forests, swamps, and temperate rainforests to snows and glaciers, while the eastern part of the country even contains a small segment of semi-arid plains. It covers 69,700 Km2 and has a population of approximately 4 million people (2021). The country has different and complex climate zones. On the West coast region close to the Black Sea, the climate is humid and subtropical with mild winters, hot summers and large amounts of precipitation; while, in the mountainous parts of the region, the annual average air temperature ranges from 2 to 10°C with a minimum of -30°C to -35°C (Droogers et al., 2012). The climate in the East of the country is characterized by a plains area with a dry subtropical climate and a mountainous area that has an alpine climate.

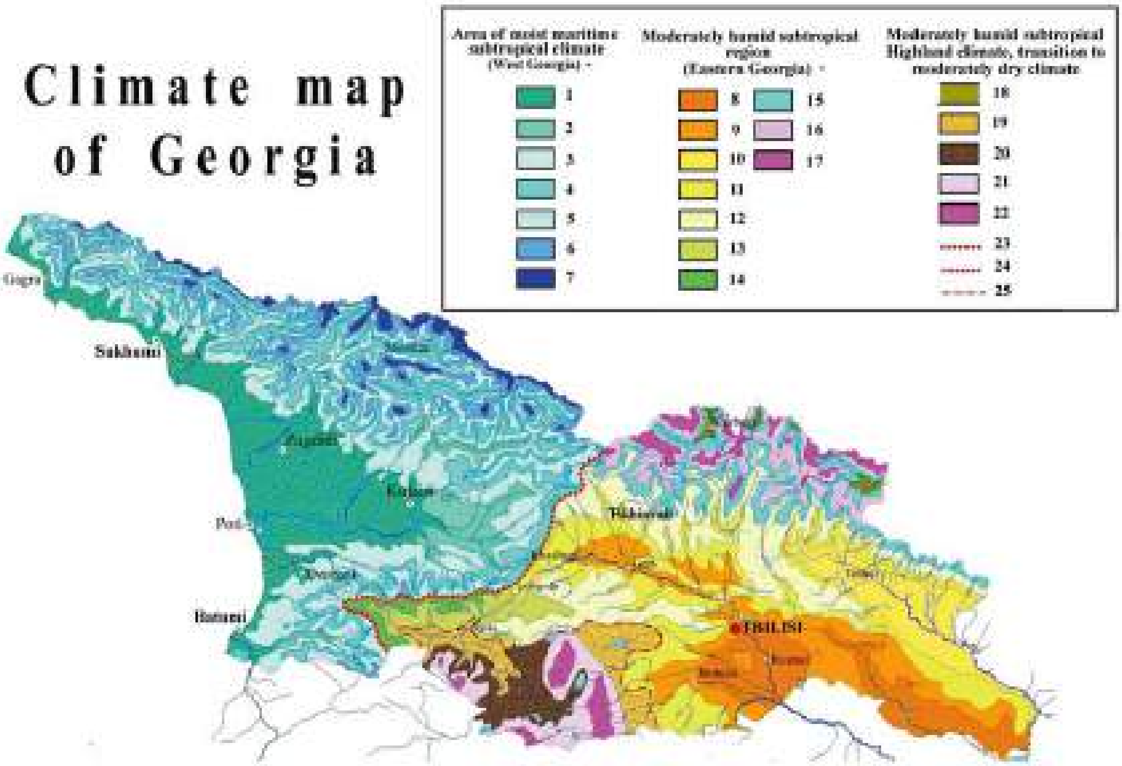

***Figure 3. Climate Map of* [*Georgia*]**

The country has 788,000 ha of agricultural land (35.5%) out of which 488,000 ha are arable (5.8%) or used for greenhouse and perennial plants, and the rest is employed for permanent pasture (27.9%). Forests cover around 40% of Georgia's territory while the alpine/subalpine zone accounts for roughly around 10% of the land.

Georgia has a wide variety of ecological and climatic zones favorable for the growth of different crops. These include cereals, early and late vegetables, melons and gourds, potato, grapes, subtropical crops, fruit variety etc. Furthermore, Georgia is one of the oldest wine producing regions of the world (FAO, 2021b). Infact, table and wine grapes are 51% of the total fruit crops produced in the country, of which 88% percent come from five sorts: grapes, apples, tangerines, peaches and nuts (Transparency International, 2020). it's very important to stress that agriculture is essential for Georgian society, in fact, it was estimated that 39% of all employees in the country work in agriculture (Transparency International, 2020) and the livelihood of 3 out of ten Georgians depends on this sector (Droogers et al, 2012).

In recent years, national agriculture has been affected by different factors such as the ongoing regional conflicts, the displacement of the labor force and, especially, the climate change. Indeed, the temperatures in Georgia have risen for all agricultural zones, and an increasing frequency of extreme heat events has already been observed in recent years. Also, the country is affected by flooding and erosion that led to US$650 million in economic losses between 1995 and 2009, and climate change is likely to increase the frequency and magnitude of flooding in this region, leading to further damages (Ahouissoussi, 2014: 97). This phenomena can delay or prevent planting of summer crops in the spring period, and during late summer, flooding can destroy the entire year's growth and prevent timely harvesting. Other climate change issues in the country include drought, frost, high winds, and hail, the last of which has been particularly damaging in recent years. The impact of all these factors is demonstrated by the decline of the share of agriculture in today's economy, representing in 2020 the 7.3 percent of the country's GDP while in 2005 it was 14.7 percent.

One of the most recent research made to assess the possible impacts of climate change on national agriculture was made by the Environmental Agency of Ministry of Environment Protection and Agriculture of Georgia using the AquaCrop model to assess the climate change impact on cereal crops (winter wheat and maize) productivity and the irrigation requirement and demands for the two main producing regions, Kakheti and Samegrelo-Zemo Svaneti for the 2050s periods (Megrelidze et al., 2021). The climate data as well as agriculture crop and soil parameters necessary to settle the modules of the AquaCrop model were taken from the database of the Georgian meteorology and agrometeorology observation network. Impact of the climate change on winter wheat productivity and water demand was assessed for the Kakheti region based on observations of the Dedoplistskaro meteorological station, and for maize, for the Samegrelo-Zemo Svaneti region based on the Zugdidi meteorological station.

For the assessment of the changes due to climate change, tendencies of crop´s yields related parameters (as growing season rainfall, carbon dioxide concentration, Infiltrated water, surface runoff, soil evaporation, crop transpiration, leaf expansion stress, etc..) were noted and irrigation water requirement were evaluated in the period 1966–2015 divided in two sub-periods were compared (1966–1990 and 1991–2015). With the aim of predicting future changes, the same indicators for the period 2021–2050 were calculated in accordance with locations and crops and compared with the first reporting period (Megrelidze et al., 2021:24). Regarding the soil, the model simulation was performed at the research territory in correspondence with the widespread main soil types. In the Kakheti region the parameters of three different soil types (Vertisols, black alkalized and natric) while in the Samegrelo-Zemo Svaneti region one type of soil (stagnic acri soils) was selected. Climate data of the period 1966–2015 were used from the database of the Georgia meteorological observation network and based on these data, favorable areas for the spread of research crops were compared in two 25-years sub-periods (1966–1990 & 1991–2015) based on agro-climatic parameters as growing degree-days, growing season rainfall and average of absolute minimum temperature.

Results showed an overall increase in cereal crop yields but also enhancement in water shortages even considering the optimum management practices under rainfed conditions. In fact, areas of the zones favorable for growing of winter wheat (where this crop can be grown in rainfed conditions) are currently increased by about 5% and will increase by up to 40% in the future and this will occur basically due to temperature growth, when growing degree-days achieve 2,100–2,200 °C at 1,200–1,500 m altitudes above sea level. Whilst the climate change has smaller effect on maize productivity, in particular: potential yields of the maize will remain quite stable from year to year, both for rainfed and irrigated agriculture and changes between the investigated periods is are insignificant

At the same time, Georgian agriculture will be negatively affected by the direct impact of temperature and precipitation changes on other different kinds of crops, such as the wine grapes, the increased irrigation demand required to maintain yields, and the decline in water supply associated with higher evaporation and lower rainfall. In fact, the phenomenon is expected to greatly decrease irrigation water availability in the country during key months for agricultural productivity. When this decline in water supply is taken into account, projected decreases in crop yields are expected to be much more substantial. Moreover, one aspect that should be stressed is that the AquaCrop model took in consideration the agro-technical measures taken against agricultural crops (such as pest and disease control, weed control, etc.) at the optimal level, which is largely inconsistent with the real situation in the country because such influences are involved in the model through soil fertility stress. Such stress was not taken into account when simulating the model, as accurate information about the above measures was not available. Thus, the real decline in yields should not only be due to changes in climatic conditions and is likely to be the result of improper exploitation of land, questionable agro-technical measures and inconsistent management. Finally, some aspects of the AquaCrop application in Georgia may require a more detailed examination because neither model not nor agro-climatic zoning approach does not take into consideration the impact of such significant factors as extreme phenomena, like floods, hail, fire risks, etc. on agricultural crop spatial distribution and productivity.

- *AquaCrop in Greece*

Greece is a country located in Southeast Europe, situated on the southern tip of the Balkans, located at the crossroads of Europe, Asia, and Africa. The country consists of a mountainous, peninsular mainland extended into the Mediterranean Sea and two smaller peninsulas projecting from it which are joined to the mainland by the Isthmus of Corinth. Greece also has many islands, of various sizes. According to the CIA World Factbook, the country has 13,676 kilometers of coastline making it the largest in the Mediterranean Basin. Moreover, It has a total area of 131,957 km2 with a population of 21 million people of which one-third of lives in and around the metropolitan area of Athens. The climate in Greece is typical of the Mediterranean climate subregion which is mild and rainy winters, warm and dry summers with, generally, long sunshine duration almost all the year. There is a great variety of climate subtypes in Greece, from the dry climate of Attiki and generally of East Greece, change over to the wet one of North and West Greece. In terms of climatology, the year can be broadly divided mainly into two seasons. The cold and rainy period lasted from the middle of October until the end of March, and the warm and non-rainy season lasting from April until September.

The agricultural land corresponds to the 63.4 percent of land of which 2.136.600 ha are arable lands (19.7%). The Greek agricultural sector suffers from a lack of many natural resources, approximately 70 percent of the land cannot be cultivated because of poor soil or because it is covered by forests. Agriculture is centered in the plains of Thessaly, Macedonia, and Thrace, where corn, wheat, barley, sugar beets, cotton, and tobacco are harvested. Also, climate change is a challenge for the national agriculture where agronomic strategies to cope with changing weather were implemented, such as, delays in the start of crop season and the use of short-duration varieties of crops or thicker sowings. For these reasons, agriculture represents only 4.1% of the national GDP and employs approximately 12% of the total labor force. While agriculture is not a thriving economic sector, Greece is still a major EU producer of cotton and tobacco and olives. As a matter of fact, Greece contributes approximately 79% of the total EU cotton production, for example, in 2015 a total area of 350,000 hectares was cultivated just for cotton, representing approximately 13% of the total cultivated land in Greece (Linker, 2015).

It was analyzed that in all Greece there is a tendency of the farmers to overuse water resources because they benefit from special prices and support from the state. This situation created an inclination of the farmers to irrigate beyond crop water needs. It is considered that typically only approximately 55% of the irrigation water is used by the crop, 12% is lost through its transfer, 8% is lost through its application and 25% is considered as excessive water, lost through evapotranspiration and surface runoff (Linker, 2015). This inefficient tendency of irrigation widely diffused in the country has led the European Union to implement different projects in order to improve the use of irrigation water via the development and implementation of irrigation strategies that take into account: soil water availability, local weather forecasts, crop physiological status and water needs in real time.

Under the EU´s project FIGARO, the AquaCrop model was implemented in a hybrid approach for optimizing irrigation in cotton cultivation in Xanthi, Northern Greece. In this model the cultivation season is split into two parts: a first one that comprehends the first five days of the crop and a second period representing the rest of the agricultural season. Accurate weather forecasts were assumed to be available for the first period, during which only one irrigation event could take place. For the second period, average historical weather data were used as long-term forecasts and rather than optimizing directly the irrigation events, the decision variables corresponded to a number of soil water levels at which irrigation would be triggered and the corresponding irrigation amounts. This hybrid approach ensured that the number of decision variables remained acceptably small so that the procedure can be computed repeatedly in real time during the season.

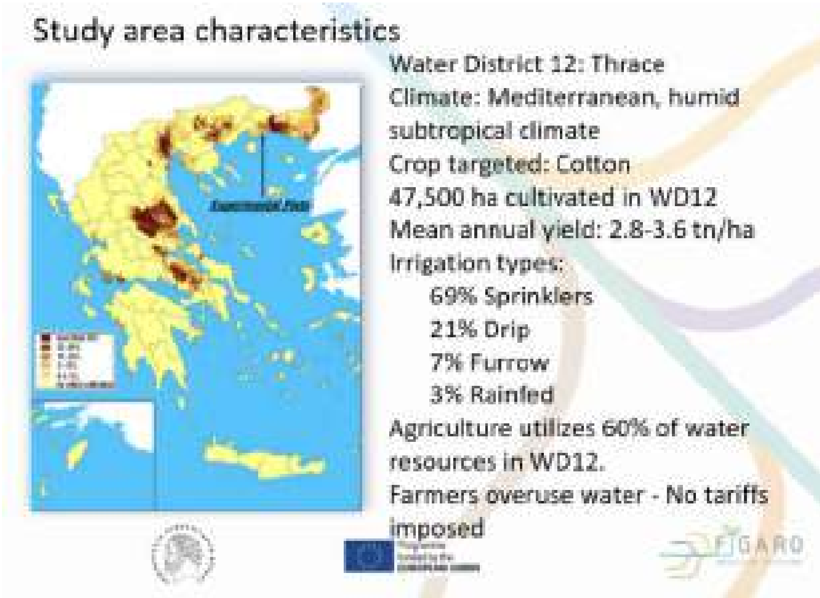

Figure 4. Greek study area characteristics

In this model the operations during the season are split into a number of periods and must specify two parameters for each period: the soil moisture at which irrigation is triggered and the amount of water to be supplied. The output of the AquaCrop simulation includes, in addition to all the variables related to crop development and soil water content, the dates and amounts of the required irrigation events. In order to estimate the cotton´s irrigation requirements, the model takes into consideration the three cotton cultivation stages (the emerge phase, the rapid growth phase and the yield formation) and the fact that during the emergence and rapid growth phases, the root zone water content should be maintained above the canopy cover expansion level. Such a policy aims at achieving a canopy cover equal to approximately 90% of the maximum at the end of the rapid growth period, thus improving the harvest index by 4-5% compared to its no-stress reference value. Also, from the beginning of the yield formation until the end of the cropping season, the total available water in the root zone should be retained roughly 25% above permanent wilting point. This way, the optimum harvest index may be achieved without a failure of pollination or any adverse effects on the green canopy cover.

The mentioned measurements have the aim to balance and solve two conflicting objectives: maximizing yield and minimizing the use of irrigation water in the cotton cultivation. This formulation has the advantage that it does not yield a single optimal solution but rather a series of solutions which are equally optimal in the mathematical sense but emphasize the trade-off between water use and yield. Splitting the season into periods during which the soil water depletion at which irrigation is triggered and the irrigation amounts are constant has the advantage that the optimization problem includes only a small number of decision variables. Unfortunately, this formulation does not provide much flexibility since the strategy remains constant during each period and future rain is not taken into account when triggering irrigation.

However, optimizing individually the amount of irrigation water for each day of the season would be prohibitive computation–wise, especially when one considers that the optimization should be repeated numerous times throughout the season. The rationale for the proposed approach is that since the long-term weather forecasts are inaccurate, one doesn't need to perform a detailed optimization of all future irrigation events but can rather optimize only the next event together with soil water content levels at which irrigation would be triggered in the future. In this fashion, the number of decision variables that need to be optimized remains acceptably small and the irrigation schedule can be computed repeatedly during the season using updated weather forecasts.

In Xanthi, this model was applied by using ten years of historic meteorological data (2004-2013) together with the cumulative daily precipitation values and the daily evapotranspiration calculated through the FAO's ETo calculator. The soil profile used in the AquaCrop simulations consisted of two soil horizons and is considered to be representative of the broader Xanthi plain area in Northern Greece. The pilot cotton field was characterized by two horizons, the first was a sandy loam layer, extending from the surface down to a depth of 30 cm, and the second horizon as a clay loam, extending from the interface to 180 cm depth.

The weather conditions of the last ten years were used to investigate three scenarios differing in terms of the weather data used in the optimization procedure:

- Scenario #1: perfect weather forecasts available for the whole season;

- Scenario #2: perfect weather forecasts available daily for the five coming days (Run #2) and historical weather data available for the rest of the season (Run #3);

- Scenario #3: only historical weather data available for future (Runs #2 and #3).

From a practical point of view, Scenario #1 is unrealistic but it provides the best achievable solutions to which the results of the other two scenarios can be compared. Scenario #2 corresponds to the case in which very reliable short-term forecasts are available. Scenario #3 corresponds to the extreme case in which no reliable short-term weather forecasts are available and one has to rely on historical data. Scenarios #2 and #3 correspond to the extreme cases which can be encountered in real-world applications. The constant improvements of short-term forecasting tools, together with the fact that the availability of these forecasts on the internet is rapidly expanding, is likely to make Scenario #2 increasingly relevant in the future. The analysis was conducted assuming that the farmer wishes to achieve a yield of 4.50 t/ha.

The results in the cotton field area showed that when perfect forecasts were assumed to be available for the whole season, recalculating the hybrid optimal solution every four days produced a final combination which was very close to the one obtained by the full optimization of daily irrigation amounts. Assuming perfect 5-day forecasts led to results which remained close to the optimality boundary: in most years, the irrigation was within 30 mm of the "true" optimal irrigation, and yield was decreased slightly or increased sometimes appreciably. On the other hand, in Scenarios #2 and #3, the almost total lack of rain during the first 2.5 months led to an expected deficit of up to 100 mm which was compensated by significant irrigation. The simulation results show that the hybrid optimization procedure developed by AquaCrop can effectively be used for optimizing irrigation scheduling. Furthermore, these results illustrate that more common strategies such as fixed irrigation amounts at regular intervals or irrigation triggered by soil water depletion lead to very significant waste of water.

- *AquaCrop in Ukraine*

Ukraine is a country in Eastern Europe and it occupies the southwestern portion of the Russian Plain (East European Plain). The country consists almost entirely of level plains at an average elevation of 175 meters above sea level. Also, it has a coastline along the Black Sea and in the far southeast, Ukraine is separated from Russia by the Kerch Strait, which connects the Sea of Azov to the Black Sea. Mountainous areas such as the Ukrainian Carpathians and Crimean Mountains account for barely 5 percent of its area. The Ukrainian landscape nevertheless has some diversity: its plains are broken by highlands running in a continuous belt from northwest to southeast as well as by lowlands.

It covers a land area of 603,550 sq km and a coastline of 2,782 kilometers with a population of 43.7 million which make it one of the most populated countries in Europe. The climate in Ukraine is mostly continental, characterized by a moderate warm and humid air coming from the Atlantic Ocean that gives warm, dry summers and fairly severe winters. Precipitation is disproportionately distributed as it is highest in the west and north and lowest close to the Carpathian Mountains, where precipitation reaches 1,200 mm (47 in) per year, while in the east and southeast precipitations are between 500 and 600 millimeter. In contrast to the rest of the country, the southern Crimean coast is characterized by a climate similar to the Mediterranean countries with long warm summers and mild rainy winters. Also, Ukraine has an extensive network of rivers, more than 73 thousand, most of which are transboundary.

The landscape of Ukraine consists mostly of fertile steppes and plateaus, crossed by rivers. Agriculture land represents approximately 70 percent of the total land, of which 56 percent is arable. Flat steppe, rich soil formed by chernozem made Ukraine an ideal area for agriculture, with agribusiness representing 9.3% of the national GDP and the employment of 14.11% of the population. Traditional crop production includes: field crop cultivation, grass farming, vegetables, fruits and nuts. Grain production is of prime importance in field crop cultivation and is combined with industrial, fodder, vegetable, melon and gourd cultures and potato crops. Within the structure of crop areas, grain crops account for 46.6%; industrial 11.7%; potato, vegetables, melon and gourd, 6.6%; and fodder crops, 35.1%. Grain production can reach 35-45 million t/year, the major grain crop being winter wheat, followed by barley, maize, rye and oats. Leguminous plants of high protein content include peas, beans, fodder lupin, soy and forage crops. Industrial crops include sugar beet (50% of the total area sown to industrial crops) and sunflower (40%).

In the last decade, the repetition and the duration of hot weather periods caused by climate change in Ukraine increased significantly. The consequences for agriculture will be related to changes in temperature and humidity conditions, but also to the reduction of soil fertility and desertification. As a matter of fact, the drought caused by adverse climatic conditions lead to crop losses in Ukraine that can range from 10 to 70 percent. This phenomenon is especially visible in the Steppe zone in the southern part of Ukraine with coastal borders. This zone is the warmest region of the country with a drought probability of 40–70% and an average annual level of precipitation about 350-540 mm (Krukivska et al., 2021). According to estimations of the scientists, the region undergoes the most significant transformation due to climate change with a rapid growth of thermal resources and the almost unchanging precipitation, annual level and amount in the summer period, which will affect the humidification of the territory and promote an increase in areas and the repeatability of droughts. Future climate risks are: critical decline in yields by the period of 2050; reduction in productivity due to the lack of adequate technical equipment in rapid climate change; the increasing erosion and loss of soil productivity due to the increasing droughts; loss of production capacity as a result of migration processes due to adverse climatic phenomena; increased risk for plants suffering from diseases and pests due to favorable conditions for the active development of many of their pathogens (Krukivska et al., 2021).

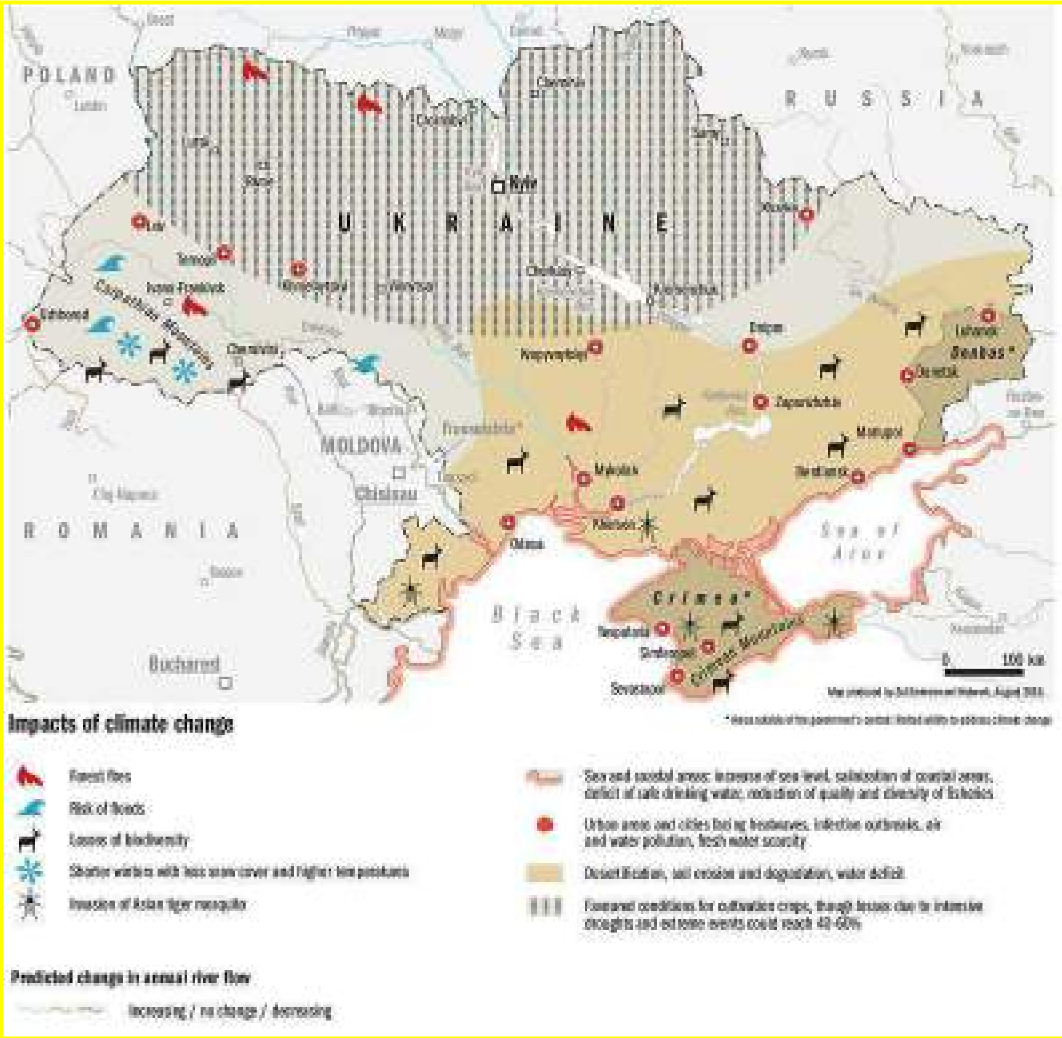

FIgure 5. Impacts of climate change in Ukraine (from [Zoï Environment Network](#))

In the Southern Steppe of Ukraine, where vast agriculture production of rice, wheat and sunflower seed is located, according to scientists (Vozhegova, 2014), water scarcity will affect more than 20% of the total area, which is also impacted by reduction in fresh water supplies. For this reason, it was experimented how the use of the AquaCrop model would benefit to precisely control the dynamics of water consumption at the level of the irrigation system in rice fields of that area. In 2017 AquaCrop was able to settle a functional irrigation regime for three rice varieties (Vicont, Premium and Ukraine-96), the adaptation of characteristics of each of the studied rice varieties was performed to enhance seeding and harvesting properties.

The model as usually is formed by four different data modules: the climatic (the include precipitation dynamics, evapotranspiration, temperatures and CO2 concentration levels), the soil, crop and management data input (that includes information on seeding rates, germination level, distance between rows and plants as well as the number of days of the vegetation season) that automatically calculated the standing density of plants and the initial size of the crop cover (Megrelidze et al., 2021). Other parameters such as the number of days from seeding to germination, the date of formation of the maximum crop cover, the date of “aging” of the crop cover and the date of full maturity of the crop were created reflecting rice varieties characteristics and duration of flowering. The data of all these modules produce an irrigation strategy and the mode of “automatic generation of irrigation regimes”. The main advantage of this mode is that the water content in the soils with lowest field moisture and water easily accessible to plants is preserved, while water losses caused by deep infiltration are limited, in this way water stress and crop losses are excluded, which is relevant for rice cultivation. Also, the AquaCrop model thanks to its “Climate-Culture-Soil Moisture” feature that includes the calculation of the optimal amount of biomass and grain yields is able to analyze the highest yields of rice of the different varieties analyzed in the Southern Steppe of Ukraine.

The experiment with the AquaCrop model showed that despite using the same irrigation rate for all studied varieties, each had a different yield, amount of biomass and water. The processing of this data had the advantage of controlling water and salt balances of the soil and all the types of stress of the different rice varieties. Stress can be adjusted by increasing or reducing irrigation rates, or by changing the timing and plant density. Finally, the results of the simulation modeling in rice field in Ukraine showed that AquaCrop can offer accuracy and reliability of the developed model for management, modeling and decision-making from the perspective of yield formation of Vicont, Premium, Ukraine-96 rice varieties as well as development of irrigation regimes for effective agricultural production were demonstrated.

Considering the climate change consequences in countries like Ukraine, water is a key limiting factor in crop production and it is necessary to use modern methodologies of agrometeorological research, like AquaCrop, based on numerical multiparameter models while using a wide range of geographic information technologies. At the same time, experts (Vozhegova, 2019;Markovska, 2021) claims that beyond crop modeling, in order to optimize the agriculture sustainability and productivity Ukraine government should encourage the farmers to use new scientific approaches regarding the application of innovative technologies in order to minimize the waste of water, energy, labor and money expenditures, pesticides and consider the location of the root system of crops to determine the optimal irrigation norms, use of solar energy as an alternative energy source, etc.

1.3 Adaptation and Mitigation to Climate Change

We can consider the use of the AquaCrop in the examples analyzed in the previous section as actions to fight against climate change and prevent the impacts it causes on the different systems of the planet. *Adaptation* and *Mitigation* measures are popular terms related to climate crisis academic literature and can be considered as actions with the aim to manage climate risks and taking advantage of any positive opportunities that may arise. However, even if these terms are related, their connotation is very different.

With the term “mitigation” we are referring to those actions and measures that are aimed at reducing the extent of climate change, while with “adaptation” we refer to those actions or measures that are based on reducing vulnerability to the effects and impacts of climate change. Therefore, we can consider mitigation as actions that address the causes of climate change, while adaptation´s actions address their impacts. Among the mitigation measures that can be put in place to avoid the increase in polluting emissions are the following:

- Practice energy efficiency;
- Greater use of renewable energies;
- Electrification of industrial processes;
- Implementation of efficient means of transport: electric public transport, bicycle, shared cars, etc;
- Carbon tax and emissions markets.

Regarding adaptation measures, there are several actions that can help reduce the vulnerability to the consequences of climate change:

- Landscape and forest reforestation;
- Creation of more varied crop fields to be prepared against natural disasters that threaten crops;
- Research and development on possible catastrophes, temperature behavior, etc.;
- Prevention and precautionary measures (evacuation plans, health issues, etc.).

Adaptation and mitigation measures depend greatly on the structural capacity of an affected system, region, or community to cope with the impacts and risks of climate change. For example, the adaptive capacity of communities is determined by their socioeconomic characteristics (Smit & Pilifosova; 2003). It's also important to mention that the impacts of climate change do not affect the entire world population in a homogeneous way. It is considered that those developing countries and those with a low Human Development Index will suffer greater effects, which will affect their Gross Domestic Product. Also, in the same region, country or community, the effects of natural disasters will not have the same repercussions on certain social groups. The territory, socio-economic situation, occupation, age, gender, disability status, health status, educational level, among others; are some variables that could be conditioning inequalities in risk perception, coping actions and responses to extreme events. Research worldwide has revealed the relationship between climate change and poverty, where it has been shown that the poorest populations are the most vulnerable to the effects of natural disasters (Guethón et al., 2019).

Adaptation

Taking actions against climate change requires a long-term inter-sectoral process. When we are analyzing the actors in the processes of adaptation and mitigation, we should identify which institutions are involved in the process and which is their level of commitment. To get an overview of all the relevant stakeholders in the field of adaptation we should consider not only state institutions but also non-state sectors (as cooperatives and businesses), civil society actors (as non-governmental organizations) and the involvement of the general population. The decisions regarding adaptations can be undertaken at any of several scales, by private individuals, local communities, national governments or international organizations. Where these adaptations are consciously planned activities, whether by public agencies or individuals, there is an interest in assessing the performance or relative merits of alternative measures and strategies. This evaluation can be based on criteria such as costs, benefits, equity, efficiency, and implementability (Smit & Pilifosova; 2003).

A wide variety of adaptation measures can be implemented in response to both observed and anticipated scenarios. The table below shows examples applied for different environmental challenges:

Table 3. Examples of adaptation measures in different sectors

<table>
<tr><th>Examples of adaptation measures for agriculture</th><th>Examples of adaptation measures to raise the sea level</th></tr>
<tr><td>

Efficient management of irrigation water;
Efficient monitoring and forecast of the weather;
Change from single-crop to polycrop farming;
Use and development of crops that are proved to be resistant to climate vulnerabilities and hillnesses;
Change agriculture production and practice: use multi-cropping and intercropping, adapting new sowing times and use off agroforestry;
Expansion of arable lands, changes in the geographical distribution of agriculture and management of agriculture´s lands;
Adoption of new technologies (ex. GIS).

</td><td>

Effective management and planning of coastlines;
Protection of coastal wetlands;
Following building codes and provide well-built building with a strong foundation against floods;
Effective land-use management;
Sediment management;
Creation of barriers that control the seawater intrusion;
A more sustainable use of water;
Use of early-warning flood alert systems;
Encourage fisheries conservation and marine biodiversity protection;
Disaster risk reduction practices that can help communities adapt to new CC conditions.

</td></tr>
<tr><th>Examples of adaptation measures in the water sector</th><th>Examples of adaptation measures in the urban sector</th></tr>
<tr><td>

Water conservation and demand management (permits, prices and taxes on water);
Improve water reutilization and recycling;
Improving the irrigation efficiency;
Improvement of sustainable and effective water infrastructure;
Increase the use of rainfed agriculture;
More cooperation between the institutions and the government in the implementation of the adaptation policies;
Create more sustainable water extraction techniques;
Removal of invasive species from water storage;
Improve the harvesting of rainwater;
Create effective desalination facilities/techniques.

</td><td>

Developing heat adaptation strategies: green walls, sidewalk greenways, reduced-albedo sidewalks and street trees;
Land use planning against pluvial and river flooding;
Create new sustainable water drainage;
Heat mapping and thermal imaging;
Urban biodiversity monitoring;
Air quality initiatives;
Implement soil retention strategies;
Awareness campaigns/education to reduce water use;
Use of cool pavements;
Promoting low flow technologies;
Diversifying power/ energy supplies;
Incorporating climate change into long-term planning documents.

</td></tr>
</table>

Furthermore, adaptation measures can be classified into general categories that represent the impact that they can have on a specific context and/or issue:

- ***Modify the threat:*** for some risks, it is possible to exercise a degree of control over the environmental threat itself. When it comes to a "natural" event such as a flood or drought, possible measures include flood control works. For example, one of the main threats of climate change is to find a solution to reduce greenhouse gas emissions and stabilize their concentration in the atmosphere;

- ***Prevent Effects:*** a frequently used group of adaptation measures with the aim to prevent the effects of climate change and variability. In agriculture, for example, such measures include changes in crop management, such as increased/decrease of irrigation use and pest control;

- ***Change of use:*** where the continuation of an economic activity becomes impossible or very risky, a change in use can be considered. For example, a farmer can substitute a crop for another more resistant to drought, in the same way, farmland can be reverted to grasslands or wildlife refuges;

- ***Research:*** the adaptation process can also be advanced with research on new technologies and new adaptation methods;

- ***Promote behavior change through education and information:*** knowledge dissemination through education and information campaigns is a form of adaptation. Such activities have received little recognition in the past, but are now gaining in relevance as the need to involve more people, sectors and groups in the environmental adaptation.

Adaptation Measures Examples

Water Management Adaptation Case: The Tamera Water Retention Landscape in Alentejo (Portugal)

Tamera is a farm of 154 ha located in Alentejo, the most arid region of Portugal. The impact of the climate change in this area is demonstrated by significant trends of increasing erosion and desertification in an area that, only a few decades ago, the streams flowed with water all year round. Nowadays, the streams swell only during the rainy season and afterward they become dry again, this situation is expected to exacerbate since the system has fallen completely out of balance. From 2006 the Tamera farm is developing a “Water Retention Landscape” (WRL) model in order to counteract the desertification process. The WRL model is composed of a system of lakes and other retention systems such as terraces, swales and rotational grazing ponds. The aim of this system is the restoration of the full water cycle: the rain which falls in the WRL area is retained by vegetation or in water bodies and recharges the groundwater, in this way, there is no rainwater runoff. This water management system has created a regenerative basis for autonomous water supply that supports the regeneration of topsoil, forest, pasture, wild fauna and food production.

From 2006 to 2015, 29 lakes and retention spaces were constructed and the area of water bodies was increased from 0.62 ha in 2006 to about 8.32 ha. After 2015, the project shifted from the construction of water management bodies to mainly focus on other interventions aiming to support water infiltration, vegetation growing and soil formation, such as swales, planting of ditches, mulching with wood chips and charcoal, and check and maintenance of dams. The main benefit of this project is to reduce the vulnerability to climate change and improve the water management. There are also a large number of co-benefits such as increased carbon storage, increased productivity and diversification of agricultural products, recreational value of lakes, increased biodiversity, increased numbers of visitors due to new water-related events, and improvement in the quality of life of local inhabitants. For example, the area of woodland has increased from 9.34 ha to 19.50 ha mainly in areas previously occupied by natural grasslands. This has led to an overall increase in carbon storage of 9.4 % per year between 2006 and 2014 (EEA, 2018: 21).

FIgure 6. Tamera EcoVillage

Reduction of Urban Heat Stress case: Antwerp´s thermal mappings (Belgium)

In order to understand and tackle the problem of heat stress in its urban areas, the city of Antwerp (Belgium) has commissioned the research organization VITO to create urban maps able to produce reliable scenarios related to temperatures and thermal comfort in the city. VITO applied, under the framework of Copernicus European Health service, the "UrbClim" climate model to map the air temperatures and urban heat island (UHI) extent with a horizontal resolution of 100m.

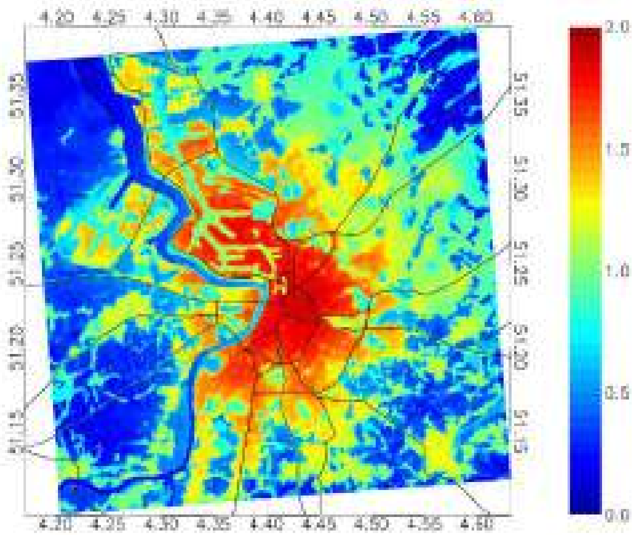

Figure 7. A Result of VITO's urban climate UrbClim model for the city of Antwerp and its surroundings

The research results indicate that Antwerp experienced in 2008-2017 twice as many heatwave days (defined as days with a maximum temperature over 30°C and a minimum temperature over 18°C) than the rural surroundings, exposing urban residents to much higher levels of heat stress compared to people living in the nearby rural areas (ClimateAdapt, 2020). To tackle the problem of heat stress in the city, different adaptation measures were created, such as:

- **Creating climate proofing buildings to reduce the local heat stress:** for all new or renovated roofs with a slope of less than 15% and a surface area of more than 20m², it is compulsory to install a green roof on top;

- **Establish early warning systems for climate change adaptation and disaster risk reduction:** such systems are in place to monitor, forecast, and warn people about e.g. tropical cyclones, floods, storms, tsunami, tornadoes, severe thunderstorms, volcanic eruptions, extreme heat and cold, forest fires, drought, etc;

- **Inform the citizens about the issue and create awareness campaigns;**
- **Improve the monitoring and forecasting systems to minimize the health impacts on the population:** this includes the installation of telemetric network and weather RADARS and the establishment of a monitoring system that provides real-time information on water levels and couples it with data on current precipitation and weather forecasts.

The main impact of the research on heat stress in Antwerp was to raise awareness about this topic at the political level, generating funding and policy initiatives to tackle this problem. In fact, the results of this research were included in the *Antwerp's Climate 2030 plan*, a climate mitigation and adaptation strategy in the framework of the Covenant of Mayors initiative.

Mitigation

Tackling climate change through mitigation is a scientific and political challenge, which requires a high level of trust and cooperation between countries and scientific institutions. Following the OECD's report *"Climate Change Mitigation: Policies and Progress"* (2015), by the year 2050, if the greenhouse gas emissions would not be reduced by 40% -70% compared to 2010 levels, terrestrial temperatures would most likely register significantly higher increases, increasing the risk of serious and irreversible effects on ecosystems, having significant impacts on agriculture and human health. National and international mitigation policies were agreed in the last decade by countries and governments, this includes climate change plans, carbon and energy taxation, emission trading systems, renewable energy support policies, regulatory standards and policies to reduce emissions and offer clean energy alternatives.

In order to have a more clear understanding of climate change mitigation policy, it is important to understand that each country has different starting points due to its national social and economic status. In fact, there is a huge variation on the level of gross domestic product (GDP) per capita and the greenhouse gas emissions from country to country. In global terms, if we need to understand from where most of the greenhouse gas emissions come from, we can consider the following sectors:

- **Energy (electricity, heat and transportation)** represent over the 70% of global greenhouse gas emissions;
- **Land use, agriculture and forestry** represent the 18.4% (especially livestock and manure animals that produce a high carbon footprint);
- **Direct Industrial Processes** represents the 5.2% of total greenhouse gas emissions, especially in the cement and chemicals production;
- **Wastewater and landfills** produce 3.2% of the total greenhouse gas emissions.

The benefits of climate change mitigation initiatives are not merely related to the protection of the environment but can represent efficient national policy making strategy. Renewable energy and clean energy technology can contribute to a country's energy security, air quality, population health improvement, flood protection, conservation of biodiversity and of the ecosystem. Moreover, in some national cases the effects of the mitigation initiatives could reduce poverty, increase energy access, improve food and water security and promote a sustainable rural economic development.

Mitigation Initiative Examples

National Climate Action Plan (Ireland)

Ireland´s first statutory mitigation strategy has as a main objective the transition to a decarbonised, climate resilient and environmentally sustainable economy by 2050. To support this ongoing work, the Plan also includes over 100 individual actions for various Ministers and public bodies to take forward the mitigation initiative. The document outlines the emissions profiles, policy frameworks and strategies to achieve climate change mitigation at the national level, and in each of the following sectors (GOV.IE,2017):

- **Decarbonising Electricity Generation:** describes the policy context within which action is being taken in the electricity sector to achieve a low carbon energy by 2050. These measures are complemented by the longer-term policy framework provided by the Energy White Paper Ireland's Transition to a Low Carbon Energy Future;

- **Decarbonising the Built Environment:** focuses on the action being taken to improve energy efficiency and reduce greenhouse gas emissions associated with Ireland's building stock;

- **Decarbonising Transport:** describes the profile of the national transport sector and its multiple objectives within Ireland's economy. As part of the longer-term vision for the sector, this National Mitigation Plan sets out an ambition that all new cars and vans sold in Ireland from 2030 will be zero emission capable;

- **An Approach to Carbon Neutrality for Agriculture, Forest and Land Use:** describes the range of actions being taken to advance the long-term vision for this sector of an approach to carbon neutrality which does not compromise capacity for sustainable food production.

Beyond the policies, the Irish government introduced a carbon tax in 2010 that applies to all fuels used in sectors not covered by the Emissions Trading System of the European Union. The tax initially applied to liquid and gaseous fuels at the rate of EUR 15 per tonne of carbon dioxide and it was extended to solid fuels in 2013. The 2021 budget implemented the government commitment to raise the carbon tax by EUR

7.50 per tonne of CO_2 per year over the decade. This would allow the tax rate to reach EUR 100 per tonne of CO_2 by 2030 (OECD, 2021).

At the same time, the government committed to use the revenue from the carbon tax to prevent fuel poverty, ensure a just transition for displaced workers and finance climate-related investment. In line with this commitment, the government allocated part of the carbon tax revenue to enhance some social welfare schemes in 2021, such as benefits for children and people living alone. This increase is expected to mitigate the impact of the carbon tax on vulnerable households. In addition, some millions of carbon tax revenue was allocated to finance the newly established national Just Transition Fund for the Midlands. The Fund provides financial support for retraining workers and for business projects that can generate sustainable jobs in a region that is being affected by the phase out of peat extraction and use (OECD, 2021).

The Air Quality and Climate Change Strategy of the Community of Madrid (2013-2020), ***"Plan Azul+"*** **(Spain)**

Plan Azul+ was a local level strategy aimed at reducing air pollution, helping to mitigate the effect of climate change, and defining adaptation strategies. The main objective was to ensure the quality of the air breathed by Madrid-dwellers. These actions were designed to help turn the city of Madrid into an urban environment characterized by a high quality of life while consolidating a shift in the city towards a sustainable urban model (Ayuntamiento de Madrid, nd). The actions of *Plan Azul+* were characterized by their cross-cutting nature and have been designed with the foremost objective of reducing air pollution while considering other additional elements aimed at effecting a change from a conventional development model to a sustainable one, for example:

- **Road traffic:** reducing the presence of private cars and incorporating new technologies to the city's vehicle pool. Not only will GHG emissions be taken into account but also black carbon emissions from traffic;

- **Residential, commercial and institutional sector (RCI):** energy efficiency, the progressive electrification of energy demand, and generation from renewable sources on a national scale were the main lines of action to achieve the proposed objectives;

- **Other modes of transport:** the reduction of greenhouse gas emissions from the Spanish electricity mix during the Plan's implementation period that would enable indirect emissions of CO_2 to be reduced in railway and metro transport. Meanwhile, AENA (the main society of air traffic management in Spain), had set up a Carbon Management Plan for the period 2016-2021 which aimed to reduce greenhouse gas emissions from airport activities;

- **Waste:** the optimization of the waste collection service, together with other actions focused on reducing consumption and promoting composting on a neighborhood scale, would reduce emissions associated with this sector.

During the 8-years plan it was achieved a reduction of CO_2 equivalent emissions in the transport sector of almost 15% and also, the reduction of global equivalent CO_2 emissions of 10% compared to 2005 (Portal Transperencia, 2020).

Even if *Plan Azul+* officially is terminated the review reports suggested for the future local policy makers to reinforce some strategies of the plan and extend it at a national level. Some of the actions that should be reinforced are:

- Promotion of electric mobility, as the main option for the decarbonization of transport;

- Sustainable governance, that is, the establishment of decision-making processes that take into account the sustainable variable;
- Adaptation Policies to climate change, since it is necessary to know the vulnerability of the different systems and propose the necessary means to enhance their resilience.

Even if good results have been obtained by the *Plan Azul+* strategy, many measures of the plan still need to be reinforced. The long-term effect of the implementation of *Plan Azul+* in Madrid city would bring an appreciable decline in air-pollutant emissions, and would lead to better air quality and remarkable health-related benefits: it´s estimated that more than 500 all-cause premature deaths could be postponed annually (Izquierdo et al., 2020).

1.4 Conclusion

Minimizing and compensating the effects of climate change on our planet is, nowadays, a high priority for contemporary society. Everyone can support and take part in strategies to protect our planet, starting from reducing emissions in your own life, learning about climate change, to supporting climate-smart policies, institutions that are embracing adaptation and mitigation projects. This work aimed to be an introduction to different aspects of climate change: the effects of water vulnerability in agriculture, crop growth technologies, global strategies to solve problems related to climate change. Moreover, strategies of mitigation and adaptation were introduced to the reader, starting from the international *AquaCrop* model against water vulnerability in crop production applied in different countries (who are cooperating under the PONTOS project) to more local initiatives enforced to adapt and mitigate the effect of climate change in urban settings like cities (ex. Madrid and Antwerp) and rural areas (ex. Tamera eco-village). One of the aims of the present research is to raise the reader's interest to learn about strategies against climate change effects in order to support and advocate for smart policies and projects to be applied to our daily life. The final message is that our planet can continue to thrive if we all work together and adapt to our changing world.

2. Description of Armenian Study Area: Lake Sevan Basin

2.1 Location and Geographic Overview

Sevan basin is situated in the Eastern part of Armenia. It covers 1/6th of the total territory of Armenia. The surface area of the basin is 4721 sq. km. It is surrounded by Geghama Mountains (from West), Vardenis Mountains (from South), Areguni Mountains (North-East) and Sevan and East Sevan (East) mountain ranges with elevations up to 3598 m (Vardenis). Lake Sevan Basin spreads from 39°52' to 40°41' of Northern latitude and from 44°45' to 45°59' of Eastern longitude. The maximum stretch from South to North is 90 km, from East to West – 103 km. One of the peculiarities of Lake Sevan Basin is the small ratio between the catchment area and the surface area of the Lake (3:1) compared to other major lakes (10:1 in average) (Babayan et. al., 2006).

Sevan is a high-mountain lake located on the altitude of 1900.65 m above the sea level. Lake Sevan is in the fifth place among the major high-mountainous lakes in the world in terms of altitude and surface area, (after the lakes Titicaca (Bolivia, Peru), Poopo (Bolivia), Namtso (China) and Qinghai (China)).

Noratus and Artanish capes and Shorzha underwater shaft-threshold are dividing the Lake Sevan into two parts: Major Sevan (910 sq..km) and Minor Sevan (345 sq. km).

2.2 Climate Characteristics

Climate in the basin of Lake Sevan is moderately continental. Its formation is influenced by the intensity of solar radiation, atmospheric circulation, the absolute altitude and topography. The high-mountainous location of Lake Sevan makes the basin cooler than other areas in Armenia.

The basin is distinguished by considerable sunshine. There are only 20-25 cloudy days in a year. The number of sunny hours in Martuni reaches 2779, which makes Martuni the sunniest territory of Armenia. The sunniest months here are July and August.

The total value of solar radiation in the lake basin is 165-170 kcal/cm^2 per year, reaching its maximum in June or July (19-20 kcal/cm^2). Part of the solar radiation is reflected by the surface of water and land, but in general the radiation balance in the basin is positive and amounts to 62 kcal/cm^2 in Sevan) - 60 kcal/cm^2 (Martuni station).

The average annual rainfall in the Lake Basin is about 595 mm, with the largest amount falling on the Eastern slope of the Geghama Massif (over 900 mm), and the smallest - over the mirror of the Lake (less than 400 mm).

The average temperature in January in the lake zone is -10°C, in the upper zones – -12°C, in July, respectively, 16°C and 8°C. Annual precipitation is 450 mm on the lake, 850 mm in the highlands. In winter, a stable snow cover is formed. Lake Sevan is famous for bristle winds (especially in the summertime). The seasonal climate change is quite significant in the basin of the lake.

Winter here is moderately cold and lasts from December to March. The average monthly air temperature ranges from 1°C to -12°C, but it can drop from -27°C to -32°C in cold snaps. Precipitation falls mainly in the form of snow. Before the decrease of the water level in the winter months, no continuous ice cover was formed on the lake. It was partially covered by ice, with the most stable ice cover recorded in the bays.

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Spring in the lake basin is cool, with frosts mainly in April and May. The average monthly air temperature at this time is 0°C to 11°C, the maximum temperature is 24°C, the minimum temperature is 15°C to 21°C. Precipitation falls in the form of rain, in the mountains - in the form of snow (for a month there are 8-15 days with precipitation). In May, thunderstorms with hail are frequent.

Summer (June - September) is usually characterized by clear sunny, but cool weather. In the mountains at night it may be frosty. The average monthly air temperature is 10°C to 16°C, the maximum temperature is 30°C to 32°C, the minimum -2°C to -9°C. Precipitation falls in the form of rain (there are 3-10 days with precipitation in a month). In the highlands for 17-20 days for a season there are fogs. In summer, thunderstorms are frequent - up to 42 days per season.

Autumn (October - November) is warm, in the highlands it is cold. The average monthly air temperature is 2°C to 8°C, the maximum temperature is 20°C to 24 °C, and the minimum temperature is -21°C to -27° C. Precipitation falls in the form of rain and snow. The snow cover appears at the end of October. In the highlands there are frequent fogs (up to 25 days per season). At this time, the winds blow from the western directions and reach a speed of 1 to 5 m/s (sometimes more than 15 m/s) (Baghdasaryan, 1971).

The following types of climate are characteristic of the Lake Sevan basin:

1. Moderate climate, with relatively dry warm summers and cold winters - It is typical for volcanic slopes and mountain slopes up to 2200 m altitude. Cold weather is dominant; snow cover (15 to 40 cm) lasts for about 4 months. The average air temperature in January is 6 to 8°C, the minimum goes down to -35 °C. The wind speed reaches (3 to 6) m/sec. Usually there are snowfalls and fog. In May - June there are thunderstorms (average 10 to 15 days), the number of precipitation fluctuates between 100 to 150 mm and the number of hail days ranges from 4 to 6. In the second half of June, the temperature rises above 15 °C.

2. Moderate, with short cool summers and cold winters - Formed at altitudes of 2000 to 3000 meters. Winter is cold and lasts for 4-5 months; the average January temperature fluctuates from -10 °C to -13 °C. The snow cover reaches 50-70 cm. Spring begins in early April, when the average air temperature rises from 0°. Summer is short, cool in many places. The average daily air temperature does not exceed 15° C. In August, the average air temperature is 13-15 °C. Autumn is cold and short. Annual precipitation is 500 to 600 mm.

3. Cold, high mountain climate - Formed in the area up to 3000 m and is characterized by great intensity of solar energy. The maximum intensity of direct sun radiation reaches 1.67 kcal / cm2 per minute. The duration of the sunshine is also great, especially in the winter when the average and low zones are covered by clouds.

Winter is cold, lasting about 6 months. In some forms of relief at the altitudes of 3800 to 4000 meters, the snow cover remains the whole year. The average snowfall is over 2 meters, and the snow cover lasts for 270 days. The average temperature in winter months does not rise from -10 °C, and, at least, decreases to -41 °C.

Spring is cold and wet. The average monthly temperature in the shortest month does not rise from 10 °C. In August, the average air temperature is below 12 °C and rises at most 20 °C. In summer, the number of monthly precipitation is about 50 mm, and there are plenty of thunderstorms. Autumn is short, cold and wet. The precipitation is mostly in the form of snow. The frost duration is 50 to 60 days. The annual precipitation fluctuates between 800 and 950 mm. The wind speeds are high all year round. The maximum is observed in winter and reaches 5 to 7 m /sec.

2.3 Topography

Lake Sevan is located in the Eastern part of Armenia and is surrounded by mountain structures on all sides: in the North-East - by Areguni and Sevan folded-block ridges, in the East - by the East Sevan Ridge, in the West and South - by Geghama and Vardenis volcanic arrays.

The range of Areguni with a length of 60 km extends southeast from the Sevan Pass to the Drakhtik River Valley consists of three blocks. The maximum height of the ridge is 2673.2 m. Its southwestern slopes are short and steep and dissected by numerous river valleys and there are widely spread steep rocky slopes

The Sevan range (length 55 km) is the highest of the ridges of Northern Armenia. It has an anticlinal structure which extends from the valley of the Drakhtik River to the Hinal dome - the highest peak of the ridge (3367m).

In the Eastern part of the Lake Sevan basin is bounded by the Sevan meridional Ridge (length 42 km). The maximum height of the ridge is 3426 m (Tsarasar). There are traces of glaciation in the summit belt of the ridge.

In the West, the Sevan depression is fringed by the Geghama volcanic massif, which is an elongated convex shield extended in the meridian direction. Its highest point is 3597m (Azhdahak), length 68km, width 48km. The slopes facing Sevan, gently sloping with a wavy relief, are dissected by numerous river valleys, and in the sectional part also by ancient glacial valleys.

From the South, the Sevan depression is bounded by the Vardenis volcanic massif, which is an oval-shaped latitudinal strike structure with a cross-shaped transverse profile. The tops of the massif rise to heights of 3000-3500m (Vardenis - 3521m) and bear the traces of ancient glaciation. The northern slopes of the Vardenis massif descend gently to the lake basin, are of considerable length and are dissected by river valleys (Boynagryan, 2006).

The Lake Sevan basin is interpreted as the Neogene-Anthropogenic depression. However, the origin of the lake is also associated with overlapping of an ancient Hrazdan river bed with lavas of Geghama volcanic massif. Traces of this old riverbed can also be seen at the bottom of Major Sevan. And so, Sevan belongs to the lakes of mixed origin.

2.4 Geological and hydrogeological structure of the basin

In the geological structure of the Lake Sevan basin, different rocks are involved, ranging from the Upper Cretaceous to modern sediments (Geological map of Lake Sevan Basin, 2003; Geological Map of RA, 2005).

Below is given the characterization of the geological structure of the lake basin according to the maps mentioned above.

The southwestern slope of Areguni Ridge, steeply descending to the lake's surface, is composed mainly of Cretacous -Eocene volcanic-terrigenous flyshe with a total thickness of up to 1500 m and only partially - volcanogenic flyshe of the same age with a thickness of 500 m.

Sevan range differs from Areguni in the composition age of rocks. Here, on its southwestern slopes, marine sedimentary rocks of the Upper Cretaceous, interrupted by intrusions of the Upper Cretaceous and Eocene age, occur in places. The sedimentary rocks of the Sevan range are limestones, marls, sandstones, siltstones, conglomerates, andesite-basalt covers, basalts, andesite basalts and their tuffs.

The southern slope of the Sevan range is distinguished by significant outcrops of the volcanogenic stratum, which encloses the gabbro-hyperbasites. In the western part of the ridge, the fine outcrops of stratified rocks of the ophiolite association are known near the Artanish Peninsula. To the east of the basin of Daranak River is exposed to the "main field" of the siliceous-effusive formation on the southern (south-western) slope of the Sevan Ridge reaching 900-1100 m (Satyan, 1984).

The western slopes of the Eastern Sevan Ridge in the northern part are composed of Lower Pliocene andesitic basalts, andesites, andesitic dacites, rhyodacites, as well as rhyolites, obsidians, perlites and their pyroclasts. In the southern part, Middle Eocene volcanogenic-sedimentary rocks (andesite-basalts, trachyandesites, trachydacites, tuff sandstones, interlayers of limestones) appear.

In the west, the lake is bounded by the eastern slopes of the Geghama volcanic massif, composed mainly of Quaternary lavas the northern slopes of the Vardenis volcanic massif, which descend gently to the lake basin, are composed of Lower Pliocene volcanogenic formations, and Lower Quaternary lava of andesitic basalts, andesites, andesic dacites, dacites.

At the foot of the ranges Areguni and especially Sevan, there are large cones carrying out proluvial material. The thickness of the proluvial in these cones reaches 25-85 m, and in individual cases - 216-250 m (Map 7).

In the South-East, Southern and Western coastal zones and slopes of Lake Sevan Basin water-bearing Quaternary lacustrine-river formations (Q1-4) and water-bearing complex of Pliocene-Quaternary volcanic rocks (N23 – Q) are widely spread. On the Northern and North-East slopes complexes of low water-bearing volcanic sedimental (₽22) and intrusive (K1- ₽2) rocks are common. Here water-bearing complex of Upper Cretaceous sedimentary, mainly carbonate rocks are spread within very small areas.

Main part of groundwater resources is formed in the complex of volcanic rocks, and the accumulation and discharge is in the complex of volcanic rocks and lacustrine-river formations. Therefore, groundwater bodies with great discharge are identified in local water-bearing complex of Pliocene-Quaternary volcanic rocks and in the water-bearing complex Quaternary lacustrine-river formations.

2.5 Hydrography

2.5.1 Lake Sevan

Lake Sevan is the largest lake in the South Caucasus, and at the same time one of the largest mountainous freshwater lakes in the world. The basin of Lake Sevan makes up one sixth of the total territory of Armenia (16%). Surface area of Lake Sevan Basin is 4721 km^2, the area of the lake itself is 1279 km^2 (according to the Hydromet data for 2017). The surface area of the lake before its artificial decrease was F=1416 km^2. Length of the lake through the larger axis of Dzkanget River mouth (northwest) to Tsovak village (southwest) is 74 km, whereas the average width is 19.2 km and the largest width across the axes is 32 km. The average depth is 46.8 m, the maximum depth is 83 m, the volume of water is 38,3 km^3 (according to the Hydromet data for 2017).

Origin of the lake

There is a number of assumptions concerning to the origin of the lake of Sevan:

- Sevan is a dam lake. Supporters of this hypothesis were P. Rohrbach (1902), E. Markov (1911), K. Paffenholz (1950). According to these authors, earlier on the territory of Sevan was a river valley, the water of which flowed into the river Araks. Then the streams of lavas dammed the valley, the flow of water stopped and started again when the dammed valley was filled with water and the latter began to pour through the reservoir.
- V. Trifonov and A. Karakhanyan (2004) believe that the flooding of the Sevan basin by water is most likely due to the growth of the young tectonic uplift at the source of the river Hrazdan, and not with the lava flow of the volcano Mets Lchasar, as many geologists have supposed.

- Sevan is a relict formation, the remnant of an ancient lagoon of the Upper Tertiary age. Supporters of this hypothesis are E. Dyakonova-Savelyeva and G. Afanasyev (1933), A. Aslanian (1947). According to Aslanyan, after the regression of the Upper Pliocene Sea, relict reservoirs were preserved. The basin of Sevan was formed in connection with the formation of the Gegham anticlinorium. During the uplifts, this basin diminished and became smaller in size than the modern Major Sevan. Minor Sevan at this time was a continent with a river valley, which was then filled with lavas of the volcano Metz Lchasar. Minor Sevan was formed, which later merged with the Major Sevan. Hypothesis of the relict origin of the lake does not meet the support of specialists.
- E. Milanovsky (1953) believes that the Sevan basin was formed at the end of the Miocene and in its development passed two stages: the stage of geosynclinal deflection of the Sevan-Kurdistan zone (finished in the Paleogene) and the stage of embedment of depression existing now (Boynagryan, 2007).

Lake Level Fluctuations in 19th and early 20th Centuries

Fluctuations in the level of the Lake Sevan in historical times and during the 19th and 20th centuries drew attention to its early explorers, who linked the phenomenon with different reasons - from the underground connection of Sevan with the Van and Urmia Lakes to filling of the part of the lake with river sediments and the influence of tectonic processes (Sarkisyan, 1962). However, most researchers still tend to accept climate change as the main cause of level fluctuations. A. Gabrielyan (1944) gave a great importance to the tectonic movements, although he also recognized the role of climate.
According to B. Bek-Marmarchev (1951), the level of Lake Sevan for the period from 1810 to 1950 repeatedly changed and the maximum value of the changes was approximately 3 m. Seasonal level changes were 20-90cm (Manukyan, 1996; Boynagryan, 2007).

Artificial Changes in Lake Sevan Level in the 20th Century

In the 1920s, as a result of the multilateral expedition surveys of the USSR Academy of Sciences, a technical plan for the use of the lake was developed, known as the “Sevan-Hrazdan” water-economic complex. It was planned to implement it in 2 phases. In the first phase (would last 50 years), the artificial reduction of the lake level would have been completed (1200 mln. m^3 per annum). The lake level would decrease by 50 meters, and the surface of the water mirror would be reduced to seven times (Major Sevan would dry completely). In the second phase, the use of long-term water resources would be stopped and the new, stable water balance of the lake would be set to 700 mln. m^3 annually. These were aimed to reduce evaporation through reduction of the surface area of the lake.

“Sevan-Hrazdan " water-economic complex includes a network of 80,000 ha of irrigated lands in Ararat valley, and a hydra-energetic complex of a cascade of 6 hydropower plants with an overall capacity of 55 MW. In natural conditions, the annual flow of the Hrazdan River was 50 mln. m^3. After the launch of Sevan HPP in 1948, the flow of the river was regulated and the river actually became an artificial canal. Groundwater outflow from Sevan before the level decrease was 85 mln. m^3 (Hydrography of Armenian SSR, 1981).

Decrease of the level of Lake Sevan started in 1933 and continued until 1981. Decrease of Lake Sevan’s water level at the end of 1980 was about 18.5 m.

In parallel with the artificial reduction of the lake's level, the ecological state of the lake is getting worse faster than it was supposed to be. The lake has been deprived of more than 40% of the water reserves within the next 10 years; the maximum depth was not exceeding 80 m. The negative effects of the decrease of the water level were evident especially in the Major Sevan. In the 1970s, it was decided to stop the water discharge and gradually raise the level in order to save the lake.

Further decrease of the lake stopped in order to restore the ecological equilibrium of the lake, which was violated largely due to artificial decrease of the level of the lake, as well as to store the strategic water reserve in the lake. The plan was to increase the level of the lake by 6 m. In order to ensure the optimal level of the lake, Arpa-Sevan tunnel (48,3 km, 1963-81) was constructed, which was supposed to annually transfer about 250 mln. m^3 of water from Arpa River (its tributary Yeghegis) to Lake Sevan. The tunnel was put into exploitation in 1981. Also construction of Vorotan-Arpa tunnel (21,6 km) was completed in 2004, which transfers 165 mln annually. m^3 of water from Vorotan River to Lake Sevan.

From 1981-2001, the level of the lake was increased (after exploitation of Arpa-Sevan tunnel) by 0.9 m (1981-1990), and then again decreased (due to excessive use of waters of the lake) by 1.68 m (1991-2001), reaching its minimum level 1896.32 m. Since then the level of the lake has been increasing (SHER, 2013).

With the exploitation of the Vorotan-Arpa-Sevan tunnel system, not only the stabilization of Lake Sevan level but also gradual increase has been ensured. On March 25, 2010 the tunnel was named "Arpa-Sevan" , named after Yakov Zarobyan.

Lake Sevan also has seasonal fluctuations of level. The highest level of the year is observed in July, the lowest is in March. The seasonal variations are about 20-30 cm and depend on the hydro-meteorological conditions of the lake.

The highest temperature on the lake surface is observed in July-August, with a maximum of 24°C. The temperature is high in the coastal areas, moreover, is higher in the eastern parts. Usually the temperature is higher in the Major Sevan than in the Minor Sevan. The reason is that the warm waters from the northern parts move to the south by the wind.

The water temperature on the lake surface does not have large fluctuations during the day: it is between 1.5°C and 2°C, rarely 3-4°C. It is worth mentioning that the "dome" of cold water in the summer months is formed in the Major Sevan, in the center of which the temperature is lower by 5-6°C.

The water temperature in Sevan varies by depth. Temperature in the bottom layer is 4-5°C during the year, and seasonal changes are not noticeable.

The convection phenomenon is quite obvious at the depth of 20-25 m. Temperature increases from the bottom to the surface during summer months. In January, reverse stratification is established, and temperature is increasing by 0,5-1°C from the surface to the bottom.

Under the previous level conditions of the lake, temperatures were lower in the near-bottom parts of the lake. After the level decreased, fluctuations increased. There is a temperature rise on the bottom of the Major Sevan: the sunrays reach the bottom and contribute to the growth of algae. Lake Sevan was an oligotrophic lake before the lake level dropped. Now the lake is in the process of eutrophication (Hydrography of Armenian SSR, 1981).

An important phenomenon in the hydrological processes of the lake is the glaciation. Prior to the level decrease, the surface of the lake only in a few years has been covered by ice. In the period from 1890 to 1960 the lake has been frozen for only 9 times, and now, when the lake level dropped about 18 meters, it is getting frozen almost every year.

In the past, the frost of Sevan used to start in the middle of January or February, and now it is about 15-17 days earlier. The ice melt begins at the end of March or early April. The ice thickness varies between 20 and 40 cm.

Sevan is one of the most transparent lakes in the world. Prior to the level decrease the maximum transparency reached 21 m, now it has dropped to 11-15 m. The highest transparency is observed in August-September, the lowest is in February-April. Transparency is high in the eastern part of Minor Sevan where the wind is weak and the depth is great.

The Law of RA "On Annual Program of Measures for Restoration, Protection, Natural Development and Use of Lake Sevan Ecosystem" envisages a maximum annual amount of water outlets from Lake Sevan to 170 million cubic meters. In paragraph 6.1 of the program established in the same law outlets exceeding a maximum annual amount of water outlets should be done "according to the relevant decisions of the Government of Armenia on the basis of two-week forecasting proposals submitted by the authorized water management body".

2.5.2 Rivers

There are 993 rivers and streams in Lake Lake Sevan Basin with a total length of 2687 km. 56 of these rivers have a length of 10-25 km, 6 – 25-50 km and 1 – more than 50 km (Table 4) (Mnatsakanyan, 2006).

Table 4. Overall Statistics of River Network within Lake Sevan Basin

Rivers by Size	<10 km	10 – 25 km	25 – 50 km	50 –100 km	Entire River Network	Watershed Area of Rivers	Density Coefficient of River Network
Quantity	930	56	6	1	993	3500 km2	0.77 km/km2
Length, km	1585	866	185	51	2687		

28 rivers (including the large springs in the form of the rivers) flow into the Sevan, and only the Hrazdan River originates from the lake. In general, most of the rivers of Lake Sevan Basin are small, their length are less than 10 km, only 6 rivers have a length over 26 km and only Argichi river is more than 50 km in length (Table 5).

Table 5. Main Characteristics of Several Rivers of Lake Sevan Basin (Resources of Surface Waters of USSR, 1973, v. 9; Chilingaryan and others, 2002, GIS Datasets of Geocom Ltd.)

River Name	Length, km	Watershed Area, km^2	Altitude at Source, m	Altitude at Mouth, m	Average incline, ‰
Argichi	56	367,2	2520	1900,6	11,1
Artanish	8	16,7	2612	1900,6	88,9
Bakhtak	31	152,1	3220	1900,6	42,6
Daranak	8	23,3	2850	1900,6	118,7
Areguni	9	11,7	2820	1900,6	102,2
Jil	10	17,5	2780	1900,6	87,9
Artsvanist	20	82,7	3260	1900,6	68,0
Astghadzor	21	48	3220	1900,6	62,8
Vardenis	30	110	3160	1900,6	42,0

Gavaraget	50	480	3130	1900,6	24,6
Dzknaget	22	86,3	2310	1900,6	18,6
Zolakar	14	31,5	2840	1900,6	67,1
Karchaghbyur	24	109,6	2905	1900,6	41,9
Lichk	8	36,9	2006	1900,6	13,2
Martuni	28	96,5	3070	1900,6	41,8
Masrik	51	675	2880	1900,6	19,2
Pambak	10	23,2	2762	1900,6	86,1
Drakhtik	11	39,5	2670	1900,6	69,9
Tsakkar	23	67,2	3180	1900,6	55,6
Geghamasar	12	21,6	3030	1900,6	94,1
Yeranos	4	7,9	1960	1900,6	14,9
Selavagetak	15	19	2650	1900,6	50,0
Pokr Masrik	15	69	2800	1900,6	60,0
Sarinar	11	14,2	3094	1900,6	108,5
Shishkert	9	18,6	2600	1900,6	77,7
Tsapatagh	8	17,3	2670	1900,6	96,2
Dali	5	7,4	2422	1900,6	104,3
Spitakajur	12	23,9	2405	1900,6	42,0

5 rivers originate from Geghama Massif, from which Gavaraget flows into Minor Sevan, and the rest 4 – Yeranos, Bakhtak, Tsakkar and Lichk flow into Major Sevan. Total flow of the rivers of Geghama Massif is 27,7 % of the total runoff of all rivers flowing into Lake Sevan.

9 rivers originate from Vardenis Massif – Argichi, Martuni, Astghadzor, Zolakar, Selavagetak, Vardenis, Artsvanist, Karchaghbyur and Masrik which flow into Major Sevan. Total flow of the rivers of Vardenis Massif is 61,9 % of the total runoff of all rivers flowing into Lake Sevan.

12 rivers originate from Sevan Massif – Pokr Masrik, Gehgamasar, Sarinar, Areguni, Daranak, Pambak, Shishkert, Tsapatagh, Jil, Dali, Noruz and Artanish which flow into Major Sevan. Total flow of the rivers of Sevan Massif is the 4,6 % of the total runoff of all rivers flowing into Lake Sevan.

2 small rivers originate from Areguni mountain range – Spitakajur and Drakhtik, and only 1 from Pambak mountain range – Dzknaget. Total flow of the rivers of Areguni-Pambak Massif is the 5,8 % of the total runoff of all rivers flowing into Lake Sevan (Map 8).

Annual average river flow into the lake is 26,8 m^3/s (without Arpa-Sevan tunnel).

In general, the coefficient of river network density within the Sevan basin is less than 1, but the southern high-mountain part is characterized with significant topography dissection (to 1,5-2,0 km/km^2). Feeding of rivers is mixed, mainly from snow and rain, but there are some specifics.

The only **river which originates** from Lake Sevan is Hrazdan River, which flows to the transboundary Araks River. Hrazdan is the longest river (141 km) which completely flows within the territory of Armenia. .

2.6 Soils

Numerous types, subtypes and varieties of mountain soils with a high-altitude distribution are found on the territory of the Lake Sevan Basin.

The lower degree of the altitude ladder is occupied by the soils of the coastal zone of Lake Sevan. These soils are actually newly formed, associated with the lowering of the lake level. On the bare ground, soil-forming was stimulated. As soil-forming sedimentary (sand, pebbles) and volcanic rocks act.

The soil of Sevan ridges is brown carbonate with 30-50% stoniness. The natural soil of the remainder of the basin is chernozem (black soil) with pH 5.8-6.2. On the southwestern shore of Minor Sevan, stony deposits predominate, on the western and southern shore of Major Sevan stoniness is 10-30%, and less than 10% in other parts of the basin.

The lands of the basin belong to 3 soil zones:

1. Mountainous (2000 - 4000 m): mountain-meadow, meadow-steppe soils,

2. Forest (1900 - 2400 m): forest gray, cellar, forest brown soils,

3. Steppes (1900 - 2450 m): black-earth, meadow-grassy, wind-protective-grassland and Sevan-water-free soil plots (wet meadow sand, incomplete silt, asparagus desert) (Babayan et. al., 2006).

2.7 Natural zones

Sevan Basin is one of the richest natural regions in Armenia. There are 5 natural zones: such as Mountain steppes, Mountain forests, Mountain meadows, as well as Alpine and Subalpine meadows.

1. Mountain steppes are mainly situated in lower regions of the basin (1900-2200 m). Climate is semi-continental with warm summers and cold winters.

2. Mountain forests are not widespread. They are common only on the Pambak and Sevan ranges (2100-2300 m). The main species for this zone is oak.

3. Mountain meadows are spread on altitudes of 2300-2600 m. Climate here is cold. This zone is mainly used for pastures.

4. Alpine and Sub-alpine meadows occupy high-mountain areas in the Sevan Basin above the 2500-2600 m (Baghdasaryan, 1971) (Table 6).

Table 6. Natural Zones and Main Soil Types in the Lake Sevan Basin

Altitude (m)	Natural Zones	Soil type
1900-2200	Mountain steppes	Typical and carbonated black soils
2100-2300	Mountain forests	Steppe-forest soils
2300-2600	Mountain meadows	Steppe-meadow soils
Above 2500-2600	Alpine and Subalpine meadows	Meadow soils

2.8 Flora

The flora of the basin is typical to the highlands of the Transcaucasus Region known with great diversity of plants. Along the shoreline of the lake the greatest artificial woodland of the country is situated, which offers various examples of natural and human affected ecological successions. Aquatic associations (plankton, benthos, ichthyofauna) are qualitatively poor with only a few dominant species, which has simplified studies on ecological relationships (food web, etc.).

About 1,600 species of vascular plants (50% of Armenia's flora) are growing in the lake basin. 48 species out of 1600 are in the Red Data Book of Armenia, 6 species are endemic: Acantholimon gabrieljanae, Alyssum hajastanum, Astragalus shushaensis, Isotis arnoldiana, Isotis sevangensis, and Ribes achurjani.

The dominant vegetation communities of the Sevan basin are mountain steppe, sub-alpine and alpine vegetation with different species of Astragalus and Acantholimon. The most characteristic arboreal plants of Sevana Mountains are junipers (Juniperus policarpos, J. oblonga). There are remains of natural oak forests in the central part of the Sevana Mountains. In the Vardenis and Geghama Mountains, sweetbrier (Rosa canina) and other species Rosa sp. are common everywhere.

After the water level decreased, the dried areas of the former lake bottom have been forested by alien species of plants. Artificial forests composed of pine (Pinus caucasica), poplar (Populus canadensis, Populus simoni), acacia (Caragana brevespina, Caragana trutex), and willow (Salix viminalis). In some areas the sallow thorn (Hippopae ramnoides) forms an almost impassable bush.

On Lake Sevan, emergent vegetation exists only in limited calm areas. Pondweeds (Potamogeton spp.) are abundant to depths of 2-5 m. Stonewort (Chara spp.) thickets cover the littoral zone to depths of 4-8 m. There is luxuriant development of aquatic vegetation in shallow coves, bogs and ponds (Babayan et. al., 2006).

2.9 Fauna

In the Lake Sevan basin there are six species of fishes (two species are in the Red Data Book of Armenia, another two are endemic). All native fish species, ishkhan (Salmo ischchan), Sevan barbel (Barbus goktschaikus), Sevan koghak (Varicorhinus capoeta sevangi) are in decline. The famous endemic ishkhan (Salmo ischchan) (means "prince" in Armenian) is now at the edge of extinction.

There are also four species of amphibians, luckily none of them considered as endangered. Amphibians are abundant everywhere that there are small ponds, pools and puddles. There are 18 species of reptiles, two of which are in the Red Data Book of Armenia. The herpetofauna is more abundant on the northeastern shore of the lake and only grass snakes (Natrix natrix and N. tesselata) are common everywhere.

Two-hundred ten species of birds (36 are in the Red Data Book of Armenia, one is endemic, and 83 are included in the Agreement on the Conservation of African-Eurasian Migratory Waterbirds of the Convention on the Conservation of Migratory Species of Wild Animals). The artificial water-level decrease influenced the number of breeding waterfowl. From approximately 60 breeders formerly, only about 25 species are registered as breeding during recent years. The Eurasian coot (Fulica atra), mallard (Anas platyrhynchos) and endemic Armenian gull (Larus armenicus) are abundant currently.

Lake Sevan serves as an important stop for migratory birds, especially in October-December months, before the lake becomes covered with ice. Such rare birds as great egret (Casmerodius albus), glossy ibis (Plegadis falcinellus), mute swan (Cygnus olor), whooper swan (C. cygnus), demoiselle crane (Grus vigro) fly here regularly during the migrations. Lake Sevan is important both as a resting and a wintering site for migratory waterfowl. Half a century ago, the area was known as a breeding area for waterfowl between the Black and the Caspian Seas. Because of the water-level decrease and draining of most wetlands, Lake Sevan's role as breeding area is now much reduced.

There are 36 species of mammals, eight of which are in the Red Data Book of Armenia. The most typical mammals are European hare (Lepus europaenus), red fox (Vulpes vulpes), wolf (Canis lupus), weasel (Mates foina) and most of the rodents.

Investigations on invertebrates have so far included only aquatic fauna: 14 plankton and 136 benthic species of different systematic groups. Plankton and benthos associations showed a close dependence on the trophic status of the lake.

Since the 1990s, an export-oriented commercial fishery (including the European Union) has developed with the recently-acclimatized long-hand crayfish (Astacus leptodactylus) abroad (Babayan et. al., 2006).

2.10 Land Cover Types Distribution within Lake Sevan Basin

Land cover has a crucial role in surface and groundwater flow formation within any river basin. For this assessment within the PONTOS project, it will be necessary to analyze the distribution of croplands and extrapolation of pilot modeling results for the entire Lake Sevan basin.

Land cover of Lake Sevan Basin was analyzed using CORINE classification and Sentinel-2 images. The Semi-Automatic Plugin of QGIS was used for the analysis. Data from above mentioned sources was combined and analyzed. Land cover was classified using the second Level of CORINE system[4] (Table 7, Figure 8).

Table 7. Land Cover Types Distribution within Lake Sevan Basin

Land Cover Type	Area, km^2	Percentage, %
Cropland	401.7	8.5
Pastures and grasslands	2242	47.4
Forests and shrubs	395.9	8.4
Bare / sparse vegetation	164.9	3.5
Built-up areas	141.8	3.0
Lake Sevan	1272.6	26.9
Other inland waters	64.6	1.4
Moss and lichen	44.3	0.9

[4] https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature-guidelines/html/

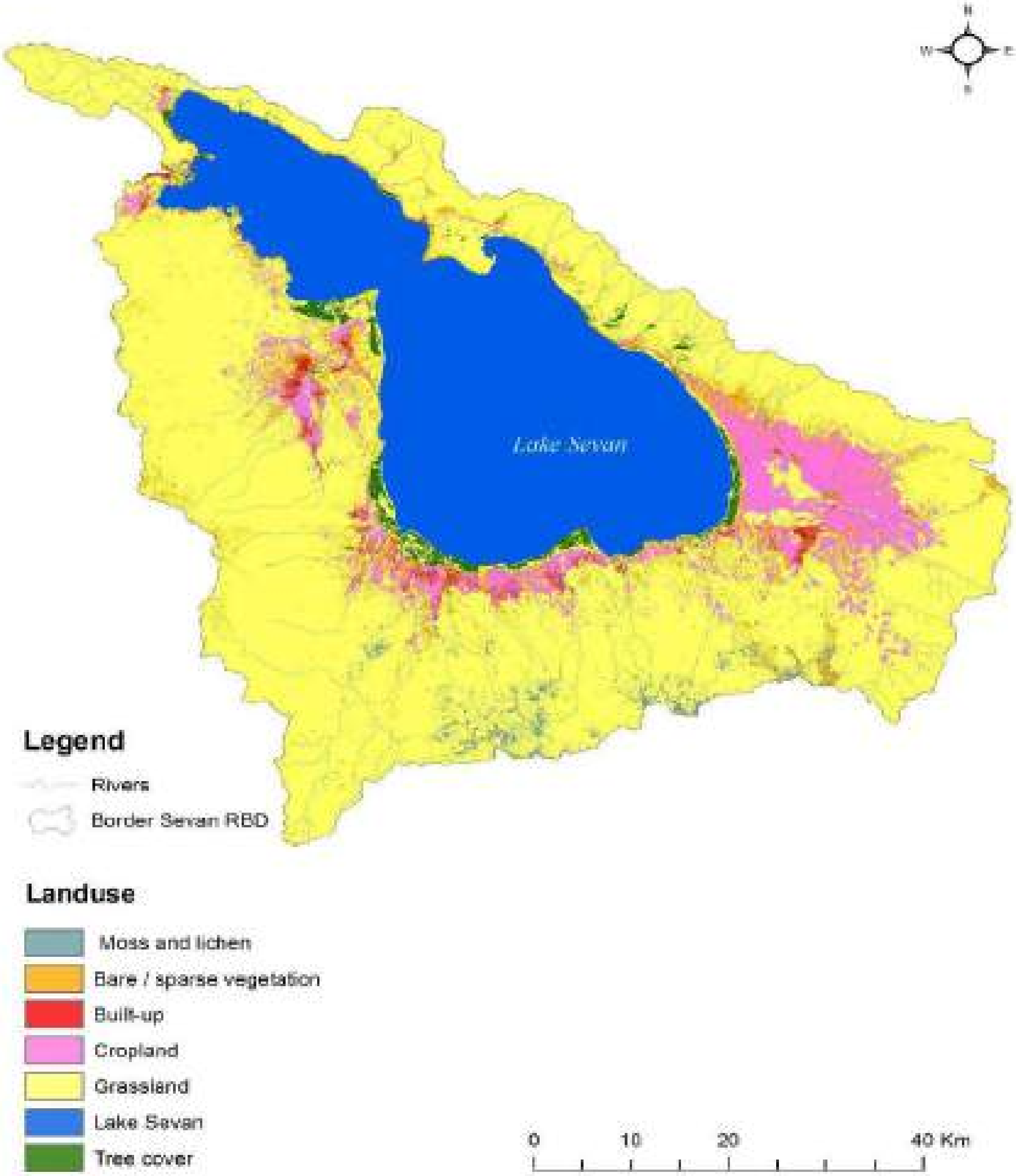


Figure 8. Land Cover Distribution within Lake Sevan Basin (Sentinel-2 data, CORINE classification system)

2.11 Ecoregions and Typology of Water Bodies

Ecoregion is a recurring pattern of ecosystems associated with characteristic combinations of soil and landform that characterize that region, within which there is spatial coincidence in characteristics of geographical phenomena associated with differences in the quality, health, and integrity of ecosystems.

Southern Caucasus countries including Armenia are situated within the 24th ecoregion (Caucasus) (Map 13).

The boundaries of the ecoregions are defined in the shape file (vector data, polygon): **wfd_shp_ecoregions.zip**, available at: http://www.eea.europa.eu/data-and-maps/data/ecoregions-for-rivers-and-lakes. It includes 25 European Ecoregions based on the ideas of Illies (1967) and adapted by the European Union to assess the ecological quality in European water bodies.

The water bodies were differentiated by surface water body types according to the descriptors defined in the system A of the WFD Annex II. Based on that, the typology for the "river" water bodies and "lake" water bodies in the Lake Sevan Basin is presented in Tables 8 and 9 below.

Table 8. Typology Parameters for the "River" Water Bodies in the Lake Sevan Basin

Descriptors	**Types**		
	I	**II**	**III**
Ecoregion	24 (Caucasus)		
Altitude	>800m		
Geology	Siliceous	Calcareous	Siliceous
Catchment size, km^2	<100		100-1000

Table 9. Typology Parameters for the "Lake" Water Bodies in the Lake Sevan Basin

Descriptors	**Types**		
	I	**II**	**III**
Ecoregion	24 (Caucasus)		
Altitude	>800m		
Geology	Siliceous		
Area, km^2	0,5-1		>100
Depth, m	<3	3-15	>15

2.12 Description of Natural Hazards

The Lake Sevan Basin is affected by various natural hazards – floods, debris flows, earthquakes, landslides, etc.

Floods are mainly observed during spring high-water period, but in some years summer they may occur in summer caused by torrential rains. Flash floods are noted on the rivers of the north-eastern shore of the lake but they do not present significant hazards.

Debris flows mainly occur on the eastern part of the basin – on rivers Hovsatsakhk, Artsatabek, Norakert, Drakhtik, Satanakhach, Tsapatagh, Pambak, Jil, Artunj, Kaputjur. Debris flows have a negative impact on infrastructure (roads), agriculture and environment.

There are 175 landslide areas registered in Lake Sevan Basin.

3. Agriculture in Lake Sevan Basin

3.1 Distribution of Agricultural Lands

Agriculture is one of the leading sectors of economy in the Lake Sevan Basin. The agricultural lands occupy about 56 % (264,360 ha) of the total land of the Lake Sevan Basin, out of which 224,200 ha are grasslands and pastures, 40,170 ha - arable lands.

The agricultural land distribution across the main river basins is presented in Table 10. As it is seen from that table, the largest areas of agricultural lands are located in Masrik (24.7%), Gavaraget (17.5%), Argichi (12.5%), Pokr Masrik (2.7 %), Bakhtak (5.8 %), Lichk (1.3%) river basins. The other river basins together hold over 35.5 % of total agriculture lands. Masrik holds about 52% of total arable lands, followed by Argichi (17.5%) and Gavaraget (8.6%). The largest grasslands are also located in Masrik (21.1%), Gavaraget (18.6%) and Argichi (11.8%) river basins.

Table 10. Agriculture Land Structure by River Basins

River basin	**Land area per river basin, ha**	
	Arable lands including small-size household farms	**Grasslands and pastures**
Masrik	12825.4	39944.7
Argichi	4324.3	22308.8
Gavaraget	2123.7	35175.9
Pokr Masrik	1750.4	4075.9
Bakhtak	977.1	11422.0
Lichk	942.5	1863.7
Others	1699.8	74099.0

Source: Gegharkunik Regional Administration, Geocom Ltd, 2010-2021.

3.2 Agricultural Production in Lake Sevan Basin

The agricultural production in the basin is focused on the grains and potatoes (Table 8), followed by livestock production, including cows, sheep and pigs.

In the Lake Sevan Basin the main crops are grains which are cultivated on about 44% of the arable land, 14.7 % are fodder crops and potatoes (Table 8).

Table 11. Crop Gross Production in the Lake Sevan Basin, 2013-2021

Crop	Cultivated land, ha								
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Grain	41,753	40,902	38,625	35,875	30,913	26,200	22,700	22,900	22,900
Potato	14,109	13,276	10,235	10,239	9,431	8,700	8,100	7,900	7,600
Vegetables	2,023	2,092	1,607	1,689	1,589	1,400	1,400	1,400	1,200
Fruits	1,488	1,488	1,384	1,403	1,407	1,300	1,400	1,400	1,400
Other	19,675	19,955	21,796	-	-	-	-	-	-

Source: Statistical Committee of the Republic of Armenia (www.armstat.am).

“Gegharkunik” Water Users Association (WUA) supplies and serves agricultural lands in the Lake Sevan Basin. The total service area of the WUAs is 3742 ha. The irrigation infrastructure consists of about 19 secondary irrigation canals, which provide water from rivers and springs). As of January 2018, the permitted annual water use for irrigation purposes in the basin comprised 10.36 million m^3, which is almost 3.65% of the total permitted water use. Due to poor condition of the irrigation infrastructure, water losses in the network currently comprise about 50%.

The irrigation data shows that the irrigation network is mainly distributed in Masrik, Argichi, Gavaraget, Karchaghbyur and Martuni river basins.

The gross agricultural product in the Lake Sevan Basin has amounted to 123.8 billion AMD in 2017 (Figure 9). One of the most important priorities of the territorial development strategy for 2017-2025 in the region is agriculture.

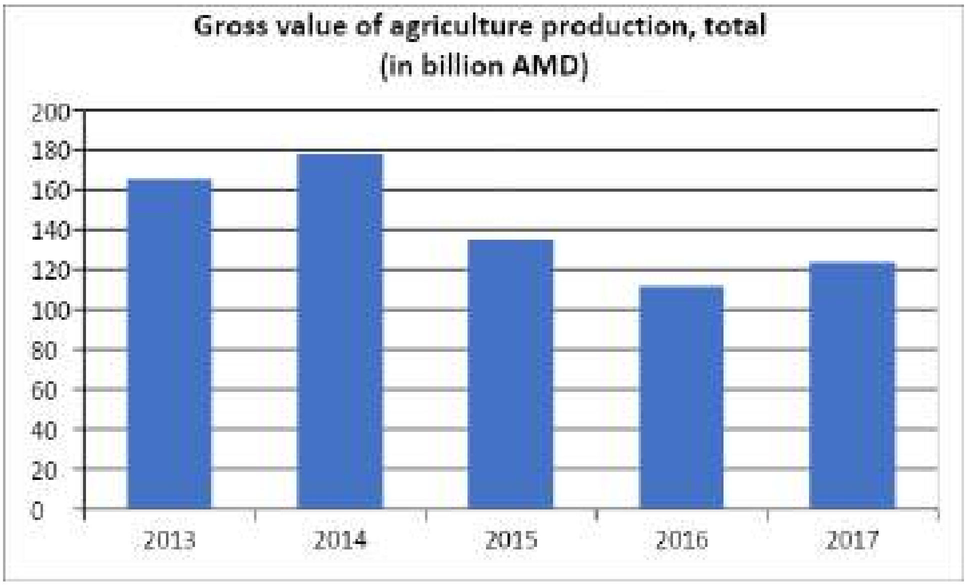


Figure 9. Gross value of Agricultural Production in the Lake Sevan Basin in billion AMD (Data source: Statistical Committee of the Republic of Armenia)

According to the statistical data (Statistical Committee of Armenia, 2014), the total annual input of mineral fertilizers (nitrogen, phosphorus, potassium and etc.) amounted to 21,000 tons which is 22.6% of the national total (93,019 t). Fertilizers are used only on permanent croplands, with an annual average area of 8,000-10,000 ha cropland treated by fertilizers. There is no data available on the organic fertilizers in the basin.

Statistical data regarding the agricultural lands is contradictory and shows that the total area of agricultural lands has decreased in recent years. However, the harvest has increased, which means that productivity per ha has increased. Personal interviews in villages showed that new irrigation and cultivation technologies are introduced in several farms, which are less water intensive. Hence, it is expected that water use for irrigation in the long run will decrease by 1% per year.

3.3 Irrigation

3.3.1 Key Water Services

Water Services are services of general (economic) interest. Water services are defined in Article 2 (38) of the WFD as: "all services which provide for households, public institutions or any economic activity: (a) abstraction, impoundment, storage, treatment and distribution of surface water or groundwater, (b) waste-water collection and treatment facilities which subsequently discharge into surface water."

In Armenian legislation there are no clear definitions of "water services" and "wastewater services". There is a definition of "water supplier", which is a physical or legal entity carrying out water "abstraction, storage, and provision to water users". The main difference between those definitions is that WFD also includes waste water collection, treatment and discharge in this term.

The water services are used for the following activities in Lake Sevan Basin:

- Water supply and sanitation,
- Irrigation,
- Watering of livestock,
- Fish farming,
- Industry,
- Hydro-power generation.

The graph below shows distribution of water abstraction by main sectors of the economy in Lake Sevan Basin. Total abstracted volume of water for 2017 was 337,586.7 thousand m^3.

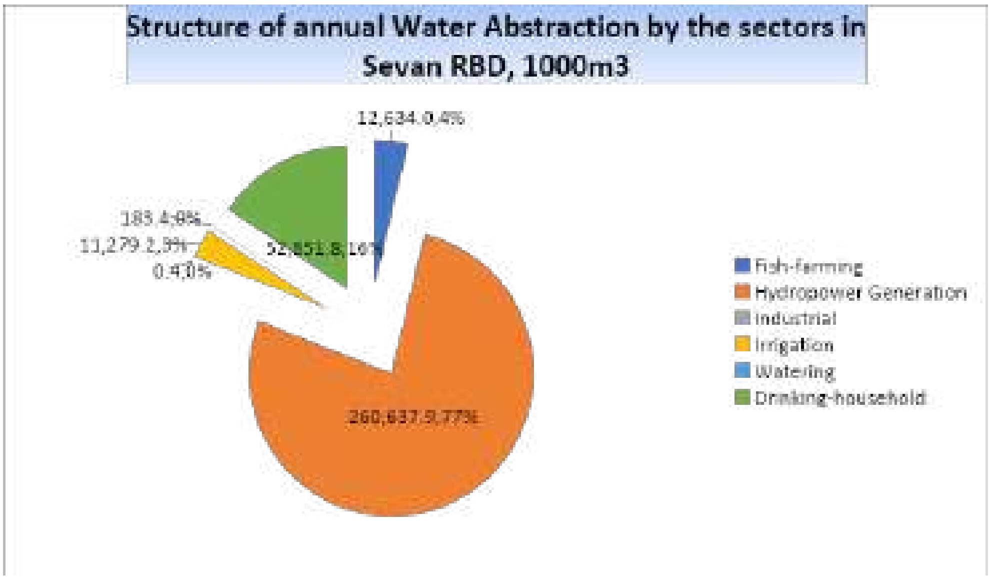


Figure 10. Structure of annual water abstraction by Sectors in Sevan basin, in 1000m^3
Source: (http:// http://wrma.am/4_1.php)

The table below shows key variables of activities that water services are used for, which will be used for the analysis and assessment of cost recovery principle:

Table 12. Description of key water services in Lake Sevan Basin

Water Service	***Variable description***	***Units***
Drinking Water Supply (Veolia jur)	No of people connected to network	46,414
Drinking Water Supply (Self-serviced)	No of people connected to network	
Sewerage (Veolia jur)	No of people connected to sewerage network	43,458
Sewerage (Self-serviced)	No of people connected to sewerage network	
Irrigation		
Grain	Irrigated land (in ha)	30
Potato	Irrigated land (in ha)	4205
Vegetables	Irrigated land (in ha)	20
Fruits	Irrigated land (in ha)	12
Other	Irrigated land (in ha)	
Watering of Livestock		
Cattle	No of animals	118543

Pig	No of animals	15049
Sheep and Goat	No of animals	110830
Horse	No of animals	1021
Poultry	No of animals	374044
Fish-farming	Total area of fish-farms (sqm)	33364
Industry		
Mining and Quarrying		N/A
Manufacturing of food Products		N/A
Manufacturing of Beverages		N/A
Manufacturing of Textiles		N/A
Other		N/A
Hydro-Power Generation	Capacity, KW	18678
Recreation and Tourism	Number of visitors	1500000

3.3.2 Irrigation Water Demand

Demand of water for irrigation was calculated by taking into account the irrigation norms for different crops as defined by the ministry of agriculture for different regions of Armenia (“Norms and regimes for irrigation of agricultural crops in RA, Manual, Yerevan, 2007, 203 p.). It should be noted that irrigation norms depend on several variables, such as soil type, clay content in soils and elevation. Since such detailed data is not available, an assumption has been made that following amounts of water are required for irrigation of the following types of crops:

- · Potato – 2400 m^3/ha,
- · Vegetables – 2400 m^3/ha,
- · Wheat – 800 m^3/ha,
- · Fruits and berries – 1800 m^3/ha

Non-revenue water for irrigation was calculated by taking into account governmental decree No 188-N adopted on February 8, 2007, which defines acceptable NRW rates for all WUAs. The acceptable rate for Martuni, Gavar and Vardenis WUA is 47.5%, 31.2% և 43.9 % respectively.

3.3.3 Irrigation Services

Irrigation services in the Lake Sevan Basin are provided by “Gegharkunik” Water Users Association (WUA). The total service area of the WUA is 3742 ha. The irrigation infrastructure consists of about 19 secondary irrigation canals, which provide water from rivers and springs. The water used for irrigation purposes was 11,279.3 thousand m^3 or 3.3 % of total water use permit volume in the basin. There are 26 major water users of irrigation water in this region, out of which 13 are rural communities and the remaining part are different users. The figure below shows the allocation of water abstraction among different users.

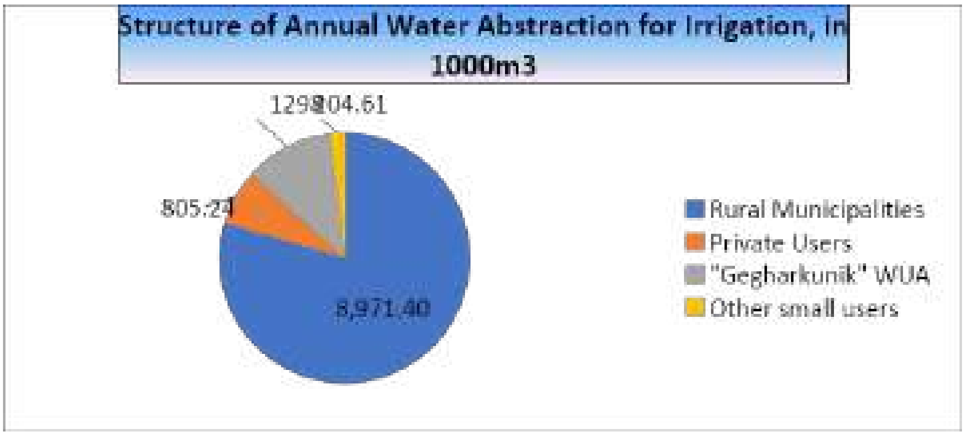


Figure 11. Structure of annual water abstraction for irrigation in Sevan basin, in 1000m^3

Source: (http:// http://wrma.am/4_1.php)

Water use for irrigation from surface and ground water resources is outlined below.

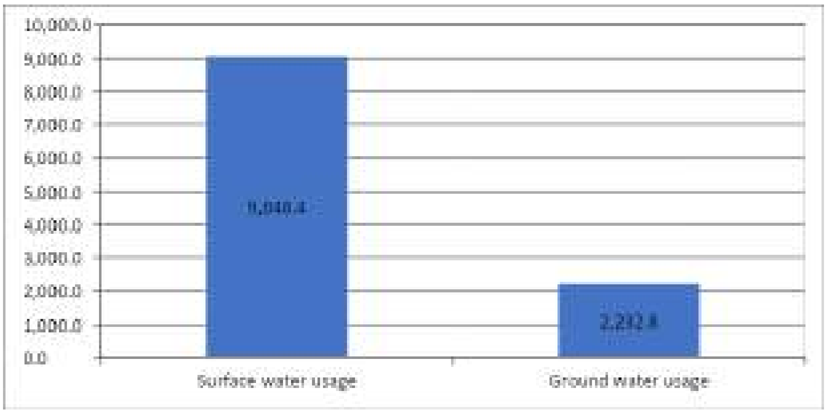


Figure 12. Surface and groundwater abstraction for Irrigation in Lake Sevan Basin, in 1000m^3

Source: (http:// http://wrma.am/4_1.php), 2017

Most of the irrigation network is maintained by "Gegharkunik" Water Users Associations (WUA), which supply water to most of the agricultural lands in Lake Sevan Basin. The total service area of the WUA is 3742 ha.

Table 13. Main Characteristics of the Canals in Lake Sevan Basin Operated by "Gegharkunik" WUA

Name of the canal	Canal type	Length, km	Discharge, m^3/sec	Water source	Purpose	Dominant crops	Service area (ha)	Irrigation supply mode
Averakneri	Secondary	6.1	0.5	Lchavan natural springs	Agriculture	Potato	56	Gravity
Sarukhan	Secondary	5.9	0.1	Sarukhan springs	Agriculture	Potato	211	Pumped
Masrik	Secondary	31.5	2.0	Akunk springs	Agriculture	Potato	1846	Gravity
Ayrk pipeline	Secondary	13.9	1.0	Ayrq River	Agriculture, Energy	Potato, wheat	90	Gravity
Dotation	Secondary	5.6	0.5	Argichi River through Getashen Canal	Agriculture	Potato	240	Gravity
Getashen	Secondary	13.4	2.0	Argichi River	Agriculture	Potato	30	Gravity
HPP Canal	Secondary	6.8	0.3	Argichi River	Agriculture, Private water users	Vegetable Potato	110	Gravity
Waterfall Stream	Secondary	2.6	0.4	Argichi River	Agriculture	Potato	348	Gravity
Lchavan	Secondary	7.2	0.4	Makenis River	Agriculture	Potato	87	Gravity
Makenis	Secondary	3.6	0.7	Makenis River	Agriculture, Private water users	Vegetables Potato	110	Gravity
Tsovak 2) Vanq	Secondary	8.2	0.2	Makenis River	Agriculture	Potato	67	Gravity
Mountain Stream Martuni	Secondary	7.0	0.5	Martuni River	Agriculture	Potato	150	Gravity
Vaghashen (Manas)	Secondary	19.3	0.5	Martuni River	Agriculture	Potato	174	Gravity
Noratus (left)	Secondary	6.7	2.5	Gegharkunik River	Agriculture	Potato	91	Out of operation
Noratus (right)	Secondary	10.8	0.15	Gegharkunik River	Agriculture	Potato	180	Pumped
Tsovinar	Secondary	5.2	0.4	Artsvanist River	Agriculture	Potato	140	Gravity
Zolaqar	Secondary	5.3	0.4	Astghadzor River	Agriculture	Potato	310	Gravity

Gegharkuni k no 1 Reser voir Canal	Secondary	2.5	0.1		Agriculture	Potato	15	Gravity

Source: EUWI+, Detailed Assessment of Modern Flow Measurement Equipment Needs for Irrigation Water Accounting in Sevan and Hrazdan Pilot Basins of Armenia (EUWI+, 2018c)

3.4 Pesticide Use in the Basin

Regarding the use of pesticides, data on amounts used per river basin in the Lake Sevan Basin are not available.

From 2012 through 2021 total annual consumption of pesticides has changed noticeably, from 431 t in 2012 to 275.3 t in 2021 (Table 14).

To assess pesticides impact on water resources the data on monitoring required. Monitoring data of pesticides is generally poor. Key pesticides are included in the monitoring schedule of Armenia (RA government resolution, 75-N, 27.01.2011), however the cost of analysis and the necessity to sample at critical times of the year (linked to periods of pesticide use) often preclude development of an extensive data set. Information on types of used pesticides is also not available.

Table 14. Pesticides Consumption in Gegharkunik Province

Assessment Parameters	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Agricultural land, 1000 hectares	481.8	481.5	481.5	481.0	481.1	481.1	481.5	481.3	481.4	481.7
Total area treated with pesticides, 1000 hectares	290.6	299.0	285.0	282.0	282.0	272.4	275.2	265.3	220.5	220.2
Total consumption of pesticides (according to the quantity of active substance), t	431.0	349.4	412.9	508.6	348.7	403.4	385.2	344.9	264.6	275.3
Total consumption of pesticides per unit of land, kg/hectare	1.5	1.2	1.4	1,8	1.2	1.5	1.4	1.3	1.2	1.25

Source: Statistical Committee of the Republic of Armenia, www.armstat.am.

4. Climate Change Trends in Sevan RBD

4.1 Changes in Air Temperature and Precipitation

Annual average temperature and total precipitation data of four operational meteorological stations were used for the assessment of the climate change trends in the Sevan basin. Observation data for the period of 1961-2021 were examined.

As seen from the charts below, increasing trends in annual air temperature are observed in all 4 meteorological stations (Figure 13).

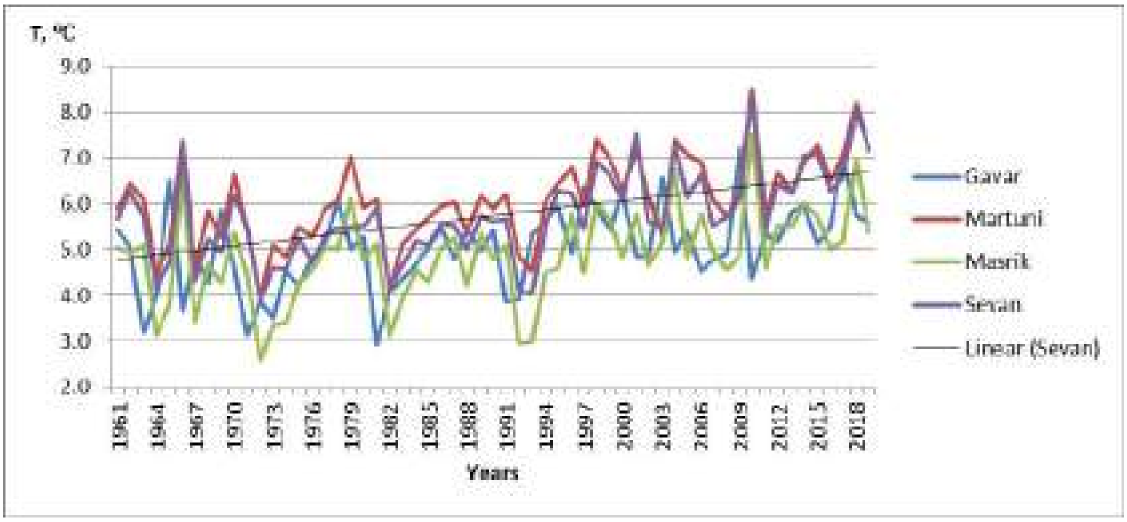


Figure 13. Annual Average Air Temperature in Meteorological Stations of Lake Sevan Basin, 1961-2021, °C (Source:Hydrometeorology and Monitoring Center SNCO, 2021)

Increasing trends in annual precipitation are observed in Martuni and Sevan (Figures 14 and 15).

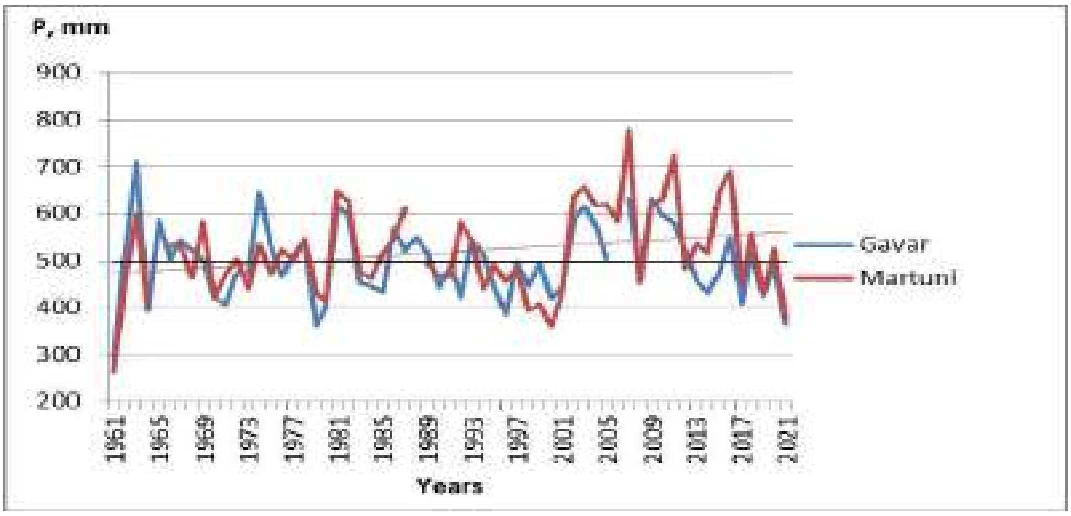


Figure 14. Annual Precipitation in Gavar and Martuni Meteorological Stations, 1961-2021, mm (Source: Hydrometeorology and Monitoring Center SNCO, 2021)

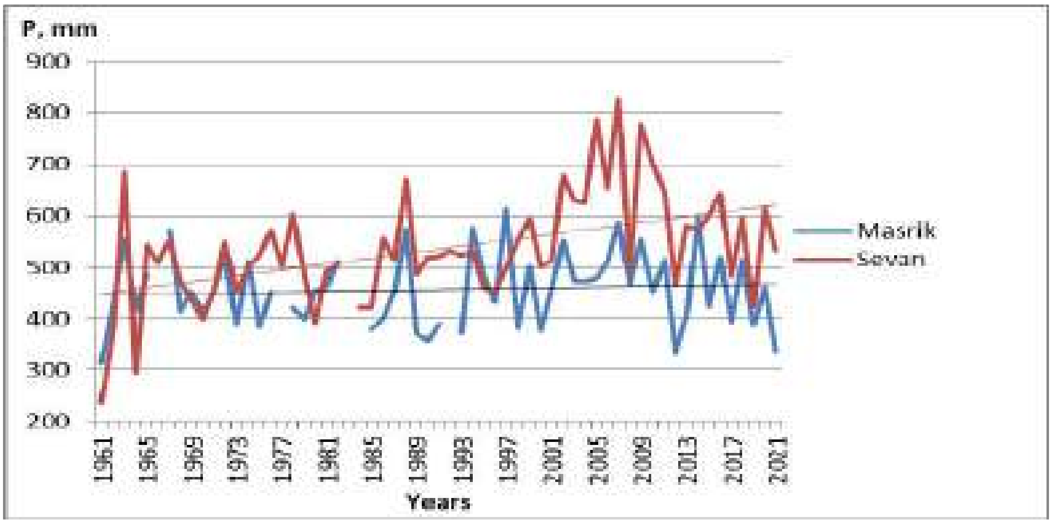


Figure 15. Annual Precipitation Masrik and Sevan Meteorological Stations, 1961-2021, mm (Source:Hydrometeorology and Monitoring Center SNCO, 2021)

4.2 Impact of Climate Change on Surface Flow

Climate change in Armenia is assessed using the CCSM4 and METRAS models in accordance with the IPCC recommended RCP8.5 and RCP6.0 scenarios for CO_2 emissions. Therefore, as per the RCP6.0 scenario (equivalent to the SRES B2 scenario) CO_2 concentration will be 670ppm by 2100 and it will be 936ppm according to the RCP8.5 scenario (equivalent to the SRES A2 scenario). Future change forecasts for ambient air temperature and rainfall have been developed up until 2100.

The results of CCSM4 model application indicate that the temperature will continue to increase in all seasons of the year. However, according to the RCP8.5 scenario, starting from the mid-21th century (2041-2100) the temperature will rise at a more rapid rate. According to the RCP8.5 scenario, it is very likely that, by 2100, the average annual temperature in Armenia will be 10.2°C, which exceeds the baseline (1961- 1990) by 4.7°C. Evaluation results for precipitation change show that, according to the RCP8.5 scenario, there might be a 5.2% increase in annual precipitation by 2070, then by 2100 the precipitation will rapidly decrease and will be around the baseline (+0.7%) (Table 15).

Table 15. Projected Changes in Temperature and Precipitation according to IPCC RCP6.0 and RCP8.5 Scenarios (CCSM4 model)

Parameter	1961-1990	2011-2040		2041-2070		2071-2100	
		RCP6.0	RCP8.5	RCP6.0	RCP8.5	RCP6.0	RCP8.5
Temperature, °C	5.5	+1.7	+1.8	+2.3	+3.2	+3.1	+4.7
Precipitation, mm / %	592/100	+18.9/+3.2	+6.9/+1.2	+13.0/+2.2	+30.7/+5.2	+22.0/+3.7	+4.0/+0.7

A METRAS regional model with a 12 km resolution is also accepted. The ACCES, CNRM, MPIM, GFDL global models are the basis of the METRAS which allowed to downscale the rough results of low-res global models for the territory of Armenia taking into account the complex mountainous topographic conditions of the country.

The METRAS model is applied for temperature and precipitation changes projection according to the pessimistic RCP8.5 scenario. Projected temperature changes are close to the values obtained from the CCSM4 model, but the precipitation values differ considerably: according to the METRAS model, the precipitation might decrease by 8.3% to 2100 (Table 16).

Table 16. Projected Changes in Temperature and Precipitation according to IPCC RCP8.5 Scenarios (METRAS model)

Parameter	1961-1990	2011-2040	2041-2070	2071-2100
Temperature, °C	5.5	+1.4	+3.1	+4.5
Precipitation, mm / %	592/100	-16/-2.7	-32/-5.4	-49/-8.3

The possible changes in surface natural flow due to the climate change impact were calculated using Climate Change Projections module of DSS developed by USAID Clean Energy and Water Programme using the projected values of changes in meteorological parameters presented above (METRAS model) and multi-year observation data on temperature and precipitation in Sevan basin (Table 17).

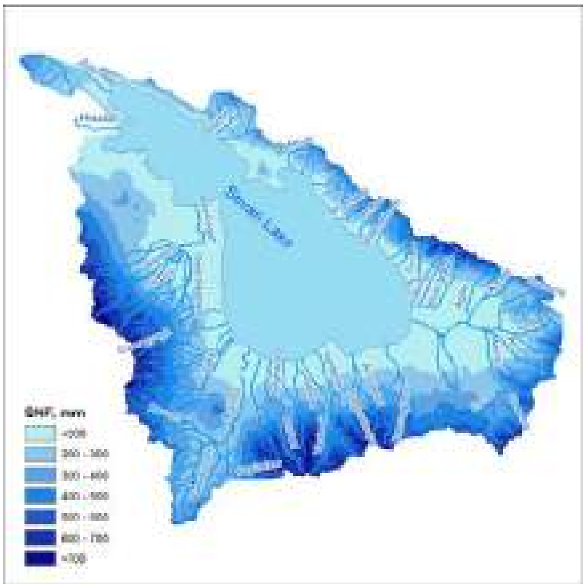
Table 17. Projected Changes in Annual Surface Natural Flow, % (METRAS)

Hydropost Code	River-Post	RCP8.5		
		2040	2070	2100
85339	Pambak-Pambak	0.8	1.7	2.5
85352	Dzknaget-Tsovagyugh	-19.7	-42.7	-62.8
85353	Drakhtik-Drakhtik	-20.3	-44.4	-64.8
85363	Masrik-Tsovak	3.4	7.9	11.1
85366	Karchaghbyur-Karchaghbyur	-12.3	-27.3	-39.6
85371	Vardenis-Vardenik	3.5	8.3	11.7
85376	Martuni-Geghhovit	0.2	1	1.1
85378	Argichi-Verin Getashen	-17.5	-38.4	-56
85379	Tsaghkashen-Vaghashen	-13.3	-28.9	-42.5
85380	Lichk-Lichk	10.3	22.9	33.1
85381	Bakhtak-Tsakkar	-2.2	-4.9	-7.2
85384	Gavaraget-Noratus	0.7	1.5	2.3

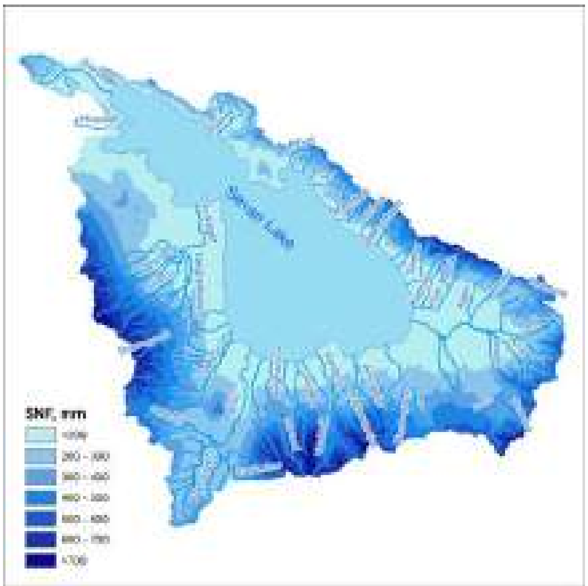
Changes in surface flow in different river basins of Lake Sevan basin are of a different nature. The most dramatic decrease in surface natural flow compared to the baseline period (1961-1990) is predicted in Drakhtik (up to -64.8%), Dzknaget (up to -62.8%), Argichi (up to -56%), Karchaghbyur (up to -39.6%) and Tsaghkashen (up to -42.5%), and the biggest increase is predicted in Lichk (up to +33.1%), Vardenis (up to +11.7%) and Masrik (up to +11.1%) river basins. Thus, climate change impacts should be considered in the planning and assessment of agricultural water demand, supply, and water stress in future.

Changes in surface natural flow were extrapolated for the entire territory of Sevan basin through spatial analysis in the GIS environment using the surface natural flow height raster calculated through DSS Water Balance module and surface flow projections (Figure 16).

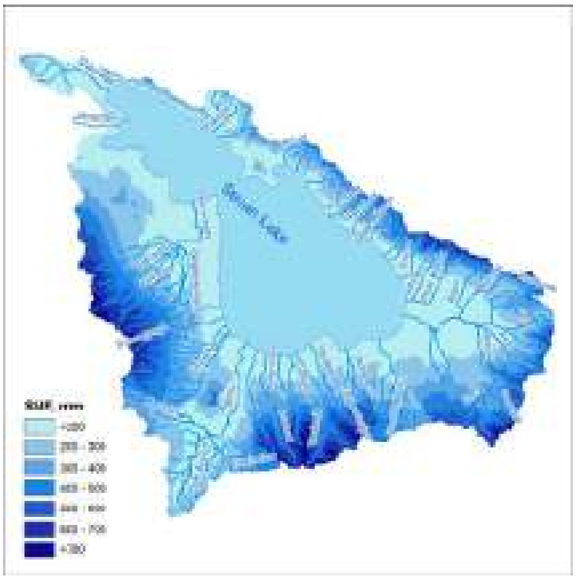
Figure 16. Projected Changes in Annual Surface Natural Flow Height (mm) using DSS Climate Change Module (METRAS model, IPCC RCP8.5 scenario)



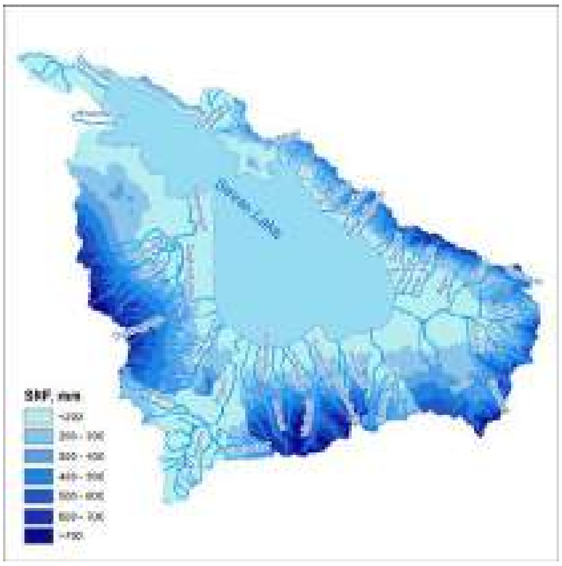
a) 1961-2017



b) 2040



c) 2070



d) 2100

4.3. Current and Future Water Supply in Lake Sevan Basin

Water supply and demand was analyzed for the multi-year period (average), 2016 (high-water year), 2017 (low-water year), as well as projected for the short-term] period (2022-2027) and 2040. Two climate change scenarios were used for water supply projection: optimistic (IPCC RCP6.0) and pessimistic (IPCC RCP8.5) (Lake Sevan Basin Management Plan, 2020).

Difference between water supply and demand (by sectors) is presented in the table below.

Table 18. Current and Future Water Supply and Demand in Lake Sevan Basin

Water Supply & Demand	Supply Source / Demand Purpose	Optimistic Scenario										Pessimistic Scenario						
		Multi-year average	**2016**	**2017**	**2020**	**2021**	**2022**	**2023**	**2024**	**2027**	**2033**	**2020**	**2021**	**2022**	**2023**	**2024**	**2027**	**2033**
Water Supply	Surface	677	756.2	595.2	676.2	675.5	674.7	674	673.2	671	666.5	675.4	673.7	672.1	670.5	668.8	664	654.2
	Groundwater	259.5	259.5	259.5	259.4	259.3	259.1	258.9	258.8	258.3	258.1	259.1	258.6	258.2	257.7	257.2	255.7	255.3
	Total	**936.5**	**1015.7**	**854.7**	**935.7**	**934.8**	**933.8**	**932.9**	**932**	**929.2**	**924.5**	**934.5**	**932.4**	**930.3**	**928.1**	**926**	**919.7**	**909.4**
Water Demand	Drinking-household	57.0	84.3	77.4	62	58.2	54.8	51.8	49	42.3	32.9	71.8	69.2	66.7	64.5	62.3	56.6	47.4
	Irrigation	*13.6*	*14.2*	*14.1*	*13.9*	*13.8*	*13.6*	*13.5*	*13.4*	*13.2*	*12.6*	*13.6*	*13.5*	*13.4*	*13.2*	*13.1*	*13*	*12.3*
	Hydropower Generation	270.9	260.6	262.6	265.8	268.4	271	273.6	276.2	278.8	281.4	260.5	263	265.6	268.2	270.7	273.3	275.8
	Industrial	0.0	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0005	0.0007	0.0003	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006
	Fish-farming	13.9	12.6	12.6	13.1	13.4	13.6	13.9	14.2	15	17.1	13.2	13.4	13.7	14	14.3	14.5	15.6
	Watering	2.2	1.98	1.95	1.99	2.03	2.07	2.12	2.16	2.2	3.02	1.97	2.01	2.05	2.09	2.14	2.18	2.99

	Total	0	373.7	368.7	356.8	355.8	355.1	354.9	355.0	351.5	347.0	361.1	361.1	361.5	362.0	362.5	359.6	354.1
Proficit/Deficit			**642.0**	**486.0**	**578.9**	**579.0**	**578.7**	**578.0**	**577.0**	**577.7**	**577.5**	**573.4**	**571.3**	**568.8**	**566.1**	**563.5**	**560.1**	**555.3**
Water demand / supply ratio			**37%**	**43%**	**38%**	**38%**	**38%**	**38%**	**38%**	**38%**	**38%**	**39%**	**39%**	**39%**	**39%**	**39%**	**39%**	**39%**

Current and future water supply and demand is also calculated for the highest agriculture water demand season, that is also the driest season (July-September).

Table 19. Current and Future Water Supply and Demand in Lake Sevan Basin for Highest Water Demand Season

Water Supply & Demand	Supply Source / Demand Purpose	Optimistic Scenario										Pessimistic Scenario						
		Multi-year average	2016	2017	2020	2021	2022	2023	2024	2027	2033	2020	2021	2022	2023	2024	2027	2033
Water Supply	Surface	115.3	128.6	101.2	115.2	115	114.9	114.8	114.7	114.3	113.5	115	114.7	114.4	114.2	113.9	113	111.4
	Groundwater	64.9	64.9	64.9	64.9	64.8	64.8	64.7	64.7	64.6	64.5	64.8	64.7	64.5	64.4	64.3	63.9	63.8
	Total	**180.2**	**193.5**	**166.1**	**180.1**	**179.8**	**179.7**	**179.5**	**179.4**	**178.9**	**178**	**179.8**	**179.4**	**178.9**	**178.6**	**178.2**	**176.9**	**175.2**
Water Demand	Drinking-household	17.1	25.3	23.2	18.6	17.5	16.4	15.5	14.7	12.7	9.9	21.5	20.8	20.0	19.4	18.7	17.0	14.2
	Irrigation	*6.8*	*7.1*	*7.1*	*7.0*	*6.9*	*6.8*	*6.8*	*6.7*	*6.6*	*6.3*	*6.8*	*6.8*	*6.7*	*6.6*	*6.6*	*6.5*	*6.2*
	Hydropower Generation	81.3	78.2	78.8	79.7	80.5	81.3	82.1	82.9	83.6	84.4	78.2	78.9	79.7	80.5	81.2	82.0	82.7
	Industrial	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0004	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003
	Fish-farming	4.9	4.4	4.4	4.6	4.7	4.8	4.9	5.0	5.3	6.0	4.6	4.7	4.8	4.9	5.0	5.1	5.5
	Watering	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.5	1.0	1.0	1.0	1.0	1.1	1.1	1.5
	Total		**90.7**	**91.2**	**92.3**	**93.1**	**93.9**	**94.8**	**95.6**	**96.6**	**98.2**	**90.6**	**91.3**	**92.2**	**93.0**	**93.8**	**94.7**	**95.8**
Proficit/Deficit			102.8	74.9	87.8	86.7	85.8	84.7	83.8	82.3	79.8	89.2	88.1	86.7	85.6	84.4	82.2	79.4
Water supply/demand ratio			**47%**	**55%**	**51%**	**52%**	**52%**	**53%**	**53%**	**54%**	**55%**	**50%**	**51%**	**52%**	**52%**	**53%**	**54%**	**55%**

According to the table above during the highest water demand season the water demand against water supply in the **Optimistic Scenario** is between 2020 to 2033 varies from 51% to 55% and roughly the same ratio is observed in **Pessimistic Scenario**.

The water supply is not equally distributed throughout the RBD. In particular, during the risk analysis there were identified water bodies with disturbances of environmental flow. In the table below, water supply and demand are presented for the highest water demand season in the river basins with such disturbances.

5. Agricultural Water balance, Productivity, and Stress Analysis - Lake Sevan Basin, ARMENIA

5.1 Assessment Methodology

The analysis of agricultural water balance, productivity, and stress has been conducted using the methodology developed by Greek partners of the PONTOS project. It consists of the steps on data collection, representative fields selection, AquaCrop model input data preparation, AquaCrop model run, developing recommendations on optimizing irrigation water amounts and schedule, and extrapolating the results for the entire watershed, in Armenian case - Lake Sevan basin.

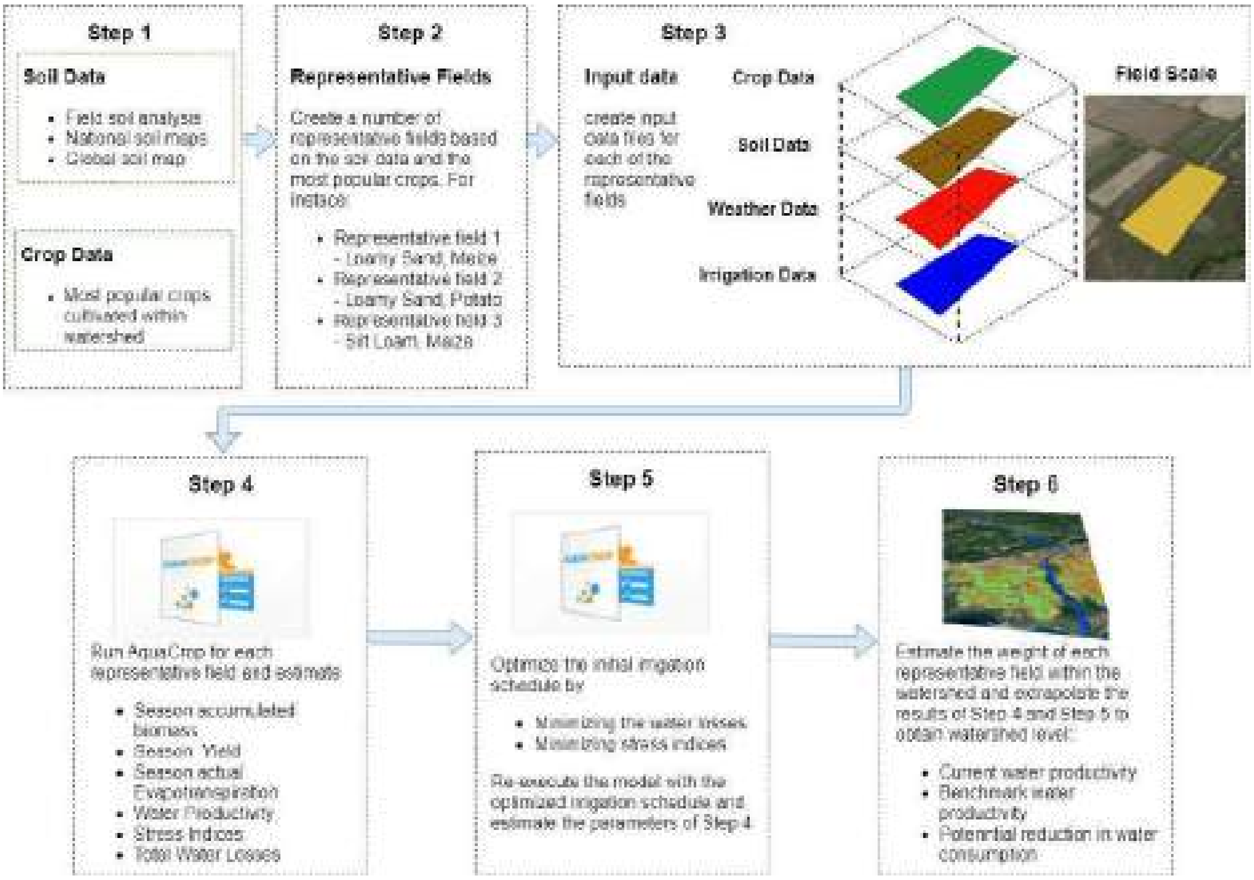


Figure 17. Proposed methodology flowchart

5.2 Armenian Pilot Sites

Four pilot sites for agricultural water balance calculation were selected and analyzed: 1. potato cropland with an area of 1.18 ha in Zolakar village (2021 vegetation season); 2. winter wheat cropland with an area of 2.2 ha in Noratus village (2020-2021 vegetation season); 3. cabbage cropland with an area of 0.177 ha in Vardenik village (2022 vegetation season); 4. maize cropland with an area of 1.18 ha in Zolakar village 2022 vegetation season).

Data for the application of the AquaCrop model for these sites is being collected. Currently, data on soil types, the start date of vegetation season, irrigation mode and volumes, pesticide/fertilizer use is collected and crop water content measured based on the crop samples taken during the field visits. NDVI/NDMI indices have been calculated for the pilot sites for 2017-2022 (vegetation seasons) based on the Sentinel-2 data. The availability of meteorological datasets to be used in the AquaCrop model was analyzed. The required meteo data will be requested from "Hydrometeorology and Monitoring Center" SNCO by the end of vegetation season.

Characteristics of agricultural activity and situation with water use in agriculture, productivity, and water stress issues in Lake Sevan Basin are being reviewed and analyzed.

Pilot Site 1: Zolakar Village

- Crop type: Potato
- Land plot area: 1.18 ha
- Soil type: Floodplain terrace soil; soil subtype: meadow; genus: pebble; depth: moderately deep; texture: clay; erosion: not eroded; stones: slightly stony.
- Start date of seeding: May 15, 2021
- Harvesting: ~September 15, 2021
- Irrigation: Started from July 1, once 10 days, ~5 times (up to ~August 20), 1,100-1,200 m^3 of water each time
- Fertilizers/pesticides: yes (pesticide)
- Estimated yield: 35 t
- Reference meteo station: Martuni
- June 19: Crop wet weight: 74 g; Crop dry weight: 9 g; Crop moisture content: 87.8%
- July 30: Crop wet weight: 117 g; Crop dry weight: 20 g; Crop moisture content: 82.9%
- August 23: Crop wet weight: 136 g; Crop dry weight: 27 g; Crop moisture content: 80.2%
- **Harvest: September 11; 17 tons of potato**

Photos from May 15, 2021

Photos from June 19, 2021

Pilot site 2: Noratus village

- Crop type: Wheat
- Land plot area: 2.2 ha
- Soil type: Mountain chernozem soil; soil subtype: ordinary; genus: mealy-calcic; depth: shallow; texture: loam; erosion: slightly eroded; stones
- Start date of seeding: August 20, 2020
- Harvesting: ~September 10, 2021
- Irrigation: rainfed
- Fertilizers/pesticides: no
- Estimated yield: 1.5-2 t
- Reference meteo station: Gavar
- May 15: Crop wet weight: 55.31 g Crop dry weight: 41.33 g Crop moisture content: 25.27%
- June 19: Crop wet weight: 22 g; Crop dry weight: 15 g; Crop moisture content: 31.8%
- Soil temperature: 20.8°C (July 30)

Harvest: August 1; 800 kg of wheat


Photos from May 15, 2021


Photos from June 19, 2021

Pilot site 3: Vardenik village

- Crop type: Cabbage
- Land plot area: 0.177 ha
- Soil type: Mountain chernozem, with loam texture, slightly eroded, moderately stony
- Start date of seeding: May 2, 2022
- Harvesting: ~September 3, 2022
- Irrigation: 128 m^3, 5 times per season, drip irrigation
- Fertilizers/pesticides: Organic fertilizers, 1500 AMD per 1000 m^2
- Estimated yield: 4500 plants, 13.5 tons (~2,700,000 AMD)
- Reference meteo station: Martuni

Pilot site 4: Zolakar village

- Crop type: Maize
- Land plot area: 1.18 ha
- Soil type: Floodplain terrace soil with clay texture, not eroded; slightly stony.
- Start date of seeding: May 15, 2022
- Harvesting: ~September 3, 2022
- Irrigation: 6 times per cycle, 1100 m^3 each time
- Fertilizers/pesticides: Selitra
- Estimated yield: 40-50 tons
- Reference meteo station: Martuni

5.3 AquaCrop Model

AquaCrop is crop water productivity model particularly suited to areas where water is a key limiting factor in crop production, especially in arid and semi-arid regions (Raes et al. 2009). The model simulates daily biomass production and final crop yield in relation to water supply and consumption and agronomic management, based on current plant physiological and soil water budgeting concepts. Therefore, the simulation of soil water balance and crop growth processes depend on crop, soil, weather, and management input data. The model deals with soil evaporation and crop transpiration as individual processes. The daily biomass accumulation is related to daily transpiration using a crop-specific water productivity parameter (WP*) normalized to climate evaporative demand (ET_0) and CO_2 atmospheric concentration. Harvestable yield is calculated from the above-ground biomass using a harvest index parameter that increases over the growing season and responds to water and temperature stresses (Boudhina et al. 2019).

5.4 Input Data

5.4.1 Climate Data

The following climatic parameters measured daily at the reference meteo stations (Martuni and Gavar for our pilot sites) were used as an input in AquaCrop:

- Daily average, maximum and minimum temperatures, C;
- Daily precipitation, mm;
- Dew point, C;
- Wind speed, m/s;
- Sunshine duration, h/day;
- Relative humidity, %; and
- Atmospheric pressure, kPa.

The reference evapotranspiration, denoted as ETo, is used in AquaCrop as a measure of evaporative demand of the atmosphere. It is the evapotranspiration rate from a reference surface, not short of water. A large uniform grass field is considered worldwide as the reference surface. The reference crop completely covers the soil, is kept short, well-watered and is actively growing under optimal agronomic conditions. [5] Reference evapotranspiration was calculated based on the climatic parameters above.

For the Pilot Site 1, 3, and 4 (Zolakar and Vardenik villages), climatic observations of Martuni meteo station for the period of May 1, 2021 to September 30, 2021 and May 1 - September 5, 2022 were used. For the Pilot Site 2, observations of Gavar meteo station for the period of April 1, 2020 - August 31, 2021 were used.

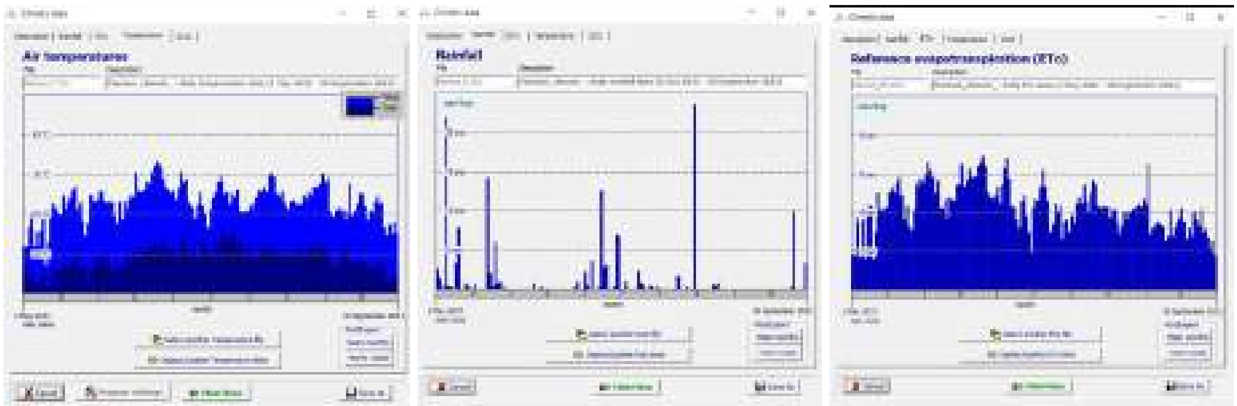


Figure 18. Climate Data Visualization in AquaCrop

[5] https://www.fao.org/3/bc122e/bc122e.pdf

5.4.2 Crop Data

Crop parameters describing its development, evapotranspiration, production (biomass and yield), and its response to soil water, temperature, salinity and fertility stress, are stored in crop files (files with extension CRO).

For Armenian pilot sites, crop parameters were obtained during field visits by interviewing farmers, taking crop samples, and monitoring the crop development throughout the vegetation period.

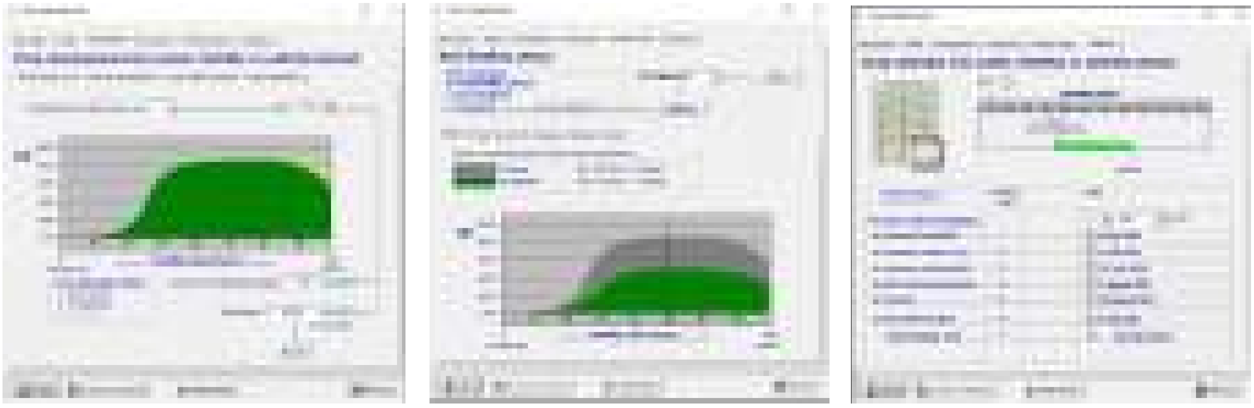


Figure 19. Crop Development and Stress Analysis in AquaCrop

5.4.3 Irrigation Data

From four Armenian pilot sites, three are irrigated (Zolakar, potato; Vardenik, cabbage, Zolakar, maize), and the other is rainfed (Noratus, wheat). Surface irrigation method is used in Zolakar potato and maize croplands with furrow irrigation technique. In Vardenik village, the farmer applied a self-made drip irrigation system. The lands were irrigated four to six times during the 2021 and 2022 vegetation periods. Information about the irrigation was collected through field interviews with farmers.

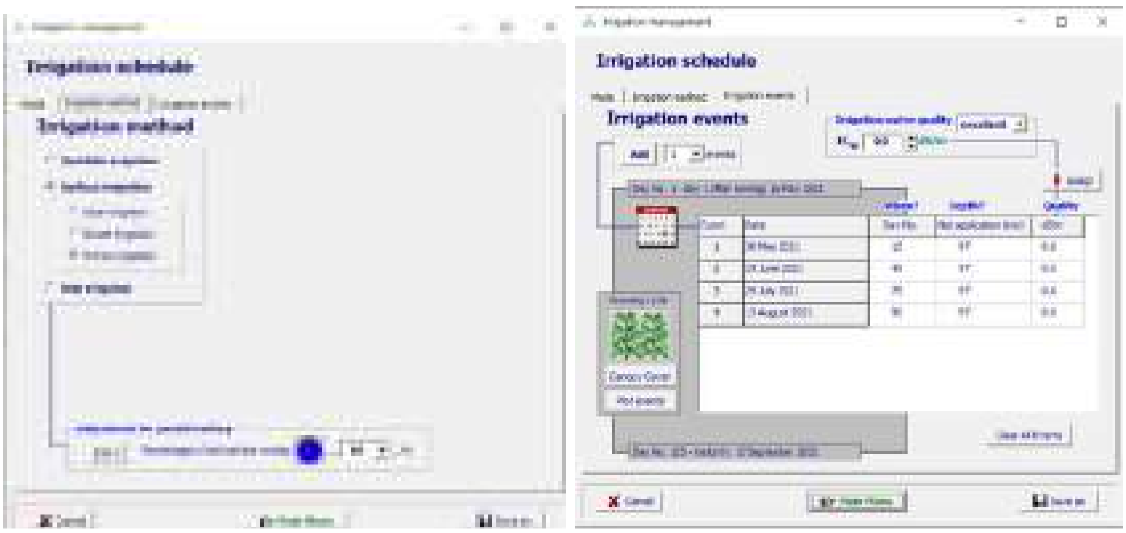


Figure 19. irrigation Information Input in AquaCrop

5.4.4 Field Management Data

Field management information represents the type of mulches and the fraction of soil surface covered by the mulches, the soil fertility level and practices that affect the surface run-off (soil bunds and field surface practices). Information on field management for pilot sites have been collected through field visits.

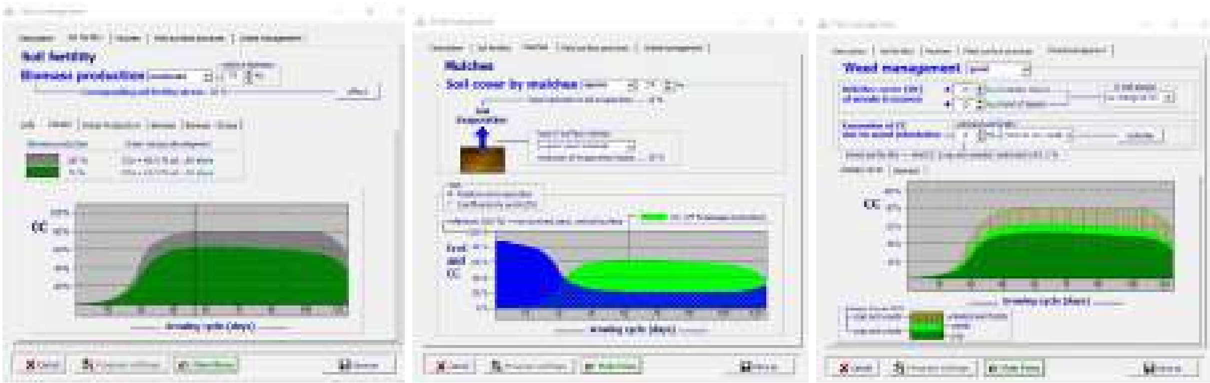


Figure 20. Field Management Information in AquaCrop

5.4.5 Soil Data

Input data on soil specifies major physical characteristics of the successive soil horizons of the soil profile. Soil information for the pilot sites was derived from the ArmSIS (Armenian Soil Information System) developed by FAO programme in Armenia.

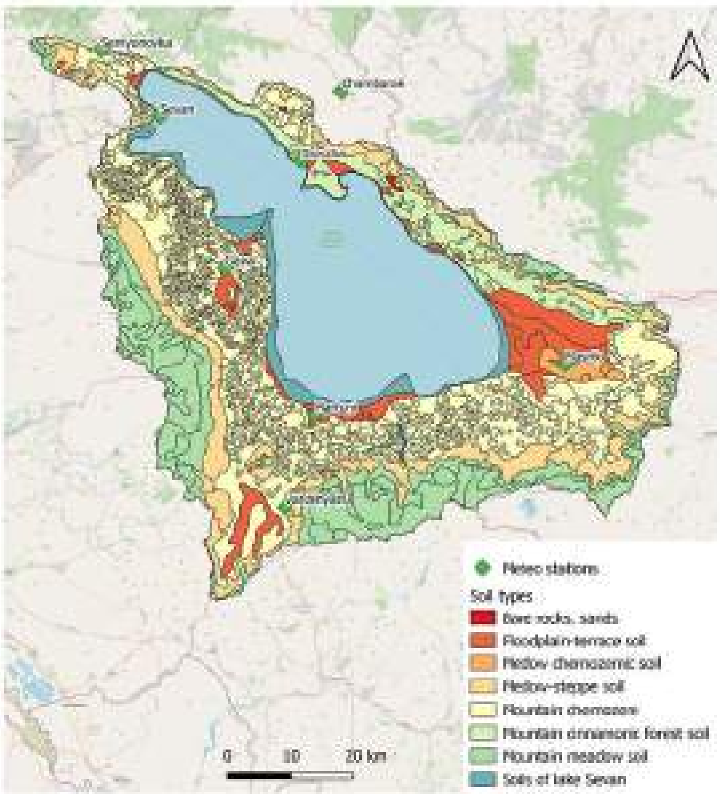


Figure 21. Soil Map of Lake Sevan Basin

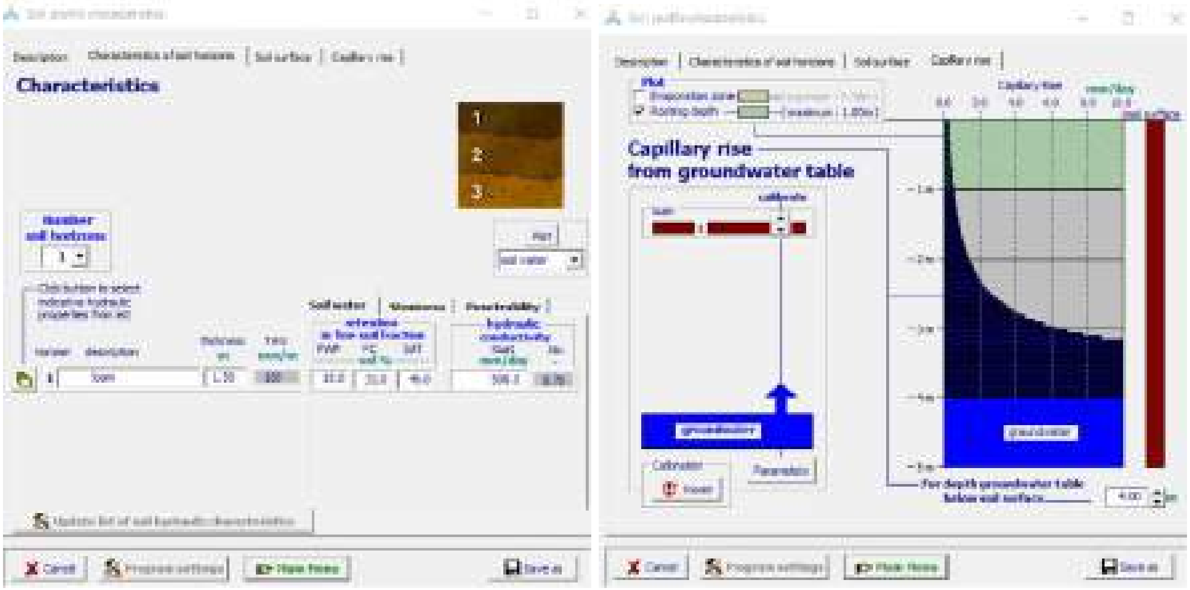


Figure 22. Soil Profile Characteristics

5.4.6 Groundwater Data

The considered characteristics of the groundwater table are its depth below the soil surface and its salinity. Groundwater data is very scarce in Armenia. Data on groundwater for Lake Sevan basin were taken from the Sevan Basin Management Plan developed in the framework of European Union Water Initiative Plus (EUWI+) project. However, the information is very rough and more field research is needed in this direction.

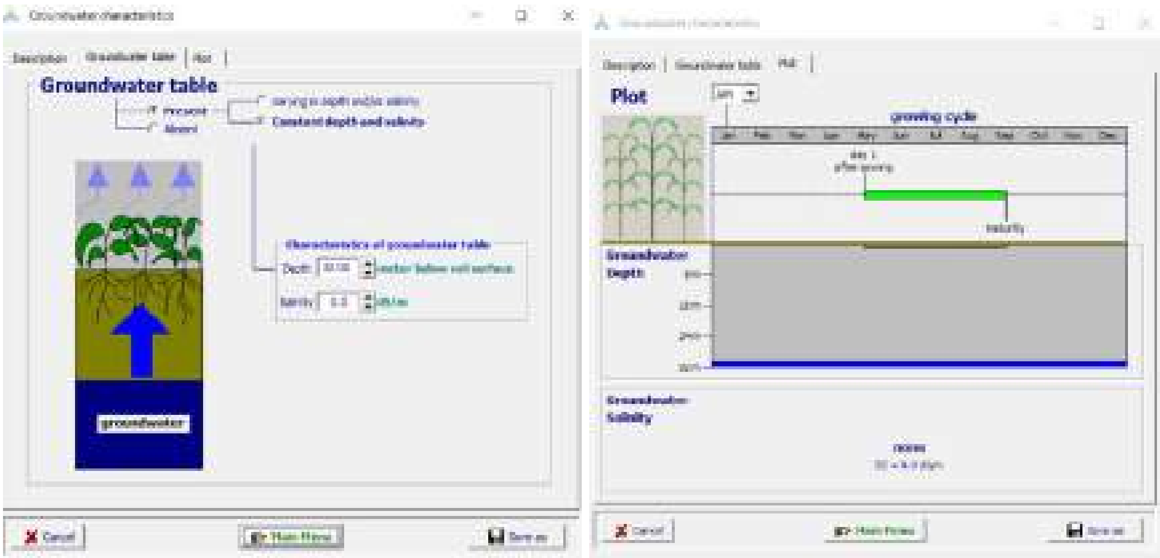


Figure 23. Groundwater Table Characteristics

5.5 Assessment Results

According to the information on irrigation that we got from the farmer in Zolakar village, in the vegetation season of 2021 (May - September) they irrigated the **Pilot Site 1** (potato cropland with 1.18 ha area) 4 times out of planned 5 due to the problems in irrigation water supply infrastructure. Each time, around 1,100-1,200 m^3 of water was supplied. Furrow irrigation technique is being used. Therefore, around **4,600 m^3** of water was used for irrigation in this vegetation period.

Information on irrigation, along with the climate, crop, and other data presented in Chapter 5.4 of this report were used for running a simulation in AquaCrop. Information on pesticides is not a part of this analysis, thus the actual yield data obtained from the farmer (17 tons) is higher than the yield simulated by AquaCrop based on the input data (8 tons). The ratio between simulated actual and potential biomass is 50%, the adjusted harvest index is 48.7%, and the ET water productivity is 1.15 kg per m^3 water evapotranspirated. Water stress indices are rather high - canopy expansion is 56%, and stomatal closure - 26%. There is also temperature (4%), weed infestation (15%), and soil fertility stresses that exist in this cropland (28%).

Figure 24. Simulation for potato cropland in Zolakar based on the applied irrigation schedule

In order to identify the optimal irrigation schedule and amounts, and find the scenario that ensures the least water stress and use of water, different irrigation strategies were tested. through the “Generation of Irrigation Schedule” menu. After applying various time and depth (mm) criteria it was identified that the most efficient irrigation scenario is using Allowable depletion (% of RAW) of 100% and the depth of 30 mm. RAW is the Readily Available soil Water in the root zone water that can be extracted without stress. Thus, it means that once RAW is fully depleted, the farmer should irrigate the potato cropland with 30 mm of water. According to that scenario, 300 mm of water will be required for the irrigation season of 2021 (30 mm x 10 times per season), which corresponds to **3,540 m^3 (1,060 m^3 or 23 % less, than it was actually applied).** The water stress will also be much less as a result of application of this scenario (canopy expansion is 3%, and stomatal closure - 4%). Productivity will rise by 16% percent, and the harvest index - by 3.6%.

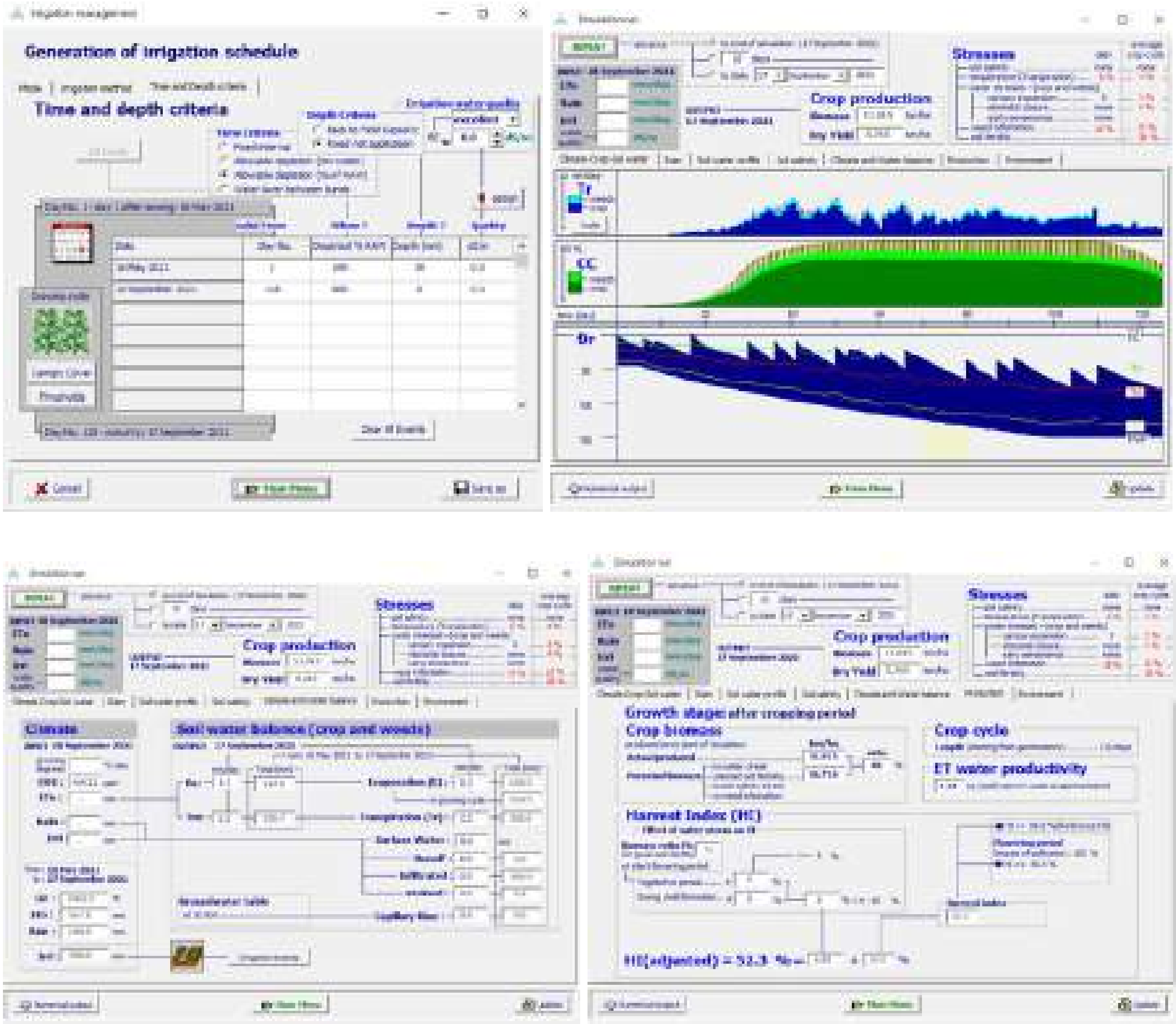


Figure 25. Simulation for potato cropland in Zolakar with application of scenario based on the Allowable depletion (% of RAW)

According to calculations presented above, for 1 ha of potato cropland 3,000 m^3 of irrigation water is needed per vegetation period in Lake Sevan basin. This amount is higher than the value set up in the Manual on “Norms and regimes for irrigation of agricultural crops in RA” (2,400 m^3) by **25%.**

Thus, for the irrigation of all 7,600 ha of potato cropland in Lake Sevan basin, **22.8 million m³** water is needed.

For the **Pilot Site 2**, wheat cropland at Noratus, the simulated actual produced and potential biomass values are much higher (1.5 and 1.7 t, accordingly) than the actual amount of the yield (800 kg) reported by the farmer. The reasons behind this are the poor agricultural practices, crop diseases. unfavorable soil conditions, and high temperature stress (up to 67%).

Irrigation schedule and amount analysis using AquaCrop showed that the value for irrigation set up in the Manual on “Norms and regimes for irrigation of agricultural crops in RA” (Yerevan, 2007) for wheat - **800 m³/ha**, can be considered as optimal for the Lake Sevan basin. Taking into account the climate change trends and issues with soil condition, it is recommended to increase that value to **1000 m³/ha**. Thus, to irrigate all 22,900 ha of grain cropland in Lake Sevan basin, **22.9 million m³** of water is required.

According to the information on irrigation that we got from the farmer in Vardenik village, in the vegetation season of 2022 (May - September) they irrigated the **Pilot Site 3** (cabbage cropland with 0.177 ha area) 5 times using a drip irrigation system. Each time, around **128 m³** of water was supplied. Therefore, around **640 m³** of water was used for irrigation in this vegetation period.

Using the applied irrigation strategy, we got a result of the ratio between simulated actual and potential biomass of 65%, and the ET water productivity is 1.86 kg per m3 water evapotranspirated. The stomatal closure stress value is 34%. There are also temperature (43%), weed infestation (3%), and soil fertility stresses that exist in this cropland (28%).

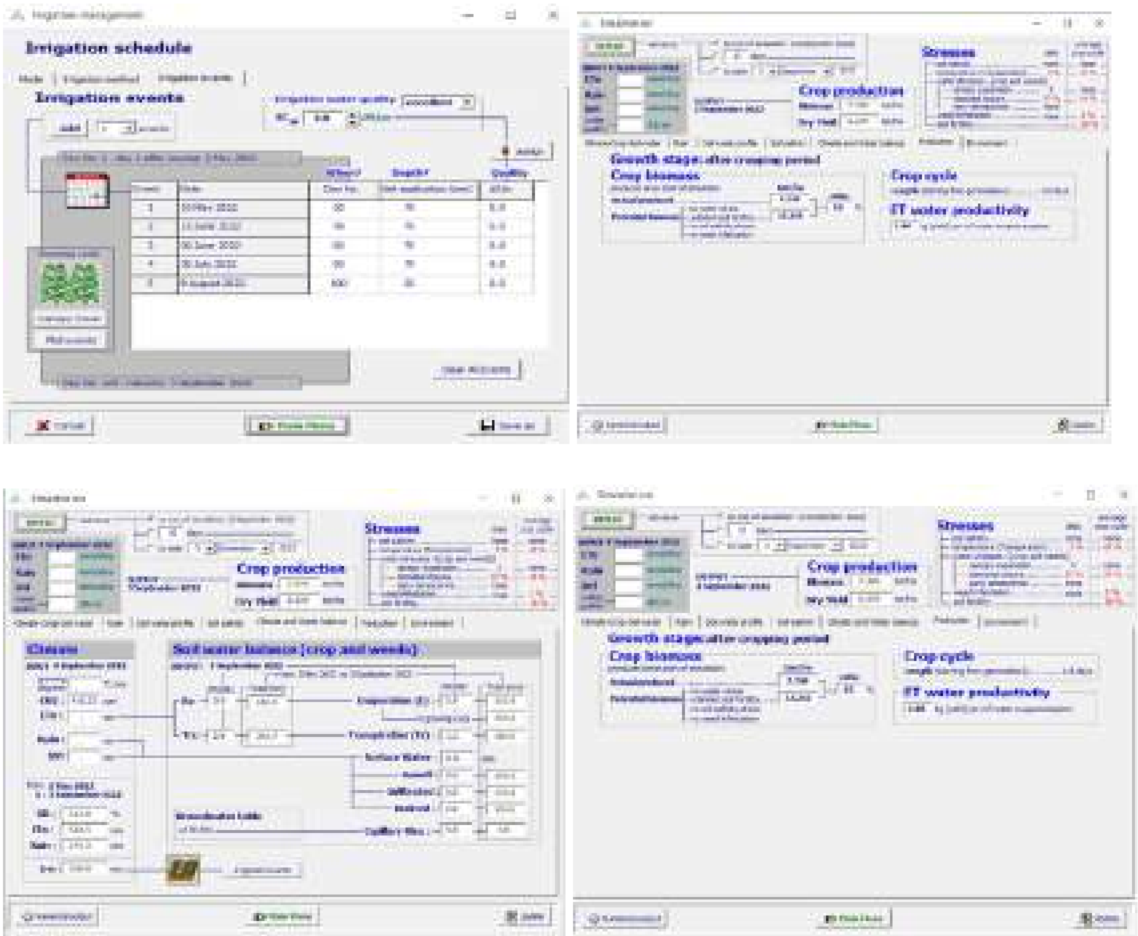


Figure 26. Simulation for cabbage cropland in Vardenik based on the applied irrigation schedule

Here also various time and depth (mm) values were tested. It was identified that the most efficient irrigation scenario is using Allowable depletion (% of RAW) of 100% and the depth of 30 mm. Thus, it means that once RAW is fully depleted, the farmer should irrigate the potato cropland with 30 mm of water. According to that scenario, 210 mm (30 mm x 7 times per season) of water will be required for the irrigation season of 2022, which corresponds to **371.7 m^3 (268.3 m^3 or 41.9 % less, than it was actually applied).** The water stress will also be much less as a result of application of this scenario (stomatal closure is 4%). Productivity will rise by 28% percent, and the ET water productivity - by 0.38 kg.

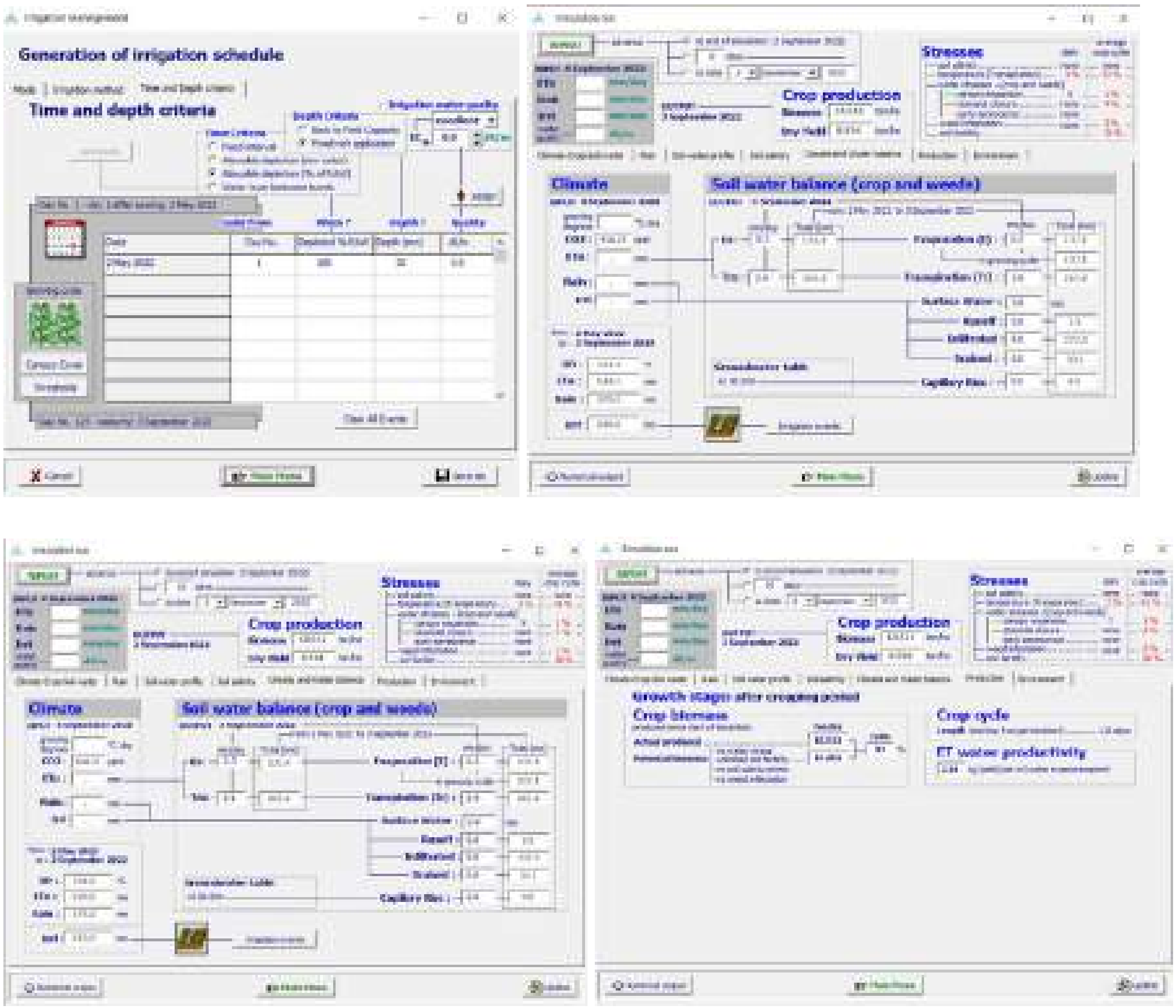


Figure 27. Simulation for cabbage cropland in Vardenik with application of scenario based on the Allowable depletion (% of RAW)

According to calculations presented above, for 1 ha of cabbage cropland **2,100 m^3** of irrigation water (using drip irrigation system) is needed per vegetation period in Lake Sevan basin. This amount is less than the value set up in the Manual on "Norms and regimes for irrigation of agricultural crops in RA" (2,400 m^3) by **12.5%.**

Thus, for the irrigation of all 1,200 ha of vegetable cropland in Lake Sevan basin, **2.52 million m^3** water is needed.

According to the information on irrigation that we got from the farmer in Zolakar village, in the vegetation season of 2022 (May - September) they irrigated the **Pilot Site 4** (maize cropland with 1.18 ha area) 6 times using a furrow irrigation method. Each time, around **1,100 m^3** of water was supplied. Therefore, around **6,600 m^3** of water was used for irrigation in this vegetation period.

Using the applied irrigation strategy, the ratio between simulated actual and potential biomass is 22%, the harvest index is 47.1 and the ET water productivity is 1.31 kg per m3 water evapotranspirated. The stomatal closure stress value is 66%. There is also temperature (32%), weed infestation (7%), and soil fertility stresses that exist in this cropland (28%).

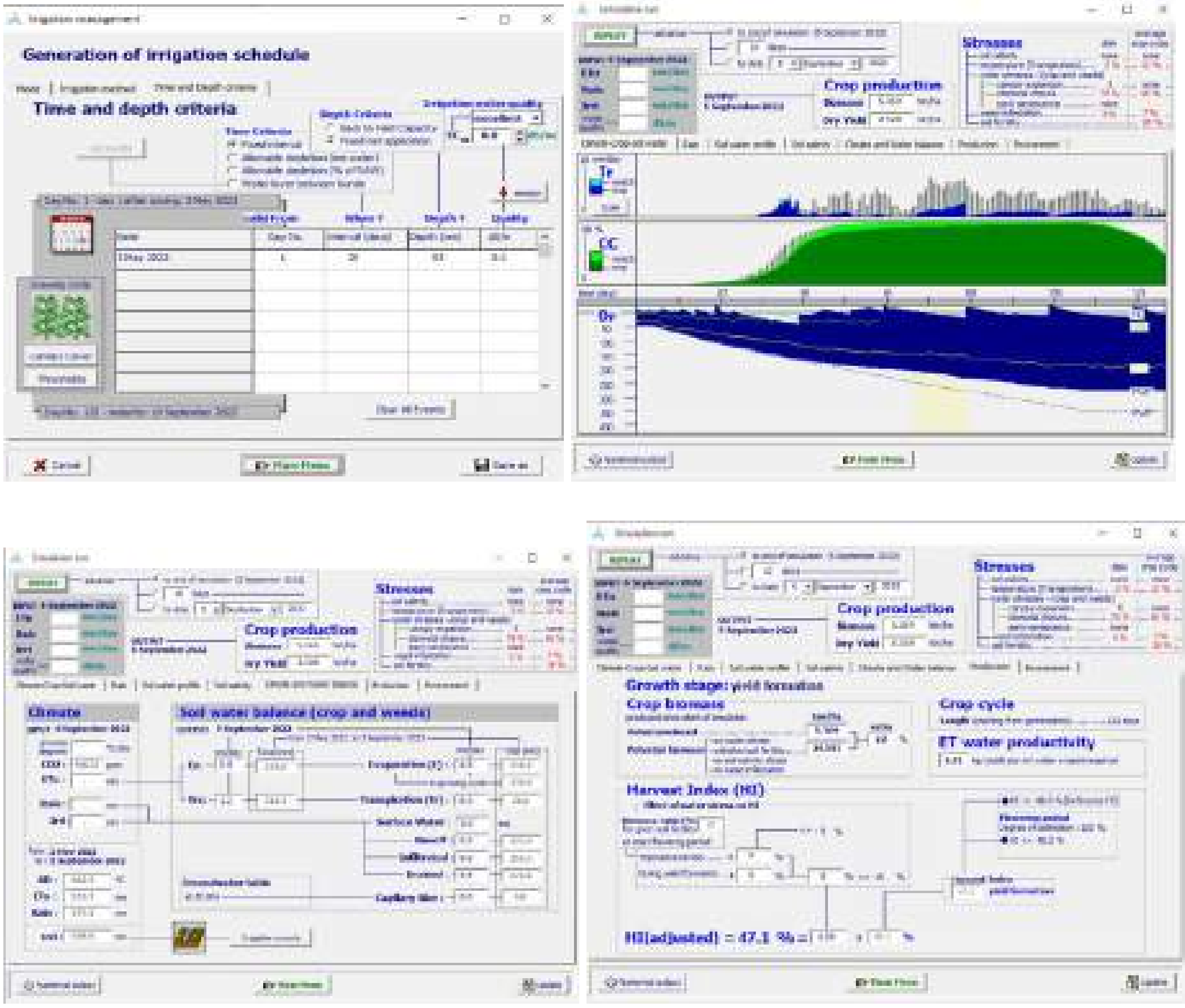


Figure 28. Simulation for maize cropland in Zolakar based on the applied irrigation schedule

After testing different irrigation schedules, it was identified that the most efficient irrigation scenario is using Allowable depletion (% of RAW) of 60% and the depth of 93 mm. According to that scenario, 372 mm (93 mm x 4 times per season) of water will be required for the irrigation season of 2022, which corresponds to **4389.6 m^3 (2210.4 m^3 or 33.5 % less, than it was actually applied).** The water stress will also be much less as a result of application of this scenario (stomatal closure is 12%). Productivity will rise significantly - by 64% percent, and the ET water productivity - by 1.13 kg.

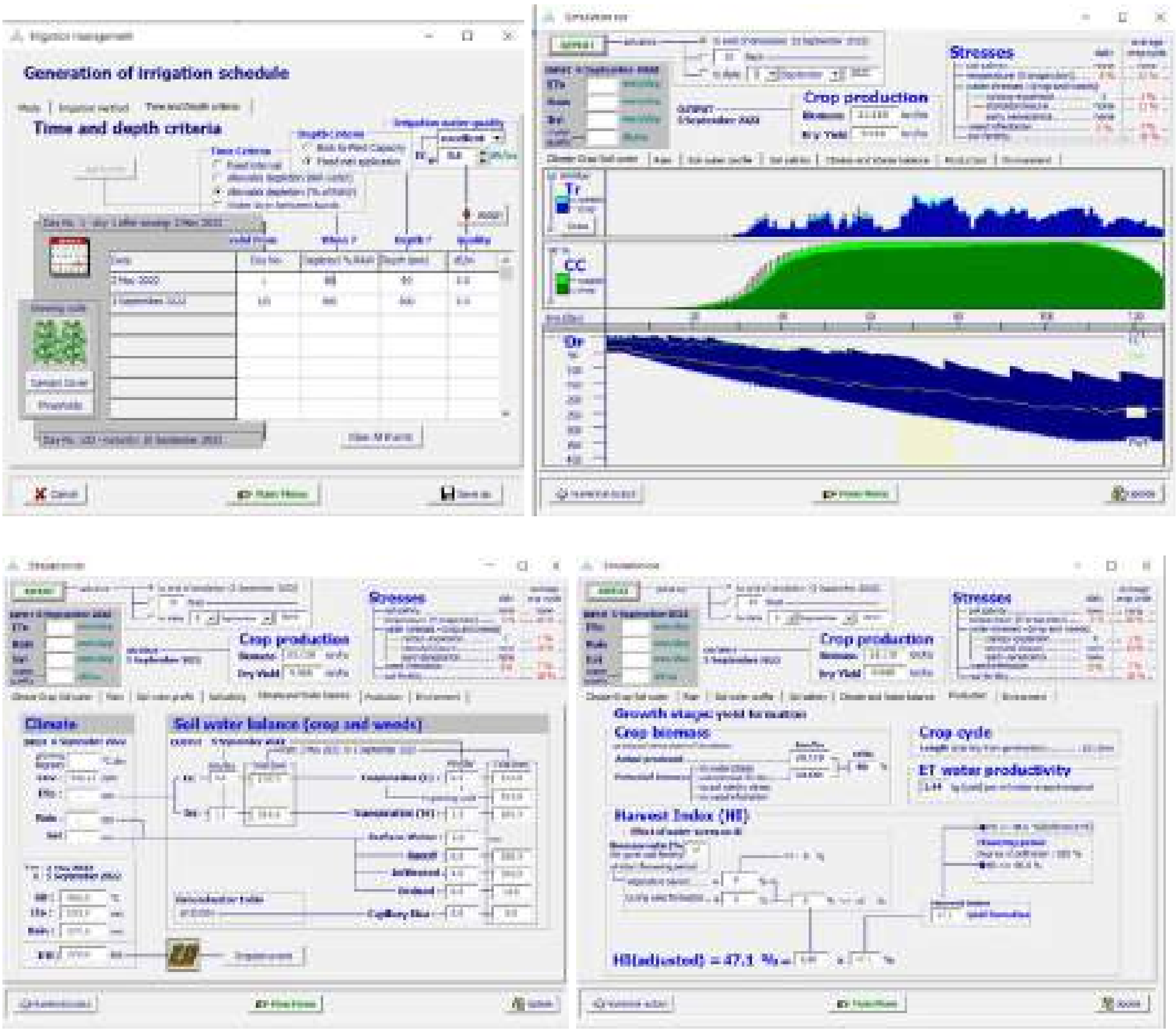


Figure 29. Simulation for maze cropland in Zolakar with application of scenario based on the Allowable depletion (% of RAW)

There is no data on total area of maize cropland in Lake Sevan basin, as well as irrigation water standard value is not established for the basin. However, it can be said by confidence that identification of this crop water demand using AquaCrop can significantly improve water saving and productivity, and decrease the stress on the crop.

5.6 Using the Copernicus Data for Monitoring, Verification, and Extrapolation of the Analysis Results

Monitoring of soil properties and crop conditions, along with tillage activity mapping, helps researchers and farmers to assess land use, predict harvests, monitor seasonal changes and assist in implementing policies for sustainable development. Sentinel data can also be used for monitoring the drought induced changes of agricultural production and pasture productivity, as well as monitoring the decline in land productivity and soil degradation due to excessive cultivation, pasturage or improper irrigation. Agricultural maps allow for independent and objective estimates of the cultivation extent in a given area or a growing season, which can be used to support the efforts to ensure food security in vulnerable areas.

Sentinel-2 data is being used for the classification of land cover types, validation of cropland area data, and, therefore, extrapolating the AquaCrop simulation results for grain, potato, and vegetable croplands in Lake Sevan basin which are the most common ones for Lake Sevan basin. The results are presented in Chapter 5.5.

Sen2r package have been set up for the Armenian study area - Lake Sevan basin, in order to continuously and automatically obtain the indices and monitor the changes related to the agricultural production and water stress such as NDVI, MSAVI2, NDWI, and NDWI2.

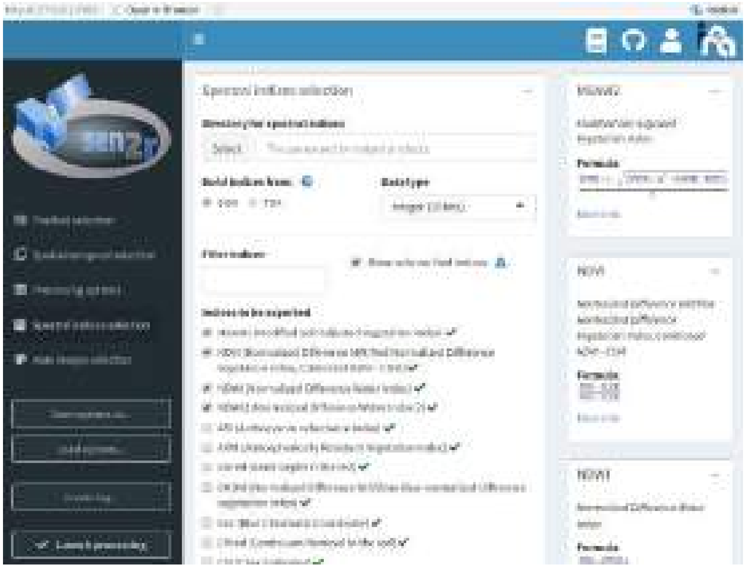


Figure 30. Spectral Indices Selection in Sen2r Package GUI

Sen2r is a scalable and flexible R package to enable downloading and preprocessing of Sentinel-2 satellite imagery via an accessible and easy to install interface. It allows the execution of several preprocessing steps which are commonly performed by Sentinel-2 users: searching the Sentinel-2 archive for datasets available over a spatial area of interest and in a defined time window, downloading them, applying the Sen2Cor atmospheric correction algorithm to compute surface reflectances, merging adjacent tiles, performing geometric transformations, applying a cloud mask, computing spectral indices and color images.

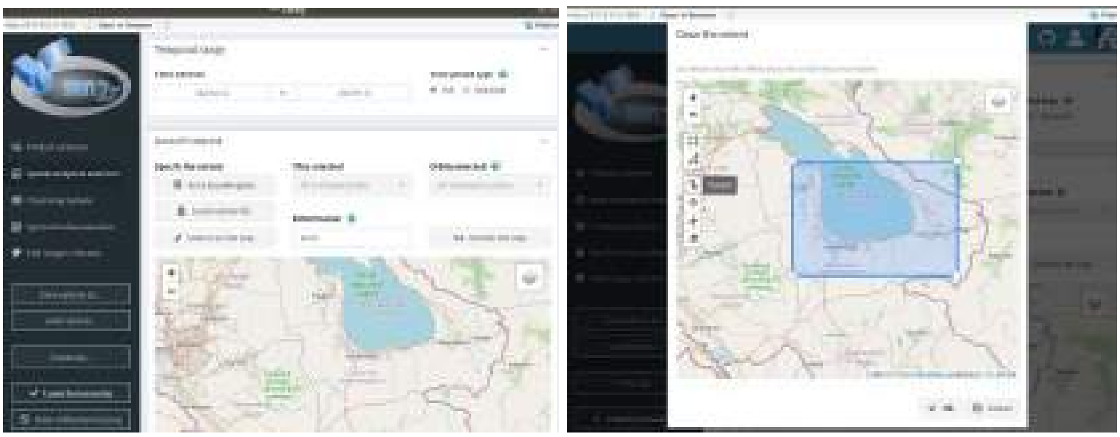


Figure 31. Spectral Indices Selection in Sen2r Package GUI

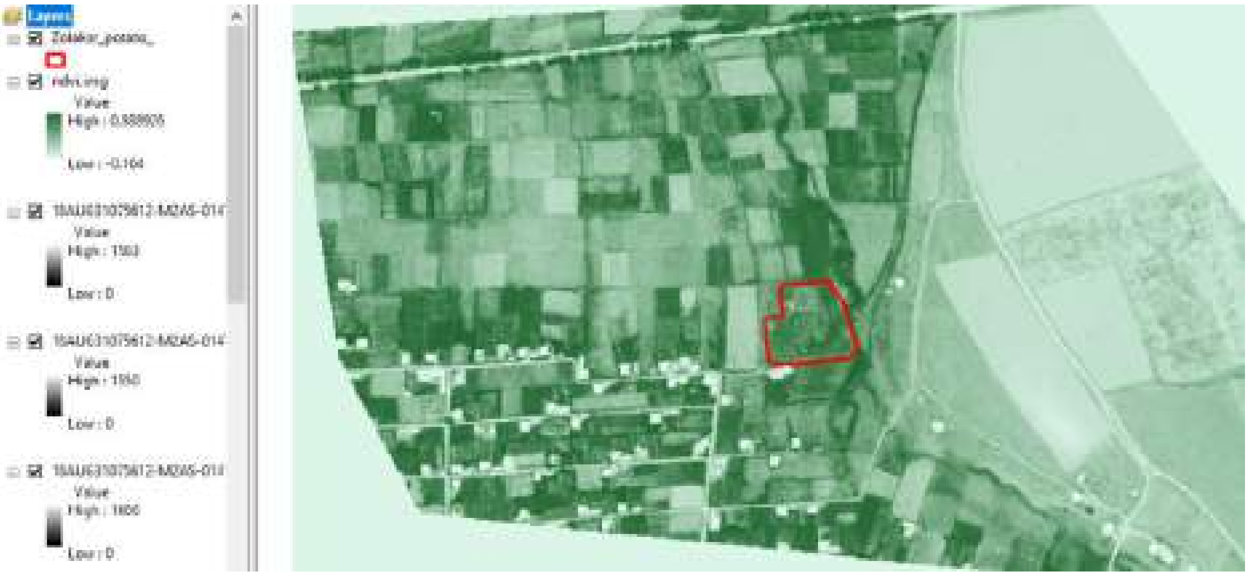


Figure 32. NDVI, MAXAR VHR Data (13.08.18)

Conclusions

Lake Sevan basin is a complex ecosystem with various water and land management issues. As the Lake Sevan is of a huge importance for the country given its economic, environmental, recreational, and cultural features, the questions regarding addressing those issues are being actively discussed in Armenia and different management plans and guidance documents are being developed.

Agriculture sector is one of the key water users in the basin. The agricultural lands occupy about 56 % (264,360 ha) of the total land of the Lake Sevan Basin, out of which 224,200 ha are grasslands and pastures, 40,170 ha - arable lands.

Despite a number of programs and plans aimed to increase water use efficiency in the agricultural sector and environmental protection of water ecosystems, the practical implementation of measures is still inefficient.

Problems related to the agricultural water balance, productivity, and water stress are related to the following factors:

- poor condition of water supply infrastructure,
- water allocation and intersectoral distribution issues,
- unfavorable soil conditions,
- inefficient farmer practices,
- lack of measures aimed at adapting to climate change.

Our assessment was focused on the last two points above trying to identify the optimal amount of water needed for irrigation of specific crops in the current and projected climatic conditions and trends and reviewing the norms of irrigation for those crops accepted in the country.

Using the AquaCrop model, and climatic, crop, irrigation, soil, groundwater, and other characteristics from ground monitoring and satellite data sources, and by testing applied and hypothetical irrigation scenarios, we identified the most optimal strategies of irrigation for most popular crop types of Lake Sevan basin. By applying those strategies, we can expect positive changes in water saving, less water stress, and higher agricultural productivity. Needless to say, the estimated irrigation schedules need to be tested on the ground and adjusted based on the actual results.

However, we should also consider the poor condition of irrigation infrastructure and average water losses of 50% and lack of measurements on irrigation water supplied. Agriculture production in the basin is being accelerated by intensive use of pesticides which is creating more environmental problems in such a sensitive ecosystem as Lake Sevan.

Therefore, the future basin development activities and measures must be aimed at solving the water use efficiency problems and the irrigation practices must become knowledge-based also taking into account the climate change trends.

Copernicus data, combined with ground monitoring information and field data from farmers, is very important for monitoring the changes in agricultural lands under changing climatic and anthropogenic conditions and planning relevant measures to address the challenges. The tools such as Sen2r package are assisting in automation of data receiving and monitoring, saving the time and resources for analytical and decision-making tasks.

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