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WP5:

Application of an integrated vulnerability conceptual approach

Del. 5.3.2:

Development of the Integrated Approach on the Negev case study

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Short Description:

General ENSURE framework developed within WP4 is applied to studying vulnerability of Negev territorial system, which is suffering from slowly developing drought during last two decades. Based on the vulnerability matrices we define hierarchy of the factors that determine Negev's robustness and vulnerability to droughts and develop a model of Negev's agriculture to this hazard. With the model we study possible scenarios of Negev's adaptation to the developing drought and provide the forecast of the vulnerability of Negev territorial system to droughts for the next decade for each of them.

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1 General presentation of the case study

Being a worldwide phenomenon, drought may occur in a wide range of climates. While the distinction between drought, aridization and global warming may not be always clear, their consequences are. Whether a part of global warming or aridization, droughts may impose extra risk on many ecosystems, and may impact the lives of many humans. This is all more so in drylands where the damage implicated by the drought is often much higher. Small imbalance in precipitation may have extensive implications on the ecosystem and the human population of drylands. The Negev is no exception.

Occupying a large area in the southern part of Israel, the Negev serves as the "bread basket" of the country, where most wheat crops are cultivated. Being mostly flat or hilly, the fine-grained loessial soils in the Negev and its moderate topography allows for intensive and extensive agriculture albeit the low precipitation that decreases from 450 mm at the northern to 100 mm on the southern boundary of the area. The major forms of agriculture are large-scale cultivation (mainly between isohyets 200 to 450 mm) and livestock grazing (mainly between the isohyets 100 to 200 mm). Whereas no indication exists as to the effect of droughts on the urban population (residing in several cities and towns) in the Negev, droughts may substantially affect the rural population and especially the agrarian population, farmers and sheep owners.

The majority of the farmers in the Negev are Jews, while most of the sheep owners are Bedouin Arabs. Both populations are engaged in reciprocal relations, e.g., Bedouin sheep owners buy some of the straw and grains that were harvested from the fields. They also buy the right to graze on the remaining straw left in the field after harvest. Drought years impose a challenge to the farmers of both groups and undermine system stability. Frequent droughts affecting the Negev in the last 20 years, during which 15 drought years were recorded, may lead to large-scale bankruptcy and abandonment of fields and settlements. However adequate protective measures can make the system robust to droughts. The vulnerability of the Negev to droughts, as an exemplar for a territorial system in the semi-arid zone, is the subject of the current research.

2 Characterization of the Negev's territorial system

2.1 The structure of the Negev's territorial system

2.1.1 The structure of the area

Two major landforms of the Negev are open-air agricultural plots and rocky hills, which are unsuitable for agriculture. Most of the agriculture is located in the northern semiarid part of the region, between 200-450 mm isohyets. Most of the open-air plots are still used for extensive i.e., rain-fed cultivation, fraction of the agriculture area, is used for intensive, i.e., irrigated cultivation, partially in the greenhouses. The major irrigated crops are fruit trees, semi-industrial crops like potatoes, carrots, cotton, vegetables such as sunflower, chili, and celery. Rain-fed crops include wheat, barely and clover. Greenhouse products include strawberries, flowers, and tomatoes.

2.1.2 Negev agricultural population

Jewish farmers in Negev reside in Kibbutzim (plural for Kibbutz) or Moshavim (plural for Moshav), both characterized by a high degree of sharing. Kibbutz is a closed community advocating equality and sharing of the community resources in an equal manner; Moshav is more open with some of the revenue shared.

Bedouin agriculture population in the Negev is partially scattered (tent dwellers) while partially reside in Bedouin towns. Most of the scattered part of the Bedouin community resides on state-owned open places, which is claimed by the Bedouins as part of their historical land (Figure 1).

(a) (b)

Figure 1: Typical view of the Negev's Jewish rural settlement of a Moshav (a) and a rural Bedouin settlement (b)

Bedouin towns that are recognized by the government are provided with infrastructure and municipal facilities. Some of the Bedouin towns emerged spontaneously and do not have legal foundations and sufficient infrastructure.

2.1.3 Negev administration

The land-use administration (Minhal Mekarke'ei Israel, MMI) is responsible for the management of the state-owned land in the Negev - allocating land to the Kibbutzim, Moshavim, Bedouin towns and farmers. Alongside, the Jewish National Fund (JNF) is responsible for the non-agricultural (forest) areas in the Negev. JNF is also involved in the construction of water reservoirs aimed at collecting runoff water.

Mekorot, the Israeli National water company is responsible for development of the Negev's water resources and allocating water quotas to settlements and farmers. Mekorot develops Negev's water infrastructure and is responsible for connection of Negev's population centers to the water network.

The Jewish Farmer Association (JFA) is responsible for the introduction of new agricultural techniques (such as no-tillage), introduction of machinery and new irrigation techniques and seed variety. High levels of solidarity between JFA members, makes JFA a powerful actor vis-à-vis the governmental and financial institutes.

The ministry of finance (MOFI) provides financial umbrella to the insurance of the farmers against the drought's hazard and to immediate financial compensation provided to the farmers following droughts.

The ministry of agriculture (MOAG) is responsible for research and the provision of professional guidance to the farmers and sheep owners.

2.2 Drought as hazardous phenomenon

The Negev system is prone to hazardous phenomenon of droughts. According to WMO (1975) drought is defined as “A deficit of rainfall in respect to the long-term mean, affecting a large area for one or several seasons, that drastically reduces primary production in natural ecosystems and rained agriculture" (Le Houérou, 1996). Yet, this definition is based on the outcome rather than on the characterization of the phenomenon that also depends on the timing of the rain.

Essential for agriculture, we define a *drought year* as one that satisfies at least one of the following conditions:

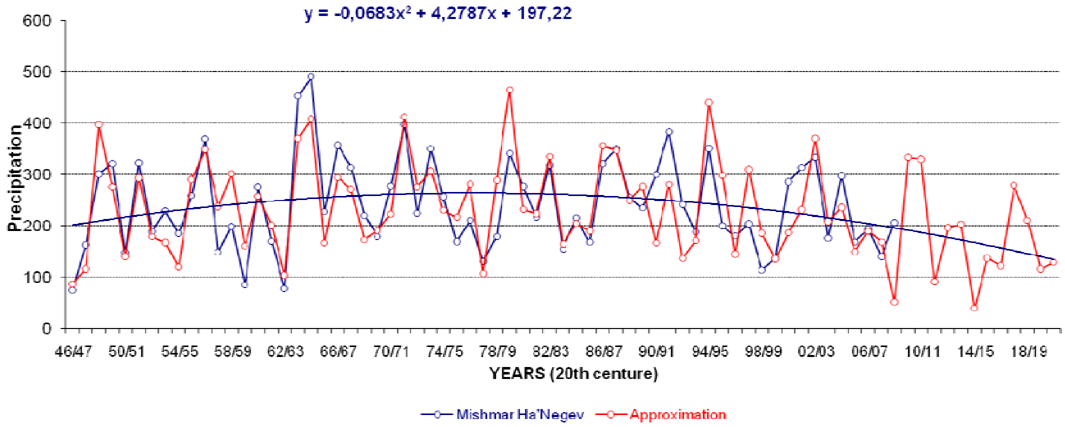
- Annual precipitation is at least 25% lower than the long-term annual mean
- Precipitation before the period of germination (end of December) is at least 40% lower than the long-term annual mean
- Hot weather period of at least 10 day occurs during the period of grain maturation (March in the Negev), thus impeding grain ripening.

It is important to note that minimum precipitation of 100 mm until mid December guarantees development of the wheat. Sufficient moisture is needed during seed maturation until March.

Deficit in water, bad timing of the precipitation or hot weather spells that substantially increase evapotranspiration during sensitive growing phases result in reduced crop yield for the Negev's farmers, shortage of grazing for the Bedouin sheep owners and consequent extra expenses for buying extra hay. This is especially so during the period of frequent droughts i.e., the period during which one of the above conditions holds for the majority of the years.

Drought is location-specific. Part of the Negev area can suffer from the drought even if the average precipitation for the entire Negev is above the threshold. This is so because the amount of precipitation in Negev essentially varies in space. For example, Figure 2 presents annual precipitation data on two adjacent kibbutzes, Beit Kama and Mishmar HaNegev that possess their own meteorological station and are located at a distance of less than 10 km. As one can see, despite the same tendency of decrease in precipitation, the amount and variation of the precipitation in two kibbutzes essentially differ. According to the Figure 2, the amount of precipitation reached its maximum in 1980s and from then on decreases 3 – 8 mm per year, but varies greatly within the seasons, years and in space.

Together with the data on the development of the irrigation system, the data on precipitation make it possible reasonable prediction of the annual yield. Indeed, the rainfall amount explains over 90% of the productivity variation in the none-irrigated fields (Sala et al., 1988). Minimal quantity of water necessary for plant growth is ~75 mm per season (Noy-Meir, 1973). Late rainstorms or a long hiatus between rains shorten the life cycle of annuals, for instance, from 10-20 to 6-10 weeks (Beatley, 1967).



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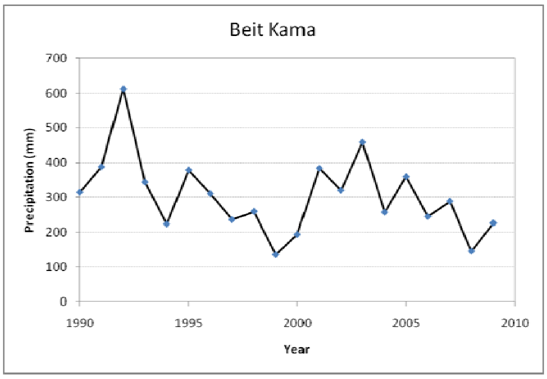

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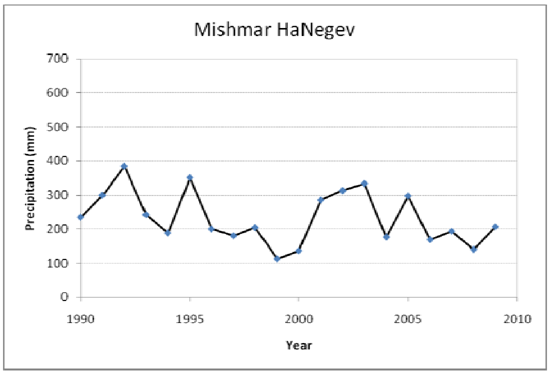

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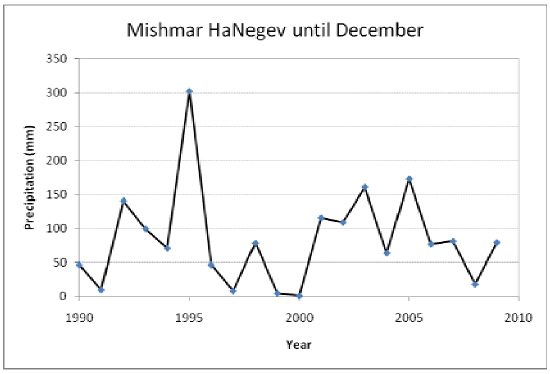

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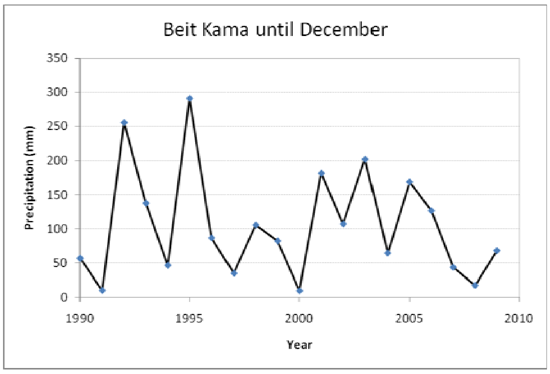


(e)

Figure 2: Available long series of precipitation data in Mishmar HaNegev kibbutz (1947 – 2010) with the prediction for 2010 – 2020 (a) precipitation in Annual level of precipitation (b, c) and the level of winter (October – Befruary) precipitation (d, e) in two closely located kibbutz, Mishmar HaNegev (b, d) and Beit Kama (c, e).

2.3 "Business-as-usual" in the Negev territorial system

To understand the influence of droughts on the Negev territorial system let us describe the "business as usual" situation. Droughts essentially influence Jewish agriculture settlements and Bedouins, especially the tent/hut dwellers among the latter. While the Jewish farmers live principally in Kibbutzim and Moshavim, the

Bedouin sheep owners either live in community centers or are scattered over Negev, concentrating, usually, along the major roads.

Most of the Negev land is state-owned. The provision of drinking water was always the state priority, while provision of the water for crop irrigation involves variety of sources (Table 1).

Table 1: National, regional and local water systems in the Negev

Type	Extent	Status	Description	Remarks
Drinkable	National	Operative	Transfers water from the central and northern part of the country and desalinized water from the coast.	The fraction of the desalinized water is still low
Highly purified	Regional	Operative	Sewage from the Tel Aviv metropolis	
Medium-Highly Purified	Regional	Operative	Sewage from major cities other than Tel Aviv like Jerusalem and Beer Sheba	Three years ago the water quality was improved
Medium-Highly Purified	local	Operative	Sewage from small settlements	
Good Quality	local	Operative	Harvested runoff water	
Brackish	Regional	Partially operative	Partly desalinized and used as drinking water and partly used to irrigate crops adapted to brackish water	
Salty	Regional	Planned	Aimed to carry the excess salt that is produced during the desalinization process to the Mediterranean	Will facilitate large scale usage of the ancient Cenomanic aquifer

2.3.1 Jewish and large Bedouin cities in the Negev are robust to droughts

As we have already mentioned, large pre-planned Bedouin towns possess the infrastructure and the municipal facilities provided by the government. The majority of the supply of these towns as well as the activities of their citizens are weakly if ever influenced by the droughts. This is also true for the Jewish towns, including the capital of the Negev, the city of Beer Sheba. Consequently, we exclude Beer Sheba, and other Jewish towns as well as officially claimed (i.e., legal) Bedouin towns from the current analysis.

Investment in sewage water purification substantially increased the amount of water available for agriculture. Mekorot, the national water company of Israel is responsible for most of these efforts, while substantial amount of capital is invested by the Jewish settlements.

2.3.2 Irrigated and non-irrigated agriculture in the Negev

As a result, about half of the agriculture plots are currently connected to pipelines and therefore are subjected to irrigation. However, the needs of nutrition and susceptibility to diseases require crop rotation. Irrigated vegetables and semi-industrial crops should be replaced every 1-2 years by wheat and legumes in order to guarantee adequate crop yield and to avoid plant diseases. As a result, five-year crop cycle is currently common in Negev, stemming from the fact that potatoes, currently the most profitable semi-industrial crop, cannot be cultivated at the same plot more frequently than once in five years due to increase disease risk. Common cycle will only include two irrigated crops, as Potato → Wheat → Carrot → Wheat → Wheat.

As far as the Bedouin sheep owners are concerned, "business as usual" includes four feeding cycles in the Negev. During February, following annual germination, the Bedouins leave their homes to graze in open fields and JNF forests for about 2 months, until the beginning of April. At the beginning of April the herds begin grazing on ca 15,000 ha of crops, mainly barely, which belong to the Bedouin farmers, where they stay until the beginning of June. From June until the end of September, right after the harvest of the wheat, the herds graze on wheat fields of the Jewish farmers, right after the harvest of the wheat. The Bedouins purchase the right to graze on these fields that include some straw and grains left in the field after the wheat harvest. From the beginning of October, when the fields are prepared for the next year cultivation, all herds return to their residency where they feed on straw and grain purchased mostly from the Jewish farmers (Figure 3).

(a) (b)

Figure 3: Grazing in the Jewish and Bedouin fields: (a) Grazing on local Bedouin fields near the Bedouin town of Rahat; (b) Grazing on Jewish agricultural fields after the harvesting

Bedouins' agriculture cycle of sheep raising can be summarized as follows: Open land and forest grazing (Feb-Mar) → Grazing on Bedouin fields (Apr-May) → Grazing on Jewish fields (June-Sep) → Feeding at their residence (Oct-Jan)

From the cycles depicted above, one may see that the longest open-field grazing is taking place at the Jewish fields. One may also see that any change in the cultivation practice of the Jewish farmers may strongly affect the amount of fields available for grazing. This is especially so once the proportion of the irrigated crops are increased in the expense of rain-fed wheat, and as a result, the amount of agricultural fields that are available for grazing may be largely affected.

2.4 The major components of Negev's territorial system

2.4.1 Lands and land-uses

Agricultural area: consists of rain-fed and irrigated plots.

In the rain-fed plots, three-year crop rotation is typical: Wheat → Wheat → Clover

In the irrigated plots, a typical crop rotation loop is five-year: Potato (irrigated) → Wheat → Carrot/other vegetable (irrigated) → Wheat → Wheat.

In case of sufficient moisture in the upper 80 cm of the soil column in spring, rain-fed or irrigated plot can be used for a second (summer) crop in the same season. Irrigated greenhouses facilitate highly intensive and sophisticated agriculture under controlled climate conditions.

Forest: Planted by the Jewish National Fund (JNF) as part as over 100 year efforts to re-vegetate the country. In certain conditions, the JNF allows sheep grazing at these forests.

Open area: covered with natural vegetation and, usually, confined to the rocky hills. Part of the open area is under the responsibility of the land-use authorities, while part serves as military training areas for the Israeli Defense Forces (IDF). During the droughts, the IDF allows for sheep grazing in these areas during non-training days.

2.4.2 Population

Jewish farmers: reside in Kibbutzim and Moshavim.

Bedouin sheep raisers: the majority of the Bedouin farmers are dispersed over Negev; some of them reside in the Bedouin towns.

2.4.3 Institutions

Land-use administration: responsible for the most state-owned land in the Negev;

Jewish National Fund (JNF): responsible for the forested plots;

Mekorot: the national water company. Mekorot is responsible for channeling drinking water from the center and northern parts of the country to the Negev and for the purification and channeling of sewage water from the Tel-Aviv metropolitan to the Negev. Mekorot is also responsible for the water quote to all settlements in the Negev.

Ministry of agriculture (MOAG): responsible for agriculture research and development and for professional instructions.

2.4.4 The drought line

Ministry of Finance (MOFI): introduced the "drought line" in the Negev, which is actually an area to the south of the 300 mm isohyets. The line demarcates this area as prone to droughts. The "drought line" area is divided into two – between 300 and 200 isohyets and to the south of the 200 isohyets. Within the 200 to 300 mm isohyets of the "drought line" area, the returns of the farmers' expenses - in case of droughts are guaranteed. The returns are sufficient for the farmer to survive the drought year, but, evidently, cannot prevent the severe economical influence of drought. To the south of the 200 isohyets the form of return is changed and a fix amount of money per every field cultivated is guaranteed. However, to get the return for the unsuccessful cultivation in the zone of less than 200 mm precipitation, the farmer must follow strict rules of cultivation that are imposed by the Ministry of Agriculture, including restriction of the cultivation to every second year only and the demand to leave the field fallow every other year.

2.5 Interactions between lands, population and institutions in the Negev territorial system

Conflicts and cooperation between Jewish and Bedouin farmers and between institutional and governmental agents are frequent in the Negev. The conflicts between state and Bedouins and between Jewish and Bedouin farmers are the result of the illegal occupation of state-owned land. In addition, theft of Jewish agricultural equipment and crops, and of the water from Mekorot by Bedouins is a common scenario in the Negev. Evacuation of the invaders from the land, if once cultivated, is virtually impossible following verdicts by the Israeli Supreme Court. Additional motivation for the illegal occupation is the compensation that the state pays in case the construction is destroyed. As a result, the number of the illegal Bedouin-owned structures that are built on state-owned land is steadily growing.

In parallel to the state-Bedouin land-use conflict, essential socio-economic relations between the Bedouin farmers, Jewish farmers and state institutions are based on mutual help and economic cooperation. Land-use authorities allow for the sheep grazing on the state-owned lands, and JNF allows, subject to some restrictions, grazing in its forests. The Ministry of Agriculture actively acquires permissions from the army to allow Bedouin herd grazing in army training zones during the weekends. Bedouin and Jewish guides employed by the Ministry of Agriculture facilitate adequate professional instructions to the sheep owners and farmers.

The economic interaction between the Jewish farmers and Bedouin sheep owners include purchasing, by Jewish farmers, rights of purifying and further use of the sewage water from the nearby Bedouin towns. Bedouin workers are widely employed by the Jewish farmers while Bedouin sheep owners purchase from the Jewish farmers grains, straw and hay to feed their herds at their residence. They also purchase the rights to graze on the Jewish cultivated fields following the wheat harvest.

During the drought years, the above interaction can lead to ambiguous consequences. If the drought is severe then the wheat or burley grain will not reach maturation and it is economically unjustified to harvest. In this case, Jewish farmers sell the entire wheat yield to the Bedouin sheep owners and the herds get essential surplus of food. This improvement is, however, temporarily and misleading. If the Bedouin farmer would decide to increase the herd in the year of extreme drought due to the high food availability, next year, if "normal", he will be prone to the capital loss just because the food supply is reduced again to a "normal" level.

Additional negative effects of the severe droughts are invasion of Bedouin herds into agricultural fields and JNF forests and firm struggle of the authorities against the Bedouin sheep owners; higher than usual bankruptcy rate of the Jewish and Bedouin farmers; abandonment of the lands and migration to the cities.

The positive social effect of the drought is intensifying intra-relationships and solidarity between the community members. It also triggers the search for technical means to alleviate the effect of the drought, enforces investments in water supply, and establishes economic mechanisms of crediting investments during the crises.

Adaptation of new varieties of sheep, new insemination techniques, growth in intensive sheep raising - all these drought-enforced development contribute to the resilience of the Bedouin sector to droughts. Investments and development of new water sources, extending the pipeline network, introducing new wheat varieties, increasing the moisture stored at the soil with the new agricultural techniques, all these consistently increases the coping capacity of the Jewish sector.

The use of purified sewage water for irrigation and extension of the irrigated areas is the most important part of the northern Negev development during the last 20 years. The revenues from the irrigated crops are several times higher than that from the rain-fed crops, thus substantially increasing farmers' capacity to cope with the unfavorable weather conditions. Indeed, during drought years, the aid of the government institutes may cover farmers' direct expenses, but does not generates any income. With the irrigated crops on part' of the land, farmer income is guaranteed, facilitating further development of irrigation in years to come.

2.6 The influence of the droughts on "business-as-usual" dynamics in the Negev

The natural and agricultural systems are substantially affected by droughts. Plant biomass is substantially reduced during drought years while, on the other hand, the ratio of shrubs to annuals decreases. By making additional plots available for grazing, the effect of the reduction in the open-field grazing is relatively small.

In contrast to natural vegetation and rain-fed crops, the drought effect is marginal for the irrigated crops. As it will be shown below, field irrigation substantially increases the wheat harvest in fields irrigated a year before.

As we mentioned above, the prediction of the annual precipitation in the Negev is not that successful. However, given the precipitation, the estimate of the yield is relatively easy and precise. The simplest relation between the yield and precipitation can be expressed as follows: Each millimeter of rain is responsible for 10 kg of grain and 7.5 kg of straw per hectare. As a result, much lower yield is expected in a drought year when precipitation is substantially lower and this directly effects Jewish farmers and, further Bedouin farmers who purchase food for the sheep. As we already mentioned above, the situation becomes especially complex during severe droughts when the grain did not reach maturation and harvesting is cancelled. Bedouin herds are allowed to graze on the un-harvested plots during these years, the sheep numbers will grow and their feeding during the next years becomes problematic.

Droughts affect summer crops as well. Once the moisture in the upper 80 cm of the plot soil is sufficient, it may serve for cultivation of the second crop during the same season, usually for growing watermelon. During drought years, the moisture of the upper soil layer is insufficient and summer crops are not grown.

3 Application of the Ensure framework to the Negev's territorial system

3.1 Preparedness of the Negev system to droughts

Matrix **1** (

Table 2) summarizes the view of the mitigation capacity of the Negev system and ***Matrix 2*** *(*

Table 3) summarizes the view of the physical vulnerability to droughts. Both matrices describe preparedness of the Negev system to the drought hazards.

3.1.1 Mitigation capacity of the Negev territorial system and its components

As can be seen in Matrix 1 (

Table 2), a variety of means aims at increasing mitigation capacity of the Negev territorial system and decreasing the vulnerability of Negev's agriculture to the drought hazard. The basis of the preparedness is the existing network of meteorological stations in the Negev. This network is managed by the trained personnel and is sufficiently dense for adequate representation of the temperatures and precipitation in the Negev, with some stations directly connected to the country meteorological database and all stations publishing their records on the web. Yet, while current and past rain data is highly available, drought forecasting is still difficult due to high variation of the precipitation. The Israel Meteorological Service (IMS) uses models in an attempt to predict droughts; their success, however, especially for the dry parts of the country is limited.

Table 2: Mitigation capacity Matrix ***(Matrix 1)***

Type of environment	System/System importance relative the other systems	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Natural and agricultural environment	*Natural and Agricutural Hazards*	Are natural hazards known and mapped?	Precipitation maps	binary	yes/no	yes, produced by the Israeli Meteorological Service (IMS)	1
				Quality	level of detail with respect to the density of meteorological stations over the area, especially in reards to the average precipitation and variation of the precipitation in time	Certainty/uncertainty of the decision making in regards to the area's resilience to drought	1
			Precipitation maps scale	map scale	Regional scale, county scale, scale of the single agricultural settlements	Certainty/uncertainty of the decision making in regards to the site resilience to drought	1
			Maps of climate change scenarios	Quantity	Various scenarios of the climatechange	Necessary for the forecasting and estimating policy alternatives	2
		Is available knowledge updated?	Precipitation maps updated	Frequency of updating	every year	Updates are obtained in a regular manner at low cost	1
		Are hazards monitored?	Does a monitoring system exist?	Binary	Yes/No	Yes, available on line by IMS	1
			Quality and distribution of meteorological stations and observation points	Regular coverage of the entire area that accound for the long-term meteorological conditions	Spatial distribution of the stations, uncertainty of the minitoring as a distance from the station (Kriging estimation of the variance of precipitation at a distance from the station)	Prediction of the precipitation in the settlements and farms that do not have a meteorological station	1
		Are monitoring systems connected to forecasting modelling systems?	Are they connected?	Level of connection	Level of integration of the monitoring system into the forecasting system	Low level of integration forllowing limitations of the global change models in semi-dry Mediterranian area	3
			Are there early warning systems?	The use of the current meteorological data for early warning	Level of use of the current data for early warning	Low level of use because of high variability of the amount of annual precipitation and its timing	3
		Structural defence measures	Number and amount of additional water sources	availability/capacity to drill new wells; connections among aqueducts	Amount of additional water supply and spatial distribution of the sources and pipelines	Location of the drillings and pipelines	1
			Possibility and capacity to use additional water sources	capacity to reuse waste water	availability of the water purification technologies and water purifying plants	Location of the water purifying stations	1
		Quality of water bodies	Drinking water/Water for irrigation only	Binary	Drinking water/Water for irrigation only	Knwledge about the network of the drinking water pipelines and the network of the purifies water for irrigation	1
			Remediation projects	Remidiation areas and stations	Location of the stations and the pipelines	Remediation projects are being carried out, mostly water purification and desalination	3

Type of environment	System/System importance relative the other systems	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Built environment	*Exposure and vulnerability of built environment*	Is exposure and vulnerability considered and acted upon its plans?	Risk scenarios availability	Binary	Yes/No	Maps of the settlements at resolution of single building	5
			Risk scenarios integrating climate change and possible droughts	level of development	Settlements and buildings which are planed to account for high temperatures	Exist partially, not in every settlement, modern buildings at high level (green buildings), old buildings just at a level of air-conditioning	5
			Vulnerability and exposure assessment considered in land use plans	Mode of inclusion		Urban seetllements are not considered in our study. Agriculture settlements are planned and developed accounting for the semi-dry climate of the Negev	5
	Rules and tools for risk mitigation	Do rules for mitigation exist? What is their expected efficacy/quality?	Building codes/rules	Building codes and rules aim at water saving, irrigation pipelines in the gardens and power supply for air conditioning	Planning rules and regulations	Buildings construction in the Jewish settlements follow planning ruels and regulations.Advanced water-saving techniques for gardening. New buildings in Bedouin settelements follow planning rules and regulations partially. Traditional Bedouin tents and structure are adapted to the semi-dry climate but do not provide the nowaday's standards of living	5
			Traditional building practice based on hazard knowledge	Capacity to re-produce traditional techniques correctly	Bedouin tents and structures	Do not provide living conditions at a modern level	5
			Land use plans embedding risk mitigation and vulnerability reduction	binary; sectoral/comprehensive; specific/generic	yes/no; expert judgement	Land-use plans limit settling and building construction over the protected areas	5
			Implementation capacity	Capacity to purify waste water	yes/no	Modern buildings in the Jewish settlements only	5
			Integration to other measures (insurance)	binary	yes/no	Yes, a part of the general ensurance framework	5

Type of environment	System/System importance relative the other systems	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Infrastructure and production sites	*Critical infrastructures*	Is vulnerability of critical infrastructures assessed and acted upon? Particularly with respect to na-techs and enchained effects on depending systems?	Vulnerability assessment of water supply, sewage and irrigation systems	Existance and level of devlopment of separate pipeline networks for drinking/runoff/purified water. Connection between the sewage system and purification plants	level of development	The level of development varied greatly between Jewish agriculture settlements. Few is done in this respect in the Bedouin sector, the succesful attampts are related to the economic ties between the Jewish and Bedouin argiculture entirpises.	1
				Network maintenance programs that embed mitigation measures	yes/no; frequency of maintenance	Water supply and irrigation networks maintanence, frequent chemical and bacteriological ananlysis of the drinking and purified water, complete separation between water suppy netwroks and purified water.	1
				New projects based on hazard/risk assessment	yes/no	Development and, specifically, irrigation projects in the Negev include essential component of environmental impact asessnment, the latter contains hazard and vulnerability assessment of major project components	1
				Level of coordination among stakeholders	Level of coordination	Relatively high level of coordination, which has developed following society's understading that the limited resourse - water - should be rationally divided between the users	1
	Production sites	Is the vulnerability of production sites considered particularly with respect to potential na-techs?	Vulnerability assessment of water production and purification sites	Estimating of the techniologically possible versus necessary levels of the water supply as dependent of the annual and long-term lavels of rains and annual timing of the rains	Overall amount of water that can be used and the distribution of the water supply in time and in space	Water quotes, for drinking and irrigation, for Jewish and Bedouin settelemnts and farms	1
			Production buildings and activities designed to save water	Where are the production sites located and what is their productivity?	The amount of water that can be saved and futher used in respect to the spatial locations of the clients	The amount of water that can be saved and futher used in respect to the spatial locations of the Jewish and Bedouin settlements and farms and connection of the dwellings, especially Bedouin tents to the water supply system	2
			Self storage of emergency water	Existance of the storage capacity	Spatial distribution and amount of the storage capacity: run-off reservoires, local purification plants including home purification of sewage water for gardening use.	Essential number of Jewish settlements have their own and significant water storage capacities. Bedouin settlement do not have these capacities, but every Bedouin family store drinking water for personal use and for the herds for several days at least	2

Type of environment	System/System importance relative the other systems	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Social system (agents)	*People/individuals*	Parameters are addressed to evaluate the capacity of individuals living in prone hazard areas of coping with hazardous events, which largely depends on the perception and awareness of risk conditions before the event occurs.	Risk perception/awareness	degree	inexistent/average/good	High level of awareness to the drought. Both Jewish and Bedouin population of the Negev are very well aware of the cinsequences of drought for their agriculture practicies and the outputs of these practices. And, conceqiently on their economic situation and well-being	2
			Early warning systems	Level of tuning to the ability to comprehend and follow up	Amount, timing and the appropriateness of the information on the anticipated climatic and weather condition in the nearest future (days, weeks) and at the seasonal and annual perspective	Complete and timely provided information, which is adequately accounted for by the Jewish and Bedouin farmers when planning their seasonal crops, areas of grazing, purchase of seed and sheep food and estimating revenues and profits	2
			Individual preparedness	degree	inexistant/average/good	Very high, every local inhabitant, no matter Jew or Bedouin is fully aware of the amount of water, cloths and other self-protecting measures	2
	Community and Institutions	Parameters are addressed to evaluate the involvement of a community into decision-making processes related to risk prevention and mitigation, the capacity of Instituions of improving risk awarenees through information and education campaigns and the level of cooperation among different institutions in charge of risk prevention/ mitigation.	Participation in development of the prevention/mitigation strategies	degree	inexistent/average/good	Jewish community is highly involved into the debates of the current and future water quotes and adapt themselves to the outcomes of these debates, Bedouin comminity makes its first steps in this direction. Iillegal connection to the water supply system and other criminal activities are taking place in the Bedouin sector	1
			Level of coordination among institutions	degree	low/medium/high	Land-use administration that is responsible for the most state-owned land in the Negev closely coordinates its activities with the Jewish National Fund (JNF) responsible for the forests. Land-use policies are coordinated with water supply, where the "Mekorot" national water company is in chanrge. Mekorot channel drinking water from the center and north of Israel to the Negev. Mekorot is also responsible for the purifying and channeling sewage water from the Tel-Aviv metropolitan to the Negev. ALl they work in close contatcs with the Ministry of Agriculture, the latter directly responsible for agriculture research and professional support of the farmers. The Ministry of Finance have introduced the "drought line" that demarcates area that is prone to droughts. The farmers within the demarcated area are guaranteed that thei expenses would be refunded in case of drought.	1
			Distribution best plant agricultural and husbandry techniques	binary	yes/no	yes, the Ministry for Agriculture developes several programs that aim at establishing optimal argicultural regimes of crop choice and growth and of husbandry in the Negev.	2
			Education programs & media campaigns	frequency and coverage	very frequent/rare; extended to the entire population at risk/only to limited groups	Multiple cources on various aspects of the agriculture practices and agriculture economics. Personal supervision at the farm, which in case of the Bedouin husbandry aims at challenging the farmer to shift from the extensive to intensive agriocultural practice	3
				taught at school in ordinary programs	yes/no	Yes, the options of professional education during the school years exist both in the Jewish and Bedouin sectors	3
				Cooperation among different ethnic communities	high/low/conflict situation	Socio-economic relations between the Bedouin populations and Jewish institutions are characterized by mutual help and cooperation. Land-use authorities allow for sheep grazing on the state-owned lands, and Jewish National Fond allows grazing in its forests. The Ministry of Agriculture acquires permissions for Bedouin herds to graze over the army training zones during the weekends. Bedouin and Jewish supervisors employed by the Ministry of Agriculture facilitate adequate professional instructions to the sheep owners and farmers. The interaction between the Jewish farmers and Bedouin sheep owners include purchasing, by Jewish farmers, rights of purifying and use of the sewage water from the nearby Bedouin towns. Bedouin workers are hired by the Jewish farmers while Bedouin sheep owners purchase from the Jewish farmers the rights to graze on the wheat straw. Jewish farmers sell to the Bedouin sheep owners straw, hay and grains.	1

The emphasis in prevention of the drought hazards is on strengthening structural and defense measures, such as developing additional water sources and water storage reservoirs, along with pipelines. In addition, numerous projects of purifying sewage water are taking place. In the southern part of the Negev, where an ancient aquifer with relatively salty water exists, desalination of this water is taking place and the purified water is used for agriculture.

One should note the peculiar circumstances of the Bedouin population. Roughly, one third of the Bedouin population resides illegally on lands, which are owned by the state. The law does not allow for connecting the houses in these areas to the domestic water system until their legal status is established. This may take years. The authorities provide drinking water for those illegal settlements and for their herds from many water points spread throughout the Negev, but there is a problem of the irrigation network there.

The effect of drought on the urban built environment is small if not negligible. Construction in the Negev always takes into account the overall high temperatures there, regardless of the drought. This is done in several ways. Some of the new buildings in the Jewish sector are already built in accordance with the modern green codes, while the majority of the urban buildings have traditional air conditioning means to mitigate the high temperatures. In many cases, computer-controlled water drip irrigation is in use for the irrigation of domestic gardens and facilitates essential water savings, approximately half of the water. Computer-controlled system further contribute for the water saving. In addition, in many caces, drought-tolerance plants with relatively low water demand are used.

While approximately half of the Bedouin population resides in concrete houses, some of them air-conditioned, the other half resides in traditional tents or huts that are built to alleviate the high indoor temperatures by facilitating easy wind breeze. Gardening in the Bedouin sector is rare and the water-saving techniques for gardens are not relevant here.

As for the infrastructure and production sites, the emphasis is given to increase water availability. This is done by several means - drilling, collecting runoff water into large reservoirs, purification of sewage water and desalinization. The majority of the purified water from the central parts of the country, including Tel Aviv metropolitan, is directed to the Negev. Nowadays, almost all sewage water from the Jewish settlements is purified in local plants. Israeli law enforces cities and towns to purify their sewage water. This law is intensively enforced over the country, including Bedouin towns. Important for the Negev is the cooperation between the Bedouin towns and Jewish farmers that take upon themselves the purification cost and the channeling of the purified water from Bedouin towns into the fields. Overall, a high level of cooperation exists between all institutes. This, in turn, facilitates several comprehensive approaches aiming to alleviate the drought hazard.

As can be seen in Matrix 1, close cooperation between farmers is manifested in the social system. Awareness to droughts is high among Jewish and Bedouin farmers and many long-term steps are taken in order to mitigate drought's effect. In this regard, it is worth noting that anticipation of a drought at a yearly scale basis is low because the existing climat models are essentially uncertain. That is, the overall preparedness of the Negev population to droughts is high.

Following the restrictions that are given by the water quote defined for each farmer and settlement, farmers are highly aware on the limited water resources. This awareness facilitates high coordination within the communities and between institutes. The Jewish farmers are actively involved in the adoption of new techniques that aim at water saving and increasing the crop yield. While the compensation of farmers within the area demarcated by the "drought line" may help out farmers by paying them back their direct expenses, this does not guarantee the well-being of the farmer. The simplest way to guarantee the profit is to become independent of the precipitation regime by developing irrigation system. As a result, essential efforts are invested to increase the amount of water available for the irrigation. The investments of the Jewish farmers into the development of new sources of water are very high, and, thus, demands for cooperation between the individuals within the communities are also high.

The cooperation is, unfortunately, less expressed in the Bedouin sector. Only limited cooperation exists in the community level. However, relatively high cooperation exists between the Jewish and the Bedouin sectors. During droughts, the Ministry of Agriculture supports Bedouin sheep owners by obtaining permissions from the Israeli Defense Forces to facilitate grazing in restricted training zones during the weekends. The Jewish National Fund also allows for grazing in many of its forests. The Ministry of Agriculture holds many training programs aiming at intensifying the sheep raising and the adoption of new varieties better suited to the harsh Negev conditions. The Ministry of Agriculture also mediates between the Jewish and Bedouin farmers. The relationships between these two sectors of the Negev agriculture are multiple, the major is purchasing rights to graze on the fields of the Jewish settlements. Bedouin herds, thus, have access to relatively cheap food supply during the summer. Bedouins also purchase straw and hay from the Jewish farmers, contributing to the economy of the Jewish sector.

3.1.2 Physical vulnerability of the Negev territorial system and its components

As can be seen in Matrix 2 (

Table 3), a variety of means aim at decreasing the vulnerability of the crops to the drought hazard. New varieties of wheat are introduced: these new varieties are better adapted to high temperatures and low water supply. As we presented above, the cultivation in the Negev, on the fields that are connected to irrigation system, is carried out by 5-year cycle, out of which during two years irrigated crops are cultivated, and 3-year cycle in the fields that are rain-fed. A steady expansion of the irrigation network results in irrigated crops in 2 years of the 5-year cycle. Following the year of irrigation, the soil retains high water content in the next year. This allows for high wheat crop during that year. In this way the effect of a possible drought is reduced.

*Table 3: ENSURE matrix for Physical vulnerability to drought (**Matrix 2**)*

Type of environment	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to test area	Scoring
Natural and agricultural environment	*Natural and agricultural ecosystems*	Are natural and agricultural ecosystems fragile to the potential effects of hazard(s)?	crops and other agricultural products	relative resistance to low level of precipitation	number of days/minimum amount of rains/additonal water supply and the timing of water supply during the growing period and the rest of the year	The variety of crops that are selected for agriculture in the Negev are characterized by high resistance to low level of water supply	1
				dependence on precipitation/irrigation	totally rain-fed/totally irrigation-dependent crops	The major Negev's crops are wheat (not irrigated), legumes (not irrigated), potato (irrigated), carrot (irrigated), other vegetables (irrigated). In time, wheat is subsituting by the other crops, in responce to the development of the irrigation system which currently cover more than 65% of the fields cultivated by Jewish farmers. These fields are cyclically irrigated, once in two-tree years; the rest of the years the residuals of the water are used by wheat and other non-irrigated crops. Wheat fields are used for sheep grazing after the harvest.	1
			cattle and sheep	relative resistance to low level of precipitation	number of days/minimum amount of rains/additonal water supply and the timing of water supply during the growing period and the rest of the year	During the year of severe droughts, when the grain did not reach maturation and harvesting is cancelled, Bedouin herds are allowed to graze on the un-harvested plots. Following unexpectedly high food supply in such years, sheep numbers excessively grow. However, next year the support of the herd becomes problematic. Wrong decision to preserve ecessive number of lambs during the extremely drought years, following high food availability, will thus cause capital loss in the next "normal" year when availability of food is regular	2
			soil capacity to maintain moisture	type of treatment	tillage/no-tillage; amount of organic matter used	The use of the no-tillage cultivation techniques and special machinery for no-tillage cultivation raise soil water-storage capacity and increase the soil moisture. Similarly, the addition of organic matter increases the moisture content of the soil and contributes to the "success" of a field.	1
				type of rotation	using crops that deplate water content/save water content	The decision to sow drought-resistant crop, such as barely, instead of drought-sensitive wheat, as well as decision on the crop rotation determines vulnerability of agricultural production. Crops rotation reduces risk of the soil exhaustion and development of diseases.	1
		Are natural and agricultural ecosystems vulnerable to mitigation measures taken during the emergency phase?	crops and vegetables	vulnerability to water shortage	high/medium/low	Jewish agriculture: High for non-irrigated crops. The field with the non-matured crops are sold to the Bedouin farmers for grazing	1
			cattle and sheep	vulnerability to water shortage	high/medium/low	Bedouin agriculture: Search for the alternative water sources, often illegal. During severe droughts food supply increses thus leading to a vulnerable husbandry related to losses in the next year	3

Type of environment	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to test area	Scoring
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make exposed systems vulnerable to drought?	Vulnerability assessment of buildings	Water pressure in the pipes, decrease of the living standards	Low/Regular/High	High vulnerability in the Jewish settelements, low in the Bedouin settlements	1
				Use of the emergency water stored at home	yes/no	Yes in both Jewish and Bedouin settlements	2
				Higher prices of the water for drinking and irrigation	high/intermediate/low	High for all, but non-felt in Bedouin settlements due to high level of illegal water use	3
Infrastructure and production sites	*Critical infrastructures*	What are the factors that make critical infrastructures vulnerable (mainly lifelines)	Vulnerability assessment of water supply system	Average lifelitime of wells	years and decades	periodically tested by Mekorot	1
				Frequency of pipelines maintanence	years and decades	central pipelines are periodically tested by Mekorot, local pipeline netweors are tested by the farmers	1
				Minimal threshold of water in tanks and reservoirs	meters	Tested by the local authorities	1
			Availability/capacity to use emergency alternative sources	Amount of water in tanks and reservoirs	cubic meters	Jewish settlements have established systems of water supply in case of extreme drought. Bedouin family rely on the use water stored in the Jewish settlement, partially legally, while partially illegally	2
	Production sites	What are the factors that make production sites vulnerable (including na-tech potential)	Vulnerability assessment of production sites	degree of dependence of production activity on water supply	high/medium/low	Local food industry does not demand excessive amount of water and, thus, is not vulnerable to droughts	1
Social system (agents)	*People/individuals*	What are the factors that may lead to injuries and fatalities?	Access to water sources per type and quality	degree of access	access to all existing sources/partial/severely restricted access	Full access in the Jewish settlements, limited access in Bedouin settlements	2
			Population preparedness to droughts	degree	high/medium/low	High for both Jewish and Bedouin sectors	1
			Access to information about water saving strategies	degree of coverage	high/medium/low	High in the Jewish and medium in the Bedouin settlements	1
	Community and Institutions	What are the factors that may lead to large number of victims?	Contingency plan	binary	yes/no; shared among stakeholders/known by few	Land-use and agriculture policy in the Negev is establshed in regards to the droughts	1
			Access to information about compensation and alternative sources of income	degree of coverage	high/medium/low	All Jewish and Bedouin farmers are aware about the "drought line" and compensation. However, the compensation relates to the investments but not to the loss of revenue, are essentially lower than the standard revenues and cannot prevent the severe economical influence of drought. In addition, compensation does not cover illegal cultivation or husbandry.	1

No-tillage techniques of cultivation are also widely adapted in order to minimize the drought effects. These techniques increase the crop yield by ca 10%. New varieties of wheat also increase the water-use efficiency. In parallel, new varieties of sheep facilitate a better endurance to high temperatures and decrease the mortality rate among the lamb.

Implications of drought may be misleading for the Bedouin husbandry. In contrast to the "regular" droughts that just cause the reduction in the yield, severe droughts may result in the immature grain ripening. During such years, the Jewish farmers prefer to sell the fields for grazing "as is", without any harvest. The sheep owners in this case have the illusion of plentiful food supply and may be tempted to increase their herds. During the following year, however, either it will be characterized by the normal precipitation or be a "regular" drought, food supply will be essentially lower. This may lead to a crisis of Bedouin farmer.

As for the built environment and the infrastructure, in addition to the exhaustion of reservoirs, droughts also act to increase the water prices. Lifelines, particularly the water installations and pipes are well kept by the authorities. Yet, the situation is much less optimistic as far as the Bedouins are concerned. As many of the farmers dwell illegally on state-owned land, their connection to water is limited. They rely on home storage following the filling up of tanks with water taken from many "distribution spots". These 'distribution spots" enhance the Bedouin preparedness to drought. Consequently, the entire social system in the Negev exhibits a relatively high preparedness.

The scores in Matrices 1 and 2 reflect the current situation relative to a hypothetical alternative during which no preparedness was taking place. The level of 1 represents the highest preparedness, higher numbers describe lower preparedness. As can be seen in Matrices 1 and 2, overall, the Negev population exhibits high preparedness.

3.2 Vulnerability to losses and resilience in the long-run

In the natural areas, long-term droughts decrease plant biomass, which further influences along the ecological food webs, through the ecological relationships and feedbacks. The same is true for the human socio-economic systems In the Negev agricultural areas drought cause the decrease the yield in the Jewish Kibbutz and Moshav and, consequently, reduction of the grazing period in these fields. As we mentioned above, drought may also have secondary feedback effects: Bedouin sheep grazing on the non-harvested field, following the lack of grain maturation, may cause the illusion of plentiful food supply and the increase in the lamb number in the herd. During the following year, once a "normal" year or even a "normal" drought takes place, food may be in shortage and the herd owner may suffer losses. The Israeli state, "global" factor for the Negev territorial system provides the compensation mechanism - the "drought line" that we have already presented. While not guaranteeing the well-being of the family, the drought line facilitates the coverage of the direct costs of the farmer's unsuccessful investment in rain-fed crops.

Different form the agriculture system, the effects of the drought hazard on the built environment is marginal, urban systems can be regarded as resilient. Drought may demand some additional investment in local water sources for the cities, but this is nonetheless insignificant because the water is supplied from the center of the country.

Matrix 3 (

Table 4) summarizes vulnerability of the Negev territorial system to losses, while Matrix 4 (Table 5) summarizes the long-run resilience of the Negev territorial system to droughts.

Table 4: ENSURE matrix for vulnerability to losses (**Matrix 3**)

Type of environment	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Natural and agricultural environment	*Natural ecosystems and agricultural systems*	Are natural ecosystems and agricultural systems fragile to the potential major effects of hazard(s)?	Crop yield, number of sheep and goats	Decrease in natural vegetation. Decrease in the crop yield or total loss due to insufficient amount or wrong timing of rains over the non-irrigated areas. Decrease of the lamb/sheep ratio in case of the regular drought	Grain-to-straw ratio for wheat and other crops, lamb-to-sheep ratio	With the development of the drought the yield is decreasing and the amount of the sheep food decreses proportionally. In parallel the length of time interval that Bedouin herds can graze over the Jewish agriculture areas is reduced from three - four to two-three months	1
		Are natural ecosystems and agricultural systems fragile to the potential secondary effects of hazard(s)?	Number of lamb and sheep	Sudden increase in lamb/sheep ratio after the sever drought, when the use of the entire (but unmature) grain production for sheep feeding becomes possible	Lamb-to-sheep ratio	After the level of precipitation passes the low threshold the grains do not maturate and the entire yield is left in the field. In this way the amount of the sheep food in such a field increases 3 - 5 times.	1
		Are natural ecosystems and agricultural systems vulnerable to mitigation measures taken particularly during the emergency phase?	The level of compensation provided by the state	The level of compensation is respect to the loss of the revenues	Annual profit of the farmer	Israeli state provides compensation in case of the drought-caused production losses. The compensation can be obtained by the farmer whose fields are within the "drought line". However, properly documented direct expenses only are accounted for. The real investment of the farmer, especially of the Bedouins, whose husbandry is partially illigal, are much above the compensation.	1
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make buildings, the urban fabric and public facilities vulnerable to losses?	Existence of public facilities and resources to face the emergency	Binary	Yes/No	Supply of electiricity for air conditioning (in modern houses) and drinking water (modern houses and Bedouin tents) for the personal use is guaranteed by the state irrespective of the annual level of precipitation.	1
			Accessibility to vulnerable areas	Binary	Yes/No	In semi-dry conditions of the Negev acceesibility is always high	1
			Accessibility to public facilities	Binary	Yes/No	In semi-dry conditions of the Negev acceesibility is always high	1
							1
Infrastructure and production sites	*Critical infrastructures*	What are the factors that make critical infrastructures stop functioning?	Existence of lifelines	Binary	Yes/No	Existing pipeline network is used for water supply for irrigation and husbandry, while the water is obtained not from the regular sources, but from the emergency resevoirs or from the water supply system in the northern paret of the country	1
			Degree of interdependence among lifelines	The ability to connect-disconnect the parts of the water supply network	High/Medium/Low	High, the parts are strongly connected and the water can be supplied from difference nodes of the network	2
			Contigency plan for lifelines, individually and in a coordinated fashion	Binary	Exist/Does not exist	Exist for the Jewish settlements. Bedouin settlements are supplied from the same sources and the supply plans account for that	1
			Degree of dependence of critical public facilities on lifelines	Degree of dependence	High/Medium/Low	High, public facilities are included into the existing contigency plans	2
	Production sites	What are the factors that may lead to halting production?	Degree of dependance of production sites from lifelines	Degree of dependence	High/Medium/Low	High for the irrigated production sites that are included into the existing continuity plans. Low for non-irrigated sites	1
			Accessibility to the production sites and to markets	Level of accessibility	High/Medium/Low	High. In semi-arid areas accessibility is always high	1
			Contingency plan for natech	Binary	Exist/Does not exist	Exist. Producion sites are included into the general contigency plans	1
			Business contigency plan	Binary	Exist/Does not exist	Exist. Businesses are considered by general contigency plans	

Type of environment	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Social system (agents)	*People/individuals*	What are the factors that may reduce coping capacity during crisis?	Access to understandable information	Existance of understandable information, level of access	Information coverage, level of access	Very high in the Jewish settelements, high in Bedouin settlements - by radio, TV, Internet	1
			Trust in information providers	Level of trust	High/Medium/Low	High, short-tern and long-term meteorological forecusts are regularly supplied and easily available from radio, TV, Internet	1
			Preparedness in case of event	Level of preparedness	High/Medium/Low	High, both Jewish and Bedouin population is highly prepared to the droughts	1
			Presence of impaired groups (elderly, sick persons, etc.)	Level of preparedness	High/Medium/Low	High, impared groups are prepared not less than the rest of the population	1
	Community and Institutions	What are the factors that may hamper effective crisis management?	Existance of contingency plan for the threats that are expected in the nearest future	Binary	Exist/Do not exist	Exist, the contigency plans are compiled at the level of a settlement or a farm; the prsonal contigency plan is a part of the community plan	1
			Training using the contingency plan	Frequency of training	High/Medium/Low	Irrelevant for the slowly developing hazard, as drought	1
			Overlapping responsiblities among agencies	Level of overlap	High/Medium/Low	High, several Ministries and Institutions (Agriculture, Mekorot, Jewish Natinal Fond, Ministry of Finance) essentially overlap in their responsibilities in regards to the effects of droughts. The communities, both in the Jewish and Bedouin settlements, are very well aware about this overlap and try to exploit it for additonal compensations or protection measures	1
			Established protocols for information sharing	Binary	Established/Not established	Established, the state institutions are repsonsible for the sharing of the information regarding drought and water supply between the setllements and farmers	1
			Established protocols for use of resources to manage the crisis	Level of cooperation between the Ministries and Institutions in regard to the water management duirng the drought years	High/Medium/Low	High, the Institutions cooperate between each other	1
	Economic stakeholders	Are economic stakeholders prepared to face crises?	Capacity to run economy and respond to crises	Degree	High/Medium/Low	High, the farmers are hightly adapted to the droughts and are very well aware about the farm management and interactions with the institutionsa and Ministeries depending on the severity of drought	1
			Capacity to invest in recovery and take preventive actions	Degree	High/Medium/Low	Relatively high. State compensations are confined to the areas within the "drought line" and are far below expected revenues and profit	1,5

Overall, the territorial system in the Negev shows high resilience. This is also characteristic of the social components of the system. The state guarantee of the descent level of income determines relatively high coping capacity of the Jewish farmers and the Bedouin sheep owners. The same is true regarding the level of preparedness, which is also high at personal or institutional levels. As mentioned above, Ministries and institutions are working together in order to guarantee the wellbeing of the population. Training, supervision, guidance and financial support - all act in unison to enable the Negev residents be better prepared and better cope with the drought hazard.

As can be seen in

Table 5, overall the resilience of the northern Negev system is high. This is true for both the natural and anthropogenic components of this system. The natural Negev ecosystems are adapted to droughts. While drought may severely affect the natural plant biomass, species diversity and seed bank are apparently less affected. Seeds are adapted for many years of residence time without losing their vitality. Species diversity is retained in preferable microhabitats where addition of water by runoff and/or subsurface flow allows their germination and seed maturation during droughts.

The same is true for the anthropogenic components of the Negev territorial system. The built environment, buildings and structures are constructed to withstand high heat loads. As for the infrastructure, the production sites are not affected by drought and the most important resource, water, the Negev does not only rely on regional resources. On the contrary, water supply mainly relies on water originating from the central and even northern parts of the country, a fact that drastically improve the system resilience to drought.

*Table 5: ENSURE matrix for resilience in the long-run (**Matrix 4**)*

Type of environment	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Natural and agriculture environment	*Natural ecosystems and agricultural systems*	Are natural environments influenced by the hazard, able to resist to the degradation or to adapt to it?	Resilience of the system and its components to the hazard stress	The ability of natural vegetation to reactivate after the dry period, when the water is supplied with the rain or irrigation. Soil fertility in the agriculture lands	Number of natural species that extincted	Natural communities have adapted to the low level of precipitation during last twenty dry years. The species that survived are able to reproduce at the current and even lower level of precipitation. These species are part of communities occupying micro-habitat at footslopes and depressions that recieve additional amount of water by runoff and subsurface flows. Seeds are adapted to withstand many yeaers of residence time.	1,5
		Are ecological and agriculture systems able to recover from the negative side-effects of mitigation measures and procedures?	Resilience of the system and its components to the negative consequences of human intervention that is aimed at preventing losses	Level of resilience	High/Intermediate/Low	Irrelevant in the Negev, mitigation measures (additional water supply) do not have negative side-effects	
Built environment	*Exposure and vulnerability of built environment*	Is the urban fabric/built environment able to recover?	Existance of plans/adjustments for recovery after severe drought periods	binary	yes/no	Irrelevant for the Negev, build environment is not influenced by the drought	
			Is urban fabric adjusted to droughts?	binary	yes/no	Yes, Negev building constructions, including modern and traditional Bedouin dwellings are very well adapted to the dry climate	1,5
			Relevance of potentially affected settlements in geographic/economic terms	Type of settlement	rural low density areas/ rurban areas/cities	Jewish built environment is the similar in all types of the settelements (kibbutz, moshav, individual farm). Bedouin built environment can be of two types - modern and similar to the Jewish and traditional tents and structures. All these types are very well adapted to the dry climate of the Negev	1,5
Infrastructure and production sites	*Critical infrastructures*	Could critical infrastructures be recoved rapidly and at low cost?	Availabilities of computerized plans of infrastructures and facilities	Degree of coverage	High/Medium/Low	High in Jewish settelements and production points and low in Bedouin sector	1
			The recovering ability of the water supply networks: network for drinking water supply and irrigation network	Ability to recover	High/Medium/Low	High, the damaged pipelines are immediately fixed	1
			The ability of recovering of the water purifying stations	Ability to recover	High/Medium/Low	High, the damage is immediately fixed, does not depend on severity of drought	1
	Production sites, including agriculture	Could production sites be recoved rapidly and at low cost?	The recovering ability of the production sites, including the sites of yield processing and storage	Ability to recover	High/Medium/Low	High, the damage is immediately fixed, does not depend on severity of drought	1
			State and regional sources of compensation, insurance and funds for recovering existing production sites and new constructions	Level of compensation, size of the funds	High/Medium/Low	The Ministry of Finance provides financial umbrella to the insurance of the farmers against the drought's hazard and, also, to immediate financial compensation of the farmers' losses following droughts.	1

Type of environment	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring
Social system (agents)	*People/individuals*	Are people in the position to be resilient in the face of a catastrophe?	Ability to resettle/protect themsleves in case of severe drought during several years	Availability of the public/private funds for resettling/protection	Level of financial support provided by the public agencies versus personal spendings	Public funding is high in the Jewish settlements following strong lobbying by the Jewish farmers association. Low in Bedouin settlements	1,5
	Community	Is the community resilient to the consequences of a drought?	Presence of particularly vulnerable population groups (eldery, impaired)	Percentage of highly valnurable population	Amount	High percentage of the eldery people in both Jewish and Bedouin settlements following general increase in the level of health service and life expectancy	1
			Unemployment rate	Percentage	Number	Low in the Jewish sector, high in Bedouin settlements	1,5
			Annual population growth rate	Growth rate	Number	Jewish settlement: adjusted to the settlement capacity. Bedouins: very high growth rate, the population is duplicated each 13.5 years	2
			Emigration/Immigration rates	Percentage	Number	Jewish settlement:population changes are adjusted to the settlement capacity. Bedouins: emigration rate is high following lack of employment in the settlements.	1,5
			Social networking	degree	high/medium/low	The positive social effect of the drought is intensifying intra-relationships and solidarity between the community members, especially in the Jewish sector	1
			Conflict and cooperation among social and ethnic groups	degree	high/medium/low	Droughts intesify interactions between the Jewish farmers and the Bedouin sheep owners. Jewish farmers sell areas for grazing after the harvest while the Bedouin sheep owners decide whether to purchase these rights or rather invest into purchasing hay and feed the herds at the barn or paddock within their own land unit. Jewish farmer can restrict grazing on agricultural fields and, in this way, to reduce the standard opportunities of the Bedouin farmer. On the other hand such a restriction would enforce intensive husbandry that would become less dependent of the food supply from the non-irrigated fileds. A decision of the sheep owners not purchase the right to graze on the fields may enforce Jewish farmers to use the straw as mulch. Population growth and an increase demand for meat may lead to intensive sheep raising which will be intensified following droughts	1,5
	Institutions	Are regional and state institutions' activities transparent, reliable and trustable?	Degree of trust in institutions	degree	high/medium/low	Medium for Jewish sector, low in Bedouin sector. Negev population considers state institutions as mostly interested in development of the country core in the north.	2
			Transparency in funds allocation	Availability of information on funds and investments and existence of independent control mechanisms	high/medium/low	Medium for Jewish sector, low in Bedouin sector. Similar to the general situation in the country	2
			Long term vision	Existence of strategic development/land use plans	yes/no	Yes, but actual development does not follow plans, both in the Jewish and Bedouin sectors	2
				Level of sharing of recovery plans and adjustments among stakeholders	high/medium/low	High, the development plans are easily available form the Ministry of Internal Affaires	1
				Exitence of reliable mechanisms of compensation	yes/no	Yes, the investments into the developing irrigation system are constantly increasing and, in addition the system of compensation to the farmers to the south of the drought line is reliable and trustable and increases the endurance of the farmers to the threat of droughts	
	Economic stakeholders	Are economic stakeholders capable/wishing to re-invest in affected areas?	Stakeholders' ecomonic level and involvement into economic activities beyond the Negev	Size of the stakeholder's enterprize, stakeholder's industrial relationships	Stakeholder's turnover	Medium in the Jewish sector, low in the Bedouin sector	2
			Stakeholders' sensitivity to economic losses	Forms and extent of the stakeholders' ensurance	Ensurance type and premium	Multiple types of ensurance widely practiced in the Jewish sector, low level of insurance in the Bedouin sector	1,5

In light with the state goal to strengthen the periphery, a combination of measures was adapted to aid and compensate the drought influence on the Negev residents. The state measures are highly effective in the Jewish sector, while less effective in the Bedouin sector. As we already mentioned, Bedouin population has very high birth rate while investment in the Bedouin children education is low and, as a result, the level of education in the Bedouin sector is essentially lower than in the Jewish sector. This is the major factor of high unemployment rate among Bedouin population and, in turn results in high emigration to the cities, where chances to find a job are higher.

Droughts intensify interactions between Jewish and Bedouin farmers. Jewish farmers sell straw and hay to the Bedouins along with the right to graze on their fields during the summer months. Since the agricultural land is limited, regardless of drought, Bedouins may not find the available grazing land sufficient to meet their demand. As a result, high population growth and subsequent increase in the lamb meat demand, enforces transformation from the extensive to intensive husbandry.

4 Dynamic view of the Negev vulnerability

4.1 Landscape vulnerability to drought as a temporal phenomenon

The landscape system remains within the *limits of robustness* until its components and function vary quantitatively. Drought can push the system beyond these limits and influence the landscape qualitatively and, consequently, the entire landscape may collapse. That is why we define the vulnerability to drought as follows:

The landscape is vulnerable to drought if its structure and qualitative functioning cannot be preserved during the period of droughts.

4.1.1 Formal view of vulnerability as a dynamic phenomenon

Let us characterize the landscape system **S** by the set of state variables $\sigma = (\sigma_1, \sigma_2, \sigma_3, \ldots)$ and ignore, for simplicity, hierarchical structure of **S** and spatial variability in S characteristics; that is, we consider **S** as "averaged" over space (Benenson and Torrens, 2004). In case of the Negev landscape, the variables are the average soil moisture, fractions of the area that is used for intensive/extensive cultivation of crops, fraction of the area that can be used for intensive/extensive husbandry, the urban and agriculture population density and the density of the farms and farmers of different kinds, etc. The values of the state variables change in time, and, thus, to characterize temporal variability of the system **S** (we consider spatial variability in the following sections), we have to characterize the state of the system **S** in time, and consider σ as $\sigma_t = (\sigma_{1,t}, \sigma_{2,t}, \sigma_{3,t}, \ldots)$.

In what follows we limit ourselves to the society-based view of **S**. To fit societal needs, the validity of each $\sigma_{i,t}$ (say, preserving "some" Negev population or "some" agriculture) is insufficient. The society need demand to preserve each $\sigma_{i,t}$ within certain limits, ($\sigma_{i,min}$, $\sigma_{i,max}$) - "limits of robustness", which are established by the society itself and are interpreted as sufficient for preserving or even development of the system according the society's view of the system's future.

In these terms, the system **S** is **robust** if it functions in a way that despite varying environmental conditions (say, precipitation level in case of the Northern Negev) all state variables $\sigma_{i,t}$ remain sufficiently far from the boundary values $\sigma_{i,min}$ and $\sigma_{i,max}$. The system **S** is vulnerable if the system's state vector $\boldsymbol{\sigma_t}$ approaches the boundaries of robustness $\boldsymbol{\sigma_{min}}$ or $\boldsymbol{\sigma_{max}}$.

In terms of landscapes vulnerability to droughts, **robust system S_r** possesses sufficient "coping capacity" that enables to preserve its structure, main parameters and the way of functioning during drought. **Robust system S_r** fully restores itself afterwards. The coping capacity of the **vulnerable system S_v** is low. **Vulnerable system S_v** qualitatively and irreversibly changes in respond to the drought.

Schematically, this definition is illustrated by Figure 4:

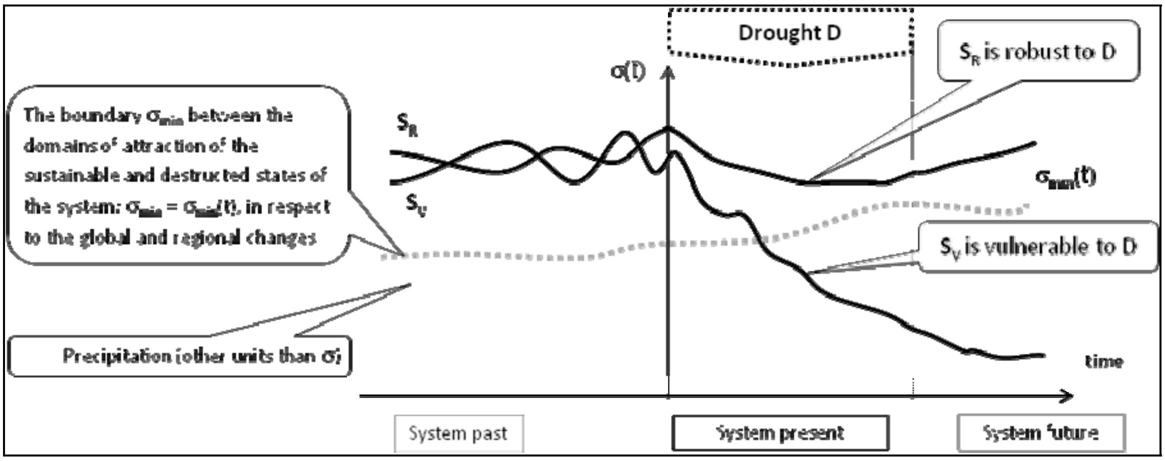


*Figure 4: **Robust system S_r** possesses sufficient coping capacity that enables to preserve its structure, main parameters and the way of functioning during drought. **Robust system S_r** fully restores itself afterwards. The coping capacity of the **vulnerable system S_v** is low. **Vulnerable system S_v** qualitatively and irreversibly changes in respond to the drought. For simplicity, only the lower limit of robustness σ_{min}, denoted in the figure as σ_b, is presented.*

Understanding system's S vulnerability to a drought D demands investigation of the system's dynamics during its entire life-span:

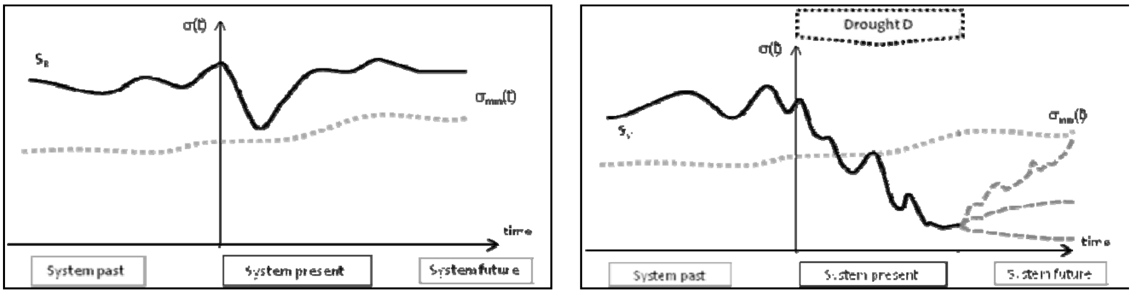
- System's past and present are critical for understanding system's preparedness and coping capacity to damage;
- Projections of the system future is critical for understanding whether the system would be able to preserve its structure, parameters and the way of functioning;

It is important to note that preparedness of the human system to a long-term hazard, as the drought in Negev, is determined by society's investment and varies greatly in time and in space, between settlements and farmers.

4.1.2 Possible influence of the drought on Negev's territorial system

No influence, sustainable development: Under regular precipitation the average Negev's agriculture production of the Jewish and Bedouins farmers is preserved. Even if random weather fluctuations result in worse conditions for some years, the system can get back to its standard level of production (Figure 5a)

System degradation: Under the influence of drought, the agriculture production of the Jewish and Bedouin farmers decrease to essentially lower than the usual level. The system undergoes irreversible changes and recovering, if ever, will take very long time (as social structures are destructed) (Figure 5b):



(a) (b)

Figure 5: General representation of the Negev's territorial system dynamics in case it is robust (a) and vulnerable (b) to drought

The frequency of droughts is very important for understanding Negev's vulnerability. Frequent drought impose the most severe threat to the system stability, as it requires high coping capacity and high financial means to overcome the hazard.

Drought year that follows a very wet year may have entirely different consequences on the crop yield. The high amount of precipitation during the wet year may affect the moisture content of fields during the drought year and may determine the success or failure of the crop.

Addition of organic matter during the previous year may determine the yield during the current year. Similarly, sowing of a summer crop such as watermelon may result in a severe depletion of the moisture content of the soil during the following year, which may result in turn in a substantial drop in the wheat yield during the following winter. By the increase in the amount of water, crop production at fields that were irrigated during the previous year may double itself. It implies more grains and straw. Likewise, the growth of wheat on fields that were irrigated during the previous year may determine the “success” of the yield of the wheat: extra moisture preserved within these soils may provide the necessary water for a relatively “successful” crop.

4.1.3 Vulnerability as spatial phenomenon

General concept of vulnerability (Figure 4) can be applied to every object or set of objects at any hierarchical level of the system's organization. If we consider, for example, the agriculture lands of a Kibbutz or of a Bedouin family, the landscape structure over this area can be more vulnerable or less vulnerable to the droughts depending on the level of land exploitation, soil organic matter, population that depends on the productivity of the area's landscape system, agriculture practice, etc. Different agents, e.g. different agriculture settlements or Bedouin families can manage their lands in different ways and, thus, the landscape vulnerability can vary in space even in case of the uniform environmental conditions and population distribution.

As a result, the local vulnerability, characteristic of the objects or group of objects of interest vary not only in time, but also in space. Some areas can be vulnerable while the other can be robust to the drought of the same intensity and duration (Figure 6).

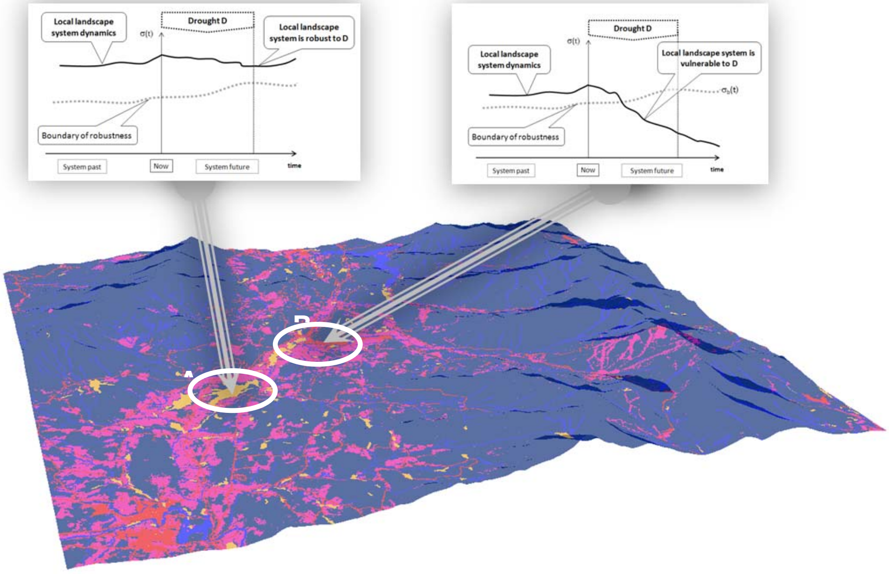


Figure 6: Spatial vulnerability to droughts: Given the intensity and duration of the drought D, the area A is robust to D, while the area B is vulnerable to D.

The ways of the spatial variation in Negev's vulnerability are numerous. The decision to sow a more drought-resistant crop such as barely instead of the more drought-sensitive wheat may determine future vulnerability and rotation of crops within a field. Despite the general necessity of rotation that aims at reducing the risk of exhausting the fields and the development of diseases, rain-fed wheat may be affected during a next drought year.

Spatial variation in area's vulnerability can result from differences in the plant demand to water or slight differences in the moisture content of the soil. While barely may be resilient at certain fields due to shallower roots and shorter growing period, wheat that requires more water, may be markedly affected by the drought. Variable response may also result from differences in the clay content of the soils and slight differences in the soil moisture content, such as a result of aspect, spatial variability in rain intensity that may lead to higher runoff (and therefore lower availability of water) in certain fields or as a result of the cultivation practice employed.

Spatial variation in area's vulnerability results from differences in the plants' demand to water and in the moisture content of the soil. The use of the no-tillage cultivation techniques and special machinery that increase the soil water storage result in an increase in the moisture content of the soil (Bonfil, 1999). Similarly, the addition of organic matter which serves to increase the moisture content of the soil (Cantón et al., 2004) may contribute to the “success” of certain fields. Higher moisture content may also characterize “sun-shaded” aspects such as the northern aspect in the Negev.

4.1.4 Effect of droughts on the relationships between the components of the Negev territorial system

Hypothetically, drought may cause large abandonment of the Jewish settlements and immigration of the Bedouin population from the rural settlements to towns. However, such an extreme scenario is unrealistic. Droughts serve as a trigger for irrigating rain-fed plots and enforce Jewish farmers to increase the investments in water supply. By forming a lobby in favor of government investment in the development and transfer of water from the wetter parts of the country, and in development additional local water sources, Jewish farmers substantially increased the system resilience. Purification of sewage water, construction water reservoirs, the use of drip irrigation (which resulted in up to 50% of water saving) ‘no-tillage’ technique, all substantially increase water availability. Especially, an increase of the urban population causes steady increase in the amount of the sewage water, regardless of the droughts and regardless of the climate fluctuations.

Droughts affect interaction between the Jewish farmers and the Bedouin sheep owners. Jewish farmers may allow grazing while the Bedouin sheep owners may decide whether to purchase the right to graze on agricultural fields or rather to purchase hay to feed the sheep at the barn or paddock in their own property. The decision of the Jewish farmers to restrict grazing on agricultural fields may, on one hand, reduce the number of herds in the Northern Negev; on the other hand this may enforce new husbandry techniques. A decision of the sheep owners not purchase the right to graze on the fields may enforce Jewish farmers to use the straw as mulch.

In summary, long-term efforts to increase water sources and irrigated area in the Negev results in high robustness of the Negev territorial system to droughts. Thirty Years ago 90% of the Negev's fields' crop was wheat; these fields could be used for sheep grazing after the harvest. Currently, half of the cultivated areas are connected to the irrigation systems and are not available for grazing during years when semi-industrial crops or vegetables are grown on these plots. The amount of fields available for grazing is thus constantly decreasing. Consequently, the pressure, on the Bedouin farmers, to switch from extensive to intensive sheep-raising is increasing. This is accompanied by internal changes of the Bedouin society, higher education demand and refusal of the young generation to serve as shepherds.

Yet, the reduction in the Bedouin sheep-feed areas is accompanied by higher yield of wheat from the plots irrigated a year before. Indeed, following crop rotation, wheat is often grown on plots that were used for irrigated semi-industrial crops or vegetables a year before. As a result, the amount of straw at these plots is substantially higher than on plots that were not irrigated. In this way the irrigated plots may compensate, at least partially, for the reduction in the amount of the fields available for Bedouin grazing.

Currently, the investments of the Jewish farmers into new water sources are continuously increasing. The tendency of the Bedouin sheep owners to switch to intensive raising is also noted. We do not have yet a definite answer whether a reduction in the grazing area could enforce the switch from extensive to intensive sheep raising. Yet, our preliminary results point to such a possibility.

4.2 Dynamic spatially explicit model of the Negev's agricultural as a tool for estimating territorial vulnerability

As it is demonstrated in the previous sections, the development and management of the Negev’s cities and towns are almost independent of the local conditions. If the annual precipitation in the Negev would continue, during the next decade, to decrease at the typical annual rate of 3-7 mm (see the chart of precipitation decline in time), the reduction, even accumulated in years, will not influence Negev’s cities and urban population. Indeed, in regards to the supplies, Negev’s cities are directly related to the center of the country (including water supply). Furthermore, the development of the Negev's cities is mostly determined by globalised Israeli economy: The jobs and the welfare in the Negev are supplied by the industry. Industrial production is directly related to the customers of the entire country and, mostly, from abroad, and their demand and is not sensitive to the change in the annual precipitation.

The agriculture compartment of the Negev territorial system is essentially less globalised. Despite country and, mostly, foreign demand for irrigated vegetables and, especially, potato, being the driving force of the Jewish agriculture, essential part of the Jewish agriculture direct and by-side production from the non-irrigated field goes for the local needs, mostly for the Bedouin husbandry. Bedouins' herds depend on this supply during, roughly, two thirds of the year. Four months of the year sheep and goats graze on the wheat fields and two more months they are fed by the hay and straw bought from the Jewish farmers.

Another source of sheep and goat food are wheat and barley cultivated by Bedouin themselves on the non-irrigated fields. This supply is exploited during two more months. Altogether, Bedouins' husbandry depends on the local supplied during eight months of the year, and all this supply comes from the non-irrigated fields. Profit from husbandry determines the welfare and development of essential part of the Bedouin population in the Negev.

Severe droughts may drastically influence the relations between the Jewish and Bedouin farmers (Figure 7). Every link between the components can be damaged. First, as the yield decreases with the drought the amount of food for the sheep and goats decreases proportionally, both in the Jewish and Bedouin fields. With farther development of the drought, non-linear effects can become important, when due to the lack of the precipitation the wheat in the fields of the Jewish farmers does not reach maturation and the entire annual yield is sold as a livestock food. This abrupt increase in food supply may shock the market and may result in the short-term decrease in prices and consequent increase in the livestock numbers. However, the increased food supply would not continue for the next year – either the precipitations would return to the average or the field would be abandoned by the farmer as non-productive.

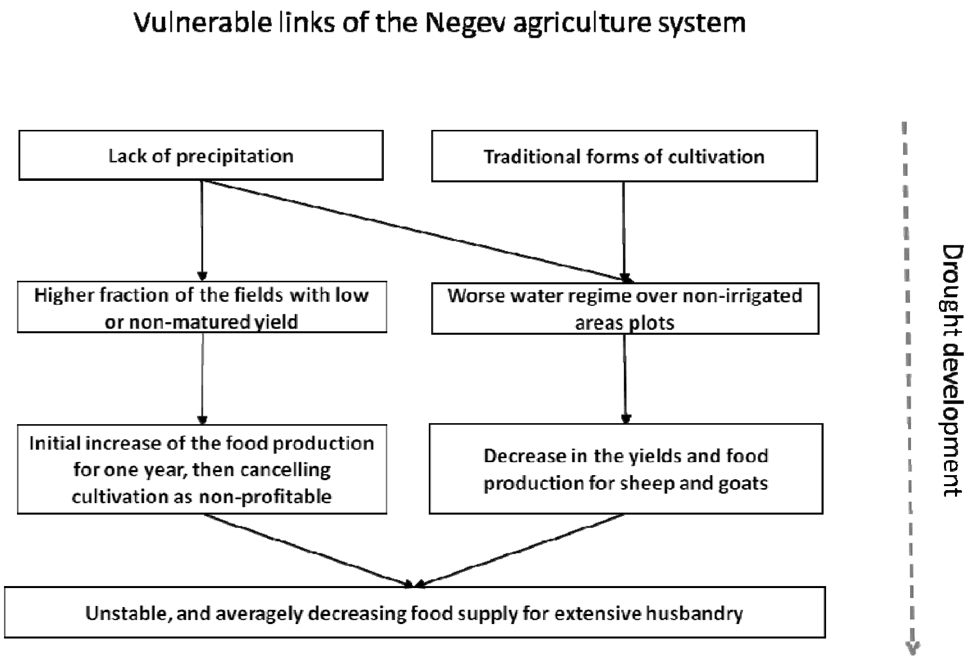


Figure 7: Vulnerable to drought relations between the compartments of the Negev agriculture system

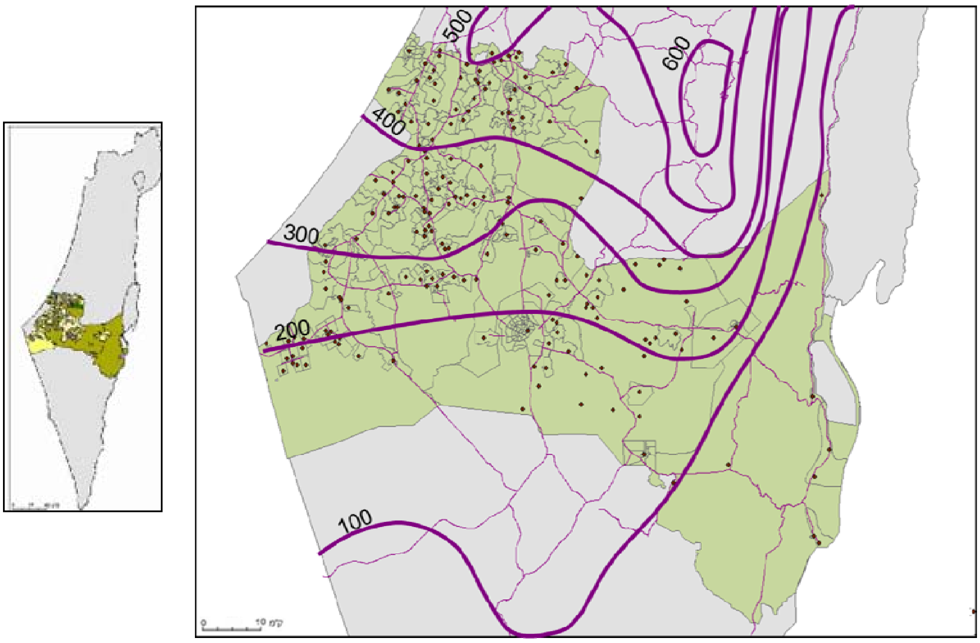
To estimate the hazards of the droughts in Negev until now and to forecast the Negev's vulnerability for the next ten years we have developed the dynamics model of Negev's agriculture. The model accounts for the factors of vulnerability and aforementioned relationships based on the scores presented in the vulnerability matrices 1 to 4. The model includes the factors that have the highest hierarchical value (score 1 in the tables) Even for these factors collecting the data and estimating their relationships demands essential and long-term work. The ENSURE project made it possible to properly estimate the influence of the majority of the factors that determine Negev's territorial vulnerability.

4.3 Model formulation

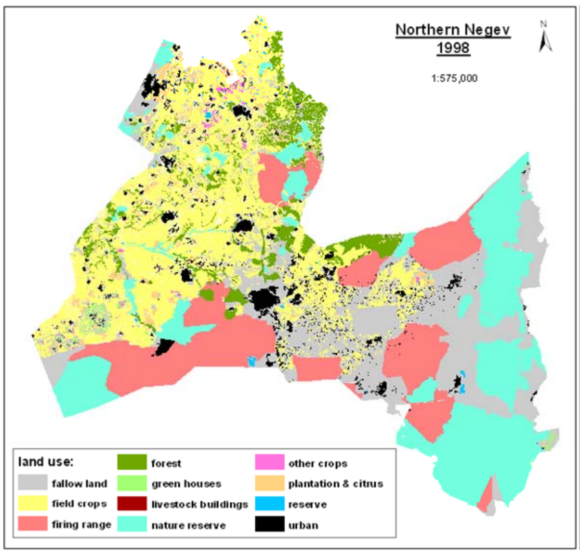
4.3.1 Model area

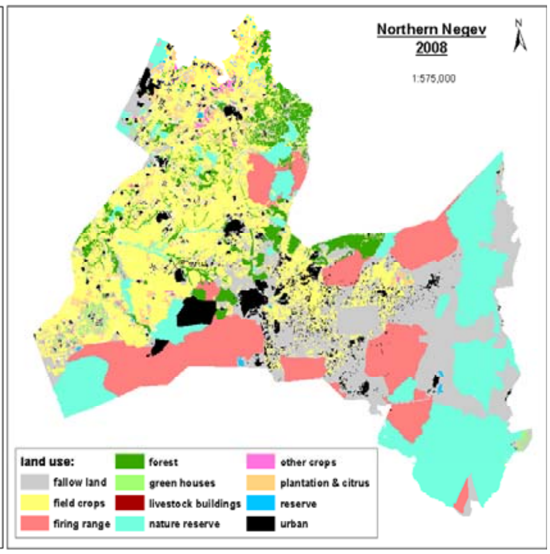
Figure 8 presents the Negev's area and the major land-uses there. The majority of the area is used for crops and pastry, thus confirming the importance of the relationships between Jewish and Bedouin farmers. Note that the precipitation in the area varies from 500 to the minimal possible for agriculture level of 150 mm. According to the agriculture maps in Figure 8 even some very southern part of the area is used for cultivation, mostly in the greenhouses. In the northern part essential part of the crops are grown in the open and non-irrigated fields.

The salient tendency of the Negev development is defined by the extremely high growth rate of the Bedouin population. Currently, it is close to 5% per year (ICBS, 2010) - such a rate would lead to the duplication of population numbers in ~15 years. Bedouin's population growth rate remains high during last 20-30 years at least. The majority of the young generation does not participate in agriculture. They either leave Bedouin towns for Beer Shaba and other large Israeli cities or stay in the Bedouin city of their origin finding jobs in the blue-color industry, as building construction or services. However, high population rates result in complete use of the capacity of traditional jobs, first and foremost of the pastry area.



(a)





(b) (c)

Figure 8: The major land-uses in the Negev (a) and the location of the agriculture settlements and long-term level of precipitation over the area in 1998 (b) and 2008 (c)

4.3.2 Governmental actions during the last 20 years

During last two decades, Israeli government undertook several important initiatives that determined the development of the irrigation system in the Negev. The main of these actions are establishing water quotas for farmers; directing purified wastewater from the north to Negev and within the Negev from Bedouin settlements to Jewish settlements; demarcation of the "drought line" and guaranteed return of expenses in case of drought for the farmers living below this line (long-standing policy, from the 1950s on).

Large-scale map in Figure 8b and Figure 8c do not allow visual recognition of the major tendency of the agriculture dynamics in the Negev – the growth of the irrigation network over the Jewish agriculture lands there. Table 6 and Figure 9 present the data on the development of the irrigation network in the Kibbutzim, which possess about 23% of the entire cultivated area in the Negev, about 31,500 of 140,000 ha, obtained from the Israeli Ministry of Agriculture. Similar tendency is characteristic for the Moshavim, but the statistics for this second group of the Jewish agriculture settlements is not available. During our field trips in the Negev in 2009 – 2010 we have observed some initial attempts of irrigation over the Bedouin owned fields, but we do not know the extent of this phenomenon.

Table 6: The dynamics of irrigation network in the Negev Kibbutzim

	Year											
Land-use	1990		1994		1998		2002		2006		2010	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Irrigated	17,960	57	18,795	60	20,167	64	20,938	67	21,919	70	22,377	71
Non-irrigated	13,429	43	12,594	40	11,221	36	10,450	33	9,470	30	9,012	29
Total	31,389	100	31,389	100	31,389	100	31,389	100	31,389	100	31,389	100

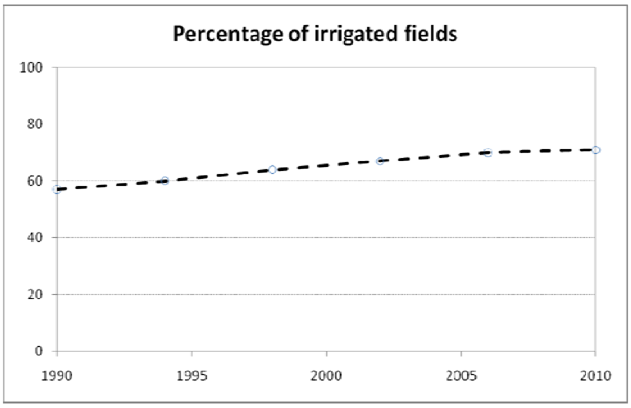


Figure 9: Overall view of the development of irrigation in the Negev during 1990 – 2010. The average rate of growth of the irrigated area in the Negev is ~ 1% a year

4.4 Major objects and agents of the Negev territorial system

We develop the model of Negev territorial system based on the Geo-simulation approach (Benenson, Torrens, 2004). The components of the Negev systems – lands, population, constructions, networks – all are considered as consisting of the objects. The objects (e.g., agriculture fields) are characterized by several attributes and, often, location. Agents (e.g., farmer) are those of the objects that behave – make decisions regarding themselves and other objects. In what follows the list of the objects and agents considered in the Negev model.

We use the following presentation format **Object name** (Attribute1, Attribute 2, ...):

4.4.1 Objects and agents that determine Negev agriculture

Objects and their characteristics:

- **Agriculture plots** (soil moisture, soil type, irrigated/none-irrigated);
- **Crops** (length of growing season, economical revenue);

Land-Use Agents and their characteristics:

- **Jewish settlements and farmers** (economic state, specialization, water quote, property rights)
- **Bedouin farmers and families** (family size, herd size, economic state, property rights);

Institutional Agent:

- **Water supply company** (amount of water to manage);
- **Regional land-use administration** (amount of the legal rights that can be allocated/reallocated)

4.4.2 Spatio-temporal actions and interactions of the Negev agents

Interaction between Land-Use Agents: Jewish and Bedouin farmers compete for lands, while cooperatively exploit agriculture production

Interactions between Institutional Agents and Land-Use Agents: Water supply policy and land-use policy is defined by the institutional agents for the land-use agents. Land-use agents accept and follow this policy fully or partially.

4.5 Drought threats and consequences as implemented in the model

Table 7: Drought threats and social economic consequences as implemented in the model

Consequences	Threat
Decrease in soil fertility and crop production; Reduction in rangelands for modern and nomadic herds.	Decrease in precipitation or water supply
Growth of non-agriculture areas; Sheep overgrazing; Erosion and land degradation	Overexploitation or overpopulation

Potentially vulnerable to drought components of the Negev territorial system and their adaptive and coping capacity are as follows:

Aspects of socio-economic vulnerability to drought: Lower level of economic cooperation between Jewish and Bedouin agriculture populations, stronger competition for water and lands for crops and grazing; the income of the Bedouins agriculture population decreases, unemployment increases; Bedouins agriculture population migrates to the cities

Resilience to droughts is achieved by the style of agriculture that loosely, if ever, depends on the level of precipitation. Main factors of coping capacity to droughts are high technical skills of the Jewish farmers and high mobility of the Bedouin population; developing new sources of water, adapting new cultivation techniques by Jewish farmers and replacing extensive sheep raising with intensive raising by the Bedouin farmers.

It is important to note that the drought's effects depend on: (a) water supply and precipitation; (b) past and present crops; (c) style of the agriculture; (d) type of soils; (e) micro-topography.

Agriculture land-use dynamics is a driving force of the model. It is simulated at resolution of a single field (Figure 10) assuming natural variation in precipitation in space and in time. The results are simulated for every location, depending on average precipitation and precipitation variation at a certain location in the Negev

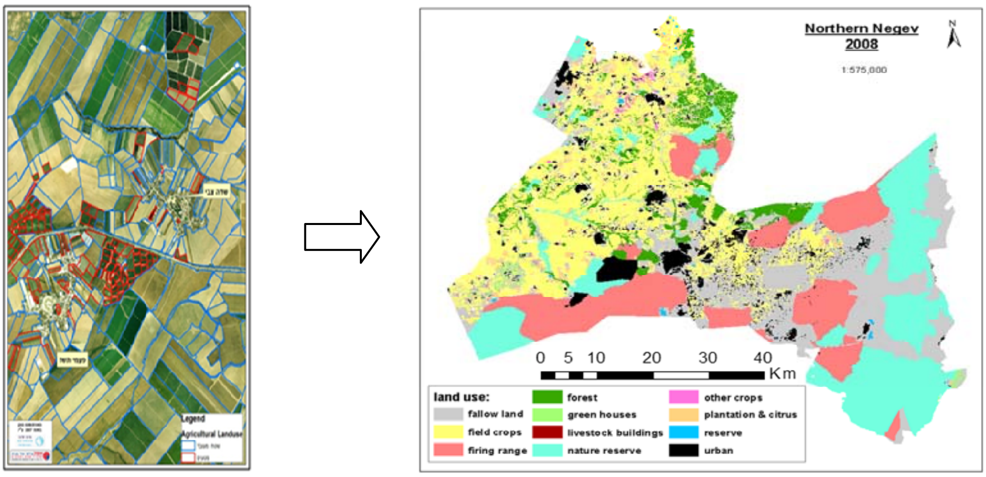


Figure 10: From high-resolution dynamics of crops in the fields to the vulnerability of the Negev's territorial system

4.5.1 The effects of drought on the model objects:

The droughts influence each one of the key agents of the Negev territorial system

Land units:

- *Agriculture plots* – decrease of the soil moisture in the open fields;
- *Crops in the open fields* – lower yield
- *Irrigated fields and crops there* – no effect

Land-Use Agents:

- *Jewish settlements and farmers* – increase in the water demand;
- *Bedouin farmers and families* – increase in the water demand, decrease in herds' food supply

Institutional Agent:

- *Water supply company* – increased water demand, pipeline network growth, conflicts between users
- *Regional land-use administration* – conflicts between land users

4.5.2 Scenarios as a tool for investigating Negev vulnerability to droughts

The vulnerability of Negev territorial system to drought depends on our forecast of the drought development. As we have already mentioned, the forecast is very uncertain. That is why we investigate the issue based on scenarios. The major parameter of the scenarios is the development of the irrigation system in the Negev. The scenarios that we consider regard not only the future of the system but also its past and cover the 30-year interval of 1990 – 2020. We consider extreme cases of the "constant decrease in precipitation" versus "no drought at all", and of "no irrigation" versus "100% irrigation" and several other scenarios. The scenarios enable estimation of the limits of the Negev vulnerability in the "worst" and "best" case and estimate the quantitative reaction of the system vulnerability on the intensity of drought and mitigation measures in case the Negev is under reasonable but continuous stress of droughts. As the example of the approach, let us consider two scenarios and their consequences:

- "**Constant decrease in precipitation" and "Irrigation system is not developing"**

The consequences: (a) lack of precipitation and (b) the irrigation system is underdeveloped. Jewish farmers abandon the area and it becomes available for the Bedouins' herds. Initially, the number of sheep grows but then the system enters a period of food shortage for the sheep. In this case emigration of the Bedouin population will take place unless drastic actions will be taken by the state, namely, essential support of the unproductive husbandry by supplying food and water for the sheep will be provided. These investments would be higher than the investments needed for a long-term investment in an irrigation system

- "**Constant decrease in precipitation" and "Irrigation system in the Jewish settlements is in steady development"**

Droughts enforce intensification of the irrigation in the Jewish agricultural settlements. Non-irrigated areas, used for wheat cultivation are reduced and, thus, the supply of the local food for the sheep may decline. However the irrigated vegetables cannot be grown every year. The productivity of the wheat and barley grown on the irrigated plots after the years of irrigation is essentially higher than in the rain-fed plots. This surplus of the yield compensate for the overall decline in the area used for the cultivation of wheat and barley. Bedouin husbandry can be thus stabilized and the state investments should be focused on the transition from extensive use of free grazing to the intensive husbandry in enclosures.

The investigated scenarios will be presented below, after the presentation of the model itself.

4.6 Presentation of the model temporal dynamics at the inter-year steps

In the model, we consider the dynamics of the Negev territorial system in years. Within a year, we consider three time steps, each characterized by different agriculture conditions and activities (Figure 11). These periods are determined by Jewish horticulture and explained in details in Section 1 of the report:

- Winter: October - February, first period of crop growth, defines seeds maturation;
- Spring: March - May, second period of crop growth, defines crop growth and yield;
- Summer: June – September, Summer crops (water melon) growth and maturation in case of sufficient precipitation.

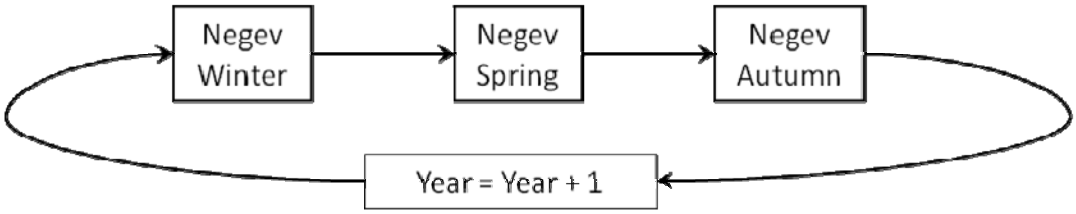


Figure 11: Principal view of the Negev territorial system dynamics as implemented in the model.

For each of the periods, we have sufficient data for describing Jewish farmers' activities and crop dynamics.

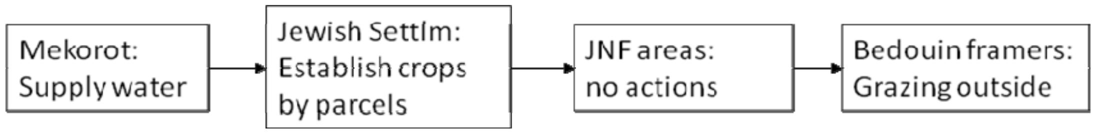
As presented in Section 1, Bedouins' husbandry has four periods of activity during a year:

- February – March: Following annual germination, the Bedouins herds graze in open fields/JNF forests;
- April – May: Grazing on crops, mainly barely, of the Bedouin farmers;
- June – September: Grazing on wheat fields of the Jewish farmers, right after the harvest (straw and grains left in the fields);
- October – January: Staying at residency, feed on straw and grain purchased from the Jewish farmers

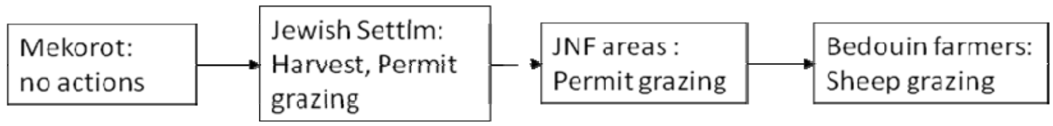
One can easily note that the longest open-field grazing is taking place at the Jewish fields. That is why we base our partition of the year into periods that are defined by the Jewish agriculture. Indeed, the change in the cultivation practice of the Jewish farmers may strongly affect this grazing schedule

4.6.1 The major processes that occur during each of the annual steps

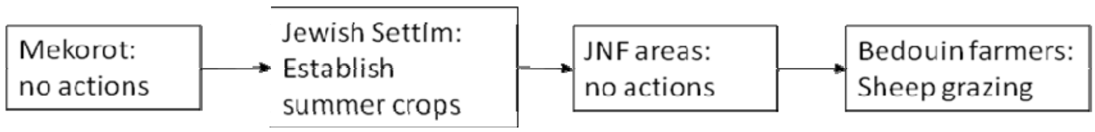
The activities of the model agents happening during each of three inter-year steps are presented in Figure 12. As one can see, we start with the activities of the Mekorot actor, who determines water supply over the entire area, proceed with the activities of the Jewish farmers and then simulate the activities of the Bedouin farmers. Each of the behaviors is parameterized and these parameters define, quantitatively, the dynamics of the model of Negev territorial system.



(a) Winter



(b) Spring



(c) Summer

Figure 12: Agents' activities during each of three yearly time steps: Winter (a), Spring (b) and Summer (c).

4.6.2 Crop dynamics and sheep food production in the Jewish farms

After the water quote is determined, Jewish and Bedouin farmers can decide which crop to grow during the year. The decision on the plot crop is, evidently, determined by the existence of an irrigation system. Irrigated plots are used first and foremost for cultivating potatoes and vegetables. During the last 20 years, potatoes and vegetables are the most profitable crops in Negev and expected to remain most profitable for at least the next decade. Potatoes and vegetables are cultivated in the winter mainly for export and cannot be cultivated without irrigation. Critical for the model is the fact that potatoes, the most profitable crop, cannot be grown on the same plot more than once in five years. This limitation defines the sequence of crops at all irrigated plots:

Irrigated plots undergo therefore a five-year crop cycle. This cycle starts from the potatoes and involved the growth of another kind of irrigated crop, usually on the third or the fourth year. During the rest of the years the plot is used for the non-irrigated cultivation of wheat or legumes. Typical sequence of crops on the irrigated plot is

Potato → Wheat → Carrot → Wheat → Wheat → Potato → ....

Non-irrigated plots undergo a 3-year cycle. Most of the years, wheat is cultivated there, while sometimes the wheat is substituted by the legumes, as, for example,

Wheat → Wheat → Legumes → Wheat → ...

To construct the crop sequences on the plots we based our model on data obtained from two Jewish kibbutzim, Beit Kama and Mishmar HaNegev, during last 20 years. The data were obtained from the kibbutz's agricultural supervisor and were sufficient for constructing Markov model of the crop sequence. To estimate model parameters we employ logit loglinear model (Agresti, 2002). In respect to the duration of the crop cycle we have chosen 5-year delay of the Markov model for the irrigated plots and three-year delay for the non-irrigated plots. The outputs of the logit loglinear model are two Markov models, for non-irrigated and irrigated plots, with 2- and 5-year delay that describes change of the crops in the plots. The Markov model for the irrigated crops has two-levels. At the first level we define whether the next year vegetable cultivation will be in two or in three years and then, at the second level, we define what would be the crops during the next two or three years. That is why we can present the transition probabilities for two years only.

Let us denote potatoes as P, vegetables as V, Legumes (mostly peas and clover) as L wheat and barley as W. Table 8 presents the probabilities of substitution of one crop by the other for the non-irrigated plot and Table 9 presents the probabilities of substituting one crop by the other for the irrigated plots.

Table 8: Probabilities of substitution for the non-irrigated plots

Non-irrigated plots			
Probability to get the crop at t + 1		Crop sequence last 2 years	
p(L)	p(W)	t	t-1
0.468	0.354	W	W
0	1.000	L	W
0.064	0.779	W	L

Table 9: Probabilities of substitution for the irrigated plots

Irrigated plots					
Probability to get the crop at t + 1				Crop sequence last 2 years	
p(V)	p(P)	p(L)	p(W)	t	t-1
0.180	-	0.468	0.354	W	W
0.091	-	-	0.909	L	W
0.146	-	-	0.854	P	W
0.216	-	0.119	0.665	V	W
0.157	-	0.064	0.779	W	L
-	-	-	-	L	L
0.064	-	-	0.936	P	L
0.114	-	0.010	0.876	V	L
0.228	-	0.066	0.706	W	P
-	-	-	-	L	P
0.099	-	-	0.902	P	P
0.171	-	0.010	0.819	V	P
0.413	-	0.121	0.466	W	V
0.150	-	-	0.850	L	V
0.232	-	-	0.768	P	V
0.356	-	0.022	0.622	V	V

The wheat yield and the amount of the hay/straw remaining in the field are estimated based on amount of precipitation and the number of years that passed after the last irrigation on the plot. Roughly, at an irrigated plot, a year after irrigation the wheat yield is duplicated and two years after the irrigation the yield is 25% higher than at a non-irrigated plot.

4.7 Implementation of the model

The general model flow chart is presented in Figure 13 and the rules of the yield calculation are presented in Figure 14. The model is implemented within the ArcGIS 10 environment. We construct the general model skeleton with ArcGIS model builder and then implement agents' decision-making rules as the VB scripts of the model blocks, see example in Figure 15.

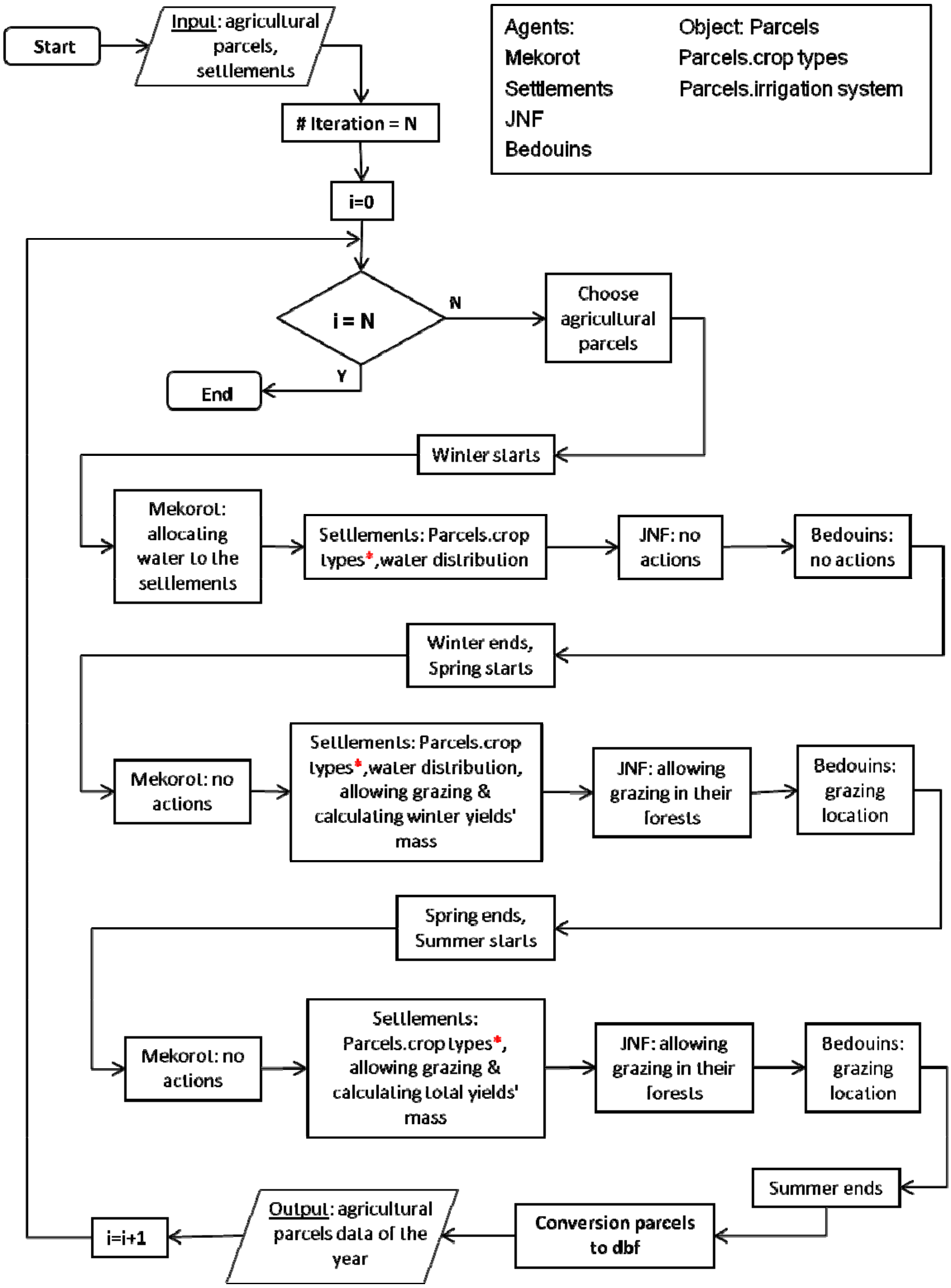


Figure 13: Negev model flow general chart

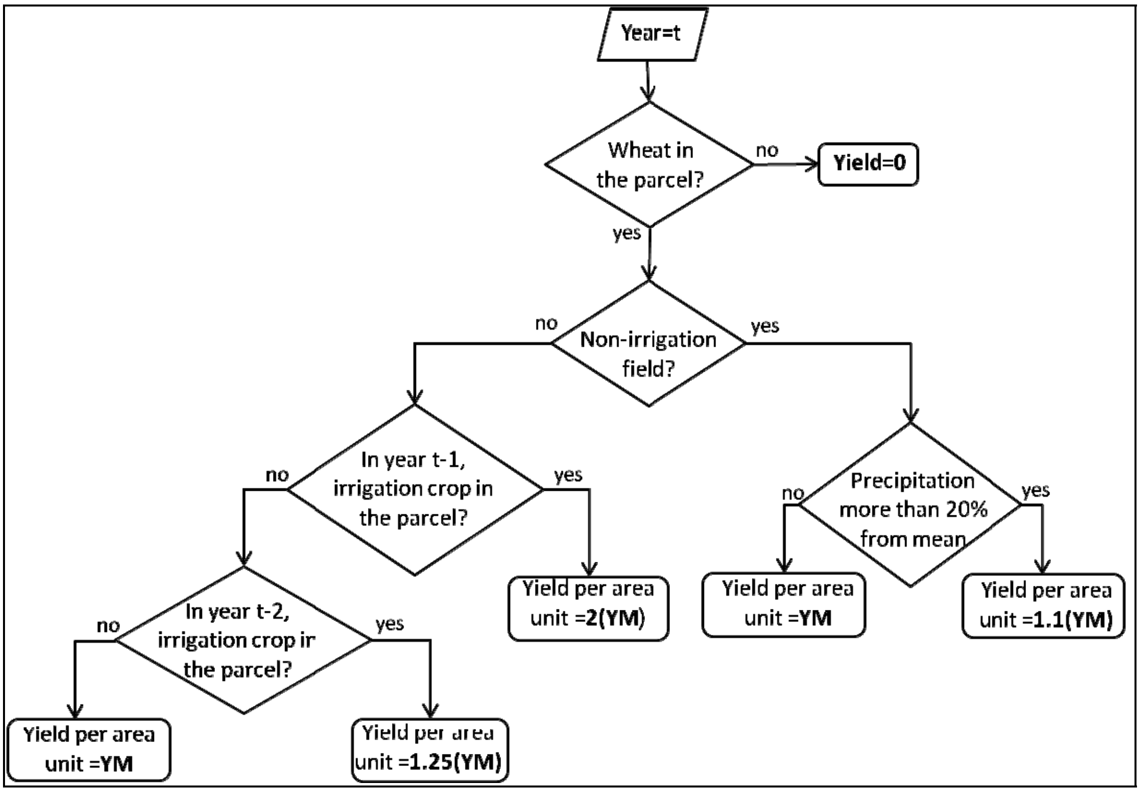


Figure 14: The rules of plot yield calculations in the Negev model

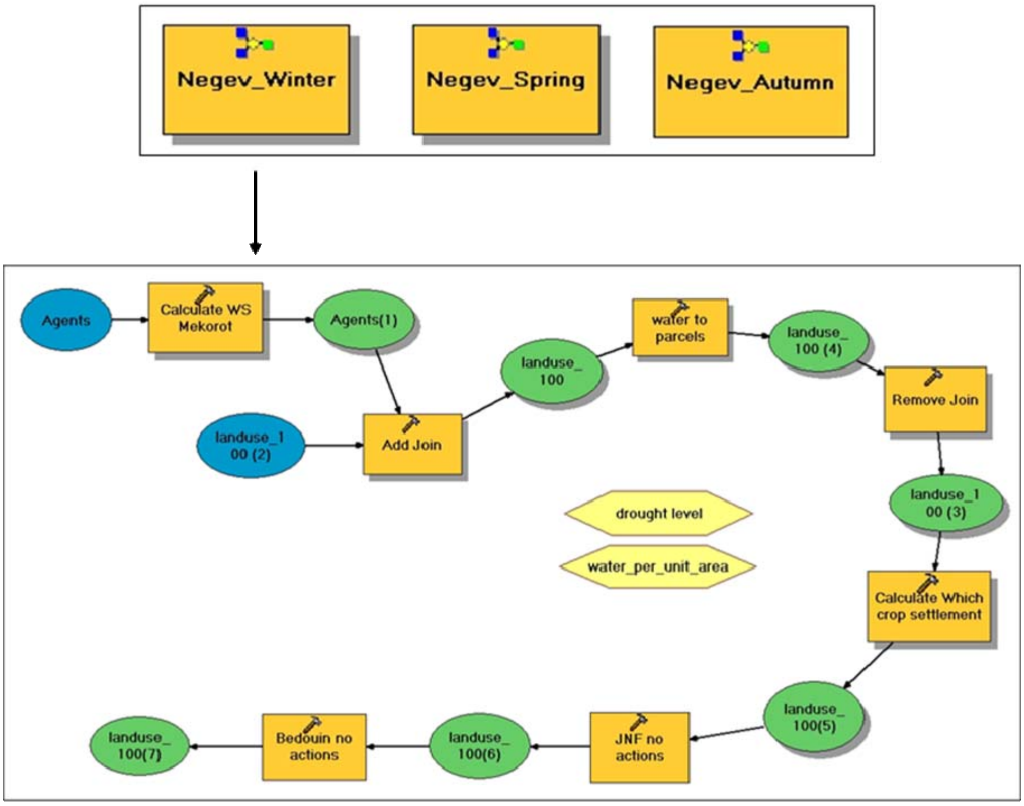


Figure 15: The example of the Negev model block as implemented with the ArcGIS 10 model builder

The model scenarios define the drought conditions and the development of the irrigation system for the 30-year period of 1990 – 2020 and then the model generates sequences of crops for every plot of the Jewish settlements that are chosen for analysis. The model employed for several Jewish settlements differs in respect to their location in the Negev, i.e. the amount of the rains registered there. These settlements are chosen uniformly covering the Negev's area and, thus, possible dynamics of the yields are obtained for the entire range of the precipitation variation. Then, the results are interpolated for the rest of the settlements in order to obtain vulnerability maps of the Negev agriculture.

4.8 Study of the model scenarios

Several assumptions regarding the development of the irrigation system in Negev are employed in the model. The dynamics of the irrigation for each of the assumed scenarios during the period of 1990- 2020 are presented in Figure 16. Eight investigated scenarios are based on the possible ways of irrigation system development and are presented in Table 10.

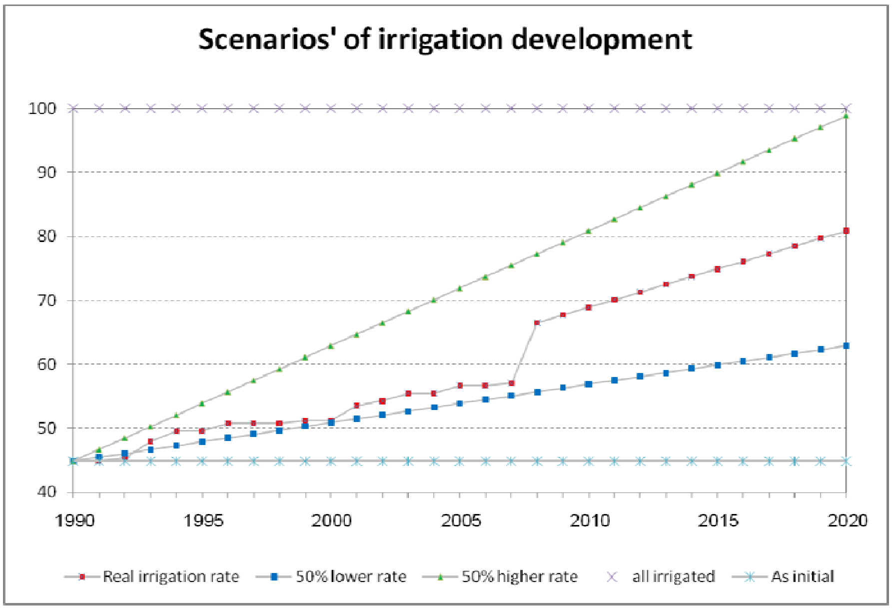


Figure 16: Five possible assumption in regards to the development of Negev's irrigation system. One more scenario considers zero level of irrigation

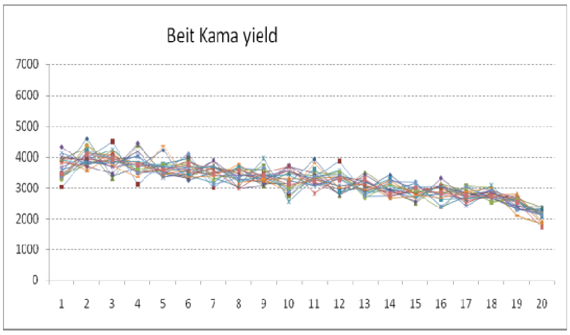
Table 10: Investigated scenarios and their names

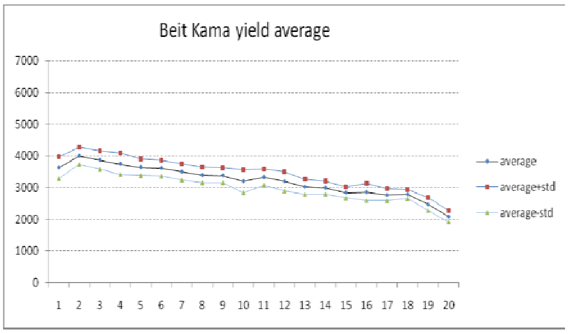
<table>
<tr><th colspan="2" rowspan="2">Investigated scenarios and their names</th><th colspan="2">Precipitation</th></tr>
<tr><th>Average precipitation for the years 1970 – 1990 is applied to the entire period of 1990 – 2020</th><th>Real-world decrease in precipitation estimated for 1990 – 2010. The rate of decrease is 5-10 mm/year and is applied to the entire period of 1990 - 2020</th></tr>
<tr><td rowspan="6">Irrigation</td><td>No irrigation</td><td>NoIr-AvP</td><td>NoIr-RP</td></tr>
<tr><td>100% of plots are irrigated starting from 1990</td><td>AllIr-AvP</td><td>AllIr-RP</td></tr>
<tr><td>Real irrigation in 1990, zero rate of irrigation network development</td><td>ZeroIr-AvP</td><td>ZeroIr-RP</td></tr>
<tr><td>Real irrigation in 1990, real</td><td>RealIr-AvP</td><td>RealIr-RP</td></tr>
<tr><td>Real irrigation in 1990, the rate of irrigation network development is 50% of the real rate</td><td>Not investigated</td><td>RealIr-RP050</td></tr>
<tr><td>Real irrigation in 1990, the rate of irrigation network development is 150% of the real-world date</td><td>Not investigated</td><td>RealIr-RP150</td></tr>
</table>

4.8.1 The influence of the random variation of precipitation on the model outcomes

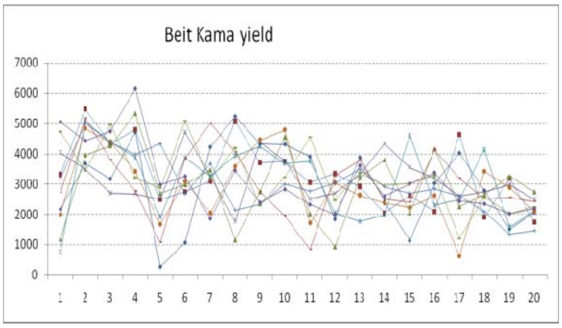
It is important to note that to reflect the space-time stochastic variation of the weather conditions, in both cases of constant and decreasing precipitation, the actual amount of precipitation is generated as an average precipitation calculated according to the linear regression plus the random error. In what follows, according to the existing data on the variation of precipitation in years, we assume that the random variation is 30% of the average for that year. We employ Monte-Carlo repetitions for estimating the influence of the random fluctuations of the weather, i.e., of precipitation, on the model outcomes

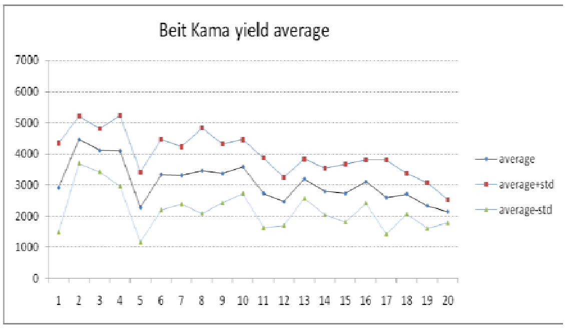
Random fluctuation of precipitation leads to essential variation of the model results. Figure 17a and Figure 17b present the outcome of the model (20 Monte-Carlo repetitions) for the crop sequence that follows Markov logit loglinear model (see Table 8Table 9 for transition probabilities) as applied to the kibbutz Beit Kama, given *there is no random variation* of the weather conditions. In reality, the random variation of precipitation is estimated as 30% of the average precipitation in a year. As can see, in this case, random fluctuations of the weather are responsible for the 80% of the random fluctuation of the model outputs (Figure 17c and Figure 17d). It is important to note that because of the non-linear effects in the model, random fluctuations also influence the averages yields obtained in the model.





(a) (b)





(c) (d)

Figure 17: The effects of the random variation of the weather conditions on the model outcomes. Twenty model trajectories for the case of zero variation of the precipitation (a); average and STD of these trajectories (b); twenty model trajectories for the case of 30% variation of the precipitation (c); average and STD of these trajectories (d);

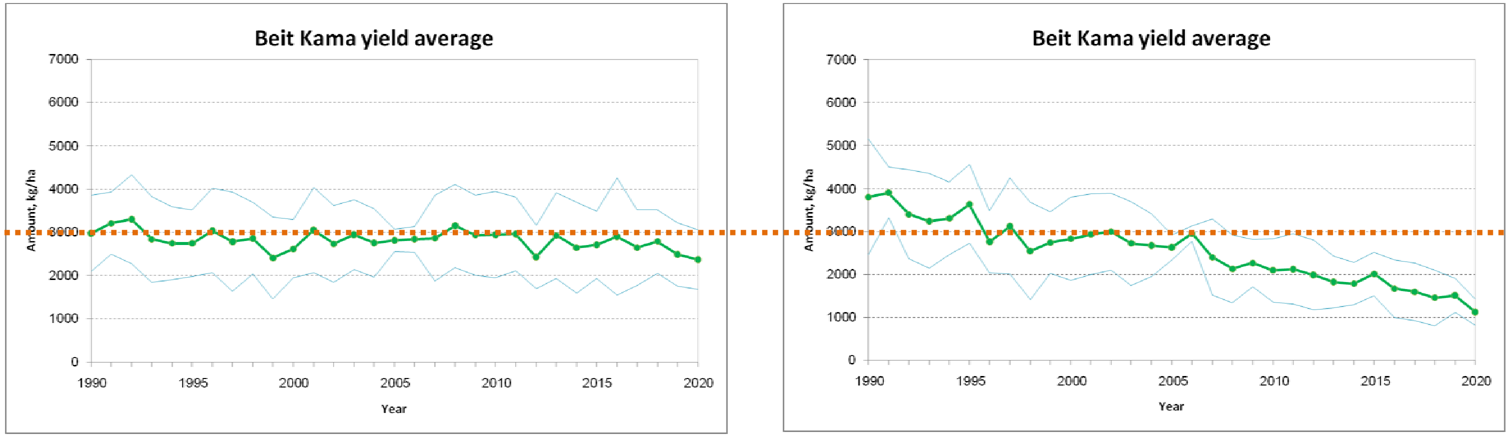
4.8.2 Agriculture dynamics in the Northern part of the Negev

The northern part of the Negev is characterized by long –term precipitation average of 300-350 mm. Figure 18-Figure 22 present the scenario outcomes and figure captions shortly characterize the influence of the assumed level of irrigation and precipitation on the dynamics of the wheat yield in Beit Kama, agriculture settlement in the Northern Negev located at the isohyet of ~300 mm. As we presented above, in case of grain maturation, the production of the sheep food is about 20% of the wheat yield. No matter what is the scenario, the level of precipitation in the Northern Negev is always sufficient for the grain maturation and, thus, the yield fully characterizes the amount of the food production.

Table 11 shortly characterizes one of the major aspects of the Negev vulnerability to drought – the level of yield in relation to the "persistent" level of 2.7 ton/ha that the territorial system has adapted to during last 30-40 years of existence. As it can be observed, in the most probable scenario RealIr-RP, in which the rate of the development of irrigation system is at a current level of 1% per year and the drought continues to develop, the 2010 yield in the Northern Negev is still close to the persistence level of 2010, while decreases about 20% towards 2020. Reasonable 50% increase in the rate of the irrigation network development may preserve the yields at a persistent level until 2020, the very end of the period of the climate forecast.

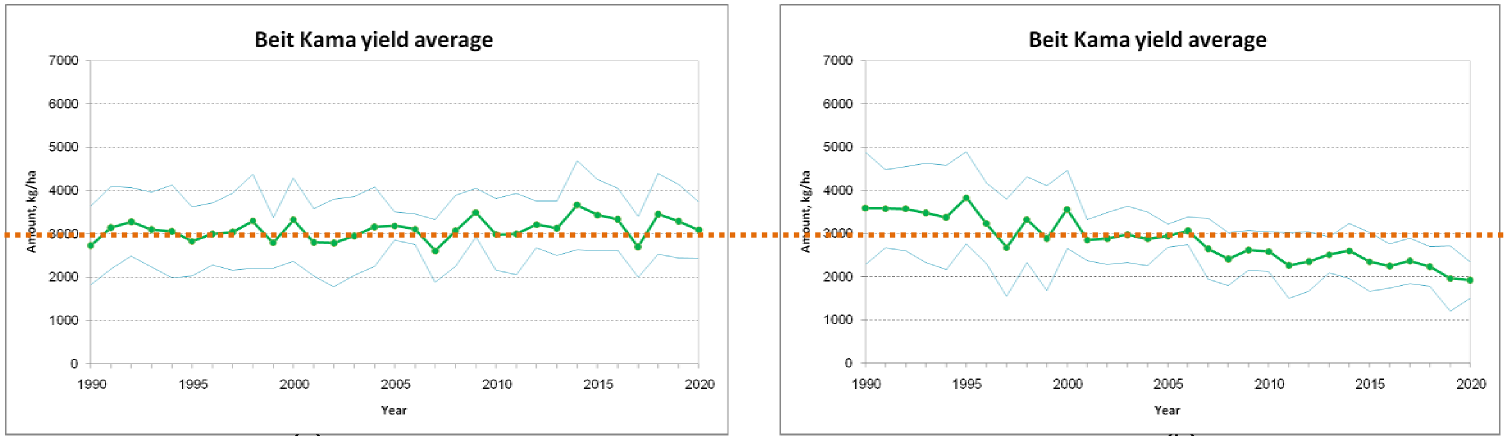
Table 11: The wheat yield in the north of Negev, where the level characteristic for the stable conditions is 2.2 t/ha towards 2010 and 2020 as obtained for the different scenarios of drought and irrigation development

<table>
<tr><th colspan="6">Wheat yield in the north of Negev</th></tr>
<tr><th colspan="2" rowspan="3"></th><th colspan="4">Precipitation</th></tr>
<tr><th colspan="2">Average for 1970 -1990</th><th colspan="2">Real-world decrease</th></tr>
<tr><th>2010</th><th>2020</th><th>2010</th><th>2020</th></tr>
<tr><th rowspan="6">Irrigation</th><td>No irrigation</td><td colspan="2">2.711</td><td>2.104</td><td>1.129</td></tr>
<tr><td>Zero irrigated</td><td colspan="2">2.881</td><td>2.375</td><td>1.314</td></tr>
<tr><td>All Irrigated</td><td colspan="2">3.623</td><td>3.018</td><td>2.496</td></tr>
<tr><td>Real irrigation</td><td>2.987</td><td>3.089</td><td>2.583</td><td>1.923</td></tr>
<tr><td>50% of Real irrigation</td><td>-</td><td>-</td><td>2.559</td><td>1.616</td></tr>
<tr><td>150% of Real irrigation</td><td>-</td><td>-</td><td>2.771</td><td>2.693</td></tr>
</table>



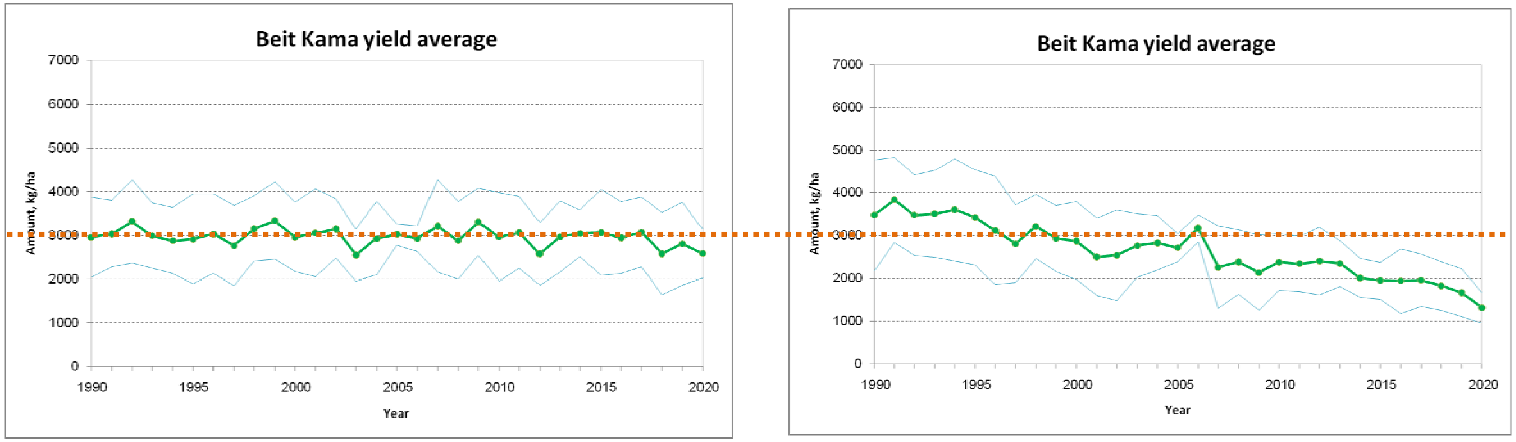
(a) (b)

Figure 18: NN, no irrigation: (a) precipitation at the average level (NoIr-AvP), (b) real drought of 1990 - 2010 (NoIr-RP). Without the irrigation system, drought results in more than double decrease in the yield



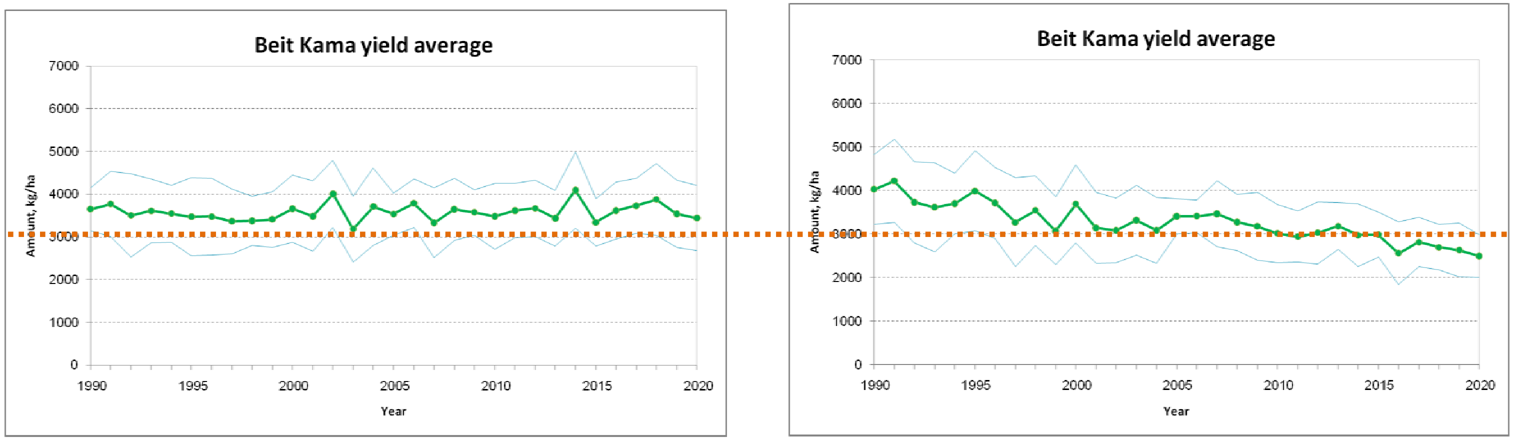
(a) (b)

Figure 19: NN, Real irrigation development (a) precipitation at the average level (RealIr-AvP), (b) real drought of 1990 - 2010 (RealIr-RP). Despite exclusion 40% of the area from wheat production, irrigation results in increase of the wheat yield 20% in case of no-drought or preserve the yield until 2010. In 2020 the yield would drop 20%



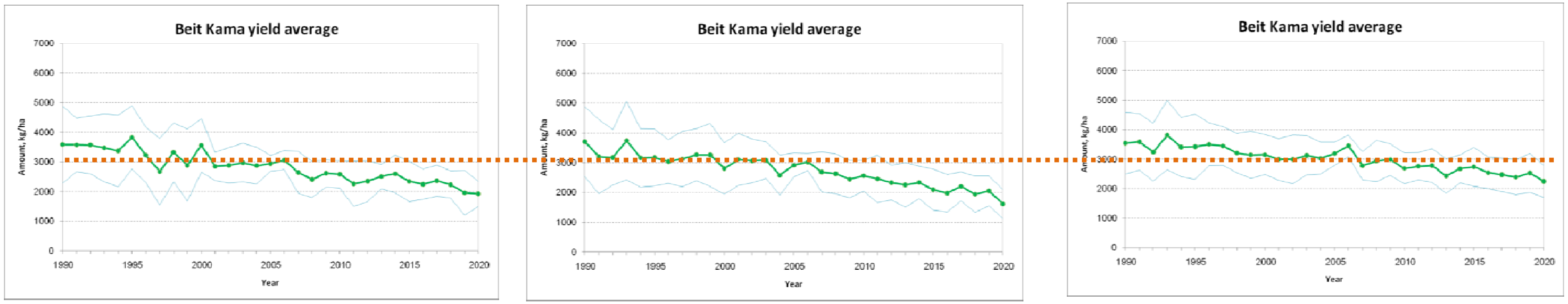
(a) (b)

Figure 20: NN, Fixed irrigation of 1990 (a) precipitation at the average level (ZeroIr-AvP), (b) real drought of 1990 - 2010 (ZeroIr-RP)
Fixed irrigation could be sufficient if the drought would not develop after 2010. After that, towards 2020, the decline in the yield is essential



(a) (b)

Figure 21: NN, 100% irrigated from 1990 (a) precipitation at the average level (AllIr-AvP), (b) real drought of 1990 - 2010 (AllIr-RP)
If all the areas in the northern Negev are irrigated then the drought, even if continues to develop at the current rate, does not harm the system



(a) (b) (c)

Figure 22: Yield dynamics in the northern Negev in case of the current rate of the irrigation system development equal to 1% (RealIr-RP) (a) and in the case of annual rate of 0.5% (RealIr-RP050) (b) and 1.5% (RealIr-RP150) (c)

Figure 23 presents comparison of the scenarios in terms of the sheep food supplied in the northern part of the Negev. As one can see, the year of 2010 demarcates the end of the period of unconditional robustness of the Negev territorial system there. From now on, if the precipitation would continue to decrease as it was during last 20 years, the system enters the domain the vulnerability. The comparison of the scenarios' results provided possible mitigation mechanisms, intensification of the irrigation at the first place and, then, transition from the traditional extensive to the intensive husbandry.

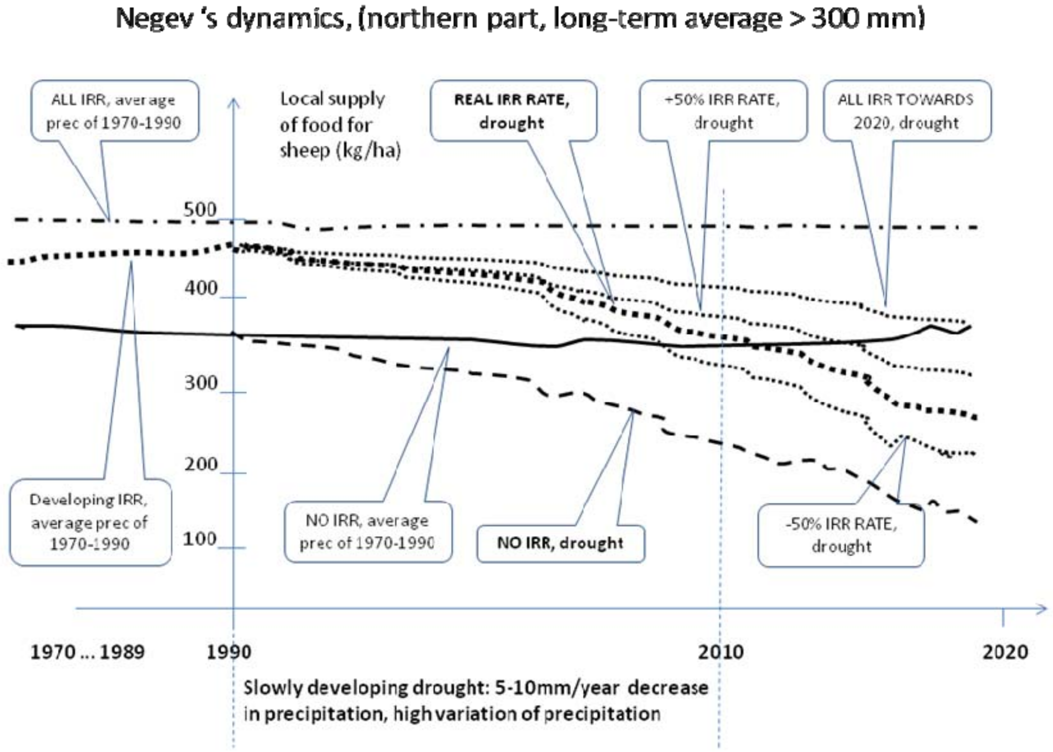


Figure 23: Development of the Negev territorial system in its northern part according to the different irrigation-precipitation scenarios as expressed through the sheep food supply.

Figure 24 presents the main model mechanisms that determine low vulnerability of the agriculture in the northern part of Negev to the droughts.

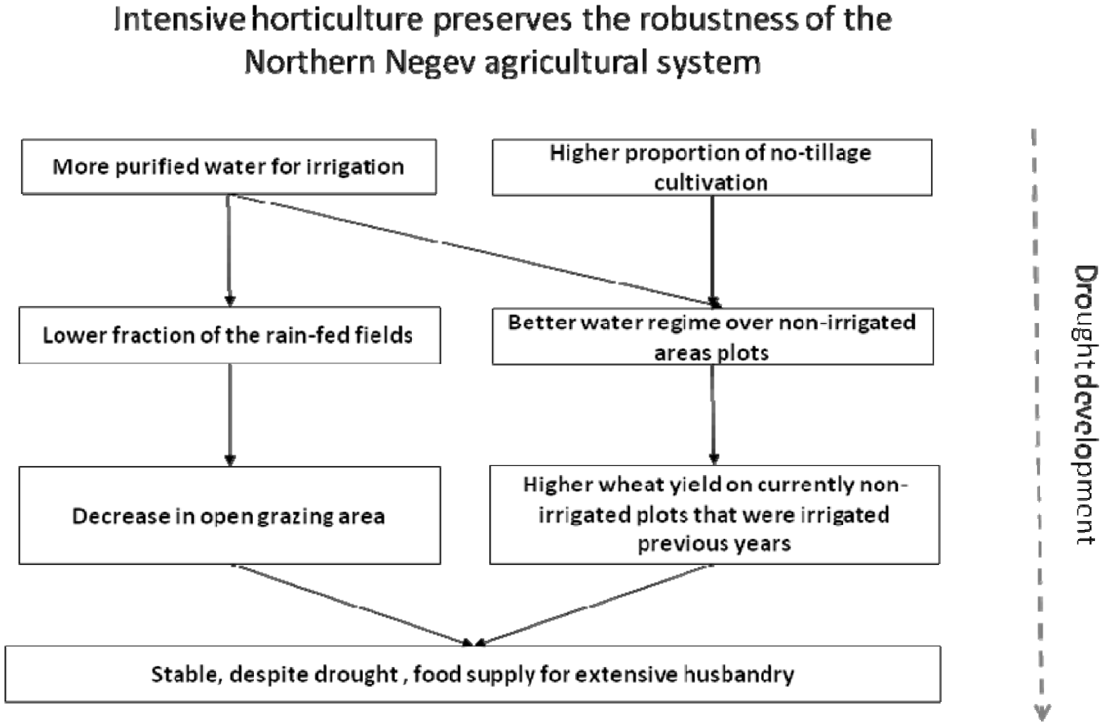


Figure 24: The major mechanism of the northern Negev robustness to drought

4.8.3 Agriculture dynamics in the southern part of the Negev

The southern part of the Negev is characterized by long –term precipitation average of about 200 mm. Figure 25-Figure 34 present the scenarios outcomes and figure captions indicate the influence of the assumed level of irrigation and precipitation on the dynamics of the wheat yield in Zeelim, agriculture settlement in the southern Negev. Two effects are qualitatively different in the southern part of Negev in comparison to the northern part. First, as long as the precipitation there declines, the influence of the decline on the yield is essentially stronger. Indeed the lower level of precipitation causes essentially lower residual soil moisture in the irrigated plots. The second effect is an essential increase in the probability of a year with "immature grain" during which the entire yield is used for feeding the sheep. This is not so in the northern part of the Negev, where the residual soil moisture sufficient enough to enable grain maturation.

Table 12 presents the level of yield in relation to the "persistent" level of 2.2 ton/ha that the territorial system has adapted to during last 30-40 years of existence. Table 13 presents the probability of a year of “immature grain”. As one can see, the most probable scenario RealIr-RP (the rate of the development of irrigation system is at a current level of 1% per year and the drought continues to develop), the 2010 yield in the southern Negev is about 10% lower than the level that could be expected in this year in 2010 in case of no-drought, while the decrease towards 2020 is about 20%. Combining this result with the 10-30% chance of a year with "immature grain" during 2010- 2020, we consider the most southern part of the Negev as becoming essentially vulnerable to the drought during the next decade in case the nowadays development continues until 2020. Immediate expansion of irrigation system to all wheat-producing areas (Figure 30) can reduce the vulnerability to a reasonable level of the 2010 in regards to the yield, but still results in essential probability (10-40%)

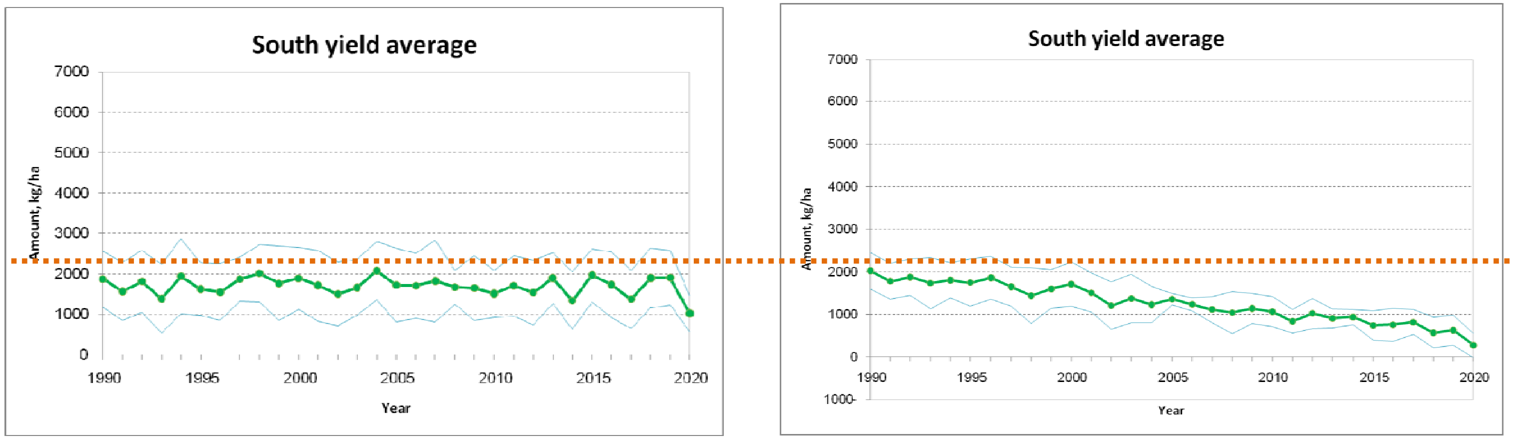
of the year with “immature grains”. The only way to mitigate the droughts in the southern Negev becomes, thus, exclusion of the sheep from the dependence on the local food supply and steady transformation of the extensive husbandry to intensive husbandry.

Table 12: Wheat yield in the south of Negev where the level characteristic for the stable conditions is 2.3 t/ha towards 2010 and 2020 as obtained for the different scenarios of drought and irrigation development

<table>
<tr><th colspan="6">Wheat yield in the south of Negev</th></tr>
<tr><th colspan="2" rowspan="3"></th><th colspan="4">Precipitation</th></tr>
<tr><th colspan="2">Average for 1970 -1990</th><th colspan="2">Real-world decrease</th></tr>
<tr><th>2010</th><th>2020</th><th>2010</th><th>2020</th></tr>
<tr><th rowspan="6">Irrigation</th><td>No irrigation</td><td colspan="2">1.624</td><td>1.063</td><td>0.28</td></tr>
<tr><td>Zero irrigated</td><td colspan="2">2.280</td><td>1.767</td><td>0.118</td></tr>
<tr><td>All irrigated</td><td colspan="2">2.851</td><td>2.281</td><td>1.665</td></tr>
<tr><td>Real irrigation</td><td>2.821</td><td>2.483</td><td>1.742</td><td>1.700</td></tr>
<tr><td>50% of Real irrigation</td><td>-</td><td>-</td><td>1.743</td><td>1.416</td></tr>
<tr><td>150% of Real irrigation</td><td>-</td><td>-</td><td>1.834</td><td>1.815</td></tr>
</table>

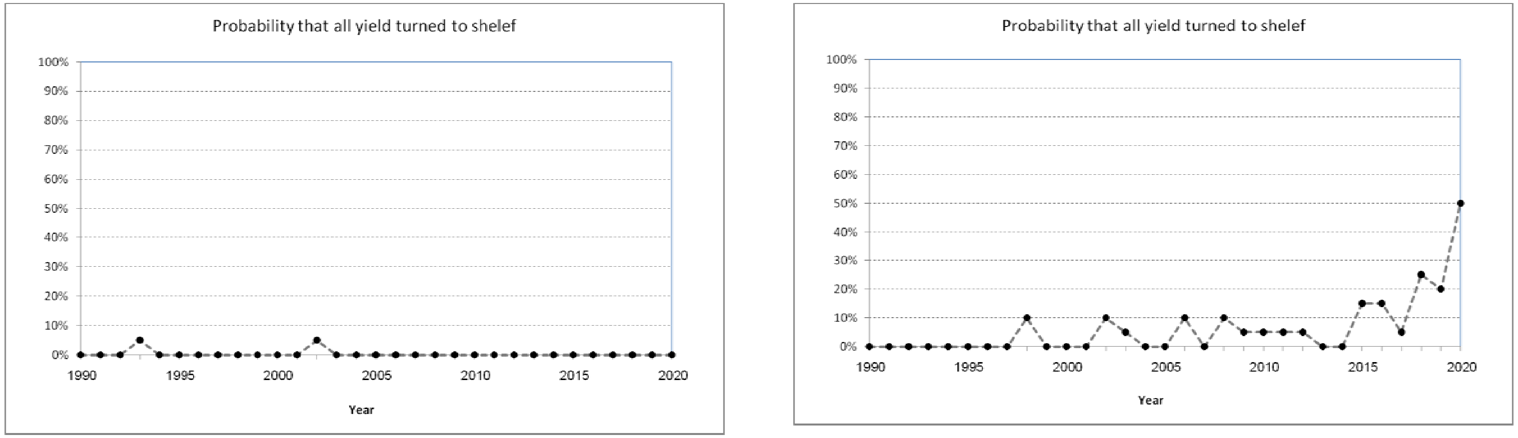
Table 13: Probability that the wheat will not reach maturation in the south of Negev in 2020 as obtained for the different scenarios of drought and irrigation development

<table>
<tr><th colspan="6">Probability that the wheat will not reach maturation in the south of Negev in 2020</th></tr>
<tr><th colspan="2" rowspan="3"></th><th colspan="4">Precipitation</th></tr>
<tr><th colspan="2">Average for 1970 -1990</th><th colspan="2">Real-world decrease</th></tr>
<tr><th>2010</th><th>2020</th><th>2010</th><th>2020</th></tr>
<tr><th rowspan="6">Irrigation</th><td>No irrigation</td><td colspan="2">0.00</td><td>0.05</td><td>0.05</td></tr>
<tr><td>Zero irrigated</td><td colspan="2">0.00</td><td>0.05</td><td>0.05</td></tr>
<tr><td>All irrigated</td><td colspan="2">0.00</td><td>0.00</td><td>0.40</td></tr>
<tr><td>Real irrigation</td><td>0.00</td><td>0.00</td><td>0.15</td><td>0.35</td></tr>
<tr><td>50% of Real irrigation</td><td>-</td><td>-</td><td>0.05</td><td>0.25</td></tr>
<tr><td>150% of Real irrigation</td><td>-</td><td>-</td><td>0.20</td><td>0.35</td></tr>
</table>



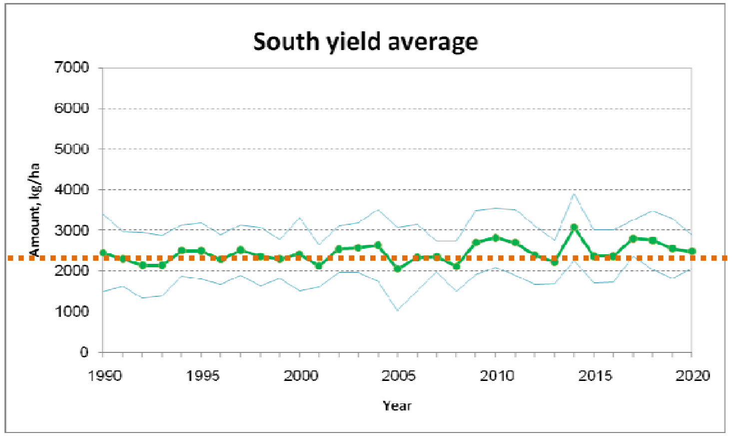
(a) (b)

Figure 25: SN, no irrigation (a) precipitation at the average level (NoIr-AvP), (b) real drought of 1990 - 2010 (NoIr-RP)

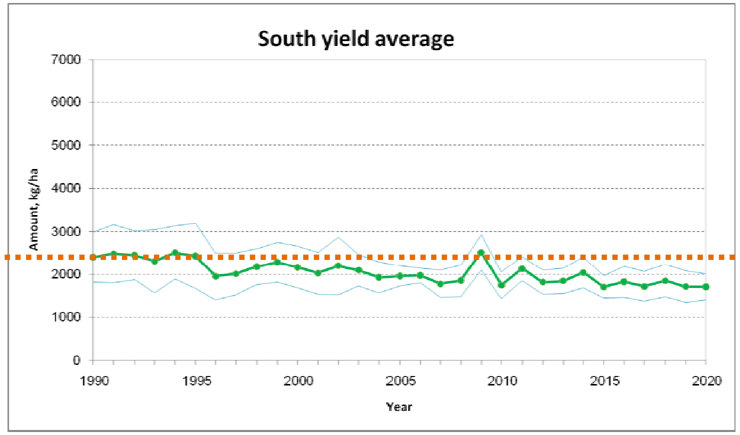


(a) (b)

Figure 26: SN, no irrigation, probability of the "season of immature grain" (a) precipitation at the average level (NoIr_AvP), (b) real drought of 1990 - 2010 (NoIr-RP)

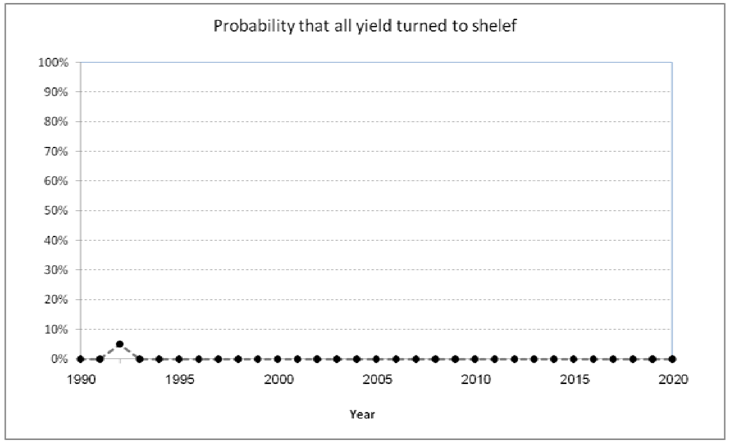


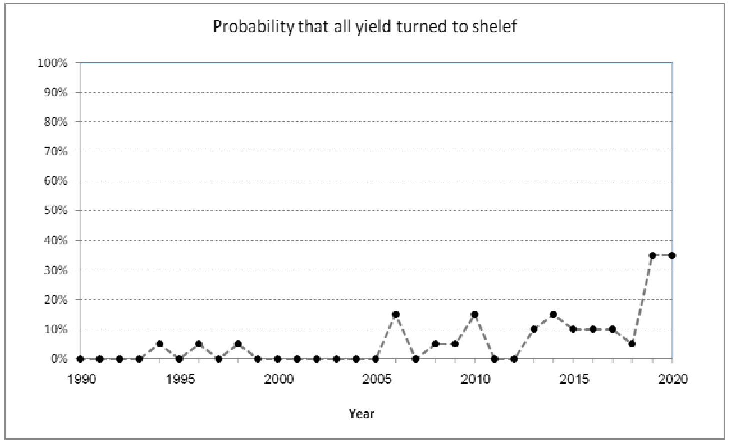
(a)



(b)

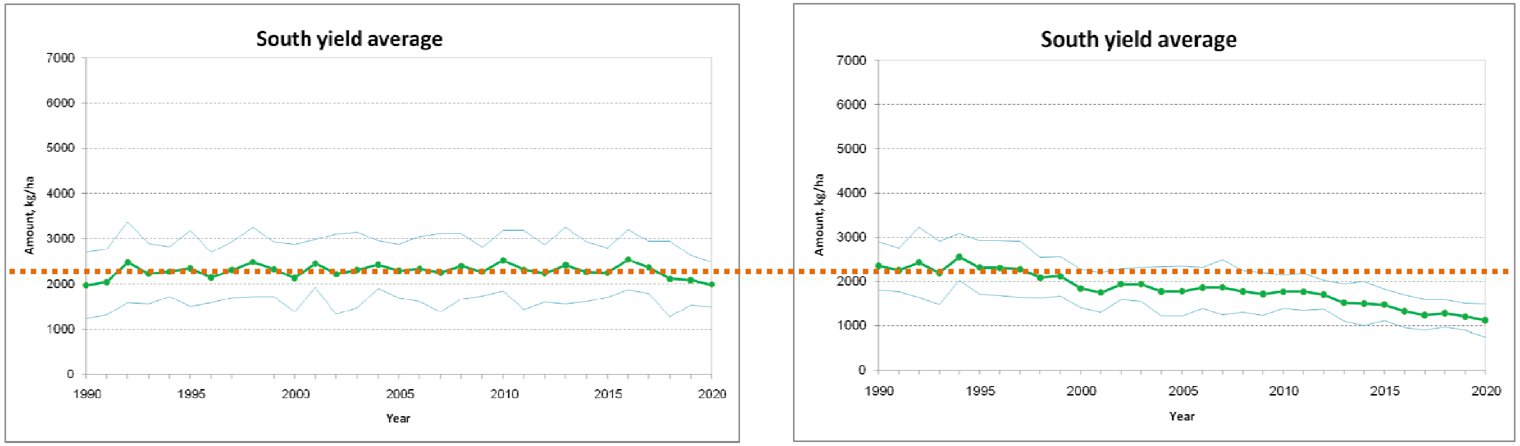
Figure 27: SN, real irrigation development (a) precipitation at the average level (RealIr-AvP), (b) real drought of 1990 - 2010 (RealIr-RR)





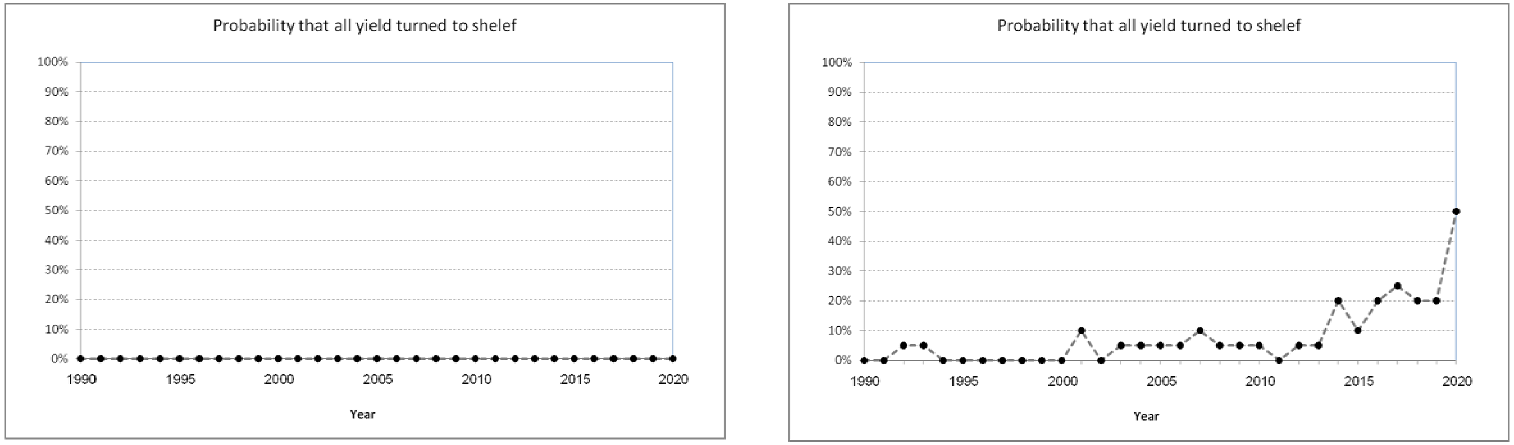
(a) (b)

Figure 28: SN, real irrigation development, probability of the "season of immature" grain (a) precipitation at the average level (RealIr_AvP), (b) real drought with the tendencies of development characteristic of 1990 - 2010 (RealIr-RP)



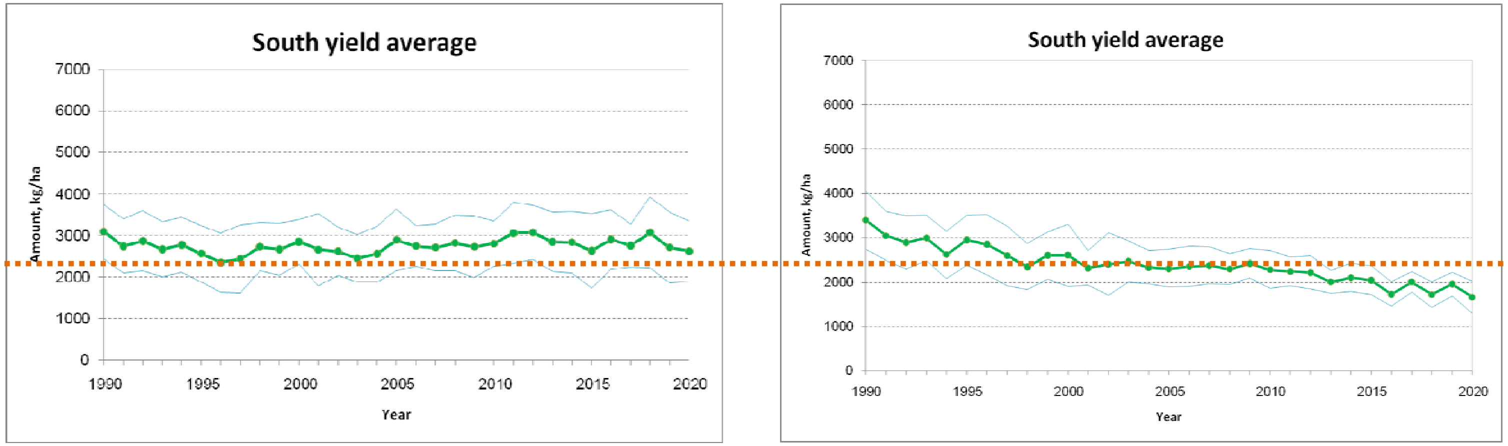
(a) (b)

Figure 29: SN, fixed irrigation of 1990 (a) precipitation at the average level (ZeroIr-AvP), (b) real drought of 1990 - 2010 (ZeroIr-RRP)



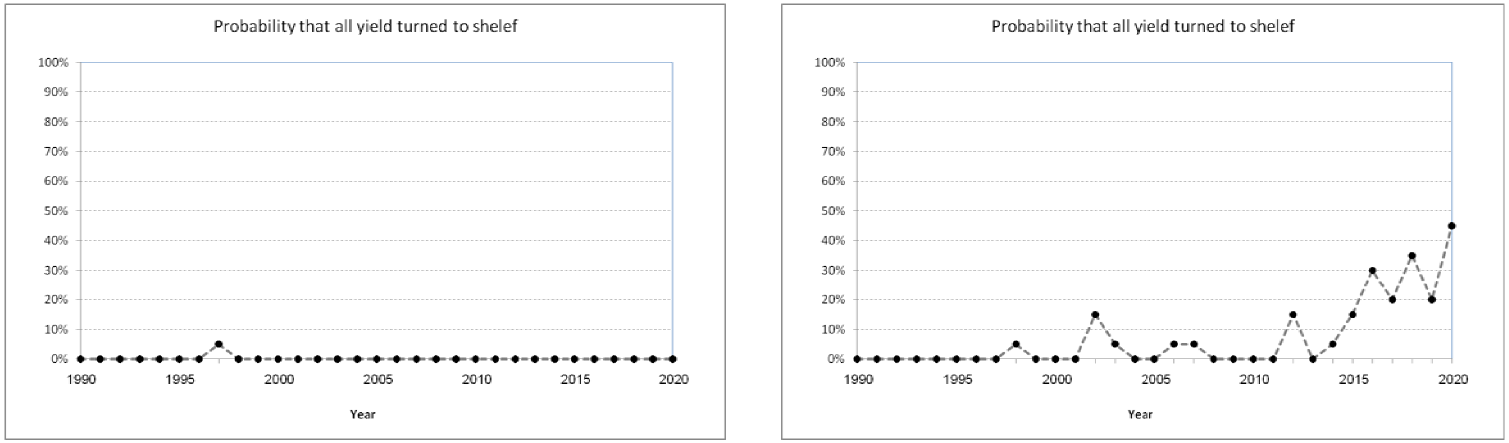
(a) (b)

Figure 30: SN, fixed irrigation of 1990, probability of the "season of immature" grain (a) precipitation at the average level (ZeroIr_AvP), (b) real drought with the tendencies of development characteristic of 1990 - 2010 (ZeroIr-RP)



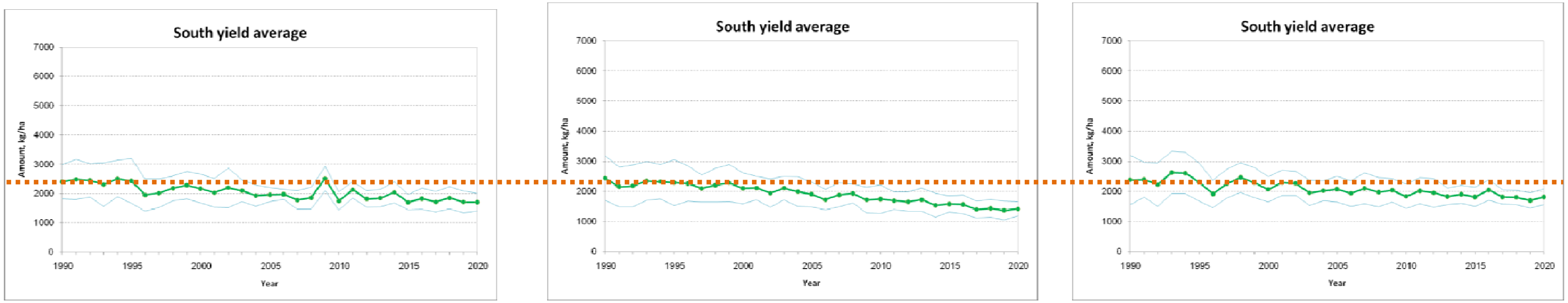
(a) (b)

Figure 31: SN, 100% irrigated from 1990 (a) precipitation at the average level (AllIr-AvP), (b) real drought of 1990 - 2010 (AllIr-RP)



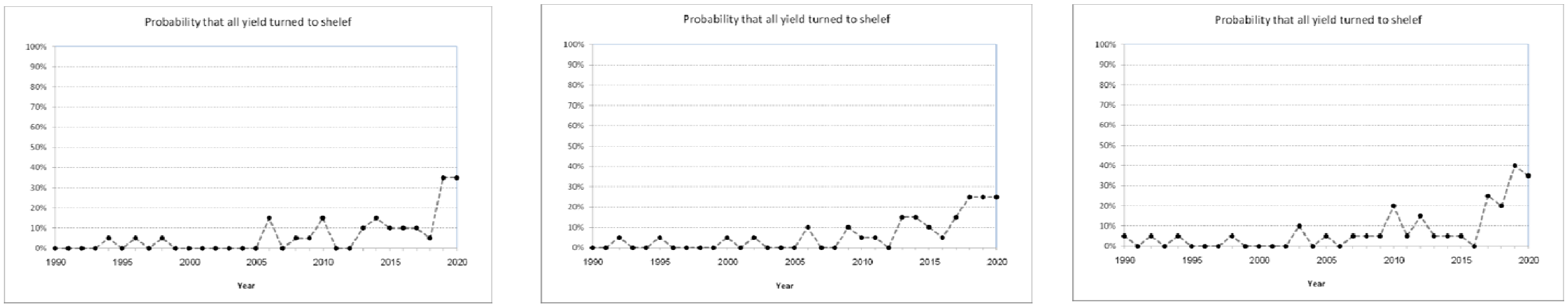
(a) (b)

Figure 32: SN, 100% irrigated from 1990, probability of the "season of immature" grain (a) precipitation at the average level (AllIr_AvP), (b) real drought with the tendencies of development characteristic of 1990 - 2010 (AllIr-RP)



(a) (b) (c)

Figure 33: Yield dynamics in the southern Negev in case of the current rate of the irrigation system development equal to 1% (RealIr-RP) (a) and in the case of annual rate of 0.5% (RealIr-RP050) (b) and 1.5% (RealIr-RP150) (c)



(a) (b) (c)

Figure 34: Southern Negev, probability of the "season of immature" grain in case of the current rate of the irrigation system development equal to 1% (RealIr-RP) (a) and in the case of annual rate of 0.5% (RealIr-RP050) (b) and 1.5% (RealIr-RP150) (c)

4.8.4 Vulnerability maps

Based on the simulation results, we construct vulnerability maps and present here two of them. Both represent real irrigation – real precipitation RealIr-RP scenario. The first map (Figure 35) represent the decrease in the wheat yield in 2010 while the second one (Figure 36), the probability that 2020 will be a year with "immature grain". These maps can serve for establishing "vulnerability line" – an area, where the sheep raising should be intensified by means of state support, and the rate of intensification that would be sufficient for preserving the system at a current level of stability towards 2020.

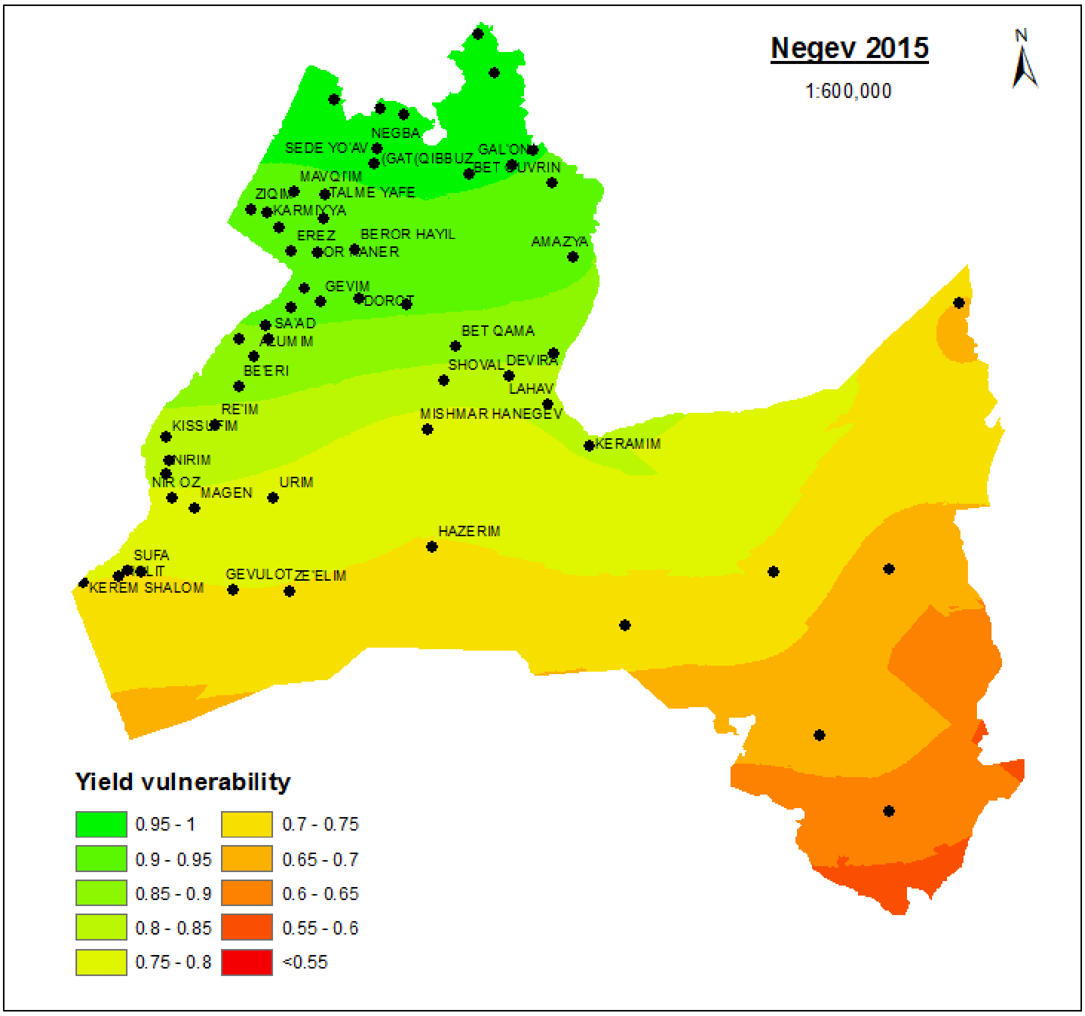


Figure 35: The ratio of wheat yield as predicted by the model for 2015 (for the weather conditions and irrigation system as observed during 1990-2010 and extrapolated to 2015) and the yield in 2015 expected for the non-drought conditions.

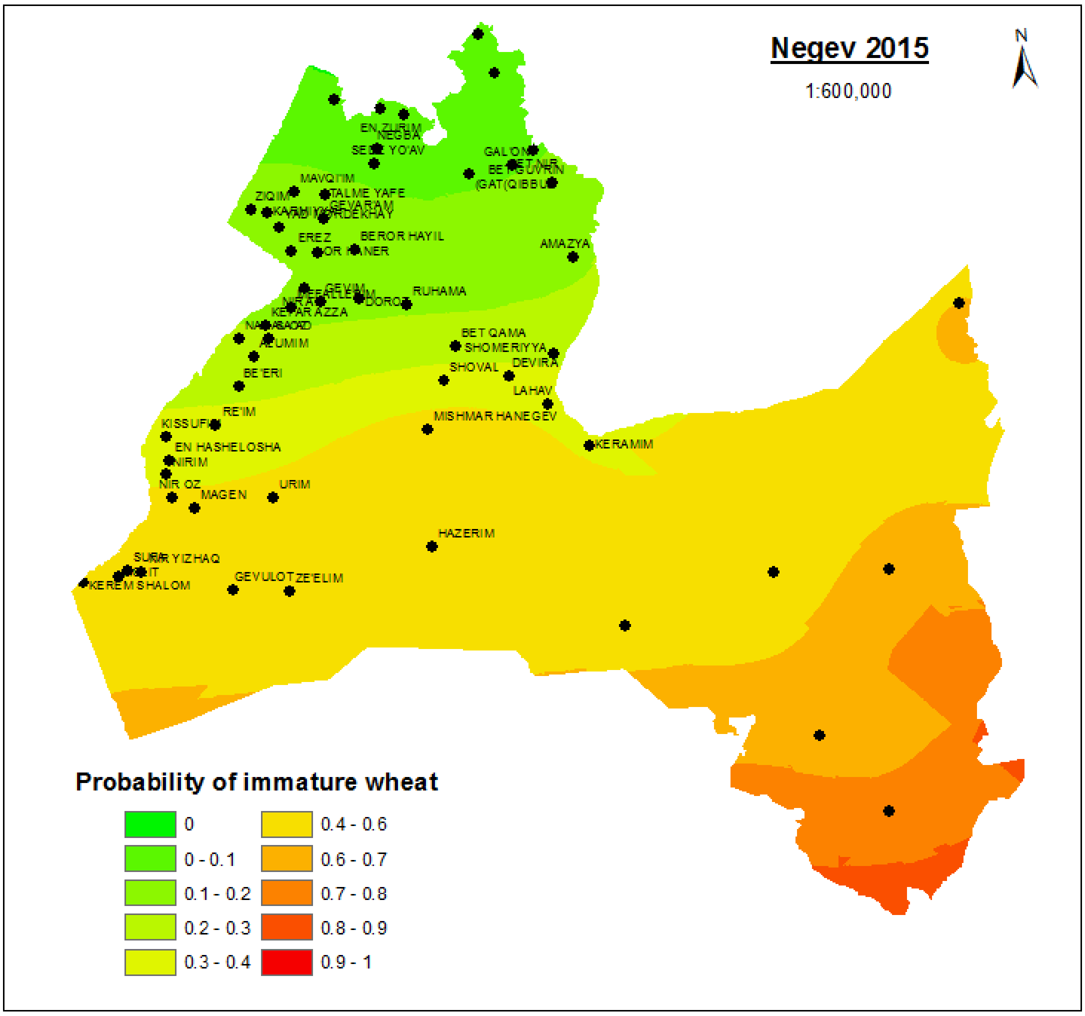


Figure 36: The map of the probability of the immature season in the Negev in 2015

4.9 The factors and bottlenecks of the next decade

Should we expect, during the next decade, further decline in precipitation? This is the basic assumption of the most realistic model scenario. We consider this assumption as pessimistic –climate changes in Mediterranean are weak and the forecasts of the climatic models are very uncertain in this area. It is quite probable that during the next decade the level of precipitation in the Negev will decline slower or remain at the level of 2010. Current policy may be then sufficient for the near future.

Another uncertain factor is the Bedouin population growth rate, which was extremely high during the last 20 years (about 4-5%/year). Will it remain the same? Would young Bedouins be interesting in participating in the husbandry, especially in its traditional, nomad, form? May it happen that the number of sheep will start to decline or the only form of the husbandry that could proceed would be intensive raising that would be based on the food supply from non-local sources? What would be the demand for lamb?

Jewish agriculture is potato-driven - will it remain the driving force? Is this potato per se? Are there other potentially profitable crops that could serve as an unambiguous reason for irrigation?

The vulnerability matrices provide the basis for investigating all these questions. However, the answers remain beyond the framework of the current research. The model of Negev vulnerability that we have developed within the ENSURE project enables incorporation of the aforementioned and many other mechanisms into the scenarios. This further facilitates the comprehensive and profound investigation of the Negev vulnerability to droughts for the next decades.

5 Conclusions of the Negev case study

- Vulnerability is a systemic phenomenon. System approach is necessary to recognize the factors and processes that are important in regards to the increase/decrease of the system's vulnerability to a hazard. These factors and processes must be few. The latter, however, does not mean that the representation of the system must be primitive
- The vulnerability of the Negev territorial system to drought is determined by the response of two major population groups – Jewish and Bedouin farmers - to the drought hazard. In ecological terms, these groups, simultaneously, compete and cooperate.
- Vulnerability matrices specify the ways in which the Negev territorial system reacts to the drought thread, present different aspects of Negev mitigation capacity and foresees potential losses and long-term dangers at all levels of the system hierarchy and for all major components of the system.
- The dynamics of the Negev territorial system depends on the limiting factors - precipitation and irrigation, and on the reaction of the Jewish and Bedouin farmers to the changes in these factors. Based on the vulnerability matrices, we have interpreted these reactions and interactions between the components of the Negev territorial system in the dynamic model of Negev agriculture development under the stress of the drought. The model enables investigation of the Negev vulnerability to droughts as dependent on the scenario of precipitation and irrigation dynamics.
- The investigation of the model confirms that as far as we instantaneously follow the decrease in precipitation and compensate for shortage in sheep food by the development of the irrigation system, the Negev territorial system remains robust to droughts. The model depicts the areas where the current tendency of coping with the droughts by developing irrigation system will be insufficient, and provides quantitative estimates of the fraction of the Bedouin husbandry that should undergo transition from the extensive to intensive raising, as well as the rate of this transition as dependent on the drought development.

During last twenty years, clear economic reasons enforce sufficiently high rate of the irrigation network development in the Negev. This development guarantees relatively low vulnerability of the Negev territorial system and confirms that human society is able to adapt and remain robust to the slowly developing hazards. The current programs, which focus mostly on the Jewish farmers, may be insufficient for the next decade. However, similar measures, aimed at intensification of the Bedouin husbandry, may preserve system robustness for the next decade, until, at least, 2020.

6 Weaknesses and strengths of the Ensure framework

6.1 Strengths:

- The ENSURE framework enforces the researcher to specify the major components of the investigated system and their vulnerability to numerous factors and hazards.
- The ENSURE framework enforces the researcher to consider the system at all levels of its hierarchy and to distinguish between the vulnerability of the system at different levels of its hierarchical organization
- The ENSURE framework enforces the researcher to consider temporal aspects of the system's vulnerability and distinguish between the vulnerability of the system to immediate, short-term and long-term hazards.
- The ENSURE framework enforces the researcher to consider the system in space and specify system's vulnerability as dependent on the location. In this way vulnerability maps can be introduced

6.2 Weaknesses:

- The ENSURE framework is over-general and demands essential specification and re-work for the case study. The framework does not provide the means for investigating the completeness of the set of the factors and hazards that are chosen by the researcher. In this way, the researcher can miss important factors that define system's vulnerability, especially when different hierarchical levels of the system organization are considered.
- The ENSURE framework ignores dynamic properties of the system that is influenced by the hazard. The accumulated effects of the hazards and adaptive properties of the system and evolution of system's mitigation capacity are hardly considered.

7 References

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