CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Water Management in Moldova

Master's thesis

Prague 2016

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Declaration

I declare that the presented diploma thesis entitled — Water Management in Moldova is my own work with use of the referred literature. I agree with the inclusion of this Thesis into the library of CULS in Prague and making it available for further study purposes.

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Date Signature

Acknowledgements

I would like to express my appreciation everyone who helped me at work on this thesis. Special gratitude belongs to my supervisor Prof. Ing. Bohumil Havrland, CSc. for his assistance, guidance and consultations which has been very helpful. Thanks belong also to Ing. Tatiana Ivanova, Ph.D., who has helped me by providing cooperation with the Moldovan party.

ABSTRACT

The Republic of Moldova faces already now ongoing impacts of the climate change since droughts presents most endangering impact for agricultural sector. Although, irrigation sector goes through rehabilitation, poor agricultural water management represents an obstacle for efficient agricultural production. This Thesis assesses agricultural vulnerability to impacts of climate change on water resources in Moldova. Assessment was carried out by estimates of irrigation water needs and by analysis of structure of farming systems in 26 central irrigation systems in Moldova. It was found that central irrigation systems in south part of central region are the most vulnerable central irrigation systems in Moldova. Two irrigation systems Masivul Suvorov and Masivul Talmaza have favorable conditions for growing short period crops, but poor conditions for growing long period crops. By change production of some strategic crops and shifts production between central irrigation systems can bring water saving and unburden water withdrawals. It was also found that farmers which irrigate, are associated with land's tenure. This could present constrains for mitigation of climate change's impacts.

Key words: Moldova, Water management, Irrigation, Climate change, Crops, Systems

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List of Abbreviations

- ACSA - National Agency for Rural Development
- CIS – Central Irrigation system
- FAO - Food and Agriculture Organization of the United Nations
- GMRSL - Global Mean Sea Level Rise
- GMST - Global Surface Temperature Rise
- IFRC - International Federation of the Red Cross and Red Crescent Societies
- IPCC - the Intergovernmental Panel on Climate Change
- IWMI - International Water Management Institute
- GDP – Gross Domestic product
- JMA – Japan Meteorological Agency
- MCC – Millennium Challenge Corporation
- NASA - the National Aeronautics and Space Administration
- NOAA - the National Oceanic and Atmospheric Administration
- PDSI – Palmer Drought Severity Index
- RCP - Representative Concentration Pathways
- UN – United Nations
- UNDP - United Nations Development Programme
- USA - the United States of America
- WUA – Water Users Associations

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1 Introduction

The present Thesis focuses on water management in Moldova which is due to expectations that the climate change will increase intensity and frequency of droughts worldwide (Republic of Moldova included) as consequence of rising temperature and change in precipitation pattern (Wanders and Wada, 2015). This trend also affects Central and Eastern Europe, where significant part is already now susceptible to frequent occurrence of droughts. Analysis of the climate change impacts in Bârlad basin (Eastern Romania) shows that mean temperature will increase in all months. The increase of mean temperature for January will be close to 4.9 °C and for August, it will be 4.3 °C in period 2071 – 2100. Estimates of Palmer Drought Severity Index also show that process of droughts already started in this area and by the end of the 21st century droughts will become normal in summer. This could have adverse consequences in agricultural production and ecosystem degradation (Dascălu et al., 2016; Bokal et al., 2014). Such adverse impacts could endanger economy and social stability of the Republic of Moldova, which is one of the poorest countries in Europe and very dependent on agricultural sector (World Bank, 2014). Agriculture in Moldova is most vulnerable sector to droughts due to expansive overexploitation of land resources and poor agriculture water management. Result of this was drought in year 2007 that affected 78 % of the total area and caused economic losses about USD$987 million. Agricultural water management in Moldova goes through reconstruction, since 10 from 78 central irrigation systems in Moldova are in state of rehabilitation (MCA, not dated). The main aim of this thesis is to assess agricultural vulnerability to impacts of climate change on water resources by analysis of distribution of farming systems in Moldova and determine their irrigation status. The assessment of concerned areas under coverage of 26 central irrigation systems which were initially suggested for rehabilitation.

2 Literature review

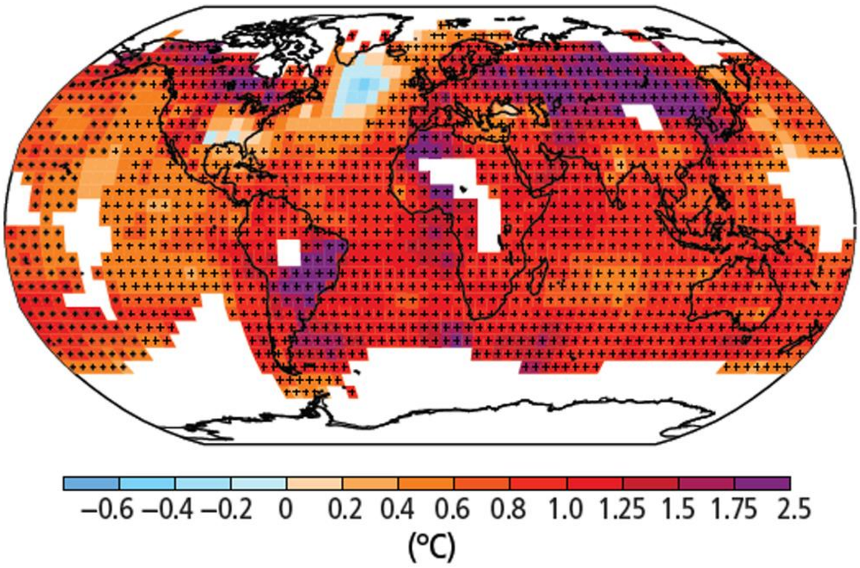
2.1 Climatic change

2.1.1 Current climate change

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural system (IPCC, 2014). According to the Intergovernmental Panel on Climate Change (IPCC), The Earth has experienced the most warmer three decades since 1850 at the surface level. Average temperature data shows a warming of up by 0.85 °C between years 1880 to 2012, while total increase between averages of two periods (1850 - 1900; 2003-2012) is 0.78 °C. As it can be seen in **Figure 1**, The major part of the Earth has been exposed to surface warming (IPCC, 2014). This trend is very identical to reports of many institutions. For example, *Annual global analysis for 2014* published by the National Oceanic and Atmospheric Administration (NOAA) with cooperation of the National Aeronautics and Space Administration (NASA) stated that year 2014 was the warmest year on record. While NASA estimated that globally temperature increased by 0.68 °C, NOAA the temperature analysis shows had increase of 0.69 °C from 20th century average (Schmidt and Karl, 2015). Finally, Japan Meteorological Agency (JMA) reported that annual global average surface temperature increased by 0.70 °C (Japan Meteorological Agency, 2014).

Besides increase of surface temperature and temperature levels of atmosphere and oceans, there are changes in water cycle, global mean sea rise and reduction of ice and snow (IPCC, 2014). For example, *Ecological impacts of Climate change* (Committee on Ecological Impacts of Climate Change 2008) claims, that the global average sea level rose by 0.178 cm per year during the 20th century. This trend is in agreement with journal article - *Ice and sea level change,* which estimated an average rise of sea level by 1.7 mm per year (Church et al., 2007). In case of ice and snow, there is evidence that summer minimum of arctic sea extent is decreasing by 11.2 % per decade. While in the 1980s there was reduction of ice thickness in Arctic sea, when new thin ice replacing thick old ice with 50 % rate of total ice cover, now first year ice makes up 70 % of total ice cover (Koç et al., 2009). On the other hand, changes of hydrological cycle cannot be so simply summarized by representative data. Therefore, this climate change will be examined in following parts of this work.

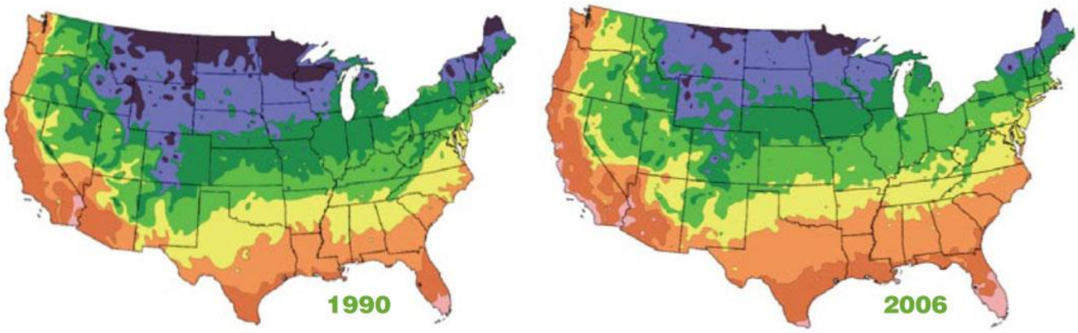
Figure 1.: Observed change in surface temperature between 1901–2012



Source: IPCC, 2014

There is no doubt, that our lives and all living forms on the earth are connected to physical surrounding. Global climate change has consequences on natural system and human society itself. Journal article *Ecological Impacts of climate change* (2008) emphasizes several impacts of climate change on the United States of America (USA). Firstly, it is shifts in species range and phenology. Many species in USA are forced to change their living condition as temperature, precipitation and other factors are influencing living conditions. From phenological point of view, many biological activities are changing their timing. According some studies some seasonal behaviors occurs 15-20 days earlier than in past (Committee on Ecological Impacts of Climate Change, 2008). This trend is represented on **Figure 2**. As it can be seen, zones which are suitable only for some plants are changing shapes and they are shifted northward in United states of America.

Figure 2.: plant hardiness zones (warmer colors indicate warmer zones)



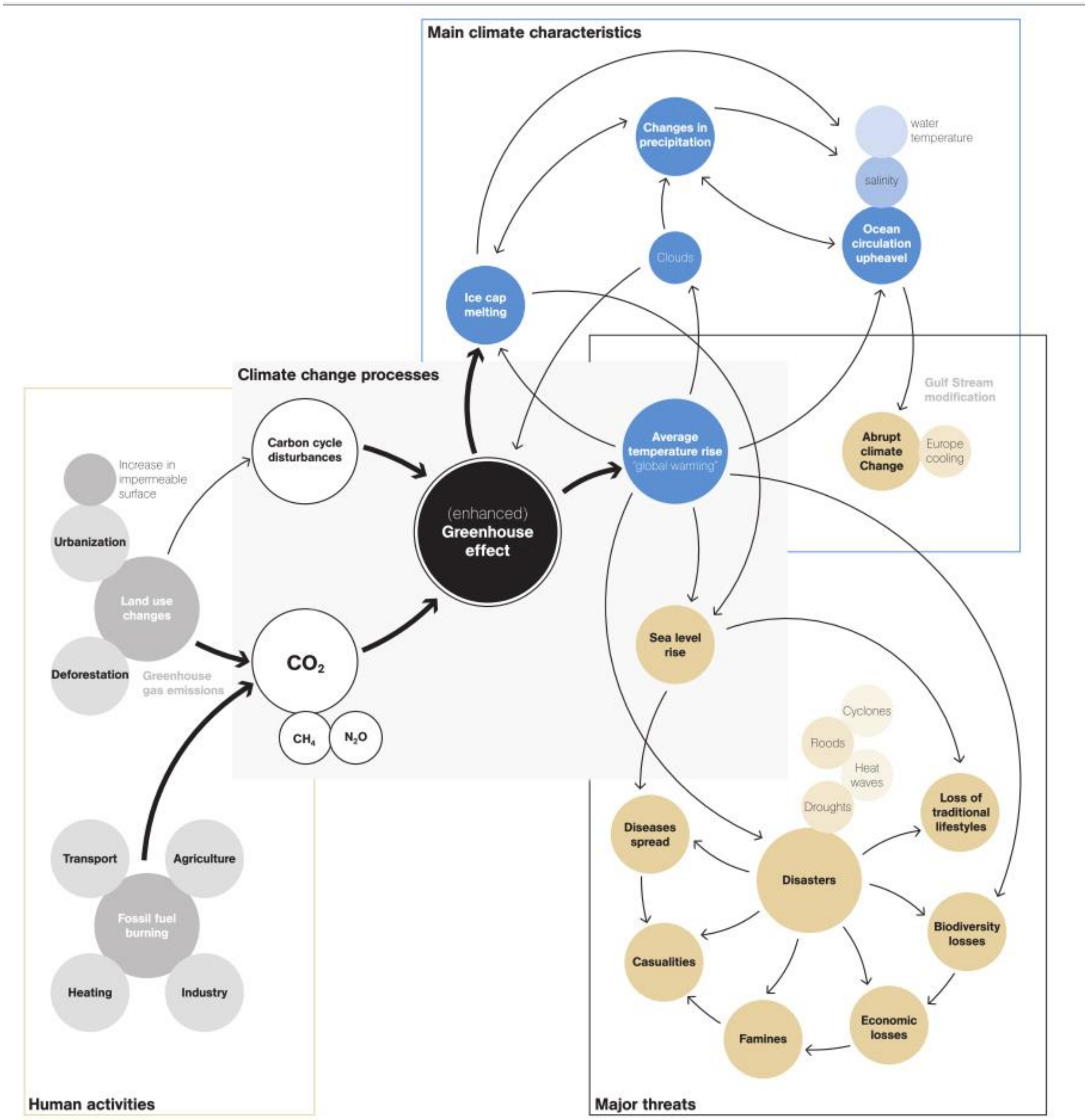
Source: Committee on Ecological Impacts of Climate Change, 2008

Secondly, climate change might affect total number of each species. For example, Quino checkerspot - one of the butterflies in North America is threatened by habitat destruction, which cannot be recovered because of climate changes. Another change in abundance can be observed in "southern" and "northern" species of seafood near central California. While southern species have become more abundant, northern species decreased their total numbers (Committee on Ecological Impacts of Climate Change, 2008). Evidence of connection between climate change and ecosystems can be also found in forests ecosystems. Journal article *Impacts of Climate Change on Forest Ecosystems in Northeast China* (2013) evidences that global and regional warming favors the growth of temperate broad-leaved forests and has negative impact on the growth of boreal coniferous forests and also increase growing season of coniferous forests at an average rate of 3.9 d per decade (Xiao-Ying et al., 2013). These evidences emphasis by only several scientific findings about impacts of climate change in attempt to provide holistic perspective on situation, which humanity is facing. Because this thesis focus on irrigation, impacts of climate change on water irrigation and agriculture will more thoroughly described in **chapter 2.2**.

As previous paragraph states, ecosystems are exposed to climate changes and so it is necessary to dedicate some part of thesis to issues - how broad human society is influenced by changes in environment. Article *Global Warming's Increasingly Visible impacts* (2005) indicates that human-caused global warming increase chance of "killer" heats waves, which can have negative impacts on human health. These heat waves are also accompanied with droughts and wildfires, which important cause of losses in many sectors. For example, July-August heat waves in 2003 resulted in massive reduction in agriculture, forestry and electric power sectors across Europe (Wang and Chameides, 2005). Global climate crisis has also effects on human rights and social justice like the right of self-determination, the rights to freely determine one's political status and freely pursue one's economic, social, and cultural development, the right "to the enjoyment of the highest attainable standard of physical and mental health" and the right to education. This civil and political rights are threatened through environmental and health consequences. Human rights are endangered mostly in societies, where human rights violation occurs, like inhabitants of low-income countries and inhabitants with low-income in high-income countries. Climate change can endanger women, children, indigenous people and workers through more difficult working and living conditions like heat waves, extreme weather events, air pollution, food insecurity and malnutrition, vector-borne diseases and Waterborne and Foodborne Diseases. There was also found connection between climate change and rate of collective violence; for example there are studies which suggest that high temperature and extreme precipitation can cause sociopolitical instability and conflict (Levy and Patz, 2015). Significant vulnerability and exposure of many human systems due to recent climate related extremes is also registered by IPPC in last report. These vulnerabilities includes damage to infrastructure and settlements, human morbidity and mortality and also aggravation of Human health and well-being (IPCC, 2014).

Finally, **Figure 3** can summarize climate change and its causes and consequences. As it can be seen, Human activities like industry or transport contributes to CO_2 contents atmosphere together with distribution of carbon cycle. This leads to reinforcement of greenhouse effect, which influences temperature on earth and ice cap. As greenhouse effect gets stronger, average temperature rises and ice cap melts. The higher temperature is an increasing risk of disasters like floods, droughts or heat waves, which can be a powerful accelerator of famine or economic losses (van der Pol et al., 2015).

Figure 3.: Climate change: processes, characteristics and threats



Source: UNFCCC, 2007

2.1.2 Future climate changes

Climate Change 2014: Synthesis report (2014) from IPPC introduces four possible scenarios for 21st century called Representative Concentration Pathways (RCP). They include scenarios RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (IPCC, 2014). These scenarios are identified by different radiative forcing, which represents several different scenarios that have similar radiative forcing and emissions characteristics. Radiative forcing is net sum of radiation between downward and upward radiating flux (W m^{-2}) due to change in atmosphere. The lowest RCP2.6 is scenario when the change in radiative forcing is from 2.6 W m^{-2} to 3 W m^{-2} before 2100. RCP4.5 and RCP6.0 scenarios predict radiative forcing at approximately 4.5 W m^{-2} and after 100 6.0 W m^{-2}. Finally, in case of RCP8.5 scenario, the radiative forcing will be greater than 8.5 W m^{-2} after year 2100 (IPCC, 2013). As it can be seen on **Table 1**, Global Mean Surface Temperature (GMST) will be getting higher with the growing radiative forcing. In case of RCP4.5, RCP6.0 and RCP8.5, GMST will likely exceed 1.5 °C at the end of the 21th century. Warming up higher than 2 °C will likely occur at RCP6.0 and RCP8.5, but unlikely it exceeds 2 °C at RCP2.6. As it can be seen the Global Mean Sea Level Rise (GMRSL) will be also higher at higher RPC model. In the case of the highest scenario, GMRSL will rise up by 0.63 m at the end of the century (IPCC, 2014).

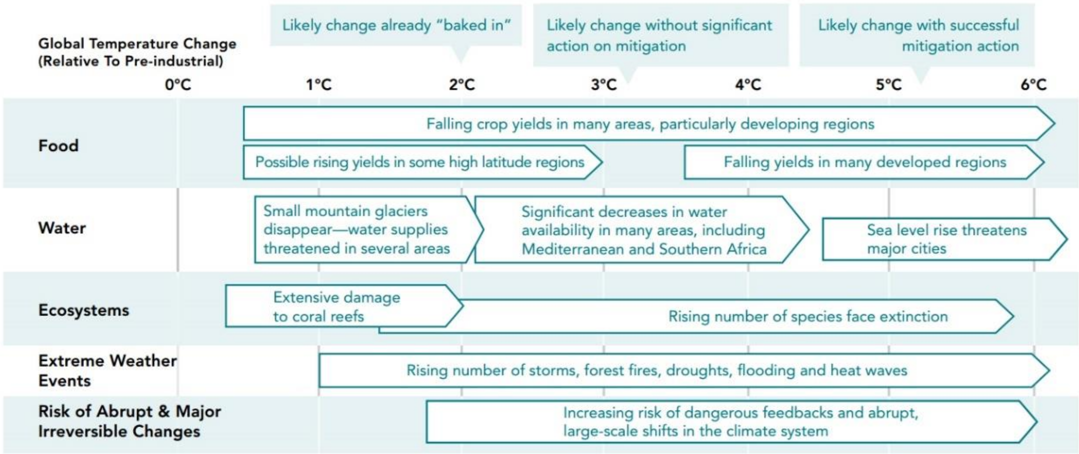
Table 1.: Temperature changes and the Global Mean Sea Level Rise for the mid- and late 21st century according to each possible scenario

	Scenario	2046-2065		2081-2100	
		Mean	Likely Range	Mean	Likely range
Global Mean Surface Temperature Change [°C]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	Mean	Likely Range	Mean	Likely range
Global Mean Sea Level Rise [m]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Source: IPCC, 2014

This warming up can have strong impact on biodiversity. Journal *Biodiversity scenarios: projections of 21th century change in biodiversity and associated ecosystem services (*2010) warns that continuing climate changes accelerate extinctions or new distributions of some species and loss of natural habitats. Major biodiversity transformation could set in, if climate change causes warming around 2°C. This could evolve into large modifications of ecosystems (Leadley et al., 2010). Paper *Climate Change action* (2009) states that 1°C rise of the Global Mean Temperature will bring higher risk of extinction of 10 % of assessed species (Convention on Biological Diversity, 2009). As it can be seen from **Figure 4**, most changes will occur, when temperature wills rise over 2°C, like risk of falling crop yields in many developing regions or already mentioned risk of species extinction (World bank, 2008).

Figure 4.: Adaptation challenges depend on mitigation progress



Source: World bank, 2008

From perspective of ecosystems, there are expectations of changes in dryland ecosystems due to altered precipitation (Convention on Biological Diversity, 2009). This can have major impact in Moldova, whose 99 percent of surface areas is classified as dryland (UNCCD, 2016). Results described in *Review of the literature on the links between biodiversity and climate change (2009)* suggest that primary production could be reduced in many temperate grasslands due to warming and following soil drying. Therefore, rainfall and evapotranspiration are important for determining community dynamics of temperate grasslands. Loss of bio-productivity and biodiversity can lead to erosion and deflation and finally to desertification (Cambell et al., 2009)

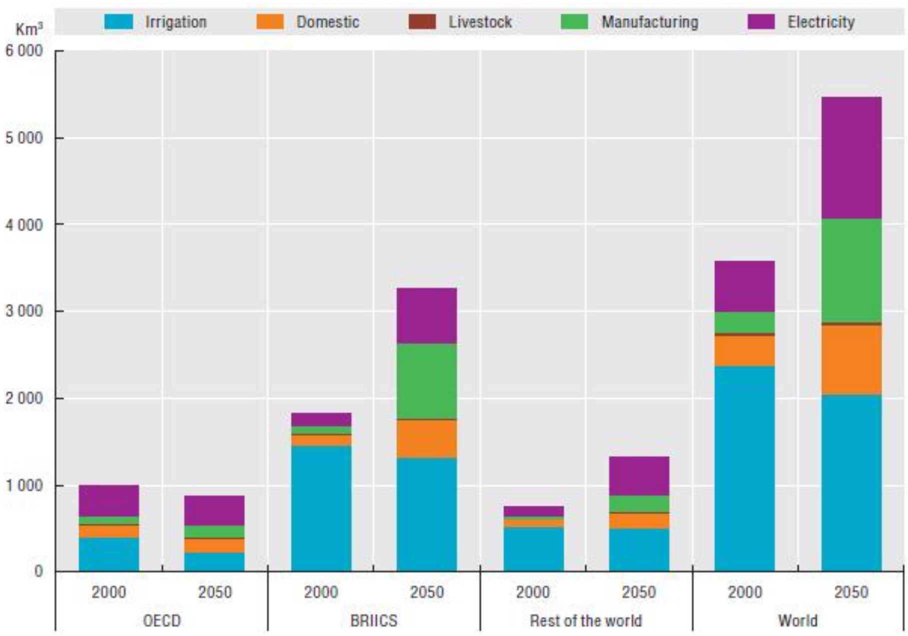
One of the most important papers - *Stern Review: The Economics of Climate Change* (2006) presents important research findings about climate change that will mostly affects developing countries with large populations and countries which rely on climate sensitive sectors like agriculture. Therefore, poor people's life, prospect to development and growth can be mostly threatened by climate change. There is a risk, that by year 2100 there can be 145 - 220 million additional poor people, who could live under the poverty line level of USD$2 per day. Heat stresses, malnutrition, water and vector related diseases could threat millions of people, but also extreme changing of dry and wet seasons can constrain capability of people to withstand these events, because of low income levels and limited access to credit. *Stern Review* also emphasizes risk of violence and conflicts due to exacerbated competition for resources as long-term deterioration will continue. Gender equality and education can be also more exacerbated through income and health problems. Because children could become more engaged in household activities and paid employment, opportunity of learning and personal development can be worse. Only threats of extreme weather events could bring losses of world gross domestic product (GDP) by 0.5 – 1 %, but correlated economic risks may destabilize whole regions. Models, expecting warming up of 6 °C, estimate 5 – 10 % loss of global GDP, while poor undeveloped countries could exceed 10 % of GDP losses (Stern, 2006). This harassing prognosis shows that world with higher temperature can bring higher chaos to especially developing world and even up to war and massive migration. Development like this can be seen in Syria, where droughts between years 2007 and 2010 were most likely caused by climate change. This worst drought in Syria modern era is probably impact caused by drier and warmer conditions rather than natural climate variability. Scientists claim that this trend is how the region react to increase in greenhouse emissions. Especially two factors are responsible for droughts in the Eastern Mediterranean. Firstly, a rising mean sea-level pressure that change precipitation patterns, secondly by drawdown of soil moisture caused by higher temperature (Kelley et al., 2015). On the other hand, the climate change can bring also positive outcomes. Paper *The economics of Global Climate Change (2015)* presents some beneficial outcomes like increased agricultural production in cold climates, lower heating costs or less deaths by exposure to cold (Harris et al., 2015).

There are several more actual topics, which match with *Stern Review (2006)* about risks in late 21th century. For example, *Elshennawy et al.* state that Egypt without policy-led adaptation investment will have about 6.5 % lower GDP in the middle of the century than in scenario without climate change, but if adaptation measures will be set up, The GDP loss will lower only 2.6 % (Elshennawy et al., 2015). Decline of economy can also be expected in those archipelago regions where usually fishery constitutes important part of people's livelihood. One of such archipelagos is Fiji, where fishery and aquaculture sectors play major role in the national economy and the climate change can bring stress in these sectors. Mainly coastal production decline is expected due to the above negative effects of climate change unless the adaptation strategies will be implemented (Dey et al., 2016). Also analysis of whole regions like *The effect of climate change and adaptation policy on agricultural production in Eastern Africa (2016)* simulated that predicted the climate change for region will bring agricultural output reduction of 1.2 % and 4.5 % due to the increasing temperature and precipitation variability in Eastern Africa (Kahsay and Hansen, 2016).

2.2 Water resources under current and future climate change and economic growth

As it can be the seen future climate change can jeopardize ecosystems and biodiversity but also the society itself. Changes, like distribution of precipitation and temperature, can impose stress on economies and slowdown development in many countries. And so it is important to get better understand resource that is important for agriculture and it is affected by climate change – water. United Nations (UN) Secretary-General Ban Ki-moon said on World Water Day, 2013: *Water holds the key to sustainable development, we must work together to protect and carefully manage this fragile, finite resource* (Jägerskog et al., 2015). Water is essential element for human livelihood and for many economy sectors, but water sources are not equally distributed for fulfilment of all human needs. Fresh water account about 2.5 % of the Earth's water and it is mostly frozen in glaciers and stored in underground and it can be obtained from many important resources of water cycle like precipitation, glaciers, river basins, wetlands or groundwater (GreenFacts, 2004). Nevertheless, freshwater resources face rising pressure of growing population and their needs. According to UN document – *Water for sustainable world (2015)* around 748 million people suffer from insufficient access to improved source of drinking water and about 1.2 billion people live in areas, where water is physically scarce. Competition between different sectors over water increases the risk of localized conflicts and endangers sustainable development, which can have a significant impact on local economies and well-being. Current trend of water supply pressure is not only caused by water scarcity, but also by inadequate natural resource use and governance. Result of bad management can be seen in the case of decrease of groundwater levels, when estimated 20 % of water aquifers are over-exploited. Increasing demand of the growing population and increase water use in such an extent that by 2030 the world will face a 40 % global water deficit and by year 2050, global water demand is expected to increase by 55 % due to growing needs of the industry, domestic use and thermal electricity generation as it is shown on **Figure 5**. Only the industrial production will increase water demand by 400 percent between 2000 and 2050 globally (WWAP, 2015).

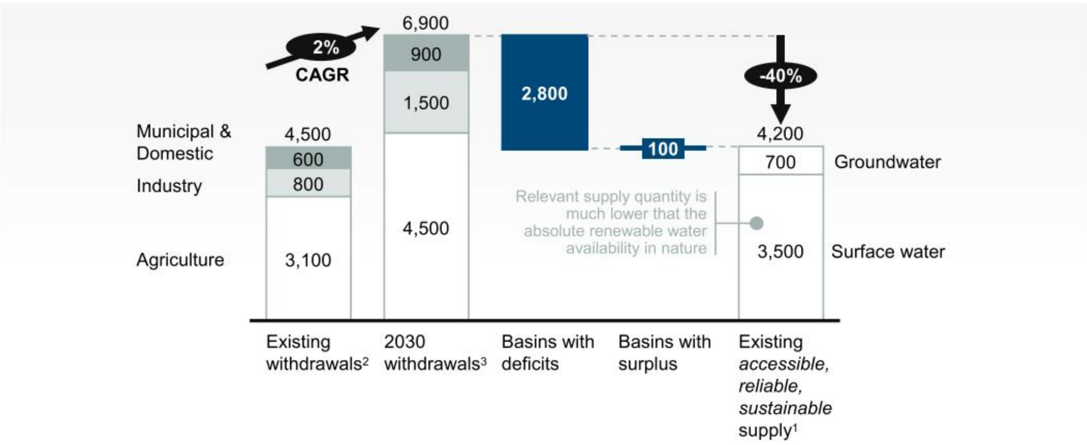
Figure 5.: Global Water demand in 2000 and 2050



Source: OECD, 2012

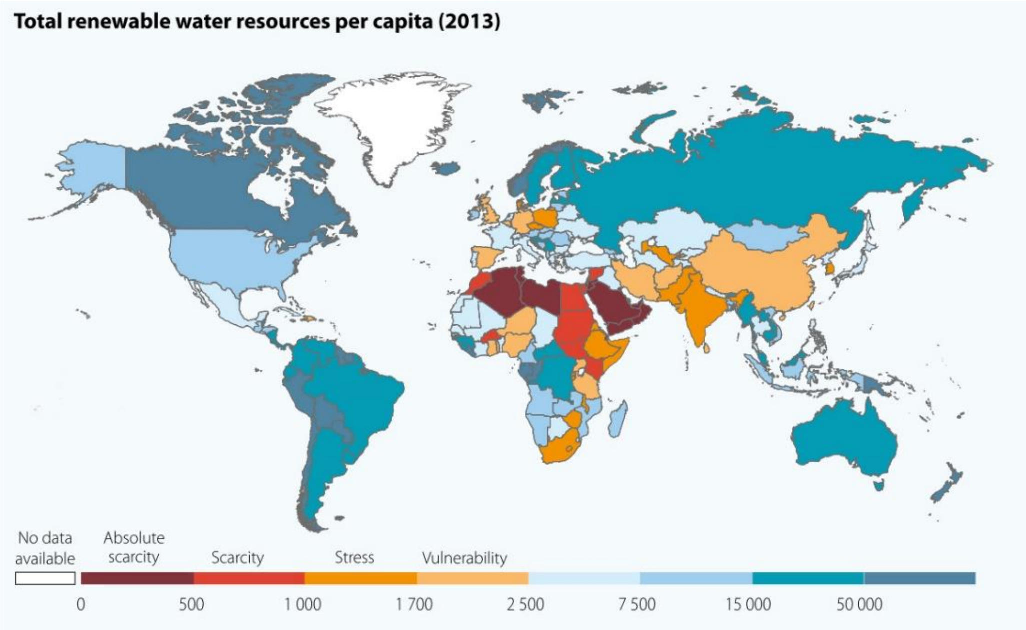
This future development is more deeply described by 2030 Water Resource Group (2009), which expects that global water requirements would grow from 4,500 billion m^3 to 6,900 m^3 (i.e by 65 %). As it can be seen in **Figure 6**, the water deficit in basins will grow by about 2,800 billion m^3 and basins with surplus represent about 100 billion m^3. Agriculture consumes about 3,100 billion m^3 and it is expected that consumption will increase to 4,500 billion m^3 (2030 Water Resource Group, 2009). Issue of distribution and availability of freshwater resources is depicted on **Figure 7**. As it can be seen, most countries with water stress or scarcity can be found in Africa and South Asia, but there are also some countries in Europe under water stress (WWAP, 2015). According to AQUASTAT database, there are already six countries, which are withdrawing more freshwater than they are able to renew. They are Egypt, Libya, Bahrain, Saudi Arabia, Uzbekistan and Yemen. But countries like Algeria, Tunisia, Saint Kitts and Nevis, Iran, Iraq, Israel, Jordan, Pakistan, Syrian Arab Republic, Tajikistan and Malta have over 50 % freshwater withdrawals of total renewable water resources (AQUASTAT, latest values). This trend is in line with journal article *The Future of Global Water Stress: An Integrated Assessment* which states that increase of water stress by 6 % can be expected for economic growth alone for first fifty years of the 21st century. According to this study, socioeconomic growth exceeds impacts of climate change in increasing risks to water stress mainly by population boom. (Schlosser et al., 2014).

Figure 6.: Global water demand 2009 - 2030



Source: 2030 Water Resource Group, 2009

Figure 7.: Total renewable water resources (m^3 per capita) in year 2013

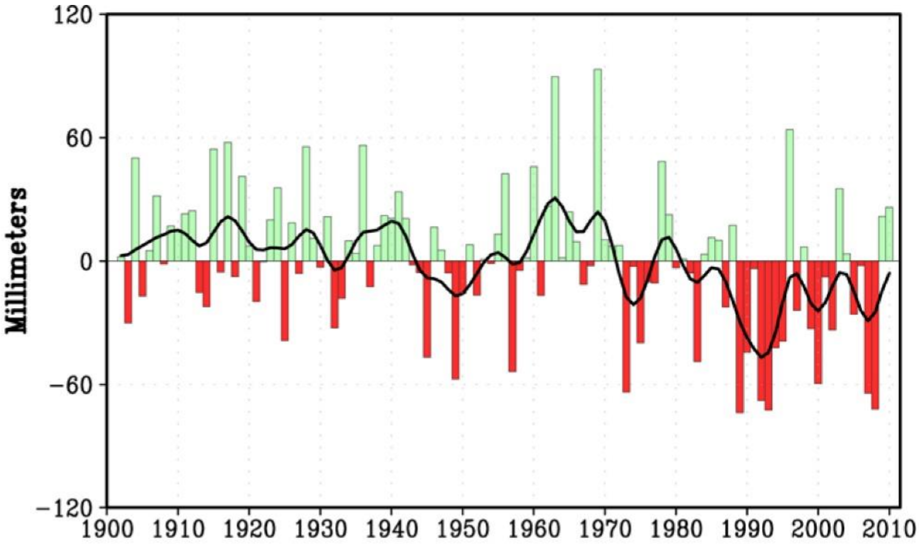


Source: WWAP, 2015

As for a climate change, freshwater resources are vulnerable to many climatic-driven factors. The global warming causes great changes in hydrological cycle such as increased evaporation and subsequently surface drying, which can lead to increased frequency of droughts and duration. However, volume of water vapor in atmosphere can be higher due to higher temperature which increases water vapor capacity. This can provide big influence on precipitation which can intensify storms, tropical cyclones or snowstorms. Generally, dry areas become drier and wet areas become wetter (Trenberth, 2006). *Climate change and water: IPCC Technical Paper VI* (2008) states that the precipitation will be higher in higher latitudes and some parts of tropics, while in sub-tropics and in mid-latitude regions the precipitation will decrease. River runoff and water availability will be changed in a similar way. The higher frequency of heavy precipitation will bring risk of floods, but at same time extreme droughts could occur in large scale. This will result in unsustainable development in affected areas. For example, large portion of Europe could face decrease of electrical generation from hydropower by 25 % by 2070s and it could also face lower agriculture yields from higher temperature and precipitation variability (Bates et al., 2008). This statement is in concert with *Climate Change 2014 Synthesis Report* (2014) which also states that climate change will reduce renewable water resources mainly in subtropical regions and increase competition for water among sectors. There is also medium confidence that the frequency of droughts will likely increase in dry regions by the end of the 21st century (IPCC, 2014).

Evidence of increased drought areas and arid areas are recorded since the 1970s over Africa, Europe, East and South Asia, eastern Australia and many parts of the northern mid-high latitudes. This trend is probably caused by rapid warming and its atmospheric need for moisture and changed circulation patterns. Even lower evaporation over some arid regions suggests that changes in precipitation and temperature plays major role in drought trend. Climate models for periods 2030 – 2039, 2060 – 2069, 2090 – 2099 project that current trend of increased droughts measured by Palmer Drought Severity Index (PDSI) can be expected in future over most of Africa, southern Europe, the Middle East, most of Americas, Australia, and Southeast Asia (Dai, 2011). For example, California is experiencing most severe droughts in history. This is probably caused by shifts in precipitation patterns which could be seen in 2013 when precipitation was lowest over the past 119 years of record. Although droughts in California are not unusual under local conditions, climate change increased average temperature by 0.6 °C and reduced snowpack by 10 % in Sierra Nevada mountains. If this trend continues, temperature can rise up even by 2.0 °C and snowpack reduction can reach 40 %. Global warming is also increasing risk of high pressure off the state's coast that blocked moist air from the Pacific Ocean and subsequently exacerbate droughts (Peel and Choy, 2014). Example of deteriorating situation can be also found in case study in Francolí river basin in Spain, where water yield will be reduced between 11.5 and 44 % while total drinking water amount will drop by the extent between 13 and 50 %. Such decreases can be expected in all the Mediterranean basin which is one of the most vulnerable regions of the world to climate changes (Marquès et al., 2013). Such a trend is confirmed by NOAA. In their article *NOAA study: Human-caused climate change a major factor in more frequent Mediterranean droughts (2011)* states that winter-time droughts are increasingly common in Mediterranean region. As can be seen on **Figure 8**, trend of precipitation decrease begun in the 1970s. So far, winter was main period of precipitation accumulation for this region and nowadays wintertime dryness can be found from Gibraltar to the Middle East (NOAA, 2011).

Figure 8.: Winter precipitation trends in the Mediterranean region for the period 1902 – 2010 [mm]



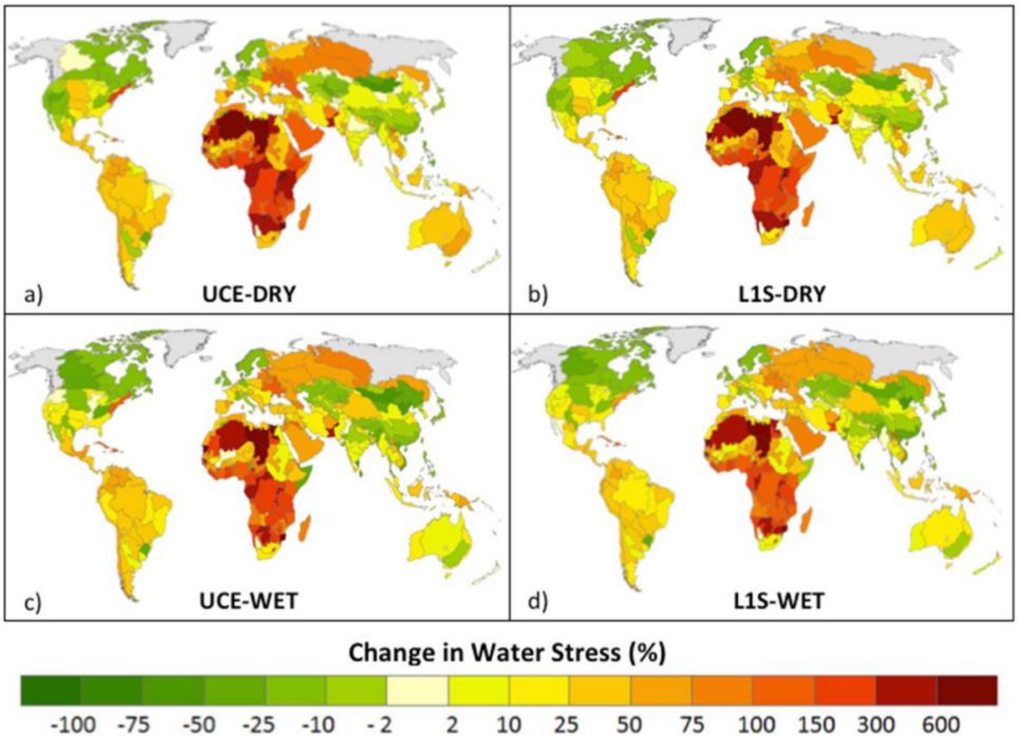
Source: NOAA, 2011

Also groundwater faces pressure from changing climate (mostly indirectly). Direct pressure on groundwater is lower than on other resources like rivers. This is because it takes much shorter time to replenish rivers than groundwater. Groundwater can be affected by disappear of glaciers and snowcaps, which can create runoff and subsequently recharge resource for aquifers. Also higher temperatures cause higher evaporation and evapotranspiration of plants, and hence lesser seepage rates of soil, desertification and disruption of groundwater storage systems (Hetzel et al., 2008).

Changes of water stress in averaged periods from 2001 – 2010 to 2041 – 2050 can be seen on **Figure 9.** All four models take into account both socioeconomic growth (under different growth conditions) and climate change impacts (under different climate patterns) and as can be seen results are not very different. The strongest increase in water stress can be seen in Africa, but highly visible change can be seen also in Europe and south America. *The Future of Global Water Stress: An Integrated Assessment* states that additional 1.8 billion people (a 53 % increase) will live under high water stress conditions by year 2050 due to economic growth and population change. 80 % of these people will live in developing countries. Another 93 millions of people could (60 million located in developed world) live in regions with high water stress caused by climate change. By

2050, Five billion people could be exposed to at least moderate water stress, caused by both climate change and economic growth (Schlosser et al., 2014).

Figure 9.: Changes in water stress index



Source: Schlosser et al., 2014

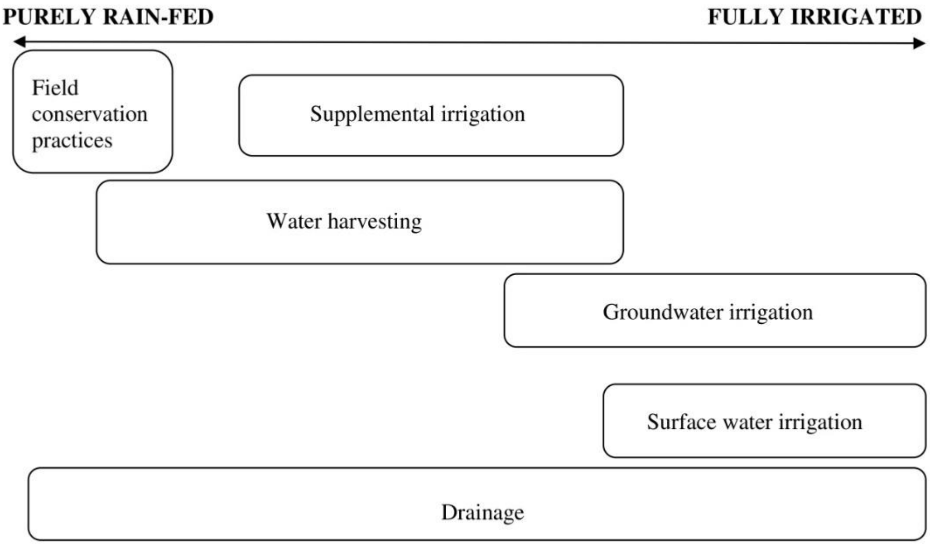
2.3 Water management in Agriculture

2.3.1 General information and position of water management in world agriculture

Water is essential factor for agricultural production. It is used for production, preparation and processing of food and it plays important role for human food security. Only agriculture alone consumes 70 % of all water withdrawals globally and produce an average of 23.7 million tons of food every day (FAO, 2014; HLPE, 2015). Regarding agriculture sustainable management of water resources, the water should be allocated efficiently and equitably between users for achievement of social, environmental and economical outcomes. This includes effective irrigation across production season, water management of rain-fed agriculture, management of drainage and conservation of ecosystems. This covers different approaches in using surface water, groundwater, harvested rainwater, recycled wastewater and desalinated water as agricultural systems and climatic conditions vary across countries. Operating these resources requires diverse sets of political, cultural, legal and institutional contexts (OECD, 2010).

Farming systems can rely on different spectrum of options as can be seen on **Figure 10.** It can rely totally on rain-fed irrigation or in case of drier climatic conditions on supplement (or substitution) of surface water, groundwater and other water resources like recycled water or desalinated water (IWMI, 2007). According to book *Rainfed Agriculture: Unlocking the Potential*, rainfed agriculture constitutes 80 % of global agriculture. In Sub-Saharan Africa more than 95 % of farmed land is rainfed, while in Latin America it is almost 90 %, and in South Asia it is 60 %, and in East Asia it is 65 % and in Near East and in North Africa it is 75 %. Rainfed agriculture production in developing countries gives grain yields in average 1.5 t/ha, while if compared with irrigated plots, 3.1 t/ha are obtained. But the grain yields differ according to local climate and soil conditions. For example, tropical regions with high humidity are able to produce 5-6 t/ha only from agriculture. On the other hand, semi-arid and arid regions are able to produce only between 0.5 and 2 t/ha. Generally, regions dependent on rainfed agriculture have low rainwater use efficiency, only about 35-45 %. Rainfed agriculture is also known by fragile environment, water scarcity, drought and land degradation due to soil erosion (Wani, 2009).

Figure 10.: Diverse options for agricultural water management



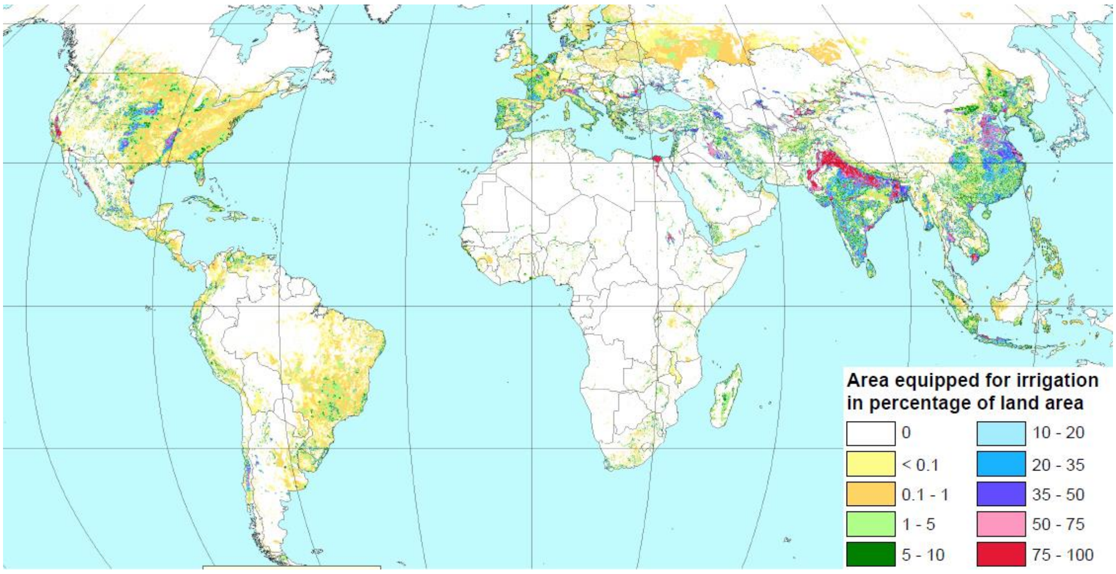
Source: IWMI, 2007

According to AQUASTAT, 324 million hectares worldwide are equipped for irrigation. That is 21 % of the total cultivated land. As it can be seen on **Figure 11** most irrigated areas can be found in China and India, which represents 42 % of world irrigation. USA, Italy, Egypt and Australia are also countries with large irrigated areas. Most irrigation is still provided by surface irrigation (280 million hectares), then by sprinkler irrigation (35 million hectares) and drip or localized irrigation is the least used irrigation (9 million hectares). Most harvested irrigated cropped area are still cereals with 61 % and vegetables with 10 % (AQUASTAT, 2014). Yields from irrigation systems are usually at least twice of those of rainfed crops. While rainfed agriculture produces 1.5 t/ha on average, irrigation produce 3.3 t/ha (IWMI, 2007). Irrigation primarily extracts water from surface water sources like rivers or lakes and secondarily from groundwater (aquifers). Surface water supplies irrigated areas by 62 % of water amount and groundwater by 38 %. Non-conventional resources of water such as wastewater and desalinated water supply irrigation only by about 1%. Treated wastewater are mostly used in peri-urban areas. Desalinated water is used for irrigation in case of high-value crops and where is no other source of water (FAO, 2011).

The population is estimated to reach 9.3 billion people in 2050, and 13.5 billion tons of foodstuff per year will be needed instead of 8.4 billion tons of foodstuff produced now

(FAO, 2014). Although, rainfed agriculture is main resource of agriculture production and will play major role in global food security, it still has gaps in water management. For example, yield gap in sub-Saharan Africa shows that production is only on 24 % level of what it could be produced under better water management (FAO, 2011). On the other hand, rising temperature will reduce yields in many regions. Especially in regions, where soil and land scarcity are of the highest importance. This can probably endanger smallholder subsistence farmers and pastoralist communities, whose water supply is already now limited. South Asia and South Africa may suffer from fall of production maize, rice and wheat. Only harvest of rice and maize can decrease between 20 – 40 % by higher temperature in tropical and subtropical regions. Decline of cereals can be expected in the Mediterranean region and in Central Asia due to combination of water stress and increased temperature (Tubiello and Velde, 2011). Under current trend, climate change can decrease agricultural production by 10 – 20 % under all scenarios and it will affects 1-3 billion people worldwide by year 2080 (Oweis et al., 2007).

Figure 11.: The digital global map of irrigation areas



Source: Siebert et al., 2013

Challenge for irrigation can be mainly find in optimization of water productivity, which has been doubled for rice and wheat over last forty years, but it will need to be increased due to higher demand (FAO, 2011). Irrigation requirements under climate change will be probably altered by changes in precipitation, evaporation and water availability, which can be different as described in the previous chapter. This could lead to higher crop irrigation requirements that may increase between 5 to 20 % globally by year 2080. On the other hand, irrigated areas will be increased by 15-17 % and also irrigation water withdrawals will increase by 9–11 % in 2050 due to meet water demand (Tubiello and Velde, 2011).

Several articles analyzing different regions about irrigation, climate change and socioeconomic growth suggest that water supply and irrigation water requirements will be altered in future. According to article *Climatic Change, Irrigation Water Crisis and Food Security in Pakistan (2013)* agriculture in Pakistan is heavily dependent on water from Indus river basin and its annual influx of 180 billion cubic meters. Agriculture yield is from 80 % produced by cultivated land which is usually also irrigated. Climate change in Pakistan has increased temperature, changed precipitation patterns, accelerate glacier melting and increase evaporation rate that will increase crop water requirements. Higher temperature and evaporation cause low crop yield. Thus farmers in Pakistan are less interested in cultivating water intensive crops like rice and sugarcane. Farming systems and rural communities suffer from floods as melting of glaciers and snow or abrupt intensive rainfall are more intensive. Finally, growing population and aggravated food supply cause that inflation rate of food prices is too high for poor people. Therefore, staple food like wheat, rice, maize, sugarcane and vegetables are too expensive for poor people (Asif, 2013). Similar development is described by *Palazzoli and others (2015)* also in Indrawati basin, Pakistan, where food security may be at stake as food demand is going to increase because of growing population and large water requirement of some crop like maize, wheat or rice (Palazzoli et al., 2015). Issues of inadequate water supply can also be found in Yakima river basin, where water users are endangered by future conditions to meet their demands. Analysis of water users indicate, that this basin was 14 % water short, and in year 2040 it may increase to 36 % shortage and in the 2080s it could even lead to 77 % shortages of water. Trend like this may decrease economic value of crop that farm production of crops may decline from about $23 million to $70 million in three counties that are related to Yakima river basin (Vano et al., 2010). *Von Gunten and others (2015)* states that water availability will decrease in the Ebro region due to climate change. They predict 10 % increase of irrigation demand in the next forty years as a result of current cropping practices. Moreover, there are plans of irrigation expansion in future, which could increase irrigated area between 30% and 50 % (von Gunten et al., 2015).

Previous information can provide better and deeper insight how climate change and socioeconomic growth can inflict higher water demand in agriculture sector. Since water is important to about 850 million rural poor people primarily engaged in agriculture, it is necessary pay attention to better and sustainable water management in agriculture (Namara et al., 2010). Otherwise, it may lead to what can be seen in Syria situation, where impacts (droughts) of climate change and socioeconomic growth caused water deficit about 651 million cubic meters between years 1995 – 2005 and between years 2000 – 2010 an area of about 40.88% of the total area of Syria was a subject to drought for 4 - 6 years. Nearly 75 % of population suffers from total crop failure between years 2007 - 2008. Wheat and barley yields dropped by 47 and 67 % and Wheat non-irrigated production dropped by 82 % compared to previous year (Erian et al., 2010). Herders in north-east of Syria lost around 85 % of their livestock. According to United nations (UN) and international Federation of the Red Cross and Red Crescent Societies (IFRC) organizations, over 800 000 people lost their entire livelihood as a result of a droughts and 2-3 million people were pushed into extreme poverty. After that, 200 000 rural villagers were forced to leave for the cities (Femia and Werrell, 2012).

2.4 Moldova country review

2.4.1 General information about Moldova

The Republic of Moldova is located in the northeastern part of Balkan region in Europe embodied between two countries – Romania and Ukraine. It has territory over thirty-three thousand km^2 with population about 3,918,000. The majority of populations belong to the Moldovan ethnicity (78.2 %). The country is considered as one of the poorest countries in region with slow economic growth, high corruption and widespread poverty (Vacek, 2015). Country economy is oriented towards agriculture which is important for employment, rural livelihoods, food security and rural growth (World bank, 2014).

Territory of the Republic of Moldova is mainly hilly with average elevation of around 147 m above the sea level. The most elevated region is in central part with the maximum altitude of 429,5 m. The soil in Moldova territory is classified into more than 745 varieties, but soil type Cherznozem (black earth) is mostly occurred soil and is found on around three-fourth of land area of country. Brown and gray soils covers 11 % of land area and floodplain and meadow soils covers 12 % of land area. The Republic of Moldova is located in Black Sea Basin with three main rivers - The Nistru (1,352 km, 657 km within the country), the Prut (976 km, 125 km within the country) and the Raut (286 hm). Moldova also has about 60 natural lakes and 3,000 reservoirs. The flora and fauna is quite rich and includes more than 21 thousand species together distributed in three natural zones – forest (11 % of territory), forest – steppe and steppe (Republic of Moldova official webpage, 2011). As it can be seen in **Table 2,** climate can be considered as Humid continental mild summer (Dfb) according to Köppen climate classification. This microthermal climate can be exclusively found in northern hemisphere and it is associated with cyclones, which bring year-round precipitation (Peel et al., 2006; Belda et al., 2014). Moldova has short mild winters and lengthy hot summers and long dry periods in the south. Precipitation is modest and varies between 600-650 mm in the north and center of country while in the south and southeast it varies between 500-550 mm (Republic of Moldova official webpage, 2011). The atmospheric air circulation is mainly composed western warm air masses from Atlantic, occasionally air masses from Mediterranean bring humid and warm air, which start up rainfalls. On the other hand, moderate-continental air from Eastern European Plains causes drought and cold air from Arctic can cause dramatic weather changes. The annual average speed ranges between 2.5 to 4.5 ms^{-1} and average relative humidity of air is 60-70 % in summer and 80- 90 in winter. Solar radiation is also different in the north (1.280 $kWh/m^{2)}$ and in the south (1370 kWh/m^2) (European Commission, 2013).

Table 2.: The seasonal climatic characterization of the territory of Moldova

Season	**Average Temperature [°C]**	**Precipitation [mm]**	**Characteristics and risks**
Winter	-3.2 – -1.2	85 – 110	Fogs, Snow storms
Spring	8 – 10	105 – 150	Heavy rainfall, thunderstorm
Summer	18.5 – 21.0	170 – 235	Heavy hail and rainfall, severe droughts
Autumn	8.3 – 10.6	100 - 135	Early frosts, fogs

Source: State Hydrometeorological Service, not dated

2.4.2 Agriculture in Moldova

2.4.2.1 General information about agriculture in Moldova

Agriculture, as the most important source of human being, is key sector of economy in Moldova. High soil quality (70 % of total area is occupied by Chernozems) and favorable climate is suitable for any kind of crops except tropical and subtropical species. Importance of agriculture can be seen in amount of agricultural land in Moldova, that account for 2026 thousand hectares, that is about 60 % of a total territory (CERTAN and CERTAN, 2012; National Bureau of Statistics of the Republic of Moldova, 2015). According to world bank, agriculture sector produced 15 % of GDP in 2014, which is quite high on Europe conditions. In Europe, More GDP value added produced only Albania. Another evidence that Moldova is agrarian society can be found in employment in agriculture, which reached 29 % of total employment in 2013 and was the highest in Europe (World Bank, 2014; Leah, 2012).

Agriculture sector in Moldova is forced to be led by individuals (farmers) and corporations. After the fall of communism era, Government of the Moldova attempted to reform the Moldovan agricultural production system. Collective and state agricultural production has been privatized and redistributed to individuals and corporate ownership. This step was done to ensure food security and improve agricultural efficiency, which in 1998 reached miserable results since the agricultural production slipped to 62 % of production in 1991. The land reform can be divided into two steps. The first one, each family in rural districts got at least 0.3 ha by small-scale privatization. By this step, by year 1999, 344,500 hectares were privatized. The second step focused on reform of the state and collective farms. The members and workers of collective and state farming got a share of land to pursue individual farming (called PAI). This action was only partly successful as in 1997 there were still about 1000 large farms with areas between 1000 ha – 2000 ha (Gorton, 2001). Form of ownership of agriculture land in year 2015 was divided between public sector which accounts 649 thousand hectares and private sector with 1850 thousand hectares. It can be seen that private sector dominates agriculture and it will be probably main contributor to food security (National Bureau of Statistics of the Republic of Moldova, 2015).

Table 3.: Structure of Agricultural Production by Branches, In All Categories of Producers [%]

Percentage; Comparable Prices				
Year	**2011**	**2012**	**2013**	**2014**
Plant production of which:	**71.7**	**61.5**	**72.3**	**67.8**
Cereals	28.0	17.9	28.9	25.4
Sugar beet (industrial)	1.6	1.9	2.4	3.0
Tobacco	0.5	0.3	0.2	0.1
Sunflower	8.9	10.5	12.7	7.9
Potatoes	7.1	2.5	2.4	4.4
Vegetables and melons and gourds	8.1	6.0	5.5	7.5
Fruits, nuts and berries	6.8	6.7	5.4	6.4
Grapes	6.1	10.4	9.0	6.8
Forage crops and other	4.6	5.3	5.8	6.3
Animal production	**27.9**	**38.5**	**27.7**	**32.2**

Source: National Bureau of Statistics of the Republic of Moldova, not dated

As it shown in **Table 3**, most Moldovan agricultural production is oriented towards plant production, mainly cereals, sunflower, vegetables, melons and gourds. It seems that agricultural production in Moldova is not very stable as it can be seen in data about gross harvest of agricultural crops for period 2006 - 2014 (**Annex**). For example, wheat production seriously declined from 691 thousand tons in 2006 to 406 thousand tons in 2007 (year of extreme drought) and then increased to 1286 tons in year 2008. Issues with repeated decline of agricultural production have also almost all other crops and always it is in year with severe drought, like in year 2012, when main summer standing crops were damaged (National Bureau of Statistics of the Republic of Moldova, not dated; Horn et al., 2008).

From the agro-climatic perspective (**Table 2**), Moldova represents region for growing a large spectrum of crops. Winter is quite favorable for autumn crops, vineyards and trees. In the spring most risk climatic phenomena represent droughts and hot dry winds, which can harm autumn crops, weeding crops and reduce tree yields. In May, hot dry winds are recorder in average in 3 – 7 days. The spring droughts are mainly recorded in April to May and their frequency is about 15 % of year. Apart from heavy rainfall, hail, strong winds and vortexes, crops in Moldova summer suffer from severe droughts. Frequency of these droughts are different across the country. In northern part, droughts occur once every ten years, once every five to six years in central Moldova and once every three years in Southern Moldova. Over the last two decades, frequency of droughts has increased and become harsher. The State Hydrometeorological Service of Moldova recorded 9 droughts between years 1990 – 2007 that cause significant decline in crop yields (World Bank, 2016). As for the Autumn, most agriculture activities focus on harvest, which has quite favorable conditions (State Hydrometeorological Service 2016).

Although, the countries of Eastern Europe are less vulnerable to climate change than other states, warming between years 1988 and 2007 is felt the air temperature increased in average by 1.1 – 2.0 °C and thus shows that issues of climate change concern eastern Europe too. By the end of the century, temperature could increase by 4 -5 °C. This likely unevenly change precipitations patterns in regions. It could be expected that amount of precipitation will increase in winter, but on the other hand decrease in summer and autumn (**Table 4**) which will reinforce the risk of droughts like in year 2007, when catastrophic drought hit 80 % of the country and caused damage valued at USD$1 billion (ENVSEC, 2012). Probably most vulnerable area to climate change is the South and South-Eastern part of Moldova, where large fluctuations of rainfall deficit and extreme temperatures occur (Nedealcov, 2013).

Table 4.: Ensemble-averaged projections of precipitation changes in comparison with baseline climate

Season	Emissions scenarios	Precipitation [mm]			
		Time horizons			
		1961 - 1990	**2010 - 2039**	**2040 - 2069**	**2070 - 2099**
Winter	SRES A2	107	7.5	11.4	10.4
	SRES B2		8.5	13.6	15.5
Spring	SRES A2	130	4.4	6	5.5
	SRES B2		6.4	12.3	11.6
Summer	SRES A2	207	-7.8	-19.3	-30.2
	SRES B2		-13.2	-16.7	-22.6
Autumn	SRES A2	11	-6.07	-16	-17.6
	SRES B2		-6.2	-6.1	-6.8

Source: UNDP, 2009

The risks of climate changes are for countries like Moldova predominantly immediate as majority of rural population is dependent on the agricultural production which constitutes their main income for livelihood. Food security and economic growth of rural population can be endangered by climate change impacts and slow process of poverty reduction. Nowadays, food security is in good condition. There are no food shortages and in ordinary years, country is able to ensure basic food for populations. On the other hand, diet of many Moldovans is unhealthy and especially people living in rural areas suffers from unbalanced vitamin and protein intake. Moreover, drought in 2007 shows that 80 % of farmers was affected by extremely small harvest. Cereal harvest was 70 % smaller than in year ago and cattle diminished by 25 %, likewise pigs diminished by 50 %. Many households were subsequently exposed to famine because of rising prices of food and depleted food supply. Because the government was not prepared to deal with impacts of drought, many families had to get the external assistance received by government (Sutton et al., 2013; UNDP, 2009).

Vulnerability of Moldova agriculture to these risk is unmistakable and although recent droughts cannot be directly tied to climate change, it is obvious that these extreme events are consistent with impacts of climate change on other places and regions. As it was stated earlier, temperature will increase and precipitation will be more variable, which is consistent with current trend. Moldovan farmers already confirmed that these changes affect their farming processes and crop yields nevertheless adaptation strategy is not suitable under current circumstances. Agriculture risks with high priority were highlighted by Ministry of Environment for Republic of Moldova and mainly concern increased risk of drought and water scarcity, increased irrigation requirements, soil erosion with salinization and desertification (aridization), increased risk of agricultural pests, diseases and wheat and maize yield decrease (MOE Moldova, 2012; Sutton et al., 2013)

Possible results of these risks are shown in **Table 5**, which represents average changes in crop yield without adaptation and no irrigation constrains. As it can be seen, almost all crops can experience decline between year 2040-2050. Most suffering crop probably is wheat with the worst possible decline of 38 % in rainfed agriculture. Although these declines are very drastic, some crops can increase their production due to increased CO_2 fertilization effects. Another potential challenge can be seen in irrigation, which can mitigate impacts of climate change as its changes are less negatives ones (Sutton et al., 2013).

Table 5.: Effect of climate change on crop yield between period 2040-2050. Relative to current yields under medium impact scenario, No irrigation water constraints and without new adaptation measure

[%]	Crop	Northern	Central	Southern
Irrigated	Maize	-8	-6	-9
	Wheat	-14	-30	-34
	Alfalfa	-7	-13	-18
	Grapes	-4	-3	-5
	Apples	0	0	-3
	Vegetables	-5	-9	-13
Rainfed	Maize	-9	-3	-10
	Wheat	-36	-38	-45
	Pasture	-17	-22	-19
	Alfalfa	-13	-18	-12
	Grapes	-4	-3	-2
	Apples	-2	-4	3
	Vegetables	-9	-13	-9

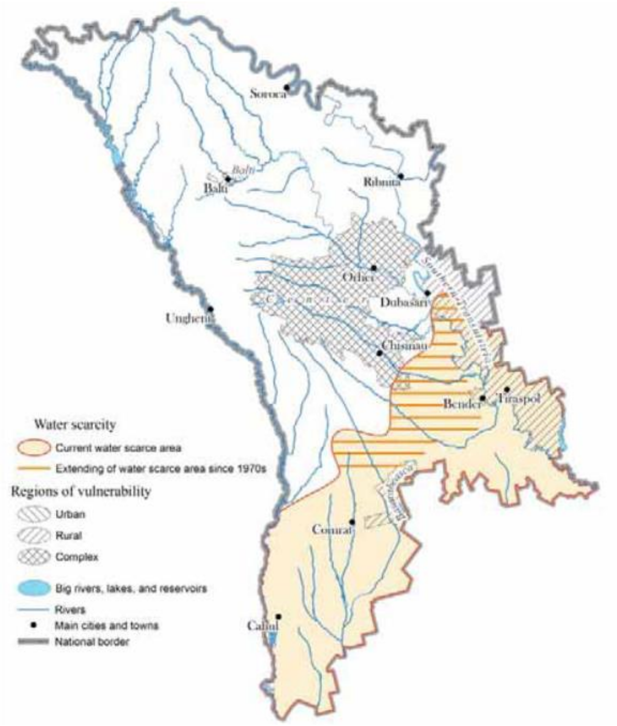
Source: Sutton et al., 2013

2.4.2.2 Water resource management and Irrigation sector in Moldova

Moldova is a country with population highly dependent on groundwater resources. About 70% of the population is reliant on groundwater sources as drinking water while only 30 % of population is supplied by surface water. Most important surface source of water is Dniester river which supplies about 83 % of total water abstracted. Second most important source of water is Prut river, which provide only 1.8 % of total water abstracted. This is probably caused by low accessibility, since this river creates borders with Romania. These two rivers contributed to total water abstraction from surface sources by 721 million m^3 in 2011. Since these two rivers are far from center of country and it is expensive for transmission, aquifers with high quality of water present better source of drinking water. However, low precipitation creates limit for full recharge of shallow wells with depth of 10 m to 15 meters and therefore it seems that more import sources of water are deep layers which constitute 70 % of groundwater resources in Moldova and they are located in Baden-Sarmat formation with depth from 50 m to 2000 m. On the other hand, these aquifers are already heavily exploited and it seems that some limitations should be introduced in future (UNECFE, 2014).

Water availability in the Republic of Moldova will be sensitive to climate change. According to UNDP estimates, there will be about 20 % less available surface water in the 2020s and in 2080s there could be 39 % less available surface water. The State Hydrometeorological Service calculated that in 2080s annual runoff could decrease even by 64 % in the southern region under the worst emission scenario (**Annex**). Therefore, secure supply for all water users will be threatened. By considering expectation that about 20 % of shallow wells will dry up and will experience a significant reduction in water levels, water scarcity will be critical after the year 2030. While the northern and central part of the country are still secured by distribution of water, southern part suffers from water deficit. The total water scarce area occupies one third of country’s territory. This affects 1/3 of all urban settlements and almost ¼ of all villages, thus 30 % of rural and 28 % of urban population. This area has about 1/3 arable area which can suffer from insufficient precipitation and irrigation will be required for many crops. It may be expected that water scarce area will spread more north to the central region (**Figure 12**), where is high concentration of rural and urban population. Higher water stress in Moldova is also expected by the World Resource Institute, which expects that majority of territory suffer by high change (40-80 %) in water stress by year 2040 (UNDP, 2009; The Republic of Moldova, 2012; European Commission, 2013; State Hydrometeorological Service, not dated; World Resource Institute, not dated).

Figure 12.: Current and future areas under water scarcity



Source: UNDP, 2009

The supply of water used for agriculture decreased from 67 million m^3 in year 1997 to 38 million m^3 in 2014. This is in line with changes of land under irrigation. While irrigated area presented about 307 thousand hectares in 1997, Lands provided with irrigation facilities contains only about 228 thousand hectares in 2014 (National Bureau of Statistics of the Republic of Moldova, 2015). On the other hand, data provided by Apele Moldovei (the administrative authority responsible for implementing State policy on water resources management, water supply and sanitation) shows that there are only about 36 000 hectares of irrigated area, from which majority is located in Lowet Nistru basin. The Republic of Moldova inherited 78 central irrigation systems (CIS) with area about 144 thousand hectares. However, these systems irrigate only small part of this area and much of this infrastructure needs to be rehabilitated (MCA, 2016; Sutton et al., 2013). This task has been undertaken by Millennium challenge corporation (MCC) which goal was to rehabilitate 16 CIS supplied by surface water from watersheds of two rivers -

Nistru and Prut in Black sea basin. While in 2008, there was only small land under irrigation (**Table 6**), MCC assumes that in 2025, at least over 70 % of potential area will be irrigated in every SIC. This rehabilitation should provide equipment to the farmers, create water user associations (WUA), and restore irrigation infrastructure (River intake, Pump stations, Electrical Systems, Underground Pipe Network, Drainage channel network) (Millennium challenge corporation, 2009). By the May 2015, only two CIS – Criuleni and Lopatna were complete while other 8 CIS were still in progress of renovation, however it was expected that by June – July 2015, 5 CIS will be completed, namely Blindeşti, Roşcani, Coşniţa, Puhăceni and Jora de Jos (MCA, 2015).

Table 6.: Central irrigation systems rehabilitation project

CIS Rehabilitation project	Potential area of Irrigation [ha]	Area irrigated [ha] in 2008
Tetcani	1,258	52
Blindeşti	521	0
Grozeşti	1,018	20
Cărpinenii de Sus	1,815	69
Leova Sud	963	0
Chircani-Zîrneşti	4,417	0
Masivul Cahul	1,930	0
Jora de Jos	1,165	119
Lopatna	506	47,5
Coşniţa	2,800	642,9
Criuleni	677	46,5
Şerpeni	1,107	0
Puhăceni	856	55
Roşcani	682	123,9
Masivul Talmaza	2,468	85
Masivul Suvorov	13,394	2528,5

Source: Millennium Challenge Corporation, 2009

Irrigation water demand on Moldova territory will also be affected by climate change, especially temperature and precipitation, which will change crop irrigation requirements. It can be expected that even low climate change scenario will increase irrigation crop requirements of some crops even by 38 %. Under the high climate change scenario, it can even be until 102%. The irrigation potential will also be lower as number of annual days when water is available for irrigation will decline by -71.4 as a result of expected larger water stress. Irrigation water demand in Moldova will probably increase in all three climate change scenarios and with demands of other sectors, it can create shortfall of irrigation water in 2040s as it is shown in **Table 7**. It is necessary to add that these scenarios of shortfalls does not take into account growth of areas under irrigation (Sutton et al., 2013; Bär et al., 2015).

Table 7.: Shortfall in irrigation water relative to the total irrigation water demand in 2040s

2040s	**Low Impact**		**Medium Impact**		**High Impact**	
Basin	thousand m^3	% shortfall	thousand m^3	% shortfall	thousand m^3	% shortfall
Lower Nistru	79	0,2	62	0,2	318	0,7
Reut	213	0,6	2000	5,6	8360	21,5
Upper Nistru	26	0,3	37	0,4	162	1,5
Kogilnic	0	0	0	0	0	0
Prut	0	0	0	0	0	0
Total	318	0,2	2099	1,5	8840	5,6

Source: Sutton et al., 2013

3 Objectives

3.1 Main Objective

The main objective of the thesis was assessment of agriculture vulnerability to impacts of climate change on water resources by analysis of structure of farming systems in Moldova and determine their irrigation status.

3.2 Specific objective

The main aim of the Thesis was accomplished through specific objectives.

(i) Analysis of structure of farming systems in CISs.

(ii) Estimating water irrigation needs for twelve strategic crops grown in Moldova under climatic conditions of central irrigation systems.

(iii) Analysis of contract type agricultural enterprises and its influence on irrigation status and possibility of irrigation.

4 Methodology

4.1 Data sources

Three types of data as main source have been utilized for purposes of this thesis.

4.1.1 Survey of land user characteristics

First type of secondary data provided by National Agency for Rural Development (ACSA) in Moldova concern characteristics of land users in coverage of 26 central irrigation systems. Data were collected by use of questionnaire and utilized for evaluation of possibility of central irrigation system rehabilitation by Millennium Challenge Corporation. Data were collected in year 2008 by ACSA personal and obtained by the author in 2015 in Chisinau ACSA department.

Questionnaire structure by chapters:

(i) **Number of Central Irrigation System**
(ii) **Geographic zone of CIS**
(iii) **Region code**
(iv) **Village code**
(v) **User's-code**
(vi) **Type of the area:** 1. for areas under 10 hectares, 2. between 10 and 100 hectares and 3. More than 100 hectares.
(vii) **Size of the area** (Hectares)
(viii) **Gender of Farm Administrator**
(ix) **Type of lease contract:** a) Processed Individually/ by the owner, b) lease but without contract, c) contract under three years, d) contract more than three years.
(x) **Irrigation system functionality:** destroyed or functional
(xi) **Irrigation status of farm:** If there is no irrigation, Irrigation supply provided by organization Apele Moldovei, Irrigation from other sources, Mix of irrigation from other sources and from Apele Moldovei.
(xii) **Crop pattern of farm:** Abandoned land or under field and technical crops or vegetables, potatoes and melons or vineyards and orchards or Mix of previous options or other cropping patterns.

(xiii) Region name

(xiv) Village name

Table 8.: Respondents in Central Irrigation systems in Moldova

CIS Number	Number of respondents
1-1	1,729
11-6	352
11-7	4,494
12-3	3,146
14-1	3,989
14-11	3,936
14-13	725
14-2	1,495
14-3	1
14-5	8,656
14-6	474
15-3	15
17-2	1,716
17-3	6,771
1-8	1,337
3-2	1,470
3-3	1,359
3-5	538
3-6	2,333
3-7	2,928
4-5-1	3,559
5-4	2,574
6-1	741
6-2	61
6-6	2,788
6-9	979
8-3	340

Source: Author's compilation

Data were collected from 58,506 respondents divided into individual Central irrigation systems as it can be seen in **Table 8**. Data from 16 CIS only were used for purposes of this thesis, which were highlighted by MCC for feasibility studies for rehabilitation. This action reduces number of respondents to 38,542 (Millennium challenge corporation, 2009).

4.1.2 Climatic data from World Water and Climate Atlas

Second type of secondary data, which were used for estimations of irrigation water needs in 16 CIS, were mainly obtained from World and Climate Atlas created by International Water Management Institute (IWMI). The Atlas includes monthly and annual summaries of precipitation, temperature, humidity, hours of sunshine, evaporation estimates, wind speed, total number of days with and without rainfall, days without frost and Penman-Montieth reference evapotranspiration rates. Data for creation of atlas were assembled from Weather stations around world for the period 1961 – 1990. Location (latitude and longitude) for chosen CISs are as follows (IWMI, not dated).:

(i) 14–13 Roscani (Lat 46 º 54 ' 15 " N Long 29 º 18 ' 56 " E)
(ii) 1-1 Tetcani (Lat 48 º 10 ' 49 " N Long 26 º 59 ' 05 " E)
(iii) 3-2 Blindeşti (Lat 47 º 18 ' 46 " N Long 27 º 40 ' 27 " E)
(iv) 3–6 Grozeşti (Lat 47 º 00 ' 11 " N Long 28 º 04 ' 35 " E)
(v) 4-5-1 Cărpinenii de Sus (Lat 46 º 45 ' 21 " N Long 19 º 22 ' 8 " E)
(vi) 5-4 Leova Sud (Lat 46 º 28 ' 52 " N Long 28 º 14 ' 55 " E)
(vii) 6-6 Chitcani-Zîrneşti (Lat 46 º 02 ' 22 " N Long 28 º 10 ' 24 " E)
(viii) 6-9 Masivul Cahul (Lat 45 º 54 ' 12 " N Long 28 º 11 ' 47 " E)
(ix) 11-6 Jora de Jos (Lat 47 º 27 ' 56 " N Long 29 º 06 ' 37 " E)
(x) 11-7 Lopatna (Lat 47 º 29 ' 49 " N Long 29 º 02 ' 53 " E)
(xi) 12-3 Coşniţa (Lat 47 º 08 ' 21 " N Long 29 º 07 ' 22 " E)
(xii) 14-2 Criuleni (Lat 47 º 12 ' 58 " N Long 29 º 09 ' 28 " E)
(xiii) 14-6 Şerpeni (Lat 47 º 01 ' 29 " N Long 29 º 20 ' 28 " E)
(xiv) 14-11 Pugăcenii (Lat 47 º 04 ' 56 " N Long 29 º 20 ' 01 " E)
(xv) 17-2 Masivul Talmaza (Lat 46 º 38 ' 28 " N Long 29 º 40 ' 11 " E)
(xvi) 17-3 Masivul Suvorov (Lat 46 º 23 ' 41 " N Long 29 º 52 ' 24 " E)

4.1.3 Crop Selection

Following crops were selected as representative crops of Moldova's agriculture according to amount of production area upon which they are grown in Moldova for estimations of irrigation water needs in all 16 CISs (National Bureau of Statistics of the Republic of Moldova, 2011)

(i) For field crops and technical crops

- **Wheat (319411 hectares)**
- **Barley (123943 hectares)**
- **Maize (348259 hectares)**
- **Sunflower (239373 hectares)**
- **Sugar beet (23301 hectares)**

(ii) Vegetables, potatoes and melons

- **Potatoes (25081 hectares)**
- **Cabbage (3612 hectares)**
- **Tomatoes (7995 hectares)**
- **Melons (6178 hectares)**
- **Onions (8260 hectares)**

(iii) Vineyards and orchards

- **Apples (44601 hectares)**
- **Wine (75143 hectares)**

4.2 Estimates of Irrigation Water need

This part of thesis focus on estimations of Irrigation water needs in 16 CISs, which were subsequently used for assessment of CIS vulnerability to water availability. Equations and estimations are based on document Irrigation Water management: Irrigation Water needs published by FAO (1986).

First step of estimation was determination of Reference crop evapotranspiration (mm/day) for every calendar month for every single CIS in concern. This was obtained through the IWMI World and Climate Atlas. Subsequent step deals modification of Kc values for every month of plant's growth. For this, determination of crop coefficient (K_c) (**Table 10**) and periods of growing stages (**Table 9**) for every single representative crop were obtained from document Irrigation Water management: Irrigation Water needs published by FAO (1986). Growing stage and crop coefficient for apples production were obtained from document Crop yield response to water (Brouwer and Heibloem, 1986; Steduto et al., 1979). Beginning of the growing period for every crop was established according to agro-climatic data provided by Hydrometeorological services of Moldova as can be seen in table 8 (State Hydrometeorological services, not dated). Formula for crop coefficient on monthly basis is as follows:

$$Kc\ month = \frac{x_1}{30} * Kc_I + \frac{x_2}{30} * Kc_2 + \cdots \frac{x_n}{30} * Kc_n (1)$$

x_n – number of days in particular stage of growth for month

Kc_n - crop factor for particular stage

Table 9.: Indicative values of the total growing period [Days]

Days	Initial stage	Crop dev. Stage	Mid-season stage	Late-season stage	Total	plan date
Melons	25	35	40	20	120	April
Onion	25	30	10	5	70	April
Potatoes	30	35	50	30	145	April
Sunflower	20	35	45	25	125	Middle of April
cabbage	20	25	60	15	120	April
tomatoes	30	40	40	25	135	April
Barley	15	25	50	30	120	April
Wheat	15	25	50	30	120	April
Maize	20	35	40	30	125	Third decade of April
Sugar beet	25	35	60	40	160	April
Grapes	20	40	120	60	240	Middle of March

Source: Brouwer and Heibloem, 1986

After the determination of Crop Coefficient for every month of growth, calculation of specific crop evapotranspiration for the whole growing periods were done as follows:

$$ET_{crop} = ET_0 * K_c\ (2)$$

ET_{crop} = Specific crop evapotranspiration [mm/day]

K_c = Crop coefficient

ET_o = Crop evapotranspiration [mm/day]

Table 10.: Indicative values of Crop coefficients for every stage of growth

	Intial stage	Crop dev. Stage	Mid-season stage	Late season stage
Melons	0.45	0.75	1	0.75
Onion	0.5	0.7	1	1
Potatoes	0.45	0.75	1.15	0.85
Sunflower	0.35	0.75	1.15	0.55
cabbage	0.45	0.75	1.05	0.9
tomatoes	0.45	0.75	1.15	0.8
Barley	0.35	0.75	1.15	0.45
Wheat	0.35	0.75	1.15	0.45
Maize	0.4	0.8	1.15	1
Sugar beet	0.45	0.8	1.15	0.8
Grapes	Special value	Special value	Special value	Special value

Source: Brouwer and Heibloem, 1986

After this step, specific crop evapotranspiration is estimated on monthly basis with assumption that every calendar month have 30 days.

$$ET_{crop-m} = 30 * ET_{crop} \ (3)$$

ET_{crop-m} - crop water needs [mm/month]

For estimation of Irrigation Water Need (IWN) is required determination of the effective rainfall, which is retained water used by plant roots after the portion of water runoff, evaporate from soil and deep percolation (Brouwer and Heibloem, 1986).

$$Pe = 0.8 * P - 25 \ if \ P > \ 75 \frac{mm}{month} (4)$$

$$Pe = 0.6 * P - 10 \ ifP < \ 75 \frac{mm}{month} (5)$$

P – rainfall of precipitation [mm/month]

Pe – effective rainfall [mm/month]

Finally, it can be estimated Irrigation water need for every crop in every month and total Irrigation water need for the whole growing season from following formulas:

$$IWN_{monthly} = ET_{crop-m} - Pe \ (6)$$

$IWN_{monthly}$ – Irrigation water need for crop [mm/month]

$$IWN = IWN_{monthly\ 1} + IWN_{monthly\ 2} \ldots\ldots IWN_{monthly\ x} (7)$$

4.3 Data processing and analysis

After obtaining, the data were transferred to SPSS and Excel, where they were cleaned and corrected. Subsequently, the data were categorized and organized for further analysis and processing. For analysis of farming systems distribution, descriptive statistics and comparison were used.

Pearson's chi-squared test has been run with Cramer's V measure to find association between irrigation status and type of lease contract by **Formula 7**. Null hypothesis assumes that there is no statistically significant association between variables. On the other hand, alternative hypothesis assumes that there is a statistically significant association and it is verifiable.

Hypothesis was determined as:

Ho: The proportion of farmers who irrigate is independent on land's tenure

Ha: The proportion of farmers who irrigate is associated with land's tenure

$$X^2 = \sum_{k=1}^{k} \frac{(nj - npj)^2}{npj} \ (8)$$

Cramer's V is Cramer's coefficient of contingency which determine level of association between variables. It takes values between 0 (No Relationship) and 1 (Perfect Relationship). Formula for calculation is as follows:

$$V = \sqrt{\frac{X^2}{n(q-1)}} \ (9)$$

In final step, Goodman and Kruskal tau was executed for determination of variables dependency on each other (Svatošová and Kába,2012).

4.4 Limitations of this study

Limitations of this study lies mainly in slightly different variability of questions under Survey done by ACSA as research has had different objective than objectives of this

Thesis. Subsequent estimation of irrigation water needs is based on crops which dominate Moldova's agriculture production and they are in accordance with cropping patterns of Survey. Therefore, there is assumption that structure of crops in CIS will be similar to structure of crop production on national level. The data can be also considered as expired from point of view of research with small basic set of data. On the other hand, extensiveness of such research is not usual from decade perspective. It should also be noted, that estimates of irrigation water needs are based on quite old calculation compared to remote sensing estimating evapotranspiration.

5 Results

5.1 Estimates of water irrigation need (IWN)

Irrigation water needs estimated for representative crops according to climate conditions of 16 central irrigation systems (CIS) can be seen in this chapter. Irrigation water needs (IWN) for vegetables, potatoes and melons can be seen in **Table 11**. The most irrigation water demanding sort of vegetable across the CISs is definitely onion, potatoes and tomatoes. On the other hand, the less demanding crops were water melons and cabbage. Most water demanding CIS in average was Coşniţa and the least demanding CIS in average was Teţcani. Results of IWR for all crops in regions were following a certain pattern. The only exception can be found in results of Masivul Suvorov and Masivul Talmaza. These two CISs have remarkable IWN for cabbage, water melons and onions, as these values were lower compared to trend of potatoes and tomatoes or sugar beet in range of all CISs (Table 12).

Table 11.: Irrigation water needs for vegetables, potatoes, melons in CISs (Red – High irrigation water need, Green – Low irrigation water need)

	Vegetables, Potatoes, Melons [mm per season]					
	Water melons	Onion	Potatoes	Cabbage	Tomatoes	Average
Coşniţa	335,586	508,1965	469,7965	314,2585	406,314	406,8303
Serpeni	330,889	503,591	466,286	309,3003	403,196	402,6525
Criuleni	330,89	502,6095	464,5345	309,9138	401,517	401,893
Masivul Talmaza	325,977	497,728	462,523	303,4383	400,063	397,9459
Pugăcenii	329,48	500,91	463,3575	308,2338	400,625	400,5213
Masivul Suvorov	324,507	494,0095	461,042	300,6483	399,357	395,9128
Roscani	327,877	498,842	461,932	305,887	399,152	398,738
Masivul Cahul	327,525	493,8955	458,7555	304,6188	397,378	396,4346
Chircani-Zirnesti	321,356	485,247	450,2745	298,7148	389,652	389,0489
Leova de Sud	320,383	483,962	447,7145	299,158	387,132	387,6699
Lopatna	320,641	485,5265	447,9715	300,4773	386,794	388,2821
Jora de Jos	320,641	485,5265	447,9715	300,4773	386,794	388,2821
Grozesti	302,772	458,0005	422,568	282,8433	364,383	366,1134
Carpinenii de Sus	301,742	450,6195	416,717	280,2445	360,947	362,054
Blindesti	286,167	433,5115	399,1415	267,562	343,494	345,9752
Teţcani	260,698	395,522	369,192	241,003	315,492	316,3814

Similar pattern can also be seen in case of field and technical crops in Table 12. Maize and sugar beet can be considered as most demanding field and technical crops across all selected central irrigation systems. Barley and wheat, which has same results, breach the uniformity in case of Masivul Suvorov and Masivul Talmaza. Their IWN were lesser than in case of other crops compared to other CISs. On the other hand, IWN for Sunflowers and Maize in these CISs were very high compare to other CISs.

Table 12.: Irrigation water needs for field and technical crops in CISs (Red – High irrigation water need, Green – Low irrigation water need)

	Field and technical crops [mm per season]					
	Sunflower	Barley	Wheat	Maize	Sugar beet	Average
Coşniţa	328,284	338,516	338,516	436,2365	525,7405	393,4586
Serpeni	326,741	332,999	332,999	434,626	522,408	389,9546
Criuleni	324,252	333,9	333,9	431,7445	520,3515	388,8296
Masivul Talmaza	325,938	326,142	326,142	433,0455	518,265	385,9065
Pugăcenii	324,1825	332	332	431,37	518,959	387,7023
Masivul Suvorov	327,7895	322,322	322,322	433,812	516,5055	384,5502
Roscani	323,142	329,482	329,482	430,1945	517,545	385,9691
Masivul Cahul	323,518	327,325	327,325	427,7405	514,3965	384,061
Chircani-Zirnesti	316,4395	321,251	321,251	419,3195	504,89	376,6302
Leova de Sud	312,8945	322,308	322,308	415,5095	501,53	374,91
Lopatna	311,319	324,301	324,301	415,1715	501,8455	375,3876
Jora de Jos	311,319	324,301	324,301	415,1715	501,8455	375,3876
Grozesti	292,4905	305,502	305,502	390,6305	473,7175	353,5685
Carpinenii de Sus	290,9945	301,497	301,497	384,462	466,8205	349,0542
Blindesti	274,514	289,602	289,602	368,284	448,4785	334,0961
Teţcani	250,462	261,518	261,518	341,082	416,144	306,1448

Results for vineyard and orchards according to CISs (**Table 13)** were also very uniform. In case of grapes, the highest IWN can be found in case of Masivul Suvorov, Coşniţa, Serpeni and Masivul Talmaza. The least demanding CIS was Teţcani both for grapes and apples. IWN for apples were the highest in Coşniţa and Serpeni and lowest in Teţcani and Blindesti.

Table 13.: Irrigation water needs for vineyards and orchards in CISs (Red – High irrigation water need, Green – Low irrigation water need)

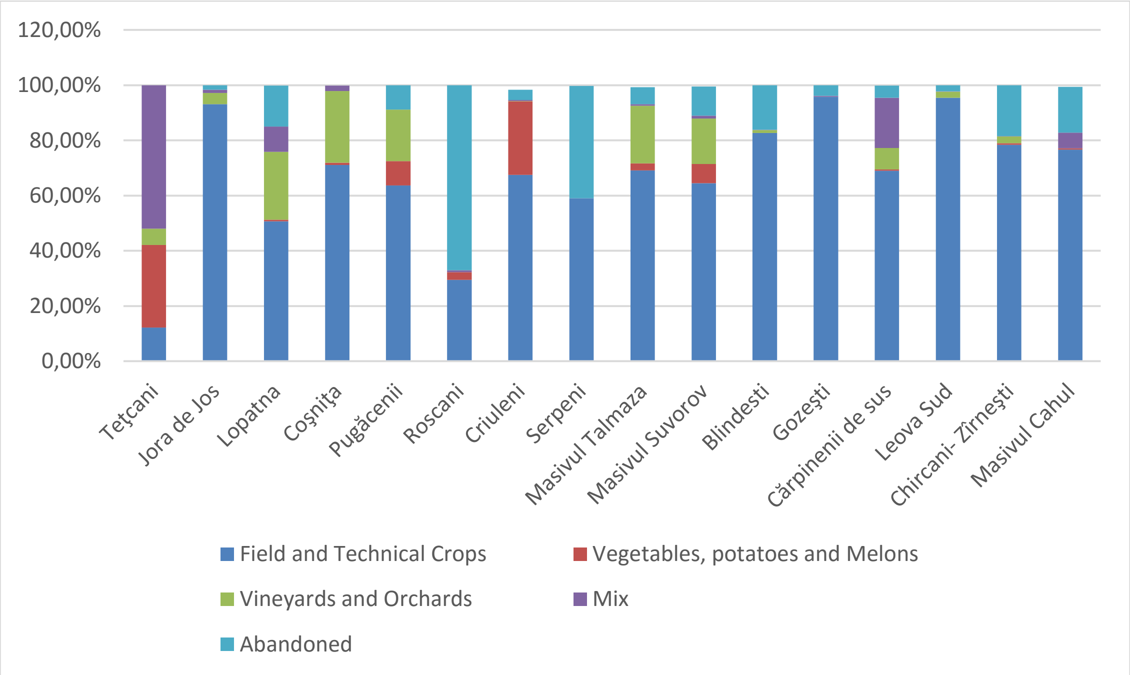
Vineyards and Orchards [mm per season]			
	Grapes	Apples	Average
Coşniţa	393,283	567,835	480,559
Serpeni	393,0355	564,805	478,9203
Criuleni	389,9725	562,114	476,0433
Masivul Talmaza	391,969	561,265	476,617
Pugăcenii	389,4385	560,488	474,9633
Masivul Suvorov	393,313	560,005	476,659
Roscani	387,6925	559,78	473,7363
Masivul Cahul	388,1665	557,59	472,8783
Chircani-Zirnesti	379,81	546,988	463,399
Leova de Sud	375,625	543,097	459,361
Lopatna	372,466	541,36	456,913
Jora de Jos	372,466	541,36	456,913
Grozesti	351,064	513,607	432,3355
Carpinenii de Sus	345,6325	498,94	422,2863
Blindesti	331,1095	486,217	408,6633
Teţcani	301,8085	451,228	376,5183

In an overview, it can be noticed that Coşniţa, Serpeni and Criuleni in the south of central region were in average most irrigation water demanding of all chosen CISs. On the other hand, CIS Roscani which is in same region and very close to like appointed CISs was less water demanding in every case. Teţcani was the least demanding region on average together with Blindesti. Masivul Talmaza and Masivul Suvorov represents deviation for crops like grapes, barley, wheat, water melons, onions and cabbage.

5.2 Analysis of structure of farming systems in CISs

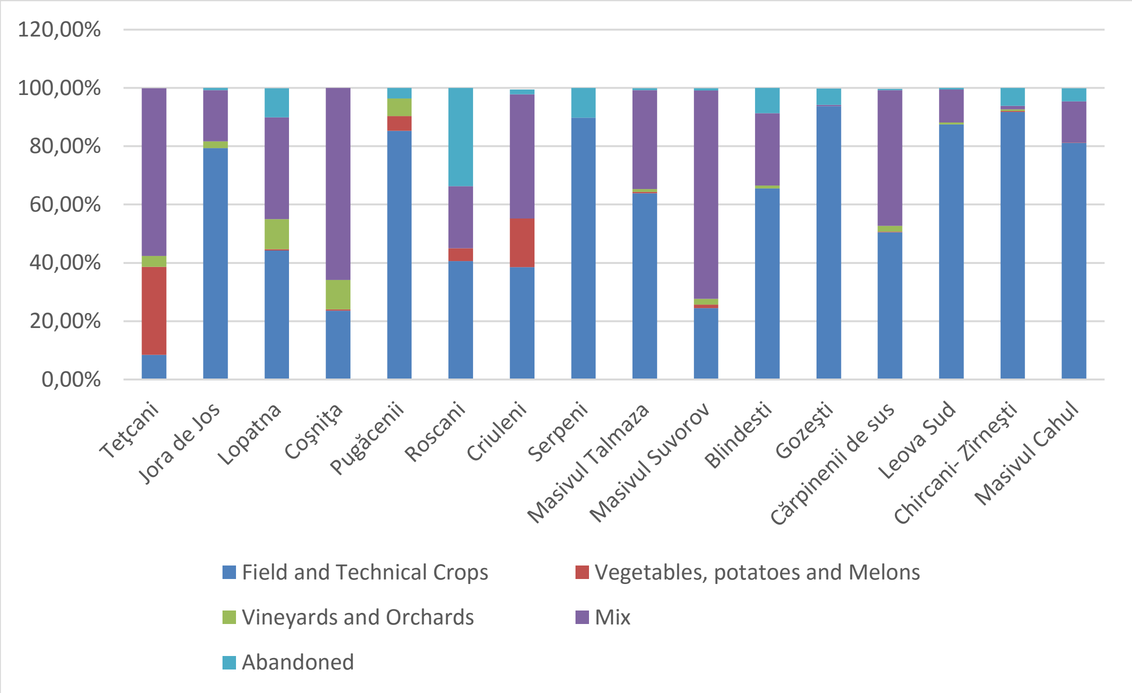
Structure of farming systems can be seen in **Figure 15** and **Figure 17**. The first figure shows percentage of farmers focused on some Cropping pattern. While the second one deals with percentage of different cropping patterns inside CISs. As it can be seen, most farmers were dependent on Field and Technical crops (more than 50%), only Roscani and Teţcani farmers focus on other cropping patterns. In case of Roscani, majority of farmers don't use their land for agriculture production (67.03 %) and in case of Teţcani, majority of farmers use dtheir land for multiple cropping patterns (51.88 %). Vineyards and orchards mainly dominate central region, in CIS Coşniţa. About 20 % and about 16 % farmers in Masivul Talmaz and Masivul Suvorov in South Region also focus on vineyards and orchards. Vegetable, potatoes and Melons provides livelihood for farmers mainly in CIS Criuleni (about 27%), Teţcani (about 30 %) and Pugăcenii (8.89%).

Figure 15.: Structure of cropping patterns in CISs (Percentage of farm administrators)



The second figure shows that field and technical crops dominated much less CIS as regards hectares of production. They dominated production only in 10 CISs (above 50 %). 3 CISs areas are mostly focus on mixed cropping patterns. On the other hand, Vegetable, potatoes and melons pattern and Vineyard and Orchards had very small percentage of area in almost every CIS. Largest percentage of vegetable, potatoes and melons production area can be found in Teţcani and Criuleni CISs. Largest share of Vineyards and Orchards area can be found in Coşniţa and Lopatna with 10.2 % (about 285 hectaters) and 10.31 % (about 200 hectares), on the other hand, Masivul Talmaz and Masivul Suvorov had only 0.98 % (about 50 hectares) and 1.93 % (about 295 hectares) area focused on this pattern.   Most abandoned land can be found in CIS Roscani, which associates with knowledge from previous figure.

Figure 16.: Structure of cropping patterns in CISs (Percentages of hectares)



As it is shown in **Table 15**, the crushing majority of farmers farm on the area under 10 hectares. Significant number of farmers having their plot area over 10 hectares can be found in CISs in Central and South regions, especially in Masivul Suvorov, Leova Sud and Coşniţa, Farms with area over 100 hectares are also very rare in accessed CIS. Most of them can be found in Masivul Suvorov, Coşniţa and Masivul Talmaz. Masivul Suvorov also dominated in numbers of small farms and total area of farms. There is no farm with area larger than 10 hectares and smaller than 100 hectares only in CIS Pugăcenii. Farms with more than 100 hectares were not found in CIS Roscani and Gozeşti.

Table 15.: Number of farmers and their holdings according to size [ha]

CIS	Under 10 Hectares	Over 10 to 100 hectares	Over 100 hectares	Hectares	Farmers
Teţcani	1721	6	2	1532,077567	1729
Jora de Jos	348	3	1	485,1501	352
Lopatna	4486	6	2	1939,4997	4494
Coşniţa	3128	10	8	2816,891467	3145
Pugăcenii	3935	0	1	1360,02404	3936
Roscani	716	9	0	561,377	725
Criuleni	1490	4	1	606,2189	1495
Serpeni	467	3	4	1160,5742	474
Masivul Talmaz	1704	6	6	5047,2839	1716
Masivul Suvorov	6732	22	17	15196,46716	6771
Blindesti	1466	2	2	1834,3198	1470
Gozeşti	2329	4	0	1151,62634	2333
Cărpinenii de sus	3547	8	4	5272,230568	3559
Leova Sud	2560	11	3	2649,36595	2574
Chircani-Zîrneşti	2776	9	3	4215,30007	2786
Masivul Cahul	970	5	4	5681,0756	979
Total	38375	108	58	51509,48236	38538

5.3 Analysis of land tenure and its influence on irrigation status

This analysis was performed in SPSS Statistical between two variables. The first one its irrigation status, was simplified because instead four possible answers only two answers were requested, and also that farmers are irrigating or not irrigating. The second variable deals with type of lease contract, which is divided on farmers with owning a land and farmers with lease contract on land. Data was also cleaned from incorrect answers and multiple answers for ownership.

Table 14.: Cross Tabulation between Irrigation status and Type of lease contract

			Tenure		Total
			Owned by farmer	Lease contract	
Irrst	Not irrigated	Count	34095	3073	37168
		% within Rental	97,2%	92,3%	96,8%
	Irrigated	Count	965	255	1220
		% within Rental	2,8%	7,7%	3,2%
Total		Count	35060	3328	38388
		% within Rental	100,0%	100,0%	100,0%

As it is shown in **Table 14,** most farmers in CIS do not irrigate. For 31789 farmers, the irrigation system has been destroyed, while only 6689 farmers answered that irrigation system was functional. Only 965 farmers were using irrigation and majority of them are also owners of the land. Farmers with some kind of lease contract irrigate only in 255 cases. It could be noticed, that 300 farmers, who irrigate, use another source of water than water from Apele Moldovei and 324 farmers use water distribution provided by Apele Moldovei and also use other source of water. The rest of farmers use water provided by Apele Moldovei.

Result of Pearson Chi-Sqaure asymptotic significance was 0.000. That was lower than 0.5 and therefore there is statistically significant association according to alternative hypothesis - The proportion of farmers which irrigate is associated with land's ownership. On the other hand, Cramer's V for this association were about 0.079 which is very weak bond and it could be considered like almost acceptable. Goodman and Kruskal tau coefficients were estimated 0.06. This shows that in both cases, there were some dependency between variables.

6 Discussion

6.1 Estimates of irrigation water needs and distribution of farming systems in CISs.

Results from the chapter 5.1 show that irrigation water needs in majority of cases are more dependent on overall climate in place than on changes during the year. As it can be seen, central irrigation systems (CIS) in the northern part of Moldova shows lower water demands than in other parts of country. Teţcani was the least demanding CIS, probably as it is most northern CIS in consideration. This can be probably due to lower average temperature and higher relative humidity. On the other hand, Southern Region cannot be considered as the most water demanding region as the literature review could suggest since CISs Coşniţa, Serpeni and Criuleni in central region shows that their irrigation water demands (IWN) are higher than in case of many CISs in South Region. According to the climate data, this was extremely likely caused by higher reference evapotranspiration than by rainfall deficit. Higher evapotranspiration was already found in other locations located further in the north. For example, analysis of crop water productivity of winter wheat in Hai basin – China shows that the average reference of winter wheat evapotranspiration can be higher in regions located further north (Yan and Wu, 2014). Another example can be found in Northern China, where the evapotranspiration was higher in the Northern and Eastern parts and lower in Southwest part (Yang et al., 2012). However, CIS Roscani which is in the same region and very close to appointed CISs is less water demanding in every IWN result. This could probably mean that there is a boundary between different agro-climatic parts of Moldova.

Results in the chapter 5.1 also shows that CIS Masivul Talmaza and Masivul Suvorov, located in the southern part of the country have lower results for short growing plants (than average), especially for barley and wheat and higher results for long growing crops, like grapes, sunflowers, and maize than average. This is probably due to favorable temperature and relative humidity in May in these two CISs, which subsequently decreases crop evapotranspiration in May and therefore creates lower total IWN of those crops, which have shorter total growing period. On the other hand, higher evapotranspiration in August and September increase IWN for long growing crops due to lower precipitation, higher sunshine and wind speed in August than in other south CIS. It should also be noted that these two CIS are located near the Black Sea coast (location: see in methodology). Evidence of similar environment conditions could be found in Southern Spain, where reference evapotranspiration values during Spring and Summer were higher in inland areas and lowest in coastal and mountainous areas. During the fall and winter, the highest values were located in coastal areas and lowest in inland areas (Cruz-Blanco et al., 2014).

Irrigation water needs (IWN) results are normal. Considering Crop Evapotranspiration in CIS Coşniţa, results for onions, melons, wheat, maize, tomatoes, sugar beet, potatoes and cabbage fit into the range of water requirements provided by FAO. On the other hand, sunflower results were smaller than minimum water requirement level. This is probably due to earlier start of growing season in Moldova (FAO water, Not dated; Steduto et al., 1979). As regards to barley, its crop characteristics were the same as for wheat. Therefore, this Thesis assumes, that water requirement range will be similar as in case of the wheat. As regards to water requirements of grapes and apples, there is no knowledge about ranges of water requirements. Ranges between the most water demanding CIS varies and the least demanding CIS varies, but it could be generally said that difference in IWN is in the range between 73 mm to 116 mm for every strategic crop.

Considering results of irrigation water needs (IWN) for crop favorable growing, it could be seen that some areas (CISs) have better conditions for potential water consumption than others. Even some CISs in the south shows, that latitude sometimes doesn't play major role in determination of water demands for crops. As it was already described, evapotranspiration requirements can differ not a just by a location, but also by type of growing season. This could lead to question – is it possible to re-allocate some crop production in Moldova from lower-valued locations to higher valued locations for increase of water productivity? Article *The New Era of Water Resource Management: From "dry" to "wet" Water Savings* (1996) consider substitution of crops grown in hot season by crops in cool seasons for large savings of water. Also moving crop production from higher evapotranspiration regions to low evapotranspiration regions can create water savings (Seckler, 1996). This scope in improvement can be seen in the Indus and Ganges

River basin, where measures by remote sensing showed that crop evapotranspiration generally increases with yield, however physical conditions have less impact on water productivity compared to irrigation and farm crop management (Cai et al, 2010). Agro-climatic level can influence physical productivity as it can be seen in the case of grain production in India, when during the normal year, physical productivity was highest at Northern region of Chhattisgarh in Mandla District (1.80 Kg/m^3) and lowest in Jabalpur in Central Narmada Valley (0.47 Kg/m^3). However, irrigation water applied was 127 mm in Mandla and 640 mm in Jabalpur. This can be attributed to difference in climate between Jabalpur's dry semi-humid conditions and Mandla's moist sub-humid conditions (Kumar et al., 2003).

This could be probably a very similar case like in case of CISs Masivul Suvorov and Masivul Talmaza. Farmers in these CISs already focus on field and technical crops, which in average have lower IWN, on the other hand some strategic field and technical crops have much higher IWN than in other generally more water demanding CISs. One should probably recommend that crops like sunflowers, which have large water demand should be replaced by less water demanding crops like wheat or barley and shift sunflower production to CIS with modest IWN. This may not be applied to just CISs in the same agro-climatic zone with same cropping pattern. For example, about 16.48 % farmers in Masivul Suvorov focus on vineyards and orchards cropping pattern. Production of wine in this CIS is very water demanding and even CIS Cosnita have better conditions for growing cultivation of wine. Reducing production in one CIS and increasing in other could save large amount of water even in cases of other crops like cabbage, water melons and onions.

CIS Criuleni have had about 27 % farmers oriented towards growing vegetables, melons, and potatoes (about 17 % of total CIS area). This cropping pattern is on average more water demanding and especially in severe agro-climatic condition of this CIS, shift of this cropping pattern to field and technical crops could bring some water saving. Moreover, CISs Pugăcenii and Roscani is in same region with lower IWN for this cropping pattern and relatively low amount farmers focused on vegetable, melons and potatoes production. Therefore, there is a possibility to shift production between CISs in same part of the country.

6.2 Analysis of land tenure and its influence on irrigation status

As literature review stated, 10 out of assessed 16 CIS were already in some phase of irrigation infrastructure rehabilitation. This probably means that farmers will get easier access to irrigation water and will be able to irrigate without constrains. On the other hand, this could also mean, that farmers will have to invest into maintenance of irrigation technology and into adaptation methods to mitigate climate change (**Table 5**). Also, 6 considered CISs will be still without full access to irrigation water. From the results in **chapter 5.3**, it can be seen, that 3328 farmers cultivated leased land. Will these farmers be willing to invest into maintenance and development of irrigation to mitigate impacts of climate changes?

Confirmation of Chi-square test shows that the proportion of farmers who irrigated is associated with the land's tenure. Even with very weak bond, one should state that development of irrigation infrastructure and equipment is faintly dependent on type of land's tenure. The case study from Norway shows that the rented land is maintained by the same way and intensity as the owned one, but on the other hand, investments in owned land leads to larger gains and less losses than in the case of investment to rented land (Stokstad and Krøgli, 2015). Also the land tenure in Malawi has important influence on the investment into the soil conservation. Probability of investment into rented plots is lower by about 14 % than in case of inherited and purchased plots (Lovo, 2016). This evidence cannot be directly used in the case of irrigation in Moldova, but it can provide clue for the future investments for mitigation of climate change's impacts. If administrators will be forced to invest into irrigation maintenance or to increase water productivity, there should be expectations that administrators of leased land will be less interested in investments.

7 Conclusions and Recommendations

7.1 Conclusion

Using the methods described in this thesis, the following set of conclusions were found:

- Irrigation water need (IWN) of central irrigation systems (CIS) in Moldova generally doesn’t vary according to the latitude.
- The most water demanding CISs can be found in the south of central region. On the other hand, the least water demanding CIS can be found in the northernmost part of Moldova.
- Short growing period crops like barley, wheat, water melons, onion and cabbage have more favorable conditions in the south region in CISs Masivul Talmaza and Masivul Suvorov. On the other hand, long growing period crops need more water than in average.
- Shifting production of some strategic crops between different CISs under different agro-climatic conditions can create water saving in irrigation sector.
- Shifting crop production in Masivul Talmaza and Masivul Suvorov from long growing period crops to short growing period crops can also bring water savings.
- The proportion of farmers which irrigate is associated with the land tenure. This can create constrains for future investments into development of irrigation and mitigation of climate change.

7.2 Recommendations

This thesis was designed like a pilot study for future research of very likely rehabilitated central irrigation systems (CIS) in consideration and so the following recommendation are focused on academic level. Recommendations are based on conclusions and limitations of this study:

- Future research should be focused on highly water demanding central irrigation systems in the south of the central region for assessment of water productivity and subsequent improvement.
- Remote sensing should be used for areas in coverage of CISs for more detailed determination of evapotranspiration. This should be also consulted with National

Agency for Rural Development in Moldova, which have access to cadastral data about farmers.

- Central irrigation systems (CISs) Masivul Suvorov and Masivul Talmaza should be thoroughly analyzed for potential shifting of crop production for water savings.

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9 Annex

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Annex 1. Annual average runoff; current climatic conditions

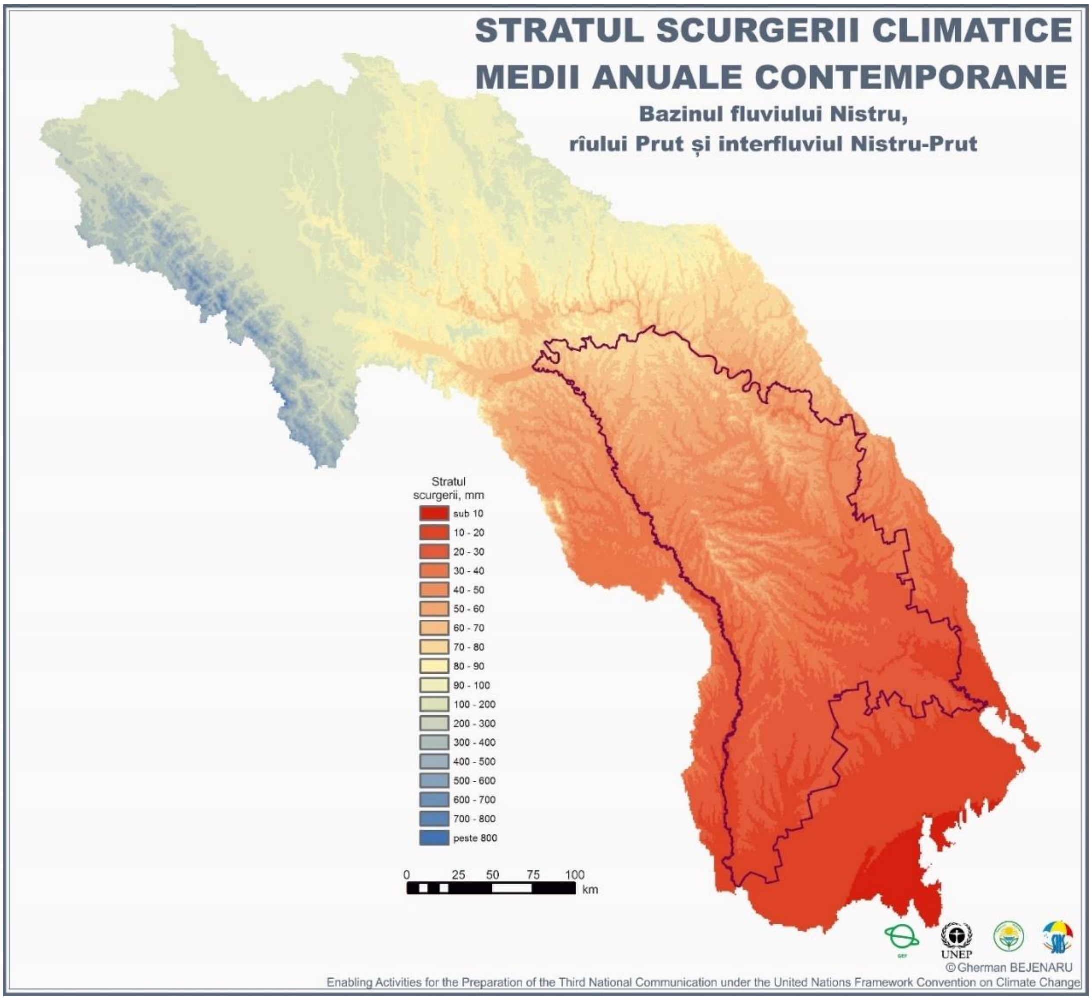
Annex 2. Annual average runoff in 2020s under different climate scenarios

Annex 3. Annual average runoff in 2050s under different climate scenarios

Annex 4. Annual average runoff in 2080s under different climate scenarios

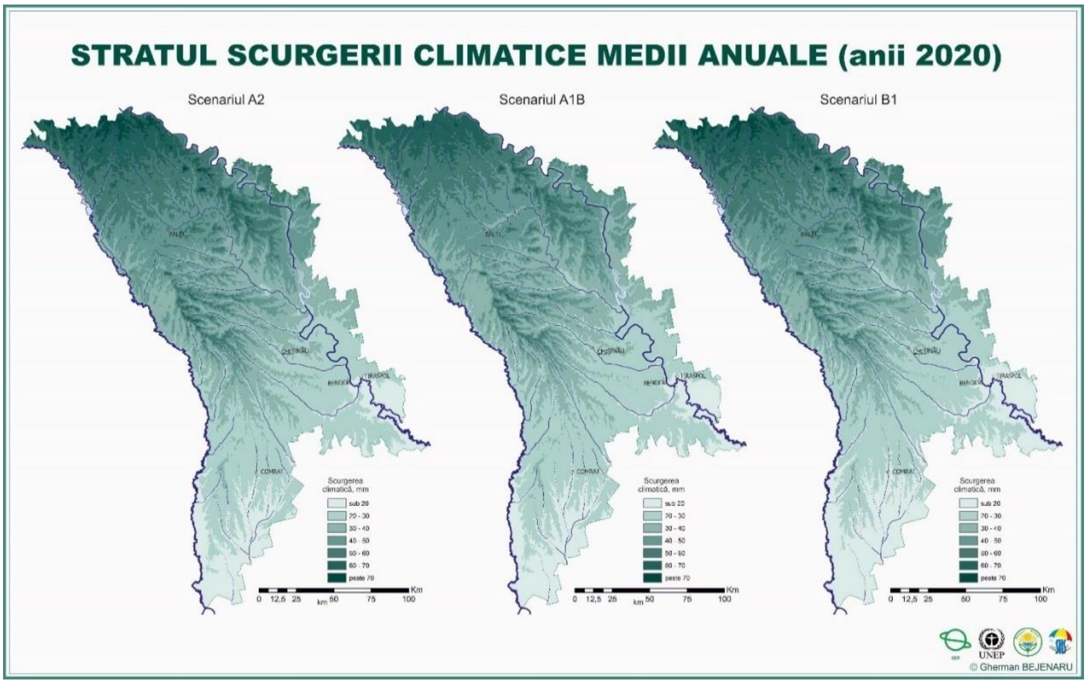
Annex 5. Gross harvest of agricultural crops (thousands of tons), by all categories of producers.

Annex 1.: Annual average runoff; current climatic conditions



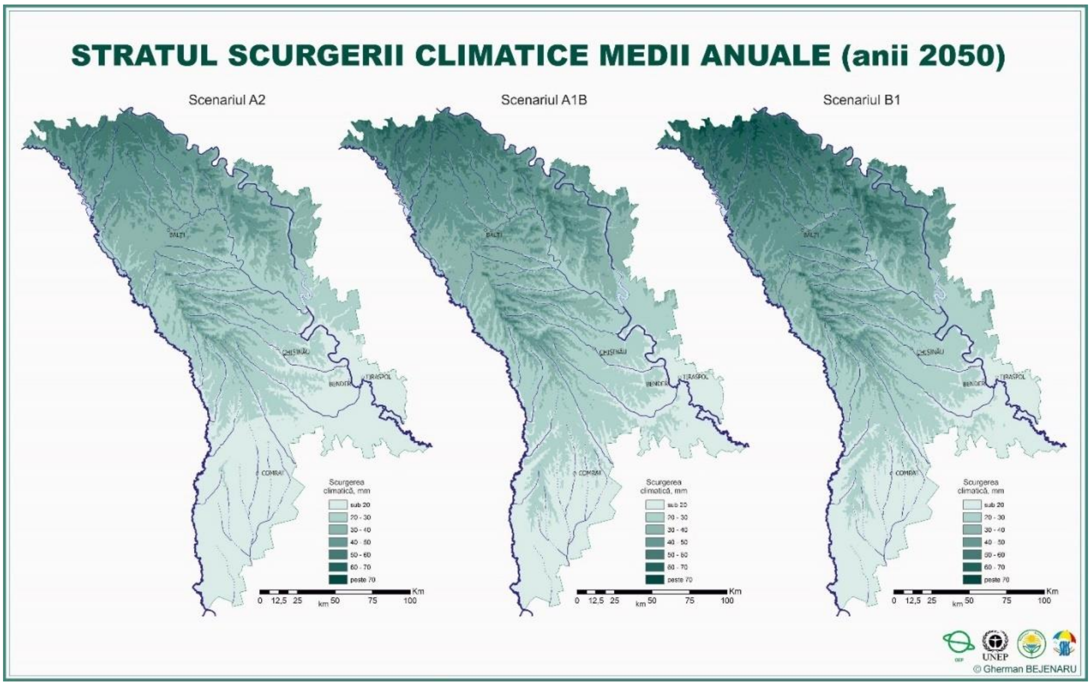
Source: State Hydrometeorological Service, 2016

Annex 2.: Annual average runoff in 2020s under different climate scenarios



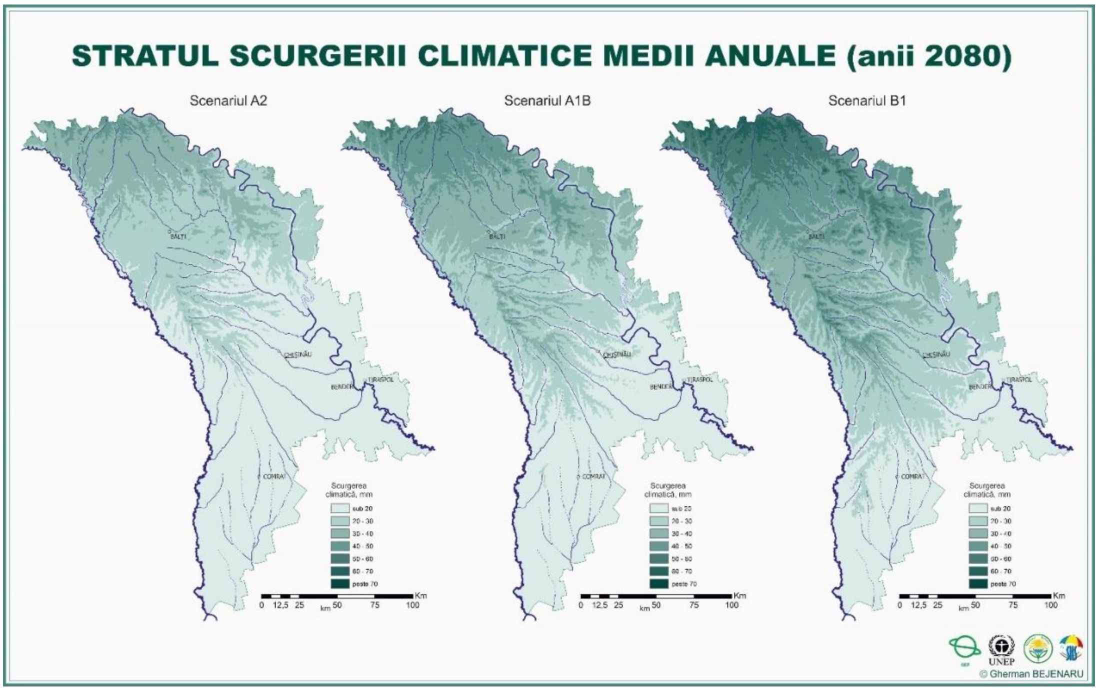
Source: State Hydrometeorological Service, 2016

Annex 3.: Annual average runoff in 2050s under different climate scenarios



Source: State Hydrometeorological Service, 2016

Annex 4.: Annual average runoff in 2080s under different climate scenarios



Source: State Hydrometeorological Service, 2016

Annex 5.: Gross harvest of agricultural crops (thousands of tons), by all categories of producers.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
	All categories of producers [thousands of tons]								
Cereals and leguminous crops – total	2290.2	901.9	3169.5	2176.5	2421.3	2498.2	1206.3	2680.8	2922.4
wheat (winter and spring)	691.4	406.5	1286.3	736.7	744.2	794.8	495.2	1008.6	1101.7
barley (winter and spring)	200.1	115.2	353.1	261.4	208.4	194.0	117.9	218.6	220.6
grain maize	1322.2	362.7	1478.6	1141.1	1419.8	1468.3	572.4	1419.2	1556.2
leguminous crops	67.5	14.1	37.1	27.8	35.8	31.8	16.3	23.1	31.3
Sunflower	379.9	155.5	371.9	284.2	382.3	427.4	296.2	504.5	547.5
Soy	79.8	39.8	58.1	49.2	110.6	78.7	48.2	65.5	109.3
rape (winter and spring)	6.9	34.2	95.4	69.1	36.7	52.5	5.9	42.8	68.2
Sugar beet (industrial)	1177.3	612.3	960.7	337.4	837.6	588.6	587.0	1009.0	1356.2
Tobacco	4.8	3.6	3.9	4.4	7.6	5.4	2.9	2.2	1.4
Potatoes	376.9	199.4	271.0	260.9	279.6	350.8	182.0	239.5	268.0
Vegetables	475.2	221.8	376.3	307.9	341.2	361.5	231.1	291.6	327.2
cabbage (different)	64.9	27.2	61.3	32.8	36.2	35.1	23.1	29.0	28.7
cucumber	38.1	15.9	22.8	22.8	20.8	26.0	20.5	23.1	25.8
tomato	104.3	46.6	83.8	84.1	57.2	83.4	48.5	51.3	57.3
dry onion	54.4	24.7	48.5	40.9	56.2	58.3	37.2	51.2	58.5
green peas	9.9	3.6	11.3	5.0	8.3	6.4	6.7	8.3	9.6
pumpkins	45.2	16.5	31.5	27.4	40.6	33.8	20.2	29.9	42.0
Melons and gourds	92.0	41.0	69.9	101.9	103.4	84.1	51.5	54.9	47.0
Forage roots	34.1	13.8	25.1	19.7	31.2	23.0	10.6	22.2	26.1
Maize for silage and green fodder	113.6	85.8	89.3	77.4	93.9	80.3	68.2	126.0	103.4

Source: National Bureau of Statistics of the Republic of Moldova, 2016