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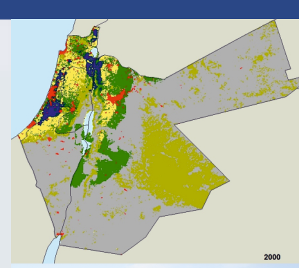
Jan Volland, Jennifer Koch, Florian Wimmer,
Janina Onigkeit und Rüdiger Schaldach

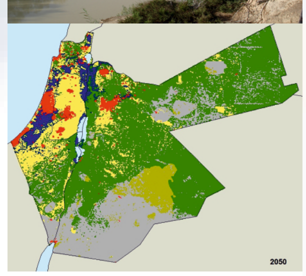
Land-use Modeling in the GLOWA-Jordan River Project

Documentation of models and simulation results

Center for Environmental Systems Research

CESR-PAPER 7





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Jordan River GLOWA

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CESR – Paper 7

Center for Environmental
System Research

U N I K A S S E L
V E R S I T Ä T

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Summary

This report presents the results from the land-use simulation study which has been carried out at the Center for Environmental Systems Research (CESR) as part of the GLOWA Jordan River project[1] (sub-project 3.3.). A central objective of GLOWA Jordan River was to analyse the vulnerability of water resources in the Jordan River basin under the influence of global change. In this context the land-modelling system LandSHIFT.JR has been adapted and applied to calculate spatially explicit scenarios of land-use change on the territories of Israel, Jordan and the Palestinian Authority (PA), and the resulting impacts on ecosystem service values. The simulation results served as input for further studies within the project context, e.g. related to water availability (Menzel et al. 2009) and the GLOWA Jordan River Atlas.

After an introduction, chapter 3 gives an overview of the materials and methods used to conduct the simulation study. First, the LandSHIFT.JR model is described, followed by a short introduction to the scenarios which were developed within the GLOWA Jordan River project. The quantitative model drivers that were derived from these scenarios are discussed in the last part of the chapter.

In chapter 4 exemplary simulation results from LandSHIFT.JR are presented. These raster maps include information on the change of land-use types and population density as well as on livestock grazing and ecosystem service values. Starting year of the simulations was 2000 while the scenarios were specified up to the year 2050. A complete set of simulated maps is included in the annexes.

[1] Glowa Jordan River has been funded by the German Federal Ministry of Education and Research (BMBF). CESR was involved in the project in phases 2 and 3 from 2005-2012.

Project members

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Rüdiger Schaldach holds a diploma in Geo-ecology from the TU Braunschweig and a PhD in environmental systems science and engineering from the University of Kassel. Since 2009 he is head of the GRID-Land research group at the CESR. As principle investigator he was responsible for the land-use studies within the Glowa-Jordan River project.

Florian Wimmer holds a Diploma in Geo-ecology from the University of Bayreuth. He started to work at the CESR in 2006 and was involved in a number of projects dealing with integrated modeling of global change impacts on water and land resources.

1. Introduction

GLOWA Jordan River was an interdisciplinary research project addressing the vulnerability of water resources in the Jordan River basin under global change. The integrated approach aimed at providing scientific support for sustainable and cooperative management practices in a highly water-stressed region. Its central goal was to increase the benefits from the region's water both for humans and ecosystems, under global change. The specific niche and strengths of GLOWA JR, as opposed to earlier approaches to water scarcity adaptation and climate variability, were

- its focus on interacting global change processes, such as climate and land use change,
- the integrative and interdisciplinary approach, and
- the continuous dialogue between scientists and stakeholders.

To that end, GLOWA JR provides an innovative framework for assessing blue, green, and non-conventional water management, overcoming the traditionally fragmented approach to sustainable resource management (GLOWA 2012).

The Center for Environmental Systems Research (CESR) was involved in the phases 2 and 3 of the project (2005-2012). During that time its main responsibilities were the development of regional scenarios (sub-project 1) and the integrated modeling of land-use change (sub-project 3.3). The scenario process was based on the Story and Simulation (SAS) approach (Alcamo, 2008) which brings together qualitative and quantitative scenarios. For the simulation of future land-use change, a regional version of the spatially explicit model LandSHIFT (Schaldach 2011), referred to as LandSHIFT.JR (Koch, 2012), has been developed and applied. In the SAS context, the simulation results are part of the quantitative scenarios.

This report documents the simulation results from the land-use modeling exercise. Beside changes of land-use and land-cover types, also changes in human population density and stocking densities of sheep and goats on grazing land were calculated. Based on this information, changes of ecosystem service values could be assessed. Simulations were performed for the four scenarios developed by the scenario sub-project 1.

Chapter 2 gives an overview of the study area. In chapter 3, the LandSHIFT.JR model and the storylines of the four GLOWA Jordan scenarios are briefly described. In addition, it includes the quantitative model drivers used for the simulations, which were derived using the qualitative scenarios as a basis. Finally, chapter 4 presents exemplary results from the modeling exercise. The complete set of all simulation results are included in the annexes.

2. Study Region

The study region includes the territories of Israel, Jordan, and Palestinian Authority (PA) (Fig. 1). The Jordan River region is bordered by Lebanon and Syria in the North, by Iraq and Saudi Arabia in the East, by Egypt in the Southwest, and by the Mediterranean Sea in the West. The region ranges from 34.22°E, 29.19°N to 39.30°E, 33.38°N.

The terrain in the Jordan River region is very heterogeneous. The Coastal Plain, stretching along the Mediterranean Sea, is flanked by the Negev desert in the Southeast and a mountainous region in the East and Northeast. In the North, the mountains force the coastal air masses to rise, and as a result, induce relatively high precipitation amounts (EXACT, 1998). A key physiographic feature of the Jordan River region is the Great Rift Valley in which the Jordan River, Lake Tiberias, and the Dead Sea are located. With 407 m below sea level, the Dead Sea marks the lowest point in the region and on the Earth's surface. The highland area in the Western part of Jordan, located along the Great Rift Valley, rises to elevations of 1200 m above sea level and drops gradually in elevation towards the East, where it develops into the Jordan desert plateau (EXACT 1998). The point with the highest elevation in the Jordan River region is the Jabal Umm ad Dami, located in the South Jordan desert, with about 1854 m above sea level.

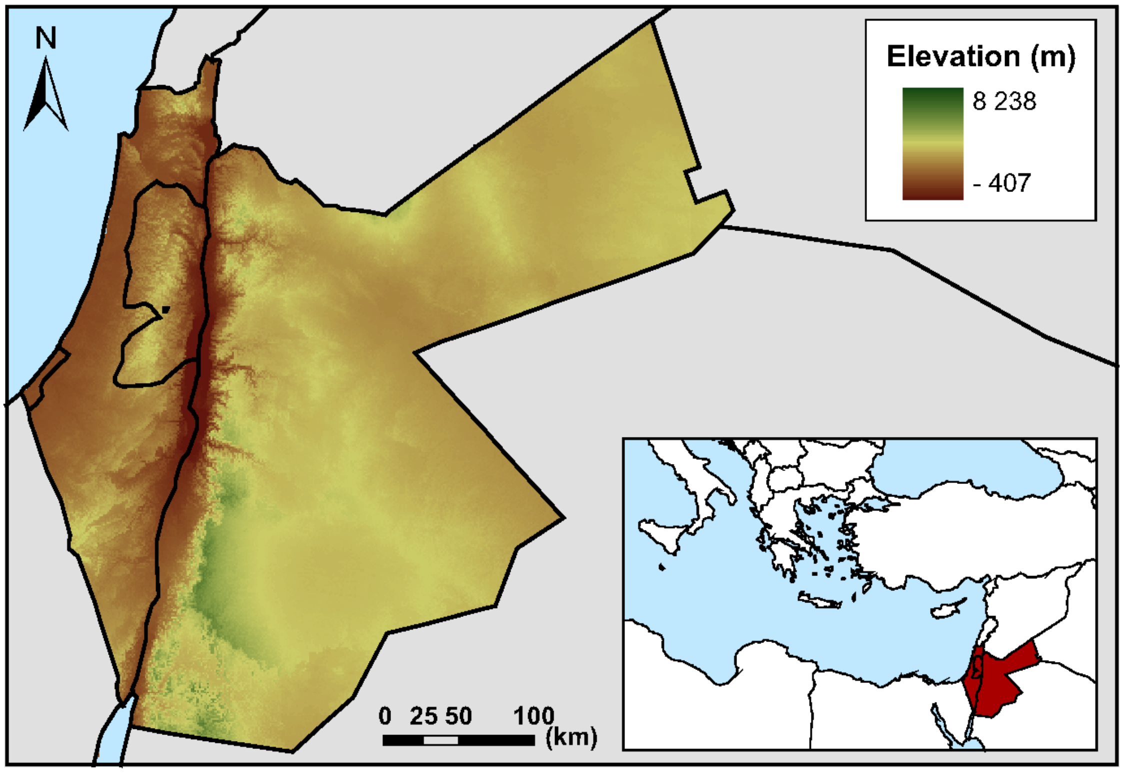

Figure 1: The study region covers Israel, Jordan, and the Palestinian Authority

The climate in the Northern, Central, and Western part of the Jordan River region is Mediterranean, characterized by hot, dry summers and cool winters (EXACT 1998). In the residual part of the Jordan River region a semi-arid to arid climate predominates. A dominant feature of the regional climatic conditions is the steep precipitation gradient, ranging from 900 mm mean annual precipitation in the Northern tip of Israel to less than 50 mm in the desert areas in the South of Israel and the South and Southeast of Jordan. Temperatures also exhibit a high spatial variability across the Jordan River region with cold winters and hot summers in the mountainous regions and more moderate extremes in the Rift Valley and the Coastal Plain (EXACT 1998). The Jordan River region covers about 116 thousand km² of land area and one thousand km² of inland water area. Approximately 76.1% of the land area in the region is located in Jordan, 18.7% in Israel, and 5.2% in PA (FAO, 2012). About 2600 km² in the region are forest area. Arable land and permanent cropland sum up to about 9200 km². Approximately 3000 km² in the Jordan River region are equipped for irrigation, about two thirds of which are located in Israel. About 17 million people live in the Jordan River region (7.4 million in Israel, 6.2 million in Jordan, and 4.0 million in PA) (FAO, 2012). The largest cities in the study region are Amman, Jerusalem, Tel Aviv, and Gaza.

3. Materials and Methods

First, this chapter briefly describes the LandSHIFT.JR model that was used to calculate land-use changes. Then the qualitative scenarios developed within the GLOWA Jordan project are introduced. The chapter ends with an overview of the quantitative model input drivers derived from these scenarios as part of the SAS process.

3.1. The LandSHIFT.JR model

LandSHIFT.JR is a regional version of the integrated modeling system LandSHIFT (Schaldach et al. 2011). It was adjusted and further developed to specifically simulate the spatial and temporal dynamics of land-use systems in the Jordan River region. A full description of the model is given in Koch et al. (2012).

LandSHIFT.JR was designed for exploring the effects of changes in socio-economic, climatic and biophysical conditions on the spatial distribution and intensity of land-use activities. In addition, LandSHIFT.JR serves as a tool to formalize knowledge on and gain new insights into the functioning of land-use systems in the Jordan River region. The main field of application in GLOWA Jordan was the simulation of spatially explicit future scenarios of land-use and land-cover change until the year 2050. These scenarios explore possible trends in land use and visualize alternative land-use configurations. Main model output are raster maps displaying changes in land-use patterns, human population density, stocking density of sheep and goats on grazing land and ecosystem service values. The spatial resolution of these maps is a cell size of 30 x 30 arc seconds (approximately 1 x 1 km).

The representation of land-use systems in LandSHIFT.JR is operationalized on interacting spatial scale levels. On these scale levels, the state variables of the modeled land-use systems are defined. There are two main spatial scale levels:

- Macro level (state or country)
- Micro level (30 arc seconds raster)[2]

The processes implemented in LandSHIFT.JR are organized in three modules (Fig. 2), which operate on the different spatial scale levels by modifying the scale-specific state variables. The Biophysics module, which describes the environmental subsystem, comprises process representations for the calculation of potential irrigated and rain-fed wheat yields, net irrigation water requirements, and Net Primary Productivity (NPP) of rangeland and natural vegetation. All the variables provided by the Biophysics module are climate dependent and, hence, differ between climate scenarios. In the project context, crop yields were calculated with the EPIC model (Williams et al. 1989, Williams 1995) while NPP of rangeland under grazing pressure was estimated with the WADISCAPE model (Köchy et al. 2008).

The Socio-economy module and the Land Use Change module (LUC module) represent the human subsystem. The Socio-economy module operates on the macro-level and provides information on

[2] For further information about spatial scale levels see Koch et al. 2012.

population growth, agricultural production and trade (implemented via the state variables crop demand and livestock numbers), and yield change due to technological progress.

For each simulation step, the Biophysics module and the Socio-economy module are executed and the corresponding state variables are updated. Subsequently, the updated information is used by the LUC module to simulate changes in land use and land cover on the micro-level. For this purpose, four land-use activities are implemented: housing and infrastructure, irrigated crop production, rain-fed crop production, and livestock grazing.

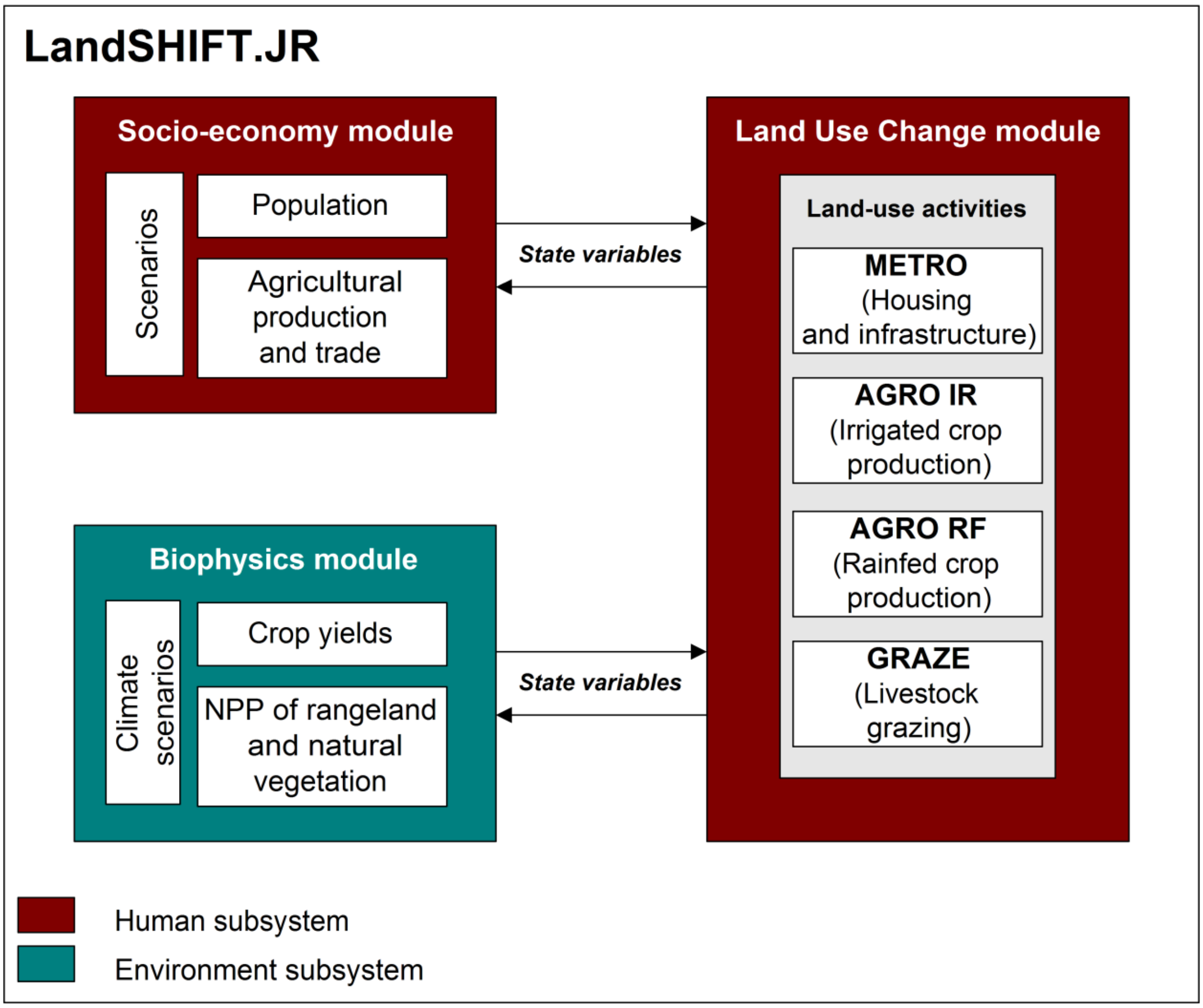

Figure 2: Conceptual structure of LandSHIFT.JR (Koch et al. 2012)

The processes representing the different land-use activities are organized in sub-modules: **METRO** for housing and infrastructure, **AGRO IR** for irrigated crop production, **AGRO RF** for rain-fed crop production, and **GRAZE** for livestock grazing. The competition between these activities for land is addressed by a ranking of the four activities, which defines the sequence of execution. The ranking can be defined flexibly based on the research question; a straightforward way of ranking land-use activities is to follow their economic importance: METRO > AGRO IR > AGRO RF > GRAZE. In one simulation step, cells occupied by a superordinate land-use activity are unavailable for a subordinate land-use activity.

In every simulation step, each land-use activity sub-module executes the functional parts demand processing, preference ranking, and demand allocation. This complies with the generalized structure of spatially explicit land-use change models as presented by Verburg et al. (2006). First, within the demand processing part, driving forces of land-use change are converted to macro-level demands for services (e.g. housing) and agricultural commodities. Second, within the preference ranking part, the suitability of the micro-level grid cells for the different land-use activities is assessed, resulting in suitability maps. The grid cells are then ranked based on their suitability. Third, within the demand allocation part, each land-use activity manipulates the dominant land-use type as well as the corresponding state variable (population density for METRO, irrigated crop production for AGRO IR, rain-fed crop production for AGRO RF, stocking density for GRAZE) of the best-suited micro-level grid cells, in order to meet the demand for the service or agricultural commodity under consideration. The range and magnitude of change is constrained by the demand for the service or agricultural commodity on the one hand and by the supply, i.e. the productivity on the particular micro-level grid cells on the other hand.

In a final step, ecosystem service (ESS) values are analyzed. The landscape valuation module of LandSHIFT.JR, which maps the value of ecosystem service to the land-use classes, takes into account the change of ESS-values over time. For this purpose, a database with ESS-values for the year 2000 and projections of ESS-values for the year 2050 for Israel, Jordan, and the PA is used. During the runtime, the landscape valuation module of LandSHIFT.JR interpolates the ESS-values for each 5-year time step between 2000 and 2050 resulting in dynamically changing maps of ecosystem service values. Detailed information about LandSHIFT.JR and its parameterization can be found in Koch et al. 2012, who use parameter settings for LandSHIFT.JR identical to GLOWA JR.

3.2. The GLOWA Jordan River Scenarios

In GLOWA JR a scenario process was initiated with the aim to provide scientific support for the management of water and land resources in the Jordan River region. Following the Intergovernmental Panel on Climate Change (IPCC), scenarios can be defined as “coherent, internally consistent and plausible descriptions of possible future states of the world. They are not forecasts; rather, each scenario is one alternative plausible image of how the future can unfold.” (IPCC 2010)

In the context of the GLOWA Jordan River project, the Story and Simulation (SAS) approach was applied to help planners, decision-makers and other stakeholders to prepare for the challenges of global and regional change. The main characteristics of the SAS approach are:

- the deployment of qualitative storylines by different groups of stakeholders and other experts,
- the application of simulation models to quantify these storylines and
- the organization of an iterative process to develop the scenarios based on a dialogue between the scientists and stakeholders.

For the GLOWA Jordan River project, four scenarios with a time horizon up to 2050 were developed in the course of six so-called Scenario Panel meetings most of them lasting several days. Figure 3 shows the main determinants driving the four “GLOWA Jordan River Scenarios of Regional Development under Global Change” (Onigkeit 2009).

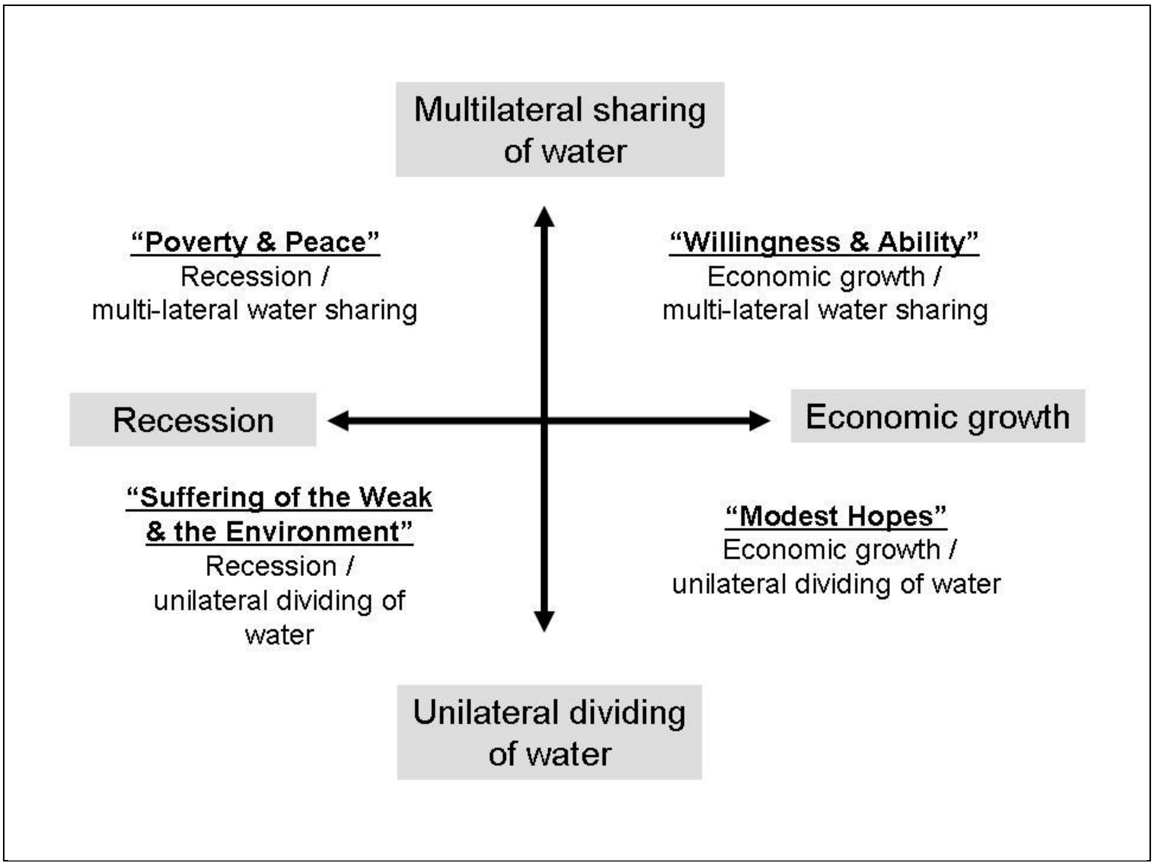

Figure 3: Scenarios of the GLOWA Jordan River Project (Onigkeit 2009)

In the following the storylines of the four scenarios are briefly described:

Willingness & Ability (WA)

The “Willingness & Ability” scenario reflects the most optimistic scenario in which peace and economic prosperity rein. Due to a strong increase of the population and a growing tourism industry together with the climate induced reduction of precipitation the pressure on water and land resources increases. A growing regional cooperation on water issues leads to a successful handling of the situation. The process starts with the development of a comprehensive regional water master plan. The overall water availability can be increased sufficiently through an early region-wide spread of high-tech solutions, such as desalination plants, waste water treatment and reuse and the realization of the Red Sea - Dead Sea canal. Conservation of resources, including an increasing efficiency of water use, gain acceptance on the medium term and overgrazing and intensive agriculture are avoided. Measures to cope with the adverse impacts of climate extremes are taken early and in a cooperative way so that substantial damages can be avoided. The availability of financial resources and an increasing level of public awareness guarantee a sustainable development in the region.

Poverty & Peace (PP)

The “Poverty & Peace” scenario represents a combination of peaceful development in the region without economic prosperity. Although water resources are being shared, water stress problems which are caused by climate change occurring over the coming decades remain an important issue because of the poor economic development. "Make peace an economic value" is the premise of the water strategy under this scenario. It allows for modest economic development through development of region-wide ecotourism realized in part by allocating sufficient water to this sector and by taking care of natural ecosystems. Water resources can be augmented through cooperation on the basis of small scale projects. First steps in tri-lateral water management can be realized very soon through third party involvement in the beginning. Political stability leads to a slow but steady spread of technology throughout the region. However, the cooperative projects remain small-scale and continue to be dependent on financial support from outside the region. The continued shortage of water resources combined with a lack of financial means requires a high level of environmental and political awareness of the regional population over the entire scenario period.

Modest Hopes (MH)

The “Modest Hopes” scenario assumes that no peace agreement can be reached but that economic prosperity prevails, kindled by international donors. This results in fairly stable conditions in the region with limited informal cooperation in form of e.g. an exchange of knowledge and technologies. The focus in water management is on increasing the supply of water by large scale desalination and reuse of properly treated waste water. Comprehensive education, training and capacity development programs allow for the realization and maintenance of water production facilities on a high technical and efficient level in all three countries. Also the efficiency of water use for irrigation is increasing fast. Additional desalination capacity and rainwater harvesting help to make up for the decreasing reliability of natural water resources. Agriculture becomes very profitable but increases the pressure on open land. Because of continued lack of political cooperation, countries refuse to let more water flow into the Dead Sea so that its water table continues to drop sharply and puts the Dead Sea at great risk.

Suffering of the Weak & the Environment (SWE)

The “Suffering of the Weak & the Environment” scenario is a worst case scenario in which neither peace nor economic growth can be reached. It represents the most vulnerable future with respect to climate change and the non-reliability of future water resources. The implementation of new and maintenance of existing infrastructure becomes increasingly difficult due to the lack of funding by international donors, who are unwilling to invest money in a politically instable region. Only in the case of extreme water crises international financing is available. With respect to the management of already scarce water resources it is perceived as critical to take actions in the very near future. The development and implementation of emergency measures are seen as an essential measure to be prepared for future climate extremes. Cooperation is possible to a limited extent on informal / technical level. A combination of inexpensive water options, traditional measures and full use of governance options (regulations & laws to save water and protect resources from pollution) are seen as most adequate strategies to cope with future water scarcity. Water is allocated in favor of the domestic sector so that agriculture is particularly affected by the situation. Donor-funded rural projects fall away and many small farmers give up and move to the growing cities. The poor suffer the consequences of a deteriorating environment most, but also the middle class is disappearing.

3.3. Main model drivers

In this chapter the main model drivers used as input for the LandSHIFT.JR simulations are described. Land-use scenarios were calculated up to the year 2050. For agriculture and population growth the four GLOWA Jordan River scenarios are used to make different assumptions about future developments (Koch et al. 2012, Onigkeit 2009). The valuation of ecosystem services was done at the CESR in cooperation with the University of Jerusalem Department of Agricultural Economics and Management, Association for Integrated Rural Development (ARID) and Arab Technologist for Economical and Environmental Consultation (ATEEC) in the GLOWA Jordan River region. For the assumptions on climate change we used five different realizations of the IPCC A1B global emission scenario and the additional assumption of constant climate conditions as in the period 1971-2000 (absence of climate change) (Smiatek et al. 2011).

3.3.1. Agriculture

The main model drivers for agriculture consist of number of grazing animals (sheep & goats) expressed in livestock units and agricultural production of cereals, vegetables and fruits. The drivers are specified separately for Jordan, Israel and the PA. Figures 4 and 5 show the assumptions for the four scenarios.

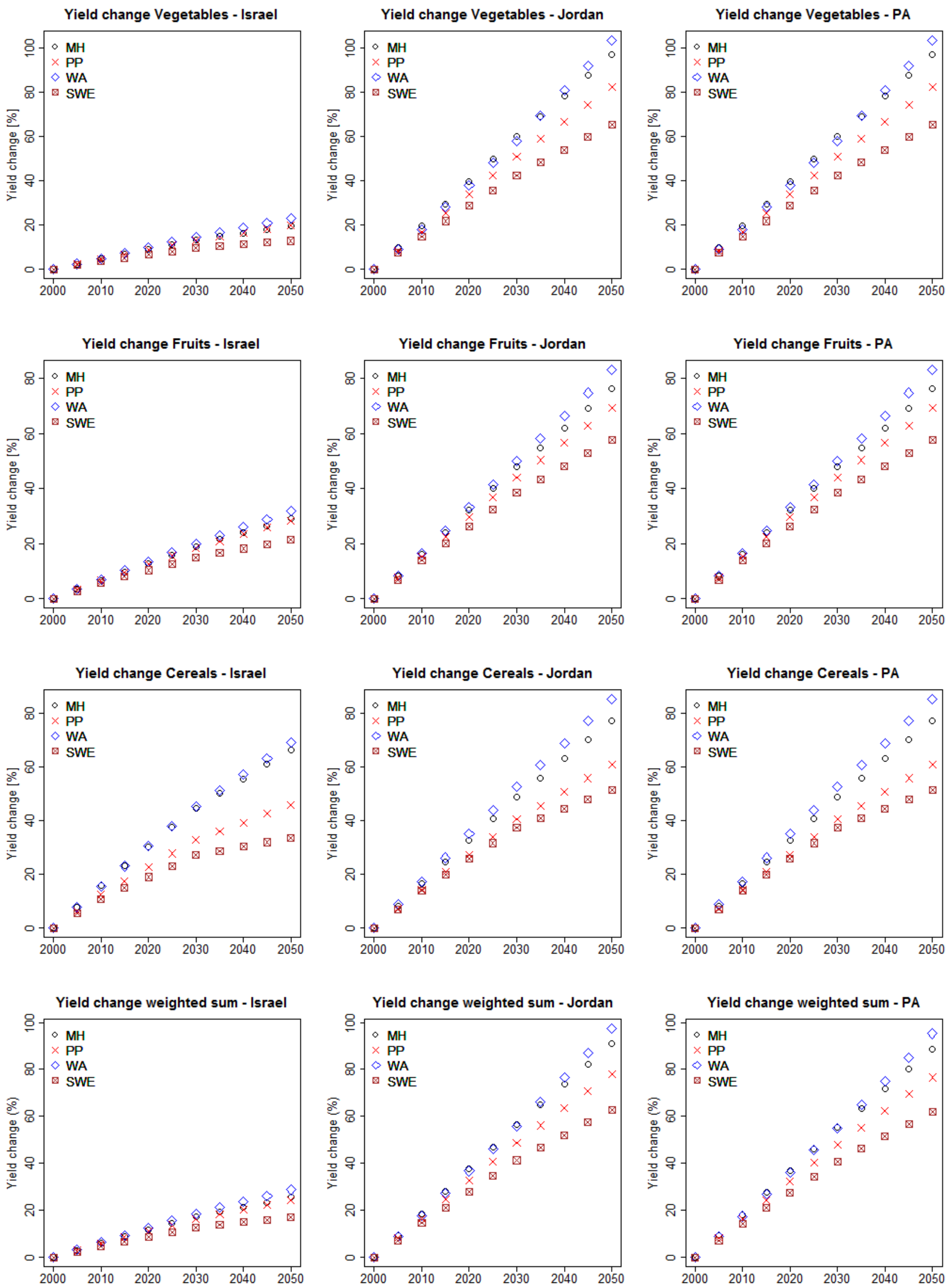

Figure 4: Agricultural production in Israel, Jordan and PA

For all scenarios and agricultural products, there is an increase of production in Israel. The Willingness & Ability and Modest Hopes (more than 100% increase) scenarios show the highest increase for every crop category due to a combination of high population and income growth. For Jordan, there is a similar development of agricultural production as in Israel. All scenarios show an increase of agricultural production. In PA, the increase of agricultural production is lower than in Jordan and Israel. The Willingness & Ability scenario shows the highest increase. The yield change differs strongly between the three countries. In Israel are only small increases (about 20%) but in Jordan and PA there are yield changes of about 100%.

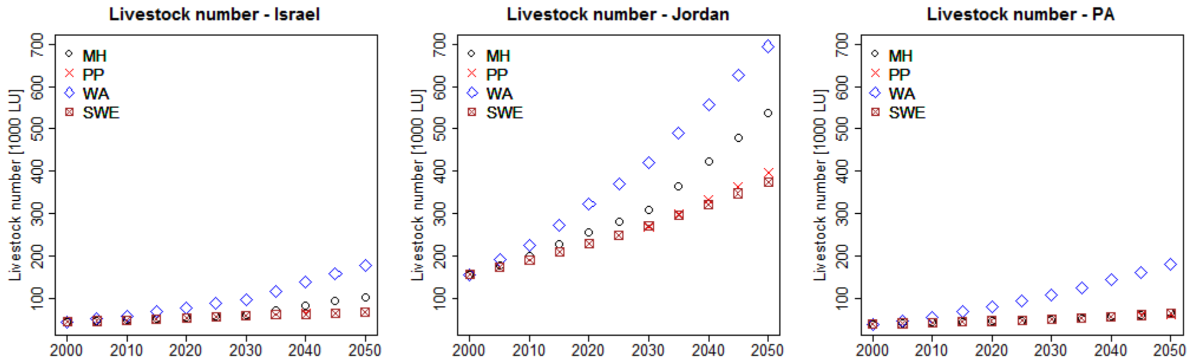

Figure 5: Grazing animals in the GLOWA Jordan River region

An overview of the development of livestock numbers (given in livestock units (LU) 1 LU= 10 sheep or goats in Israel and 20 sheep or goats in Jordan and PA) in the GLOWA region, which are composed of sheep and goats, until 2050 is given in Figure 5. Based on the livestock number, the amount of required forage, which has to be provided by grazing land, was calculated for LandSHIFT.JR (Koch et al. 2012; Koch et al. 2008). This is done under consideration of the daily forage demand per animal and the share of grazing in feed composition. The main trend is an increase of livestock numbers over time which is also due to the strong growth of the regional population and of individual income especially under the WA and MH scenario resulting in an increasing demand for livestock products. Two scenarios show a comparable trend (Poverty & Peace and Suffering of the Weak). The Modest Hopes scenario shows a high increase of livestock numbers from 2030 to 2050. The scenario with the highest increase (over 15 million sheep or goats) is the Willingness & Ability scenario. The resulting impacts of these assumptions for open space in the region are presented in chapter 4.

3.3.2. Population growth

The development of regional population numbers under the four scenarios is shown in Figure 6. A high increase of population was estimated for all scenarios. Population number is expected to more than double within 50 years. Under the WA and MH scenario, the increase in Israel (about 6 million) and PA (about 3 million) is larger than under PP and SWE.

Figure 6: Population growth in the GLOWA Jordan River region

3.3.3. Ecosystem services

Ecosystem goods (such as food) and services (such as climate regulation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997). These services are transformed into monetary terms for the GLOWA JR project. The ecosystem service values (Table 1) for Jordan and PA used in this approach were assessed by local GLOWA JR partners. For Israel, the ESS-values in 2000 were developed at the CESR for different land-use types based on former work of our Israeli partners (A. Fleischer, Hebrew University of Jerusalem and M. Sternberg, Tel Aviv University). Moreover, CESR took on the task to project ESS-values of the Israeli landscapes for 2050. To identify the ESS-values, different methods were used. For example, the partners in Jordan derived the ESS-values according to the travel cost method, willingness to pay method, damage cost method, and different market prices for wood or housing (King and Mazzotta 2000). In PA, only the contingent valuation method and productivity valuation method were used. For Israel, the ESS-values were estimated with data for agricultural products and livestock in combination with values from Costanza et al. (1997). The assumptions about future values for ESS result in changes from 2000 to 2050. The values increase or decrease, depending on whether a revaluation or devaluation occurs.

	Ecosystem service values (US$/ha)					
Land-use type	**Israel**		**Jordan**		**PA**	
	2000	**2050**	**2000**	**2050**	**2000**	**2050**
Barren or sparsely vegetated	142	319.5	3.5	1.2	120	270
Cereals irrigated	317.7	714.8	1129.3	1067.9	3280	7380
Cereals rain-fed	138.7	312.1	170.3	159.4	1020	2295
Closed shrublands	574	1291.5	77.8	30.6	0	0
Cropland/natural vegetation mosaic	92	207	0	0	140	315
Croplands	4103.5	9233	3361.4	3646.2	2990	6727.5
Fruits excl. melons irrigated	1836.4	4131.9	2391.9	1962	1864	4194
Fruits excl. melons rain-fed	717.3	1613.9	860.8	748.7	816	1836
Grasslands	232	522	0	0	280	630
Mixed forests	969	2180.3	291.7	192.6	486	1093
Open shrublands	339.2	763.1	8.8	2.2	640	1440

Other crops rain-fed	10658	23980.5	175.9	141.5	970	2182.5
Permanent wetlands	14785	33266.3	645	80.7	0	0
Rangeland	99.9	222.8	30.6	11.2	380	855
Urban and built-up	120.1	270.2	110.1	247.6	100	225
Vegetables incl. melons irrigated	4716.4	10611.9	5991.2	5233	9860	22185
Vegetables incl. melons rain-fed	1842.3	4145.2	1962.3	1771.4	3120	7020
Water	8498	19120.5	10848.4	14439.2	0	0
Woody savannahs	309	695.3	0	0	0	0

Table 1: Ecosystem service values assigned to land-use types in the three countries for 2000 and 2050

3.3.4. Climate Change

For each GLOWA Jordan River scenario, the land-use simulations were carried out for different climate variants (Table 2). These include simulations driven by an ensemble of five regional climate projections for the IPCC emission scenario A1B (Samuels et al 2011; Smiatek et al. 2011). Moreover, a variant without climate change is available, i.e. assuming constant climate conditions as in the period 1971-2000 throughout the simulation period.

Climate variants	Description	GCM-RCM combination
No climate change (no CC)	The climate data for the baseline period (1971-2000) were used throughout the simulation period 2000-2050. This variant shows only the impacts of possible pathways of socio-economic development.	ensemble average: ECHAM5-MM5 v3.5, ECHAM5-MM5 v3.7, HadCM3-MM5 v3.5, HadCM3-MM5 v3.7, ECHAM5-RegCM3 = TAU
Maximum CC impact	Regional climate projection leading to the most adverse impact on crop productivity	ECHAM5-MM5 v3.5
Minimum CC impact	Regional climate projection leading to the least adverse impact on crop productivity	ECHAM5-RegCM3

Table 2: Climate scenarios for the GLOWA Jordan River project

4. Simulation Results

This chapter shows an overview of LandSHIFT.JR simulation results of land-use change, livestock density, population growth and ecosystem service values. For each type of model output, the basic maps for the year 2000 and the maps for the year 2050 in the scenario Modest Hopes are shown exemplarily. In order to demonstrate the impact of climate change on land-use change, the simulation results in the year 2050 driven by the six different assumptions on future climate conditions (see 3.3.4) are compared. All other results are shown in the annexes.

4.1. Land-use results

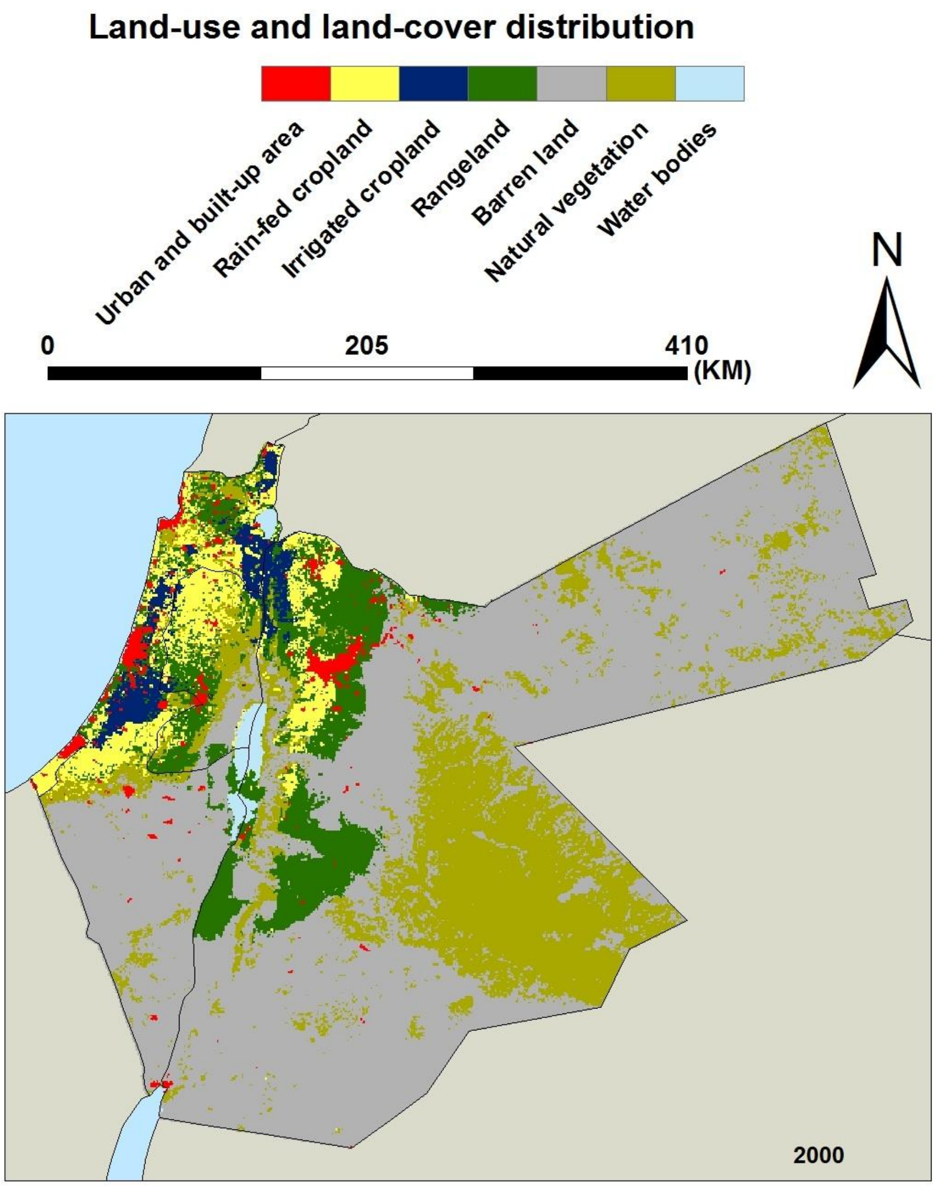

Figure 7: Land-use and -cover map for GLOWA Jordan River in 2000

Figure 7 shows the spatial distribution of land use and land cover in the Jordan River region for the year 2000. Most of the area in Jordan and southern Israel is barren land or natural vegetation. Land use in northern Israel, north-western Jordan, and the whole area of the PA is dominated by rangeland and rain-fed cropland. Irrigated cropland is located near the Mediterranean coast in Israel and in the vicinity of Lake Tiberias.

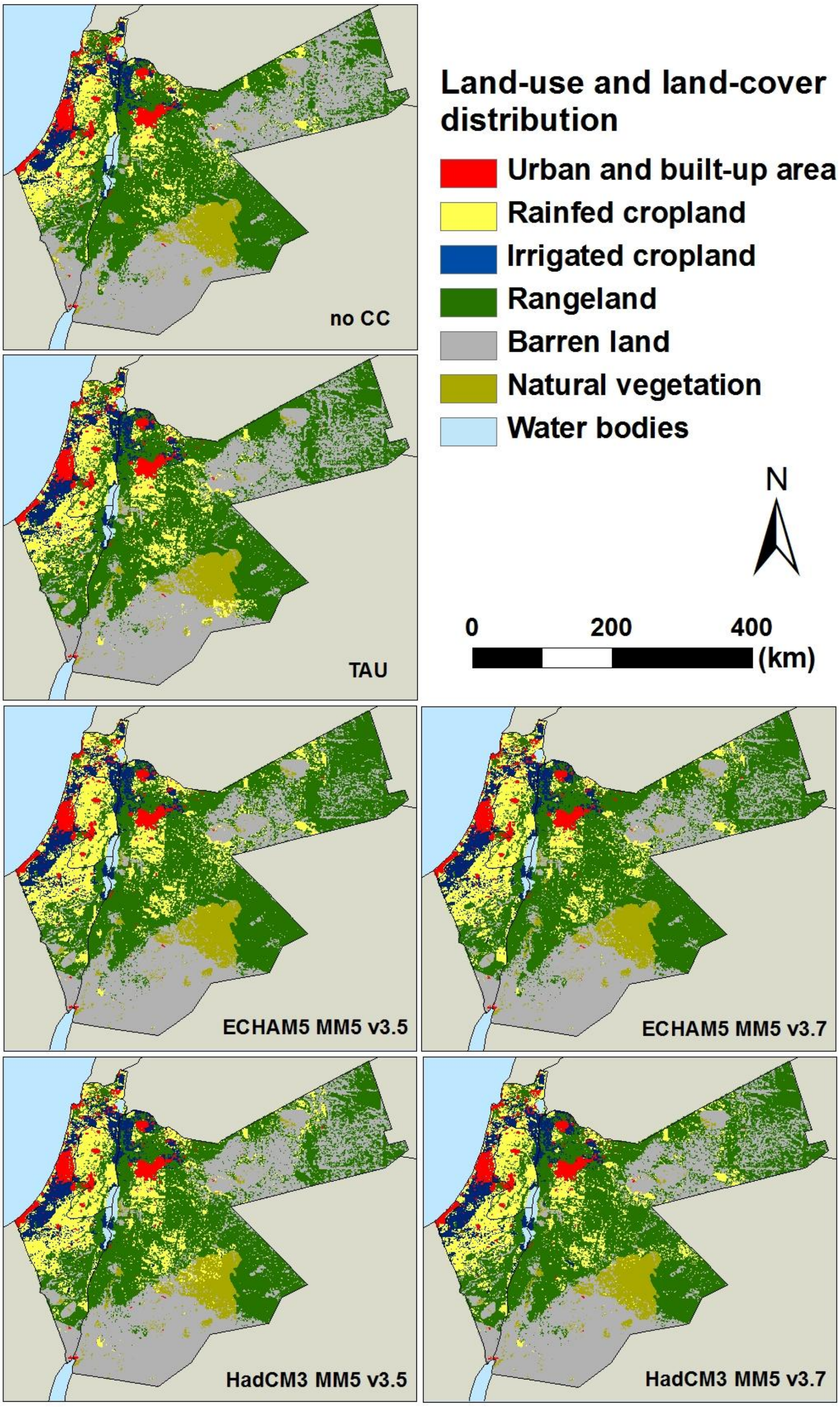

Figure 8: Land-use maps for the scenario Modest Hopes in 2050 based on six different climate variants

Figure 8 shows the land-use and land-cover distribution in 2050 under six different climate variants and the Modest Hopes socio-economic scenario drivers. Compared to the base year, a strong increase in rangeland area was simulated for 2050. The difference between the five climate variants for the year 2050 is relatively small. Also rain-fed and irrigated cropland area is increasing. The increase in urban area, which is driven by strong population growth, is the same for all climate variants because it is independent of climate conditions.

4.2. Livestock density results

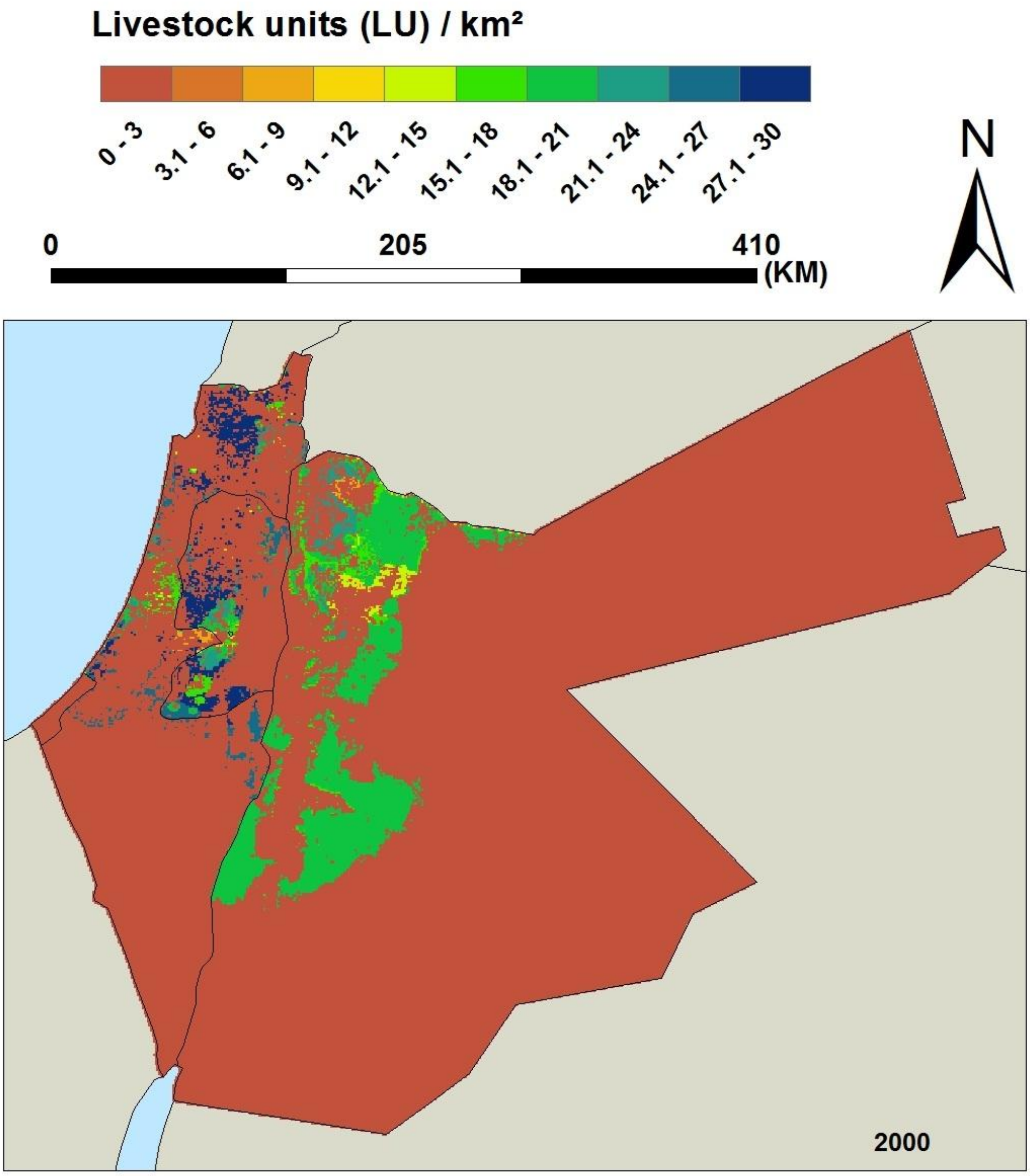

Figure 9: Livestock density in the GLOWA Jordan River region in 2000

Figure 9 depicts the distribution of livestock density on grazing land in the Jordan River region for the year 2000. Most of the goats and sheep are allocated to the north-western part of the region. The highest density of livestock was simulated in PA and northern Israel.

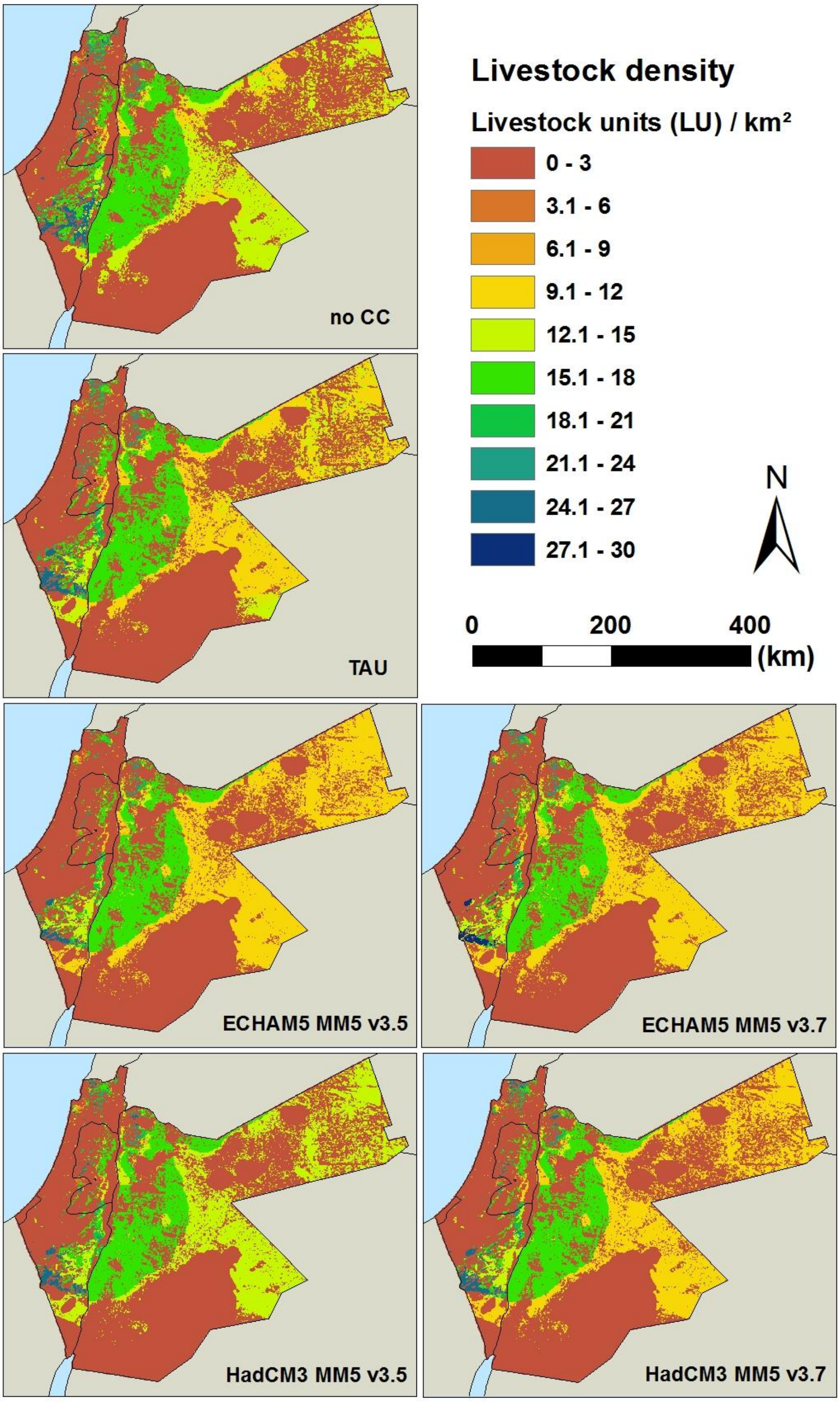

Figure 10: Livestock density for Modest Hopes in 2050 based on six different climate variants

During the scenario period, the increase in livestock numbers lead to an expansion of grazing land by a factor of up to 4.5. As can be seen in the maps, rangeland covers more than 50% of the region by 2050 (Fig. 10). Due to the lower stocking capacities of marginal areas, the livestock density on the newly allocated rangeland areas, especially in eastern Jordan, is smaller than on the areas shown in the basemap. Livestock density in 2050 showed the highest values (up to 28 LU/km² in southern Israel) for the simulation based on climate input from ECHAM5 MM5 v3.7. The areas with initially high livestock density in Israel were converted into agricultural cropland because rainfed and irrigated agriculture have higher priority than livestock grazing.

4.3. Ecosystem service value results

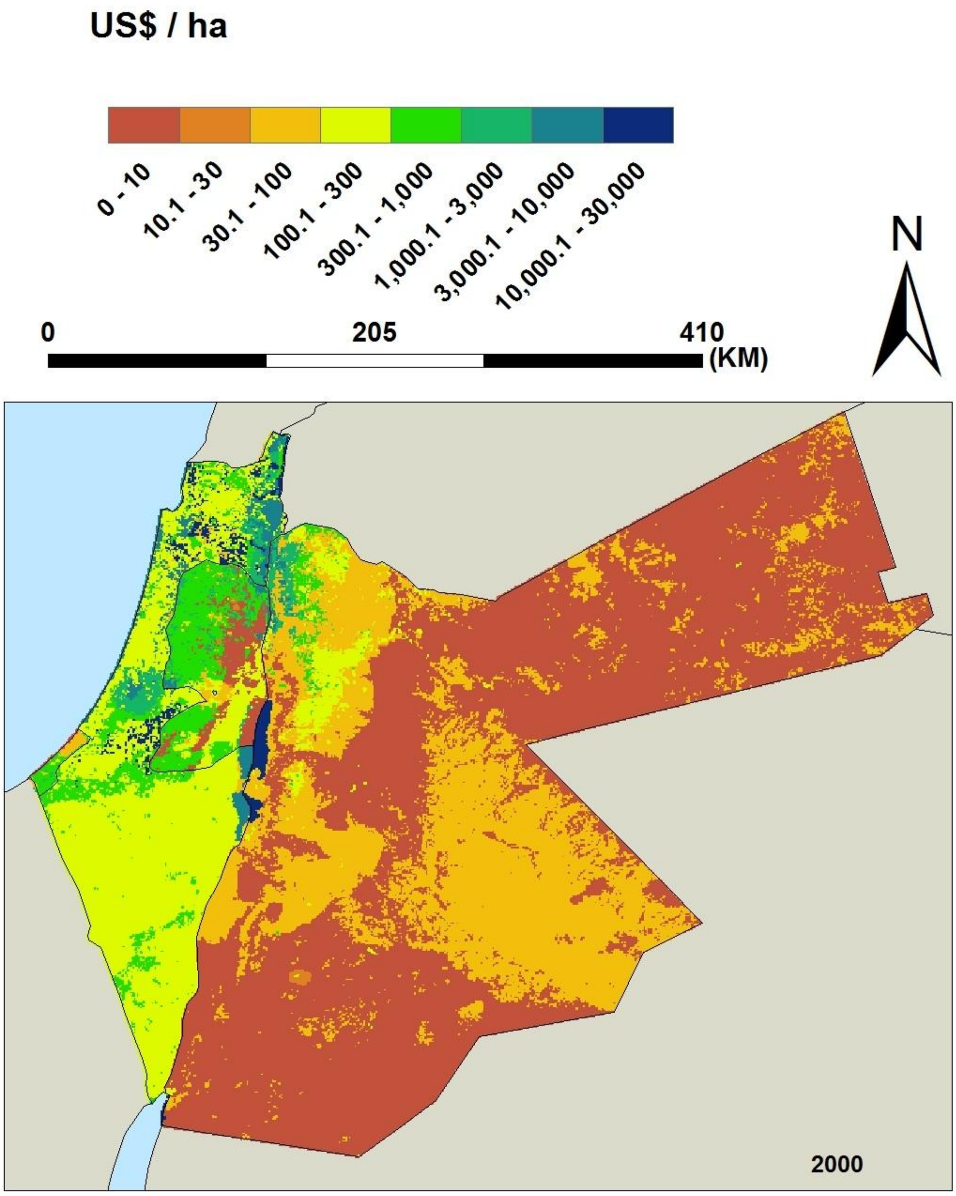

Figure 11: Ecosystem service value map for GLOWA Jordan River in 2000

Based on land-use and the identified values for ecosystem services, Figure 11 shows the distribution of ESS-values in the Jordan River region in the year 2000. In this figure, the effect of the different calculation methods used to determine the ESS-values in Jordan, Israel, and PA can be observed. The shoreline of the Dead Sea, for example, has three different values because it has a share in each of the three countries.

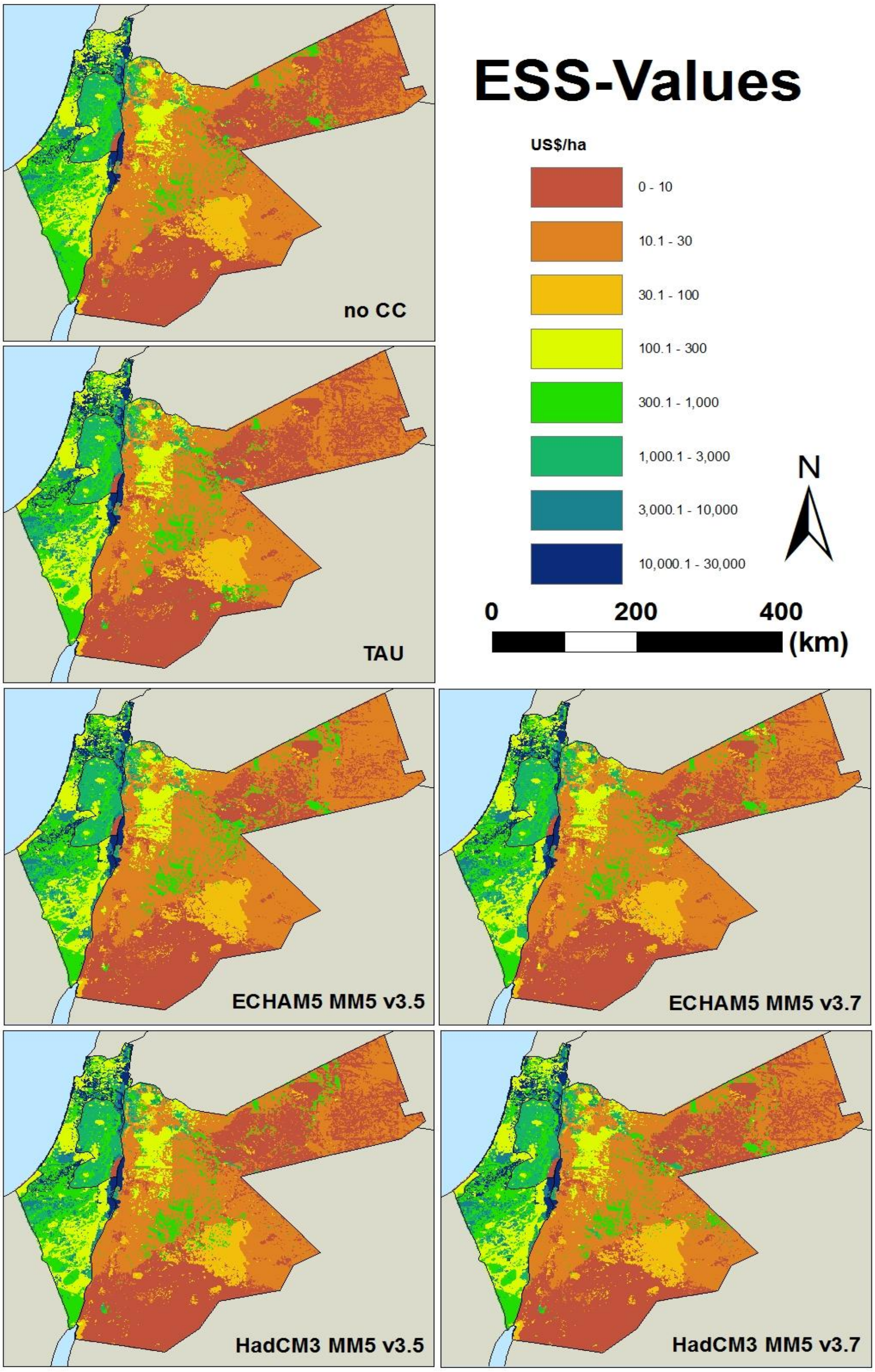

Figure 12: Ecosystem service value maps in 2050 with six different climate variants

A main part of the area in the GLOWA JR region has an increase of ESS-values by 2050 (Fig. 12). This is because either the land-use/land-cover is converted to types with higher values or the value of the land-use/land-cover type was assigned a higher value in the future. Most of the area which has a small value (0-10 US$/ha) in 2000 is given a higher value in 2050. The differences between the climate scenarios are small.

4.4. Population density results

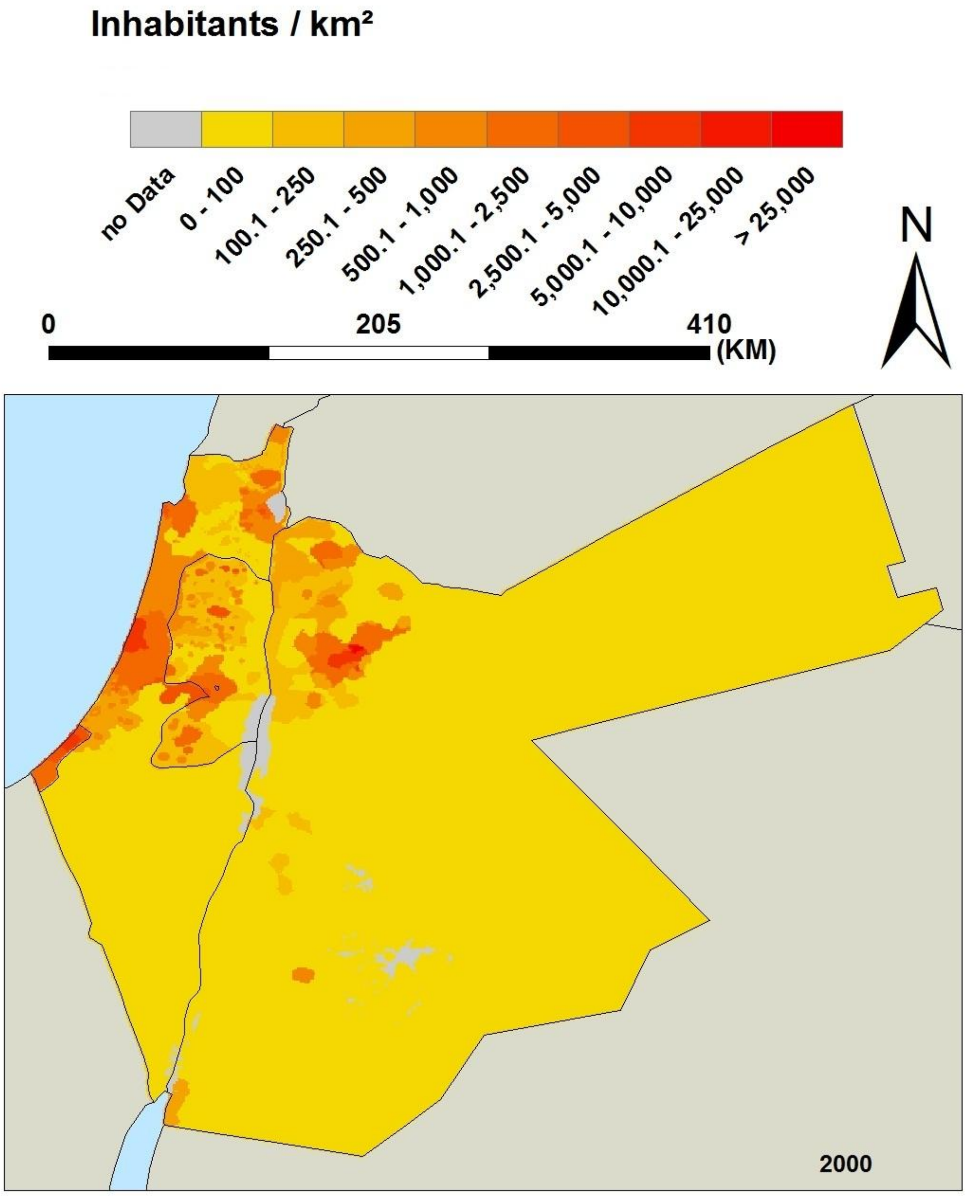

Figure 13: Population density in the GLOWA Jordan River region in 2000

The Figures 13 and 14 show maps of population density. Since the land-use activity "housing and infrastructure" is simulated independent of climate conditions, we show the population density in the base year (Fig. 13) and the year 2050 under the four GLOWA Jordan River socio-economic scenarios (Fig. 14) instead of comparing the results based on different climate input.

The population density in 2000 is divided into two extremes. Most of the study area has a very small population density, because of deserts and areas with no water. Population density is highest in and around the biggest cities, e.g. Amman, Jerusalem, Tel Aviv, and Gaza, and in the coastal region in Israel.

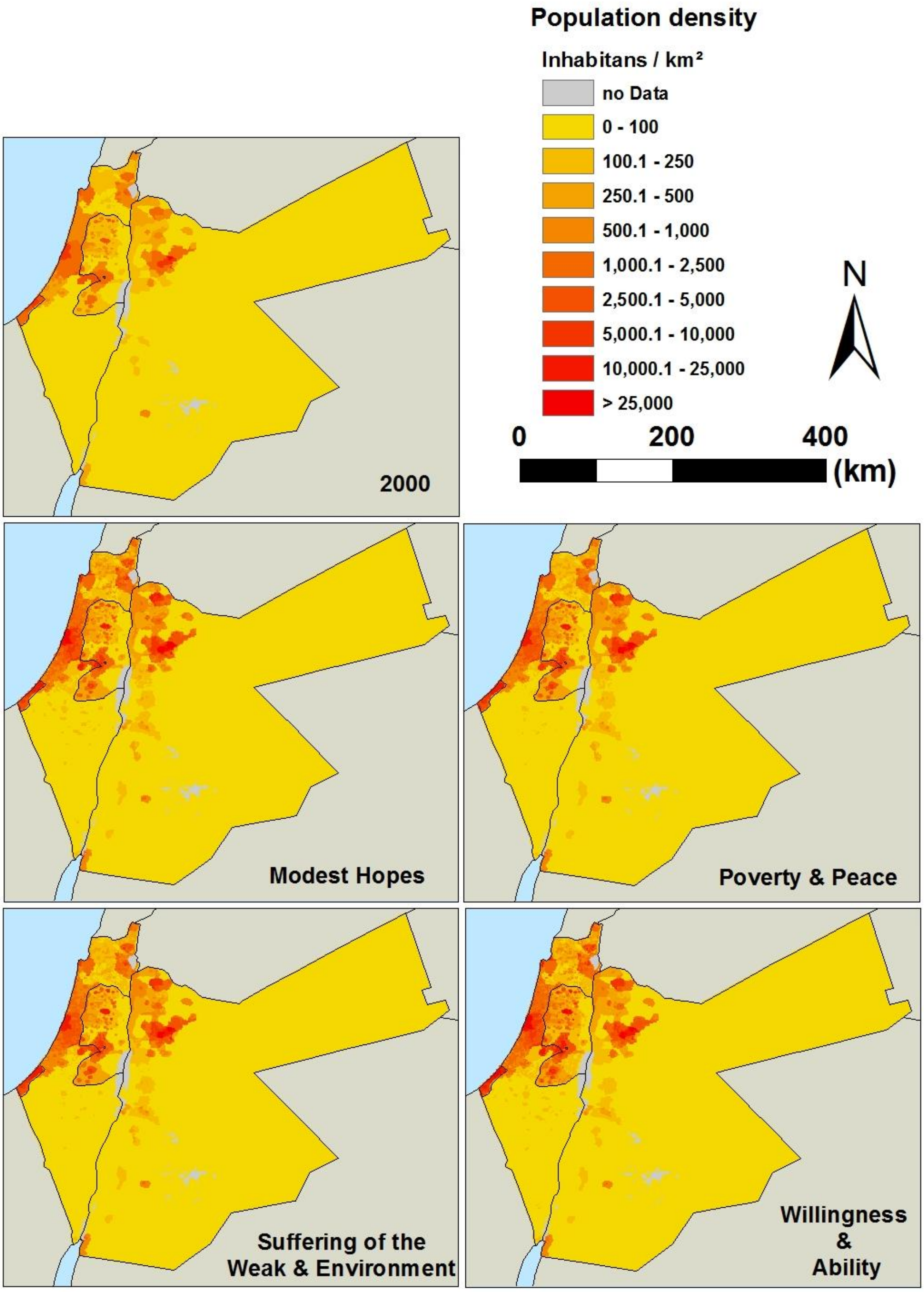

Figure 14: Population density maps for GLOWA Jordan River in 2050 under the four GLOWA JR scenarios

On the one hand, there is a fast growth of urban land (population density above 5000 people/km^2) at the edges of existing cities or urban centers. On the other hand, rural population density (less than 5000 people/km^2) increases uniformly and proportional to the initial population density, which is distributed homogeneously over administrative units. Differences between the four GLOWA socio-economic scenarios are as well very small. The main difference is the amount of population density. In the Modest Hopes scenario for example there are areas with more than 25.000 inhabitants per km².

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6. Annex

Annex 1: Land-use maps

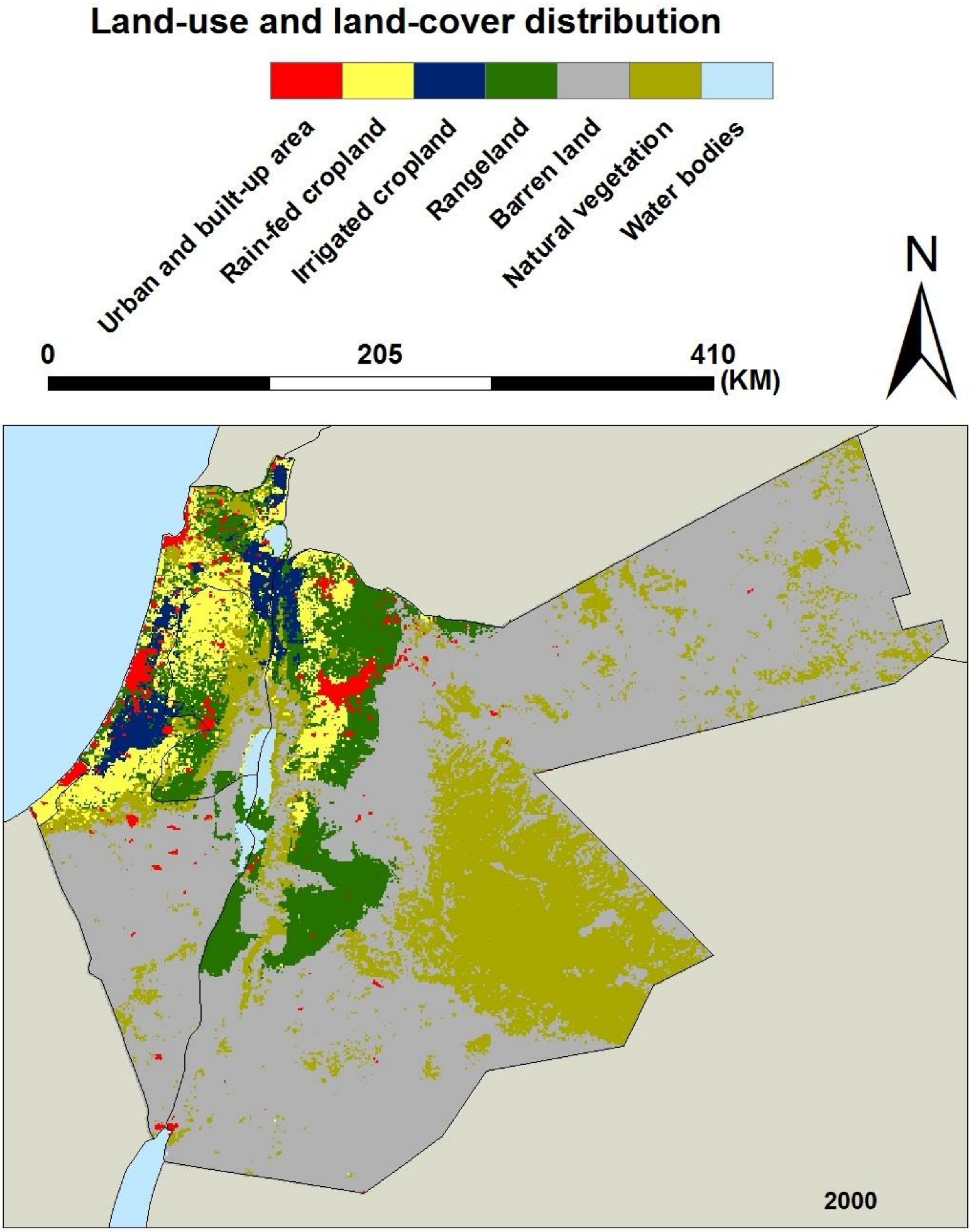

Figure 15: Land-use map for GLOWA Jordan River in 2000

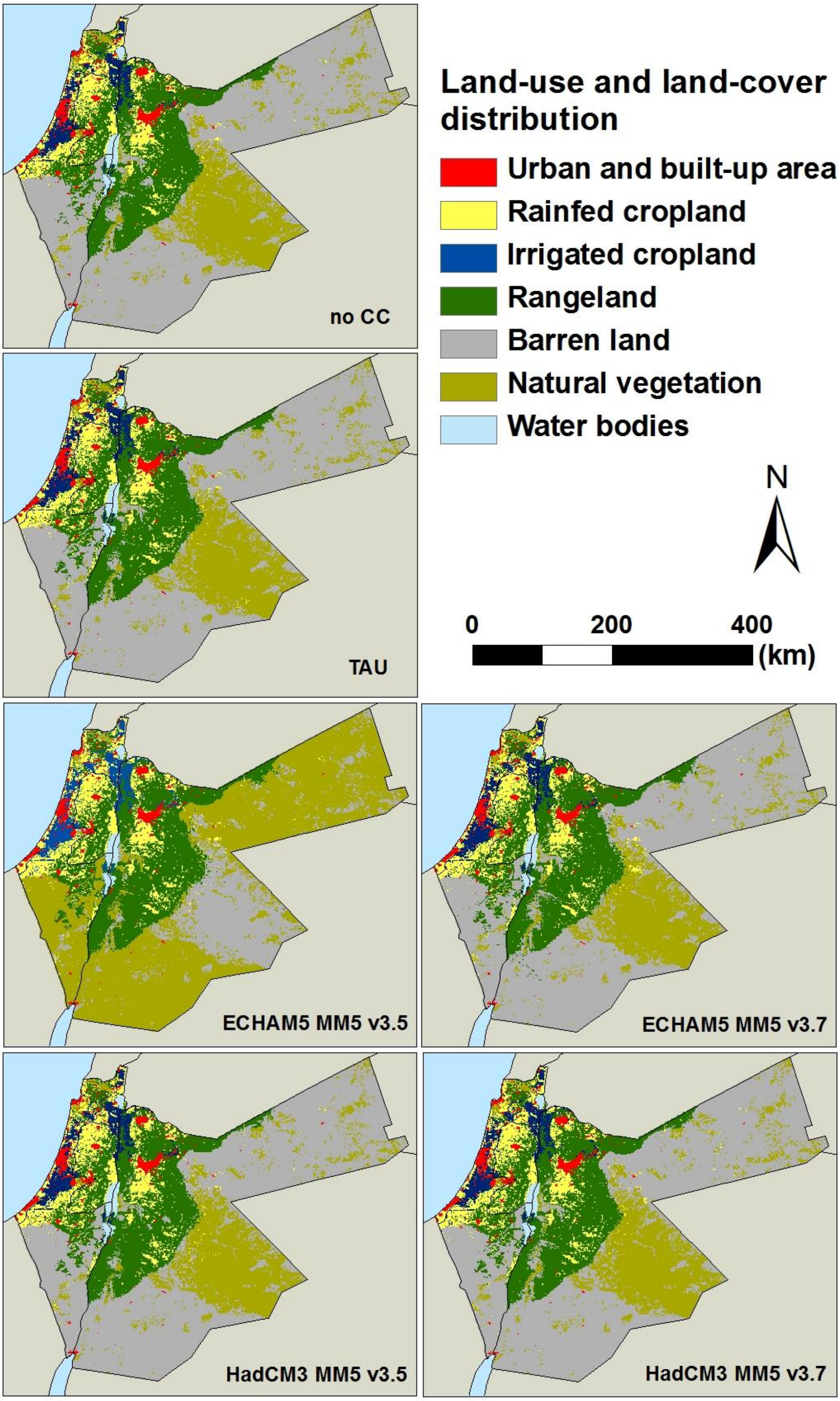

Figure 16: Land-use maps in 2025 with six different climates and the Modest Hopes scenario

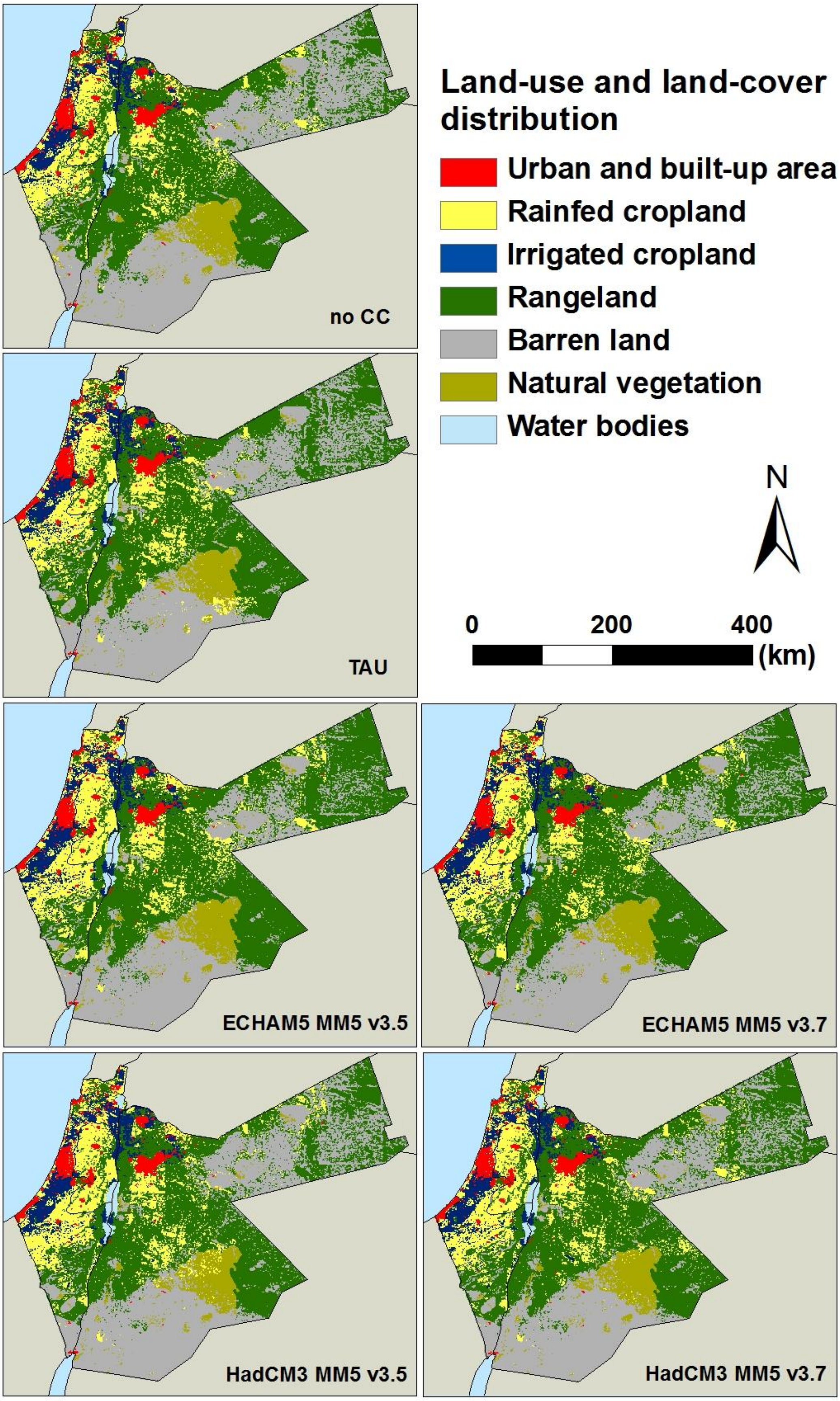

Figure 17: Land-use maps in 2050 with six different climates and the Modest Hopes scenario

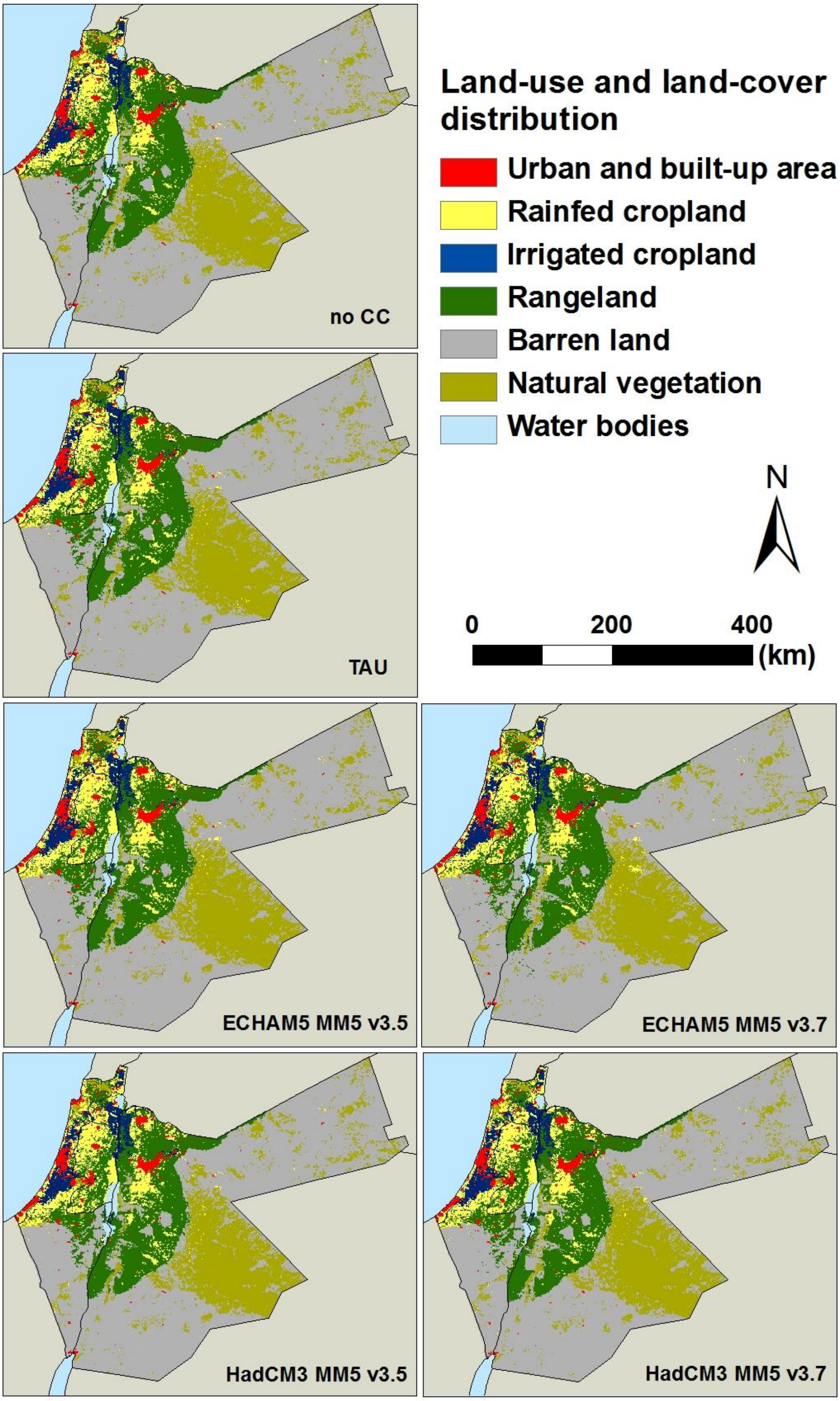

Figure 18: Land-use maps in 2025 with six different climates and the Poverty & Peace scenario

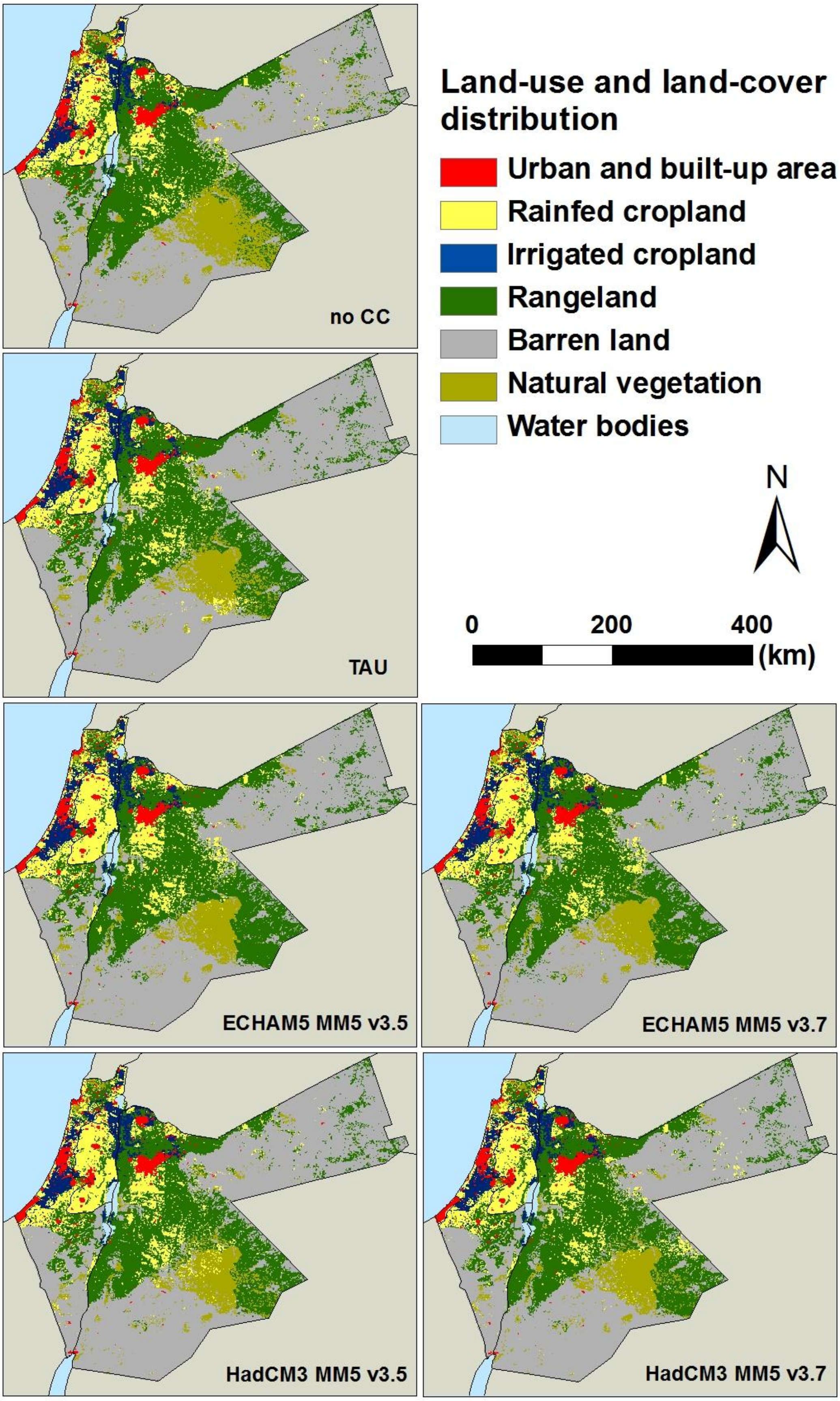

Figure 19: Land-use maps in 2050 with six different climates and the Poverty & Peace scenario

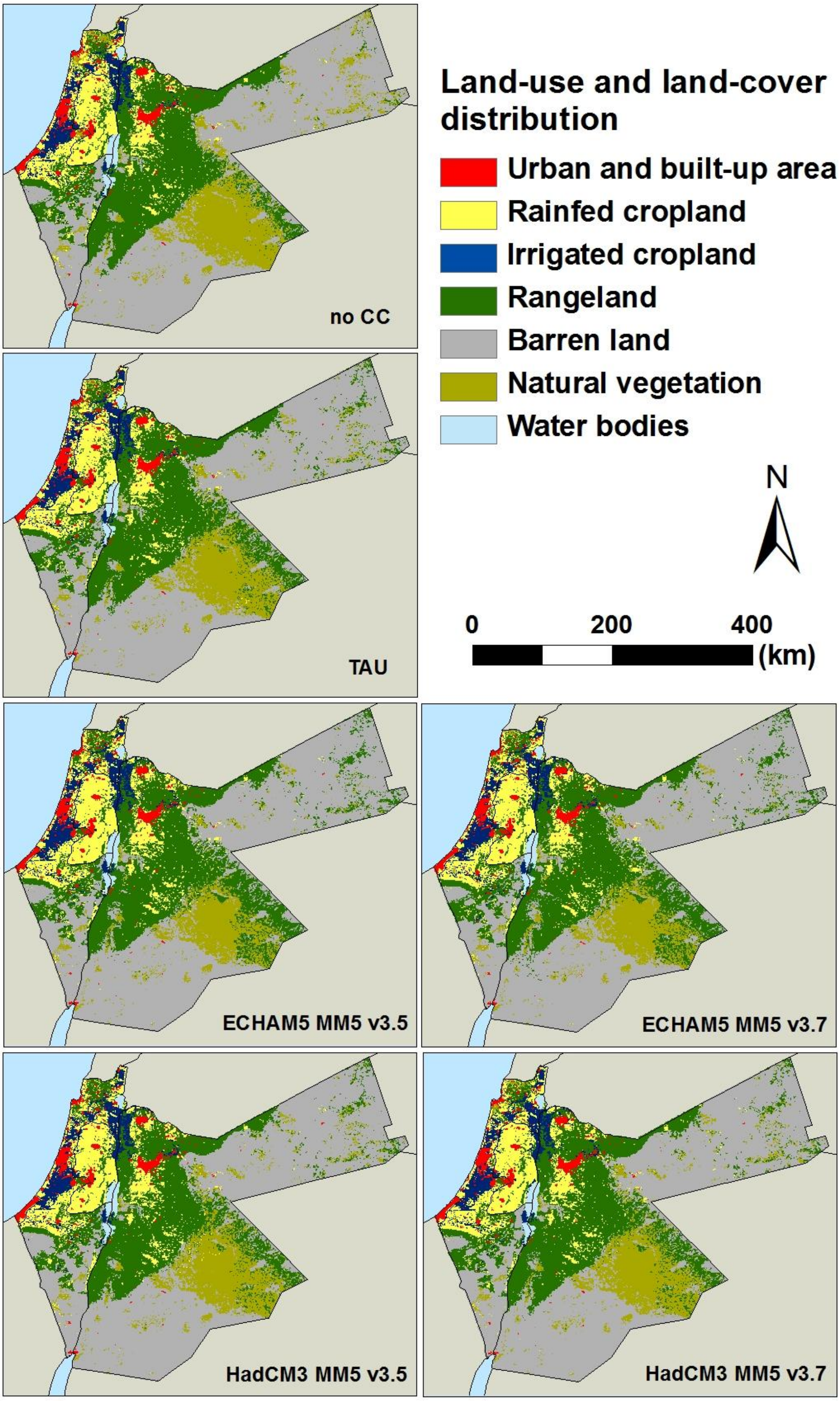

Figure 20: Land-use maps in 2025 with six different climates and the Willingness & Ability scenario

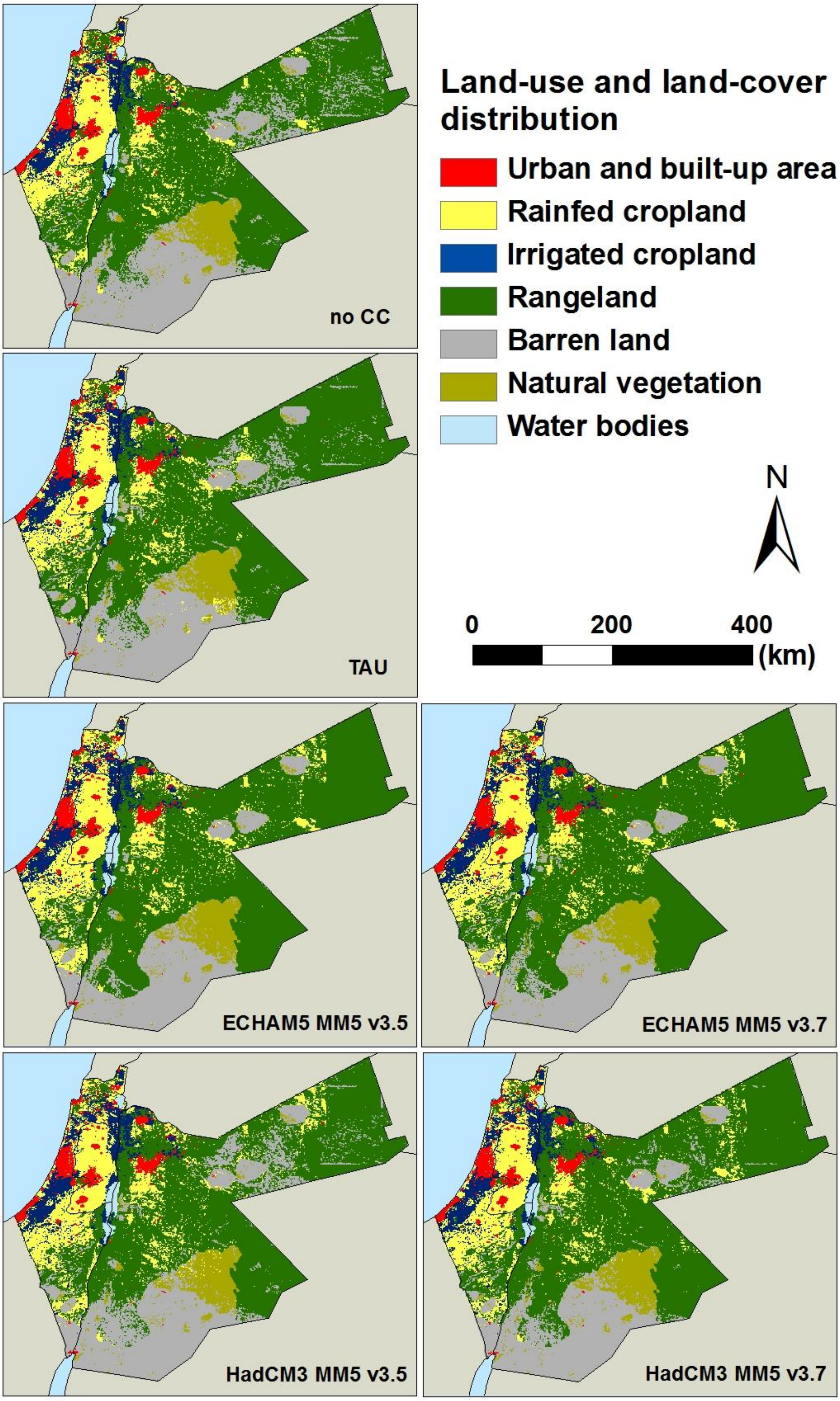

Figure 21: Land-use maps in 2050 with six different climates and the Willingness & Ability scenario

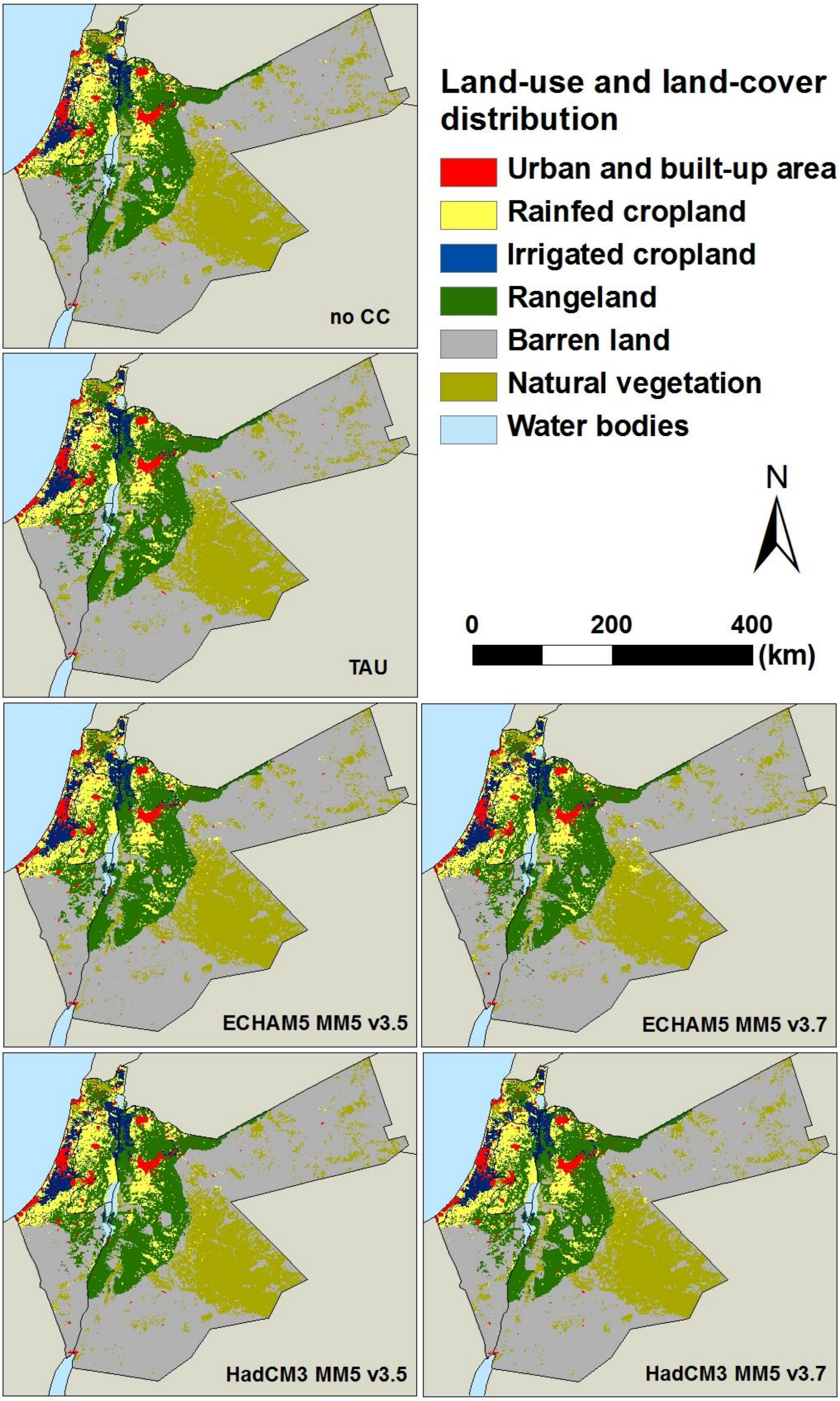

Figure 22: Land-use maps in 2025 with six different climates and the Suffering of the Weak & Environment scenario

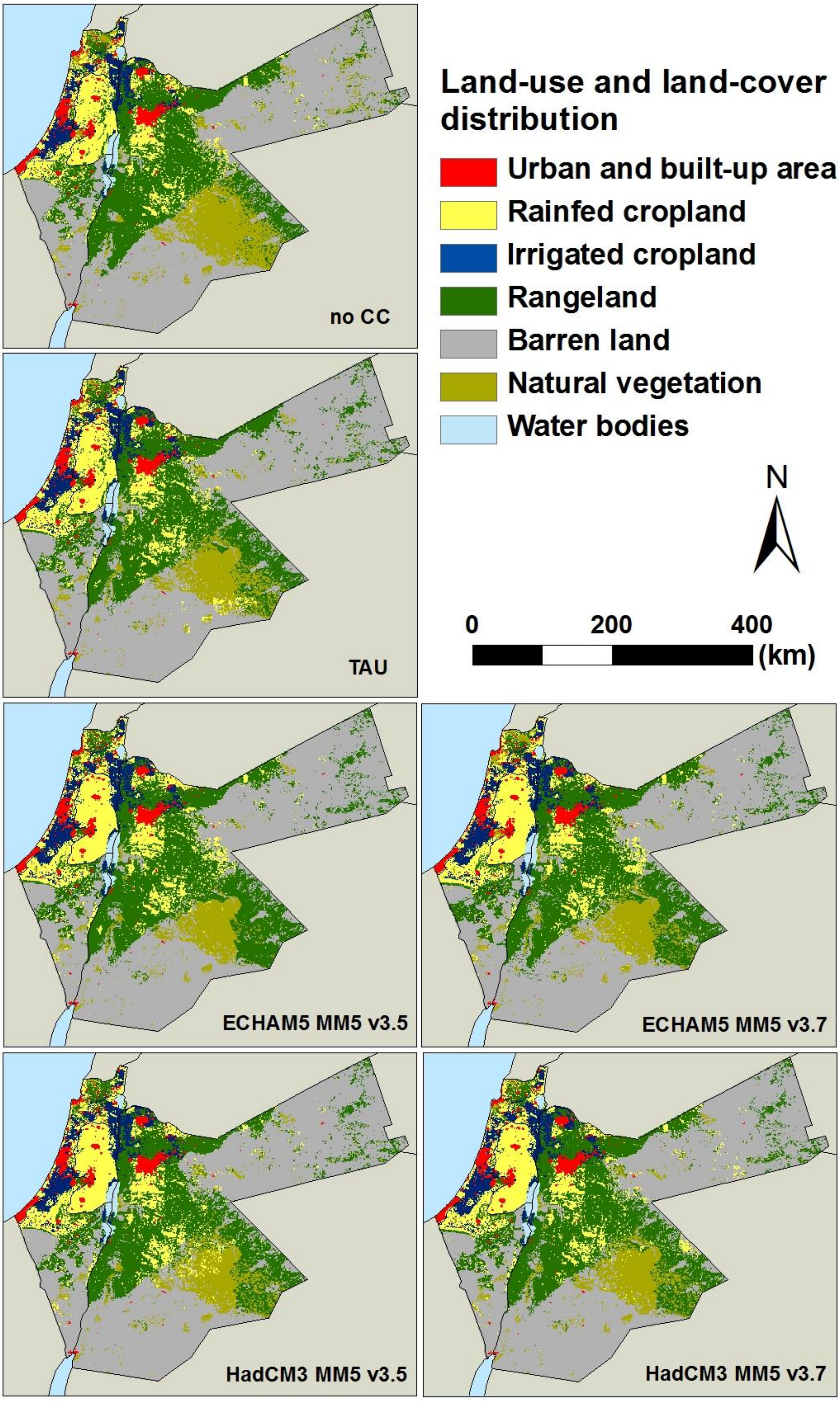

Figure 23: Land-use maps in 2050 with six different climates and the Suffering of the Weak & Environment scenario

Annex 2: Livestock density maps

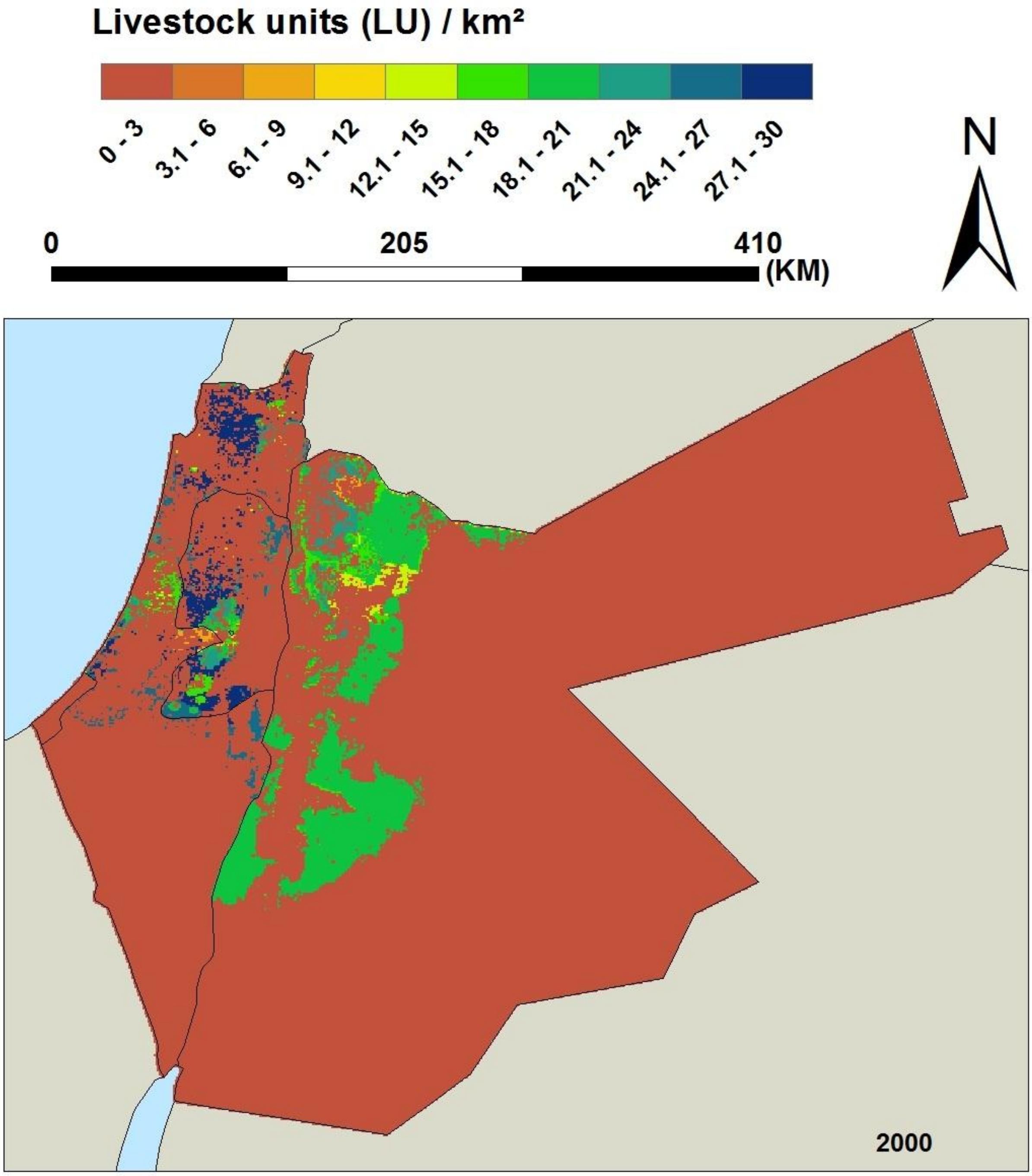

Figure 24: Livestock density in the GLOWA Jordan River region in 2000

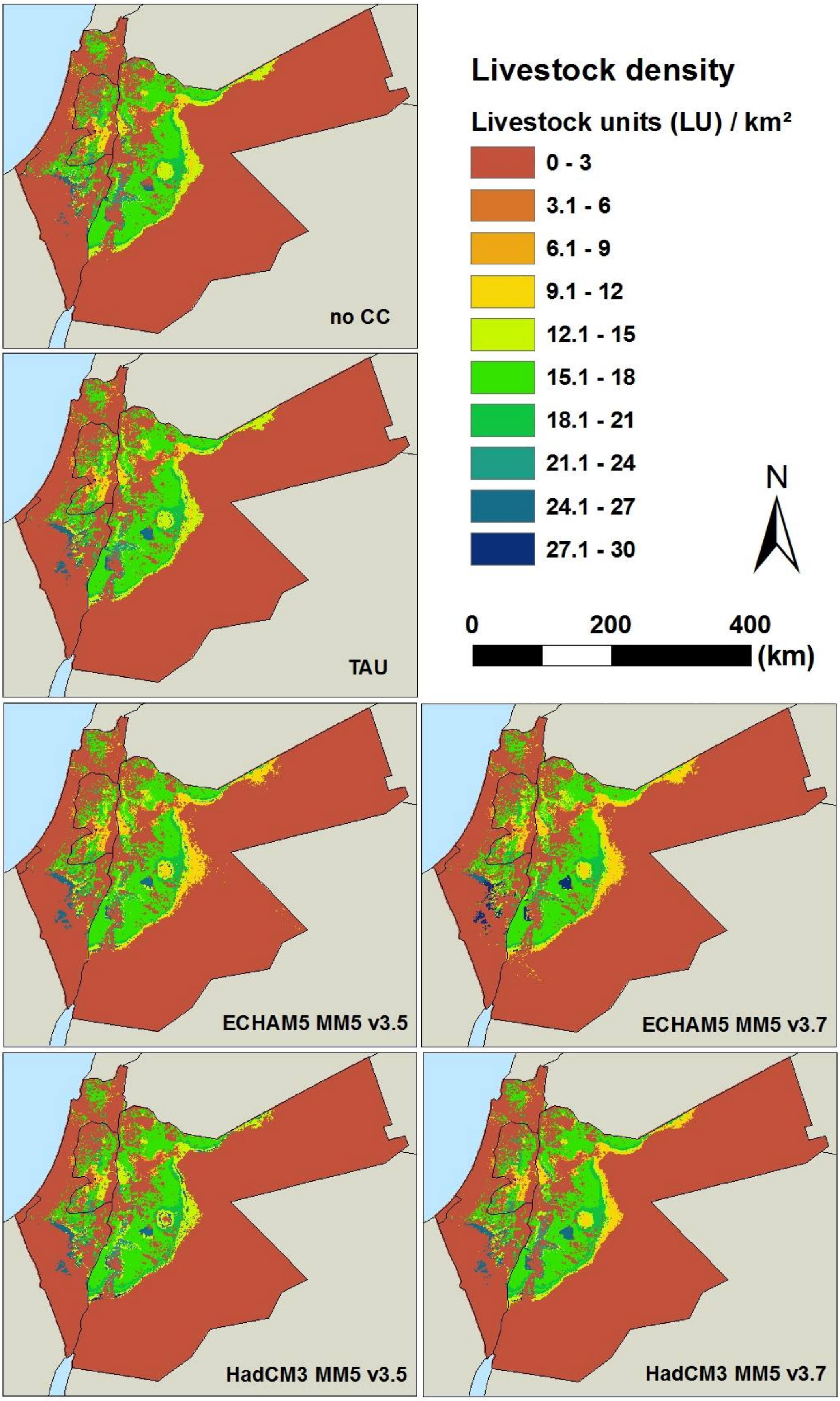

Figure 25: Livestock density maps in 2025 with six different climates and the Modest Hopes scenario

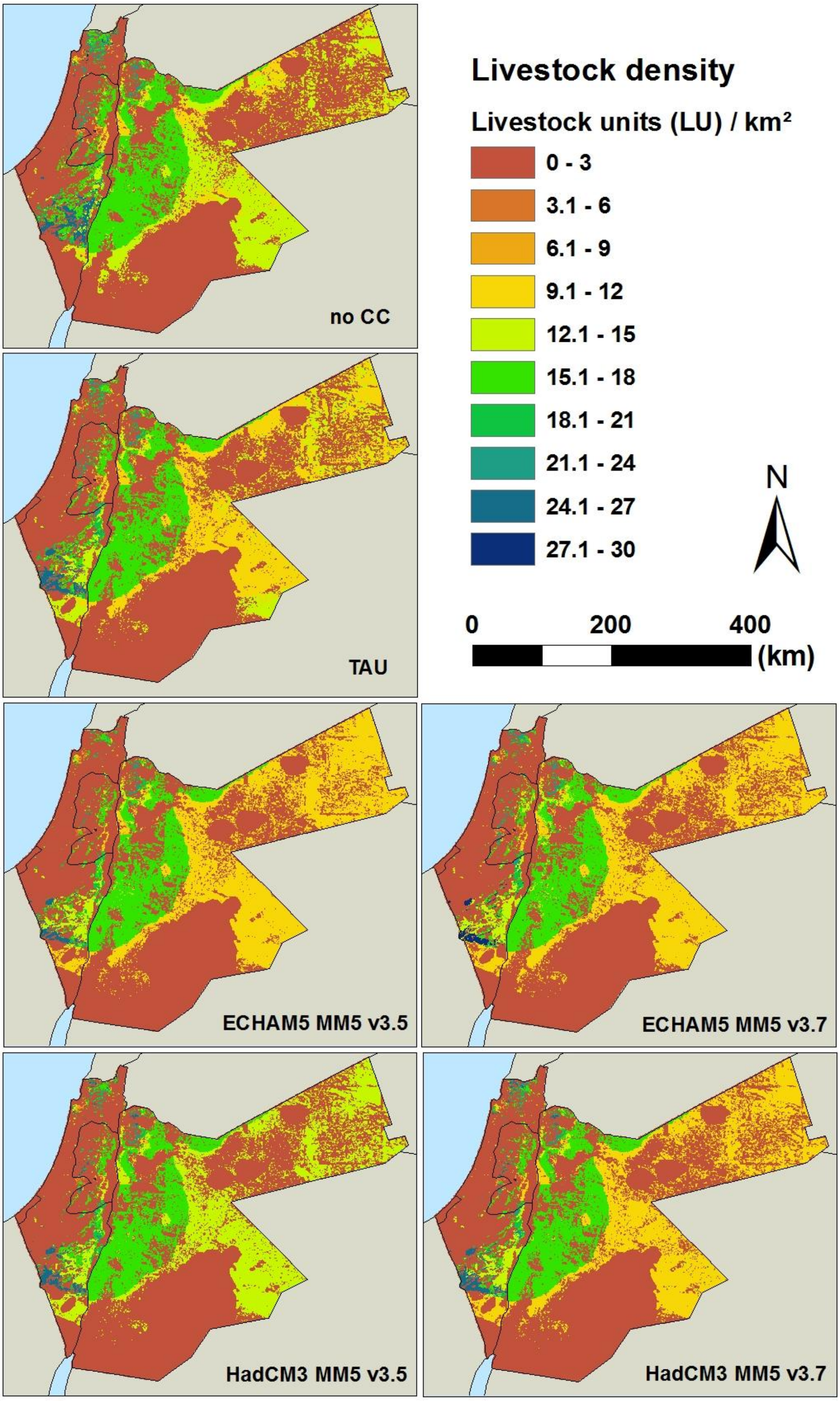

Figure 26: Livestock density maps in 2050 with six different climates and the Modest Hopes scenario

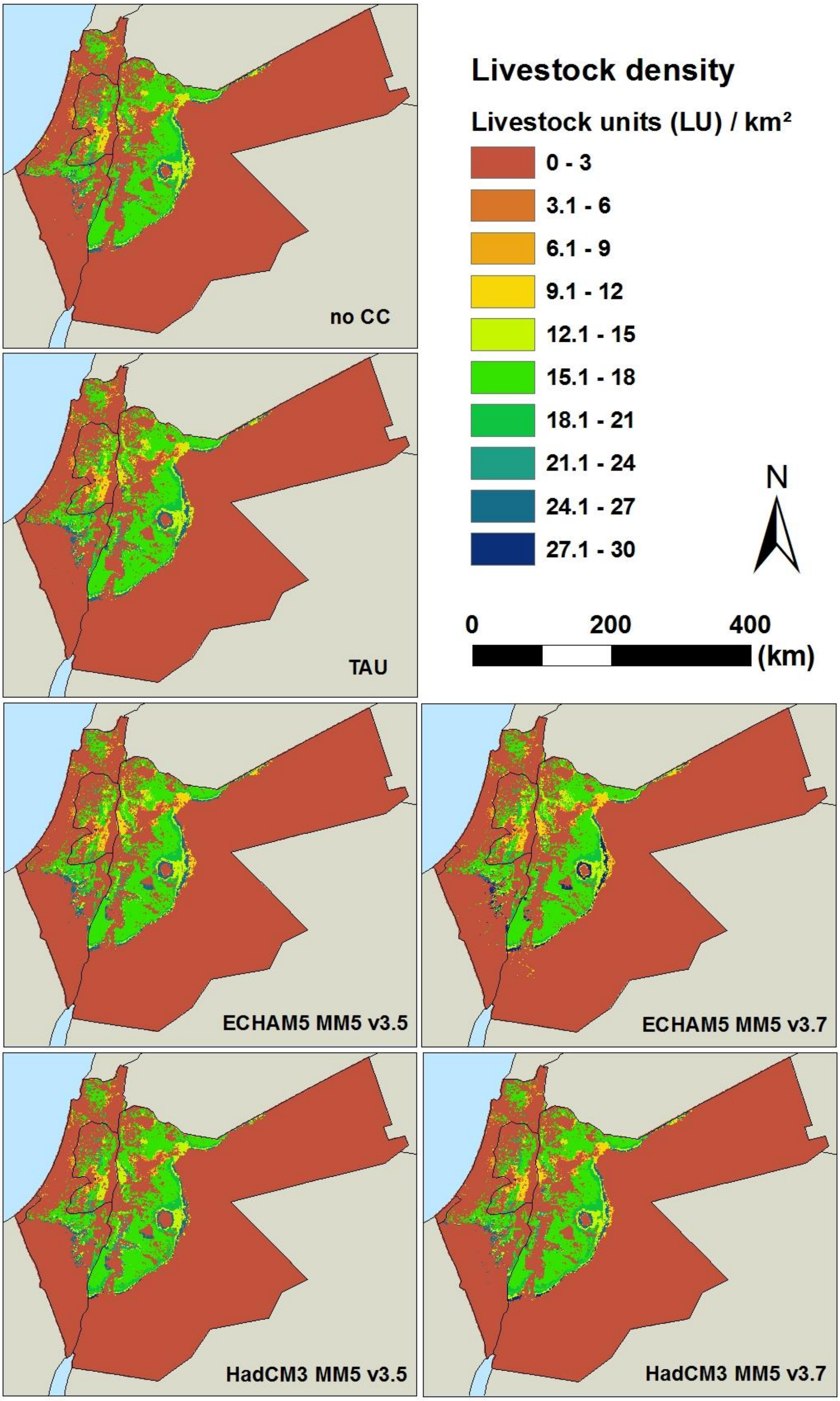

Figure 27: Livestock density maps in 2025 with six different climates and the Poverty & Peace scenario

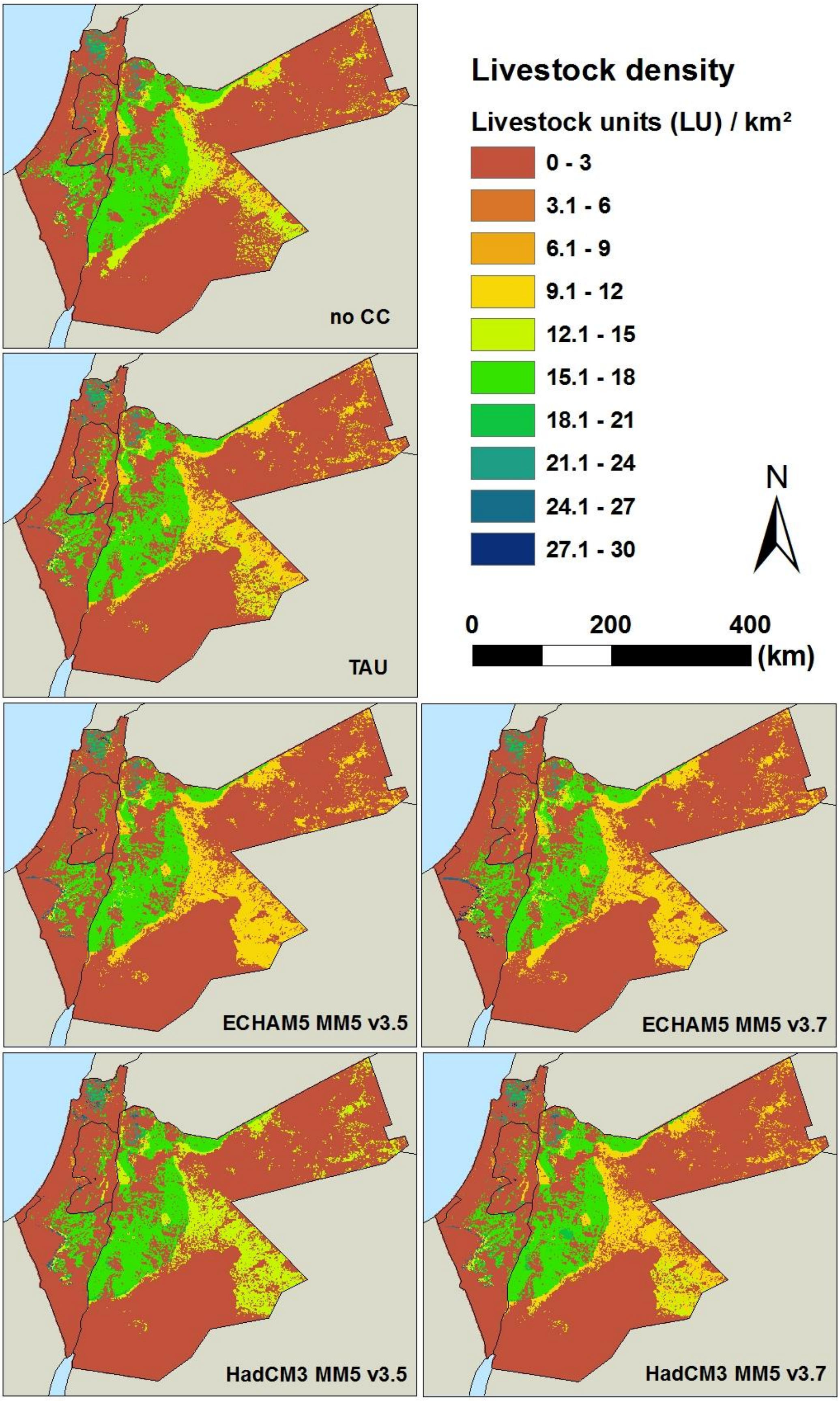

Figure 28: Livestock density maps in 2050 with six different climates and the Poverty & Peace scenario

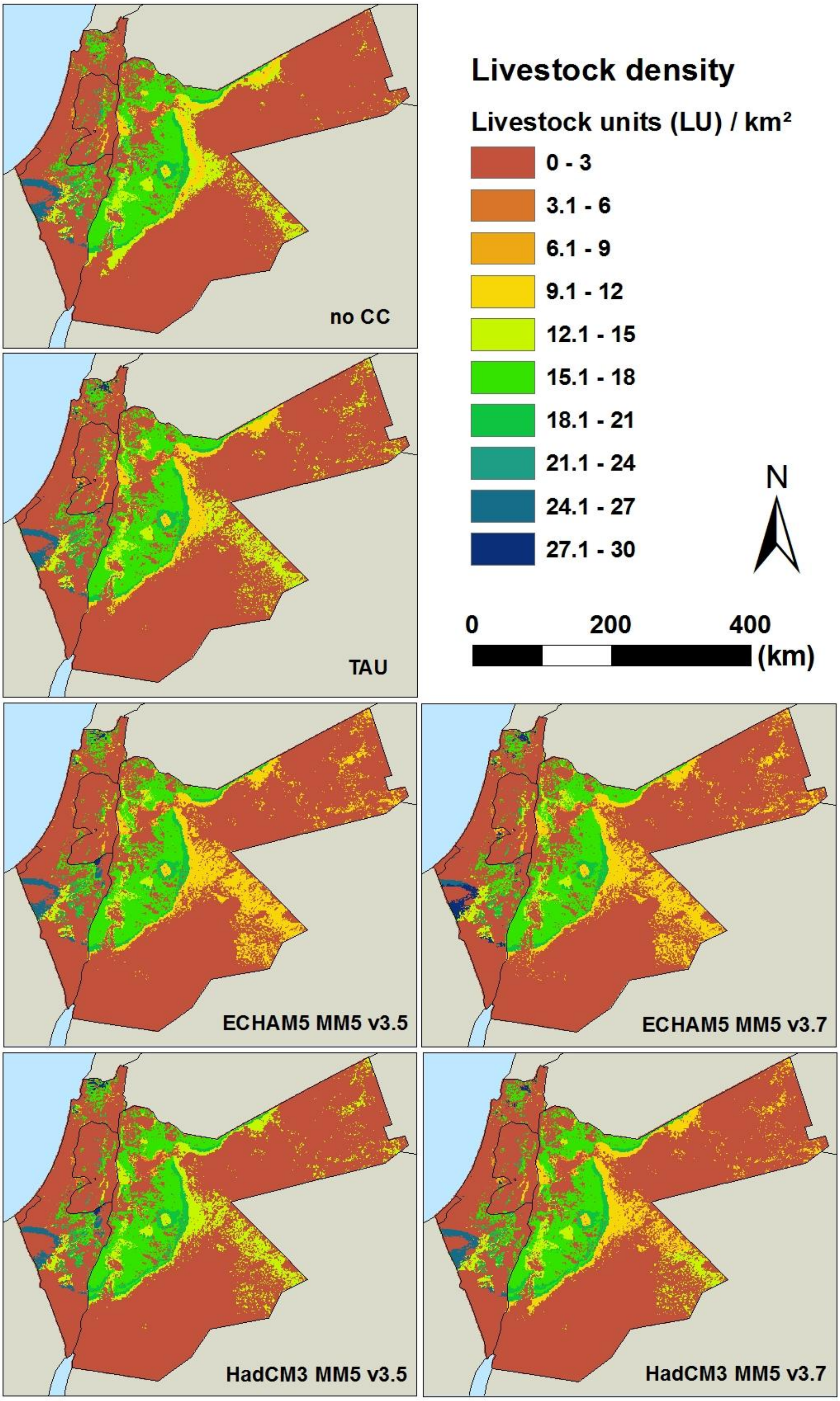

Figure 29: Livestock density maps in 2025 with six different climates and the Willingness & Ability scenario

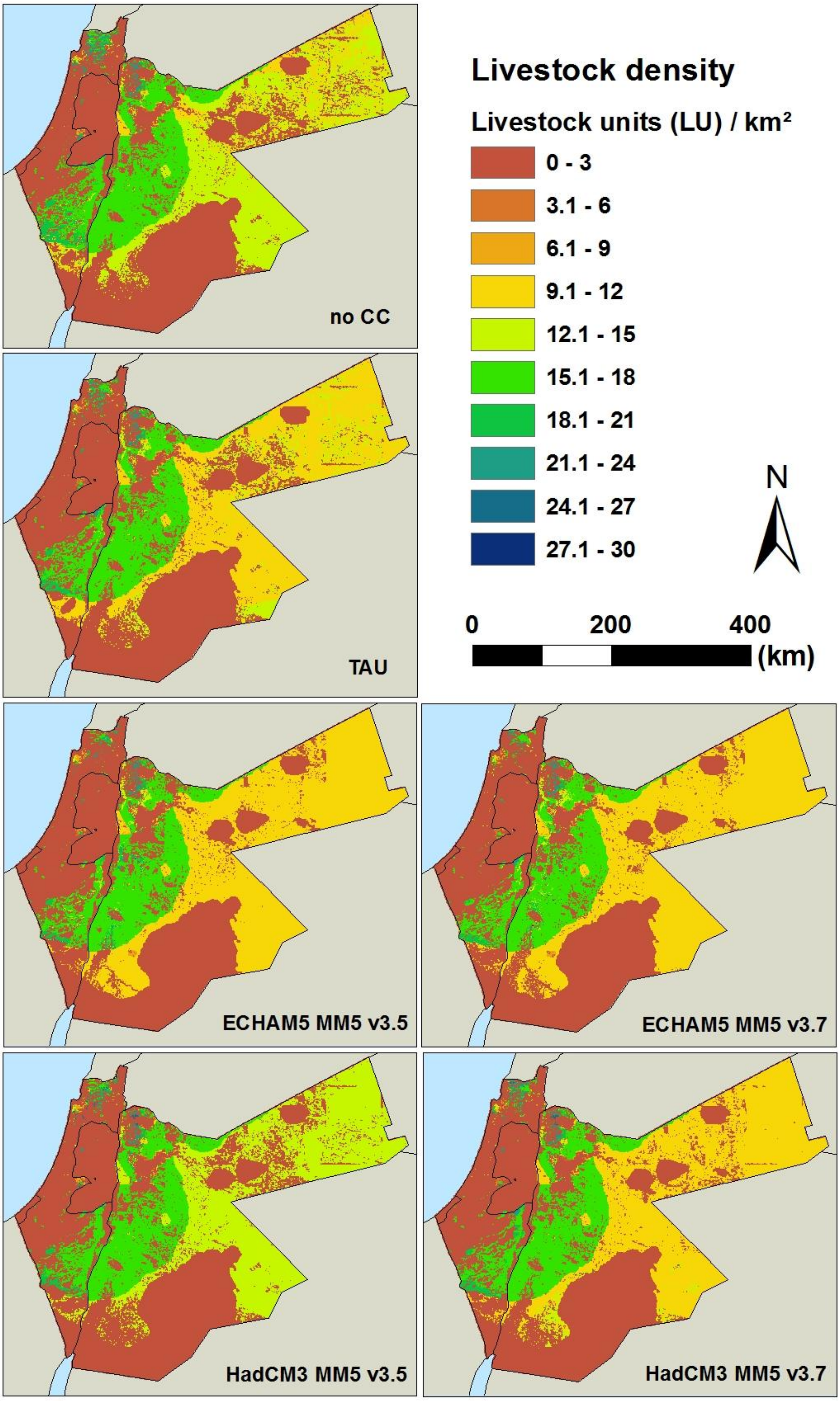

Figure 30: Livestock density maps in 2050 with six different climates and the Willingness & Ability scenario

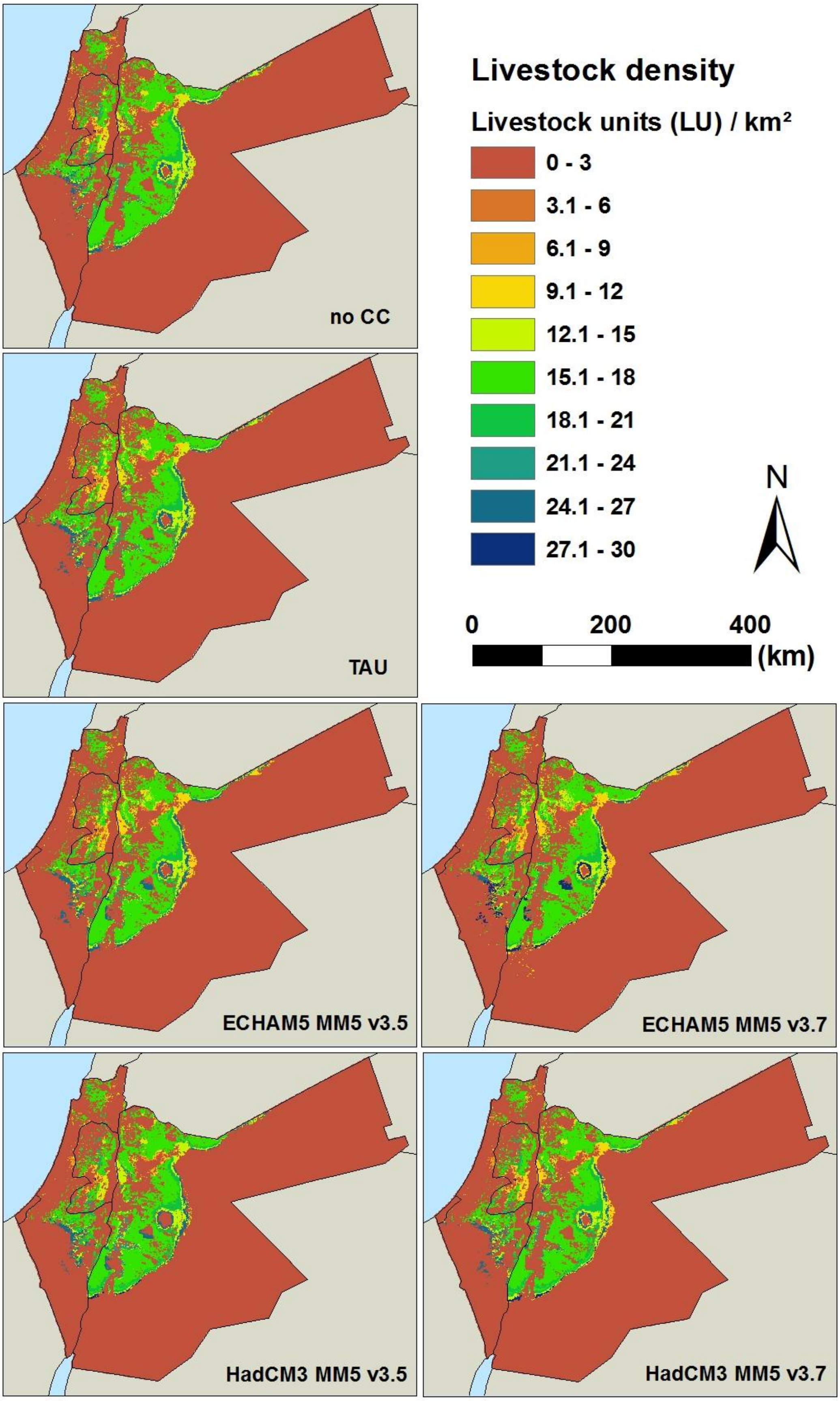

Figure 31: Livestock density maps in 2025 with six different climates and the Suffering of the Weak & Environment scenario

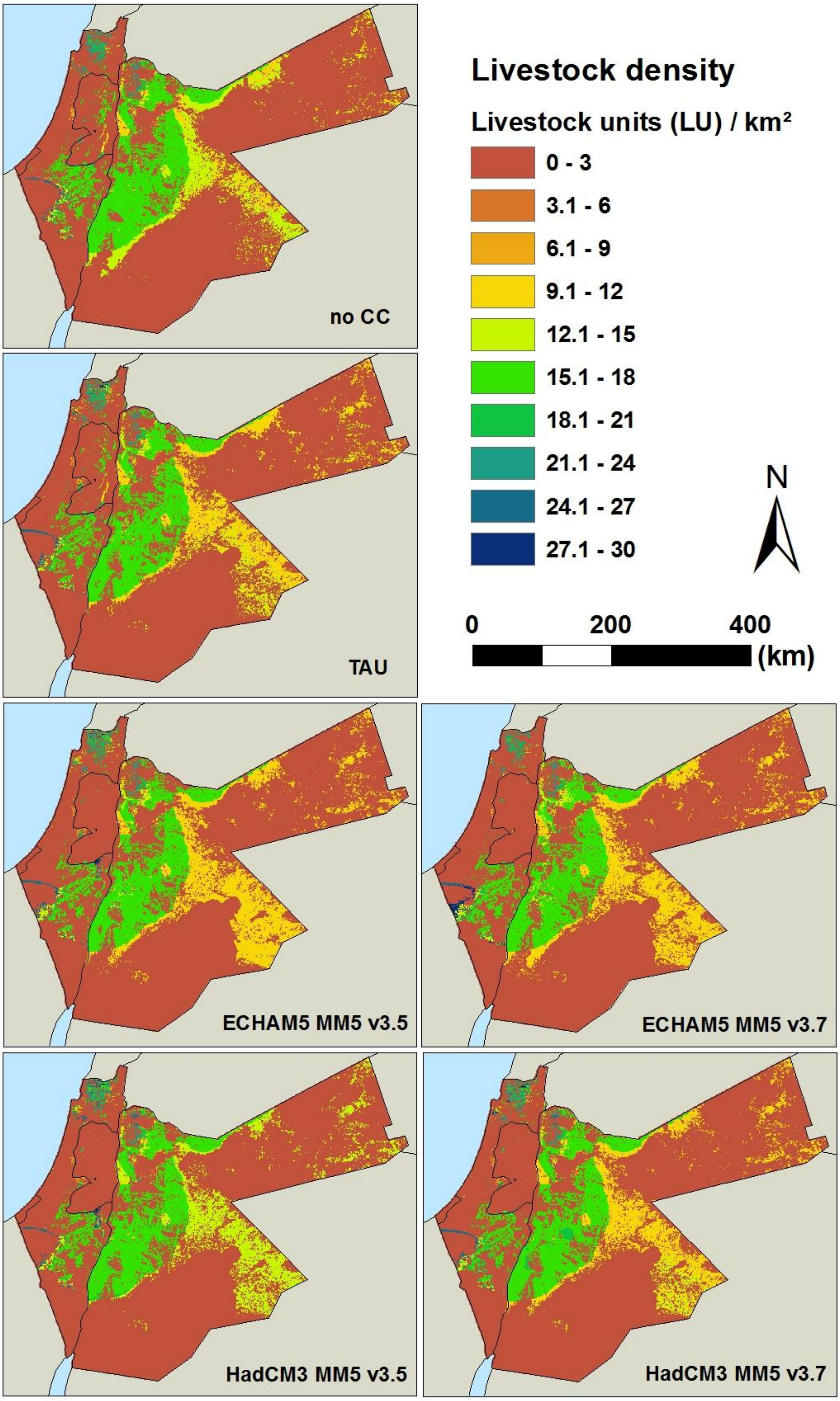

Figure 32: Livestock density maps in 2050 with six different climates and the Suffering of the Weak & Environment scenario

Annex 3: Ecosystem service value maps

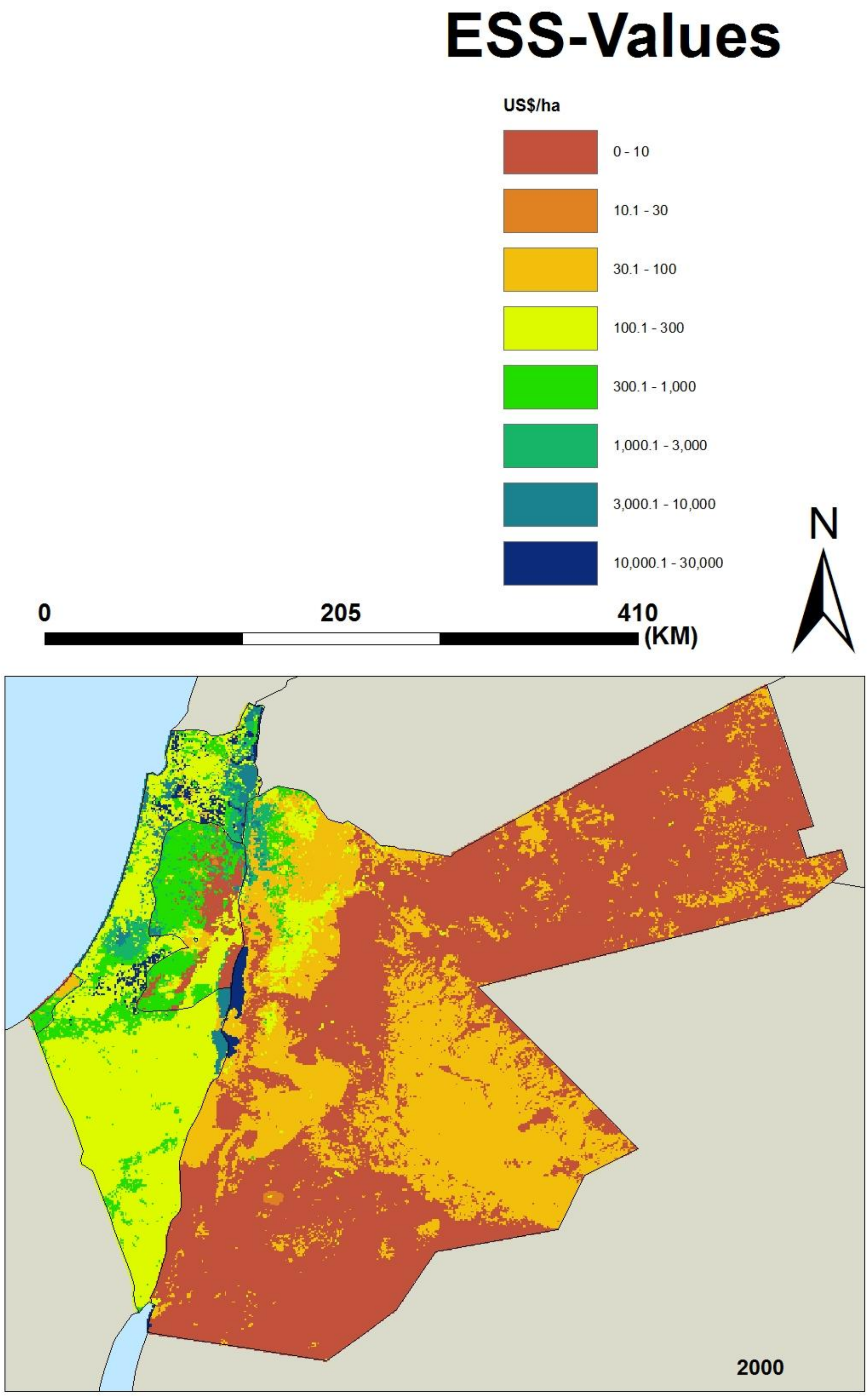

Figure 33: Ecosystem service value map for GLOWA Jordan River in 2000

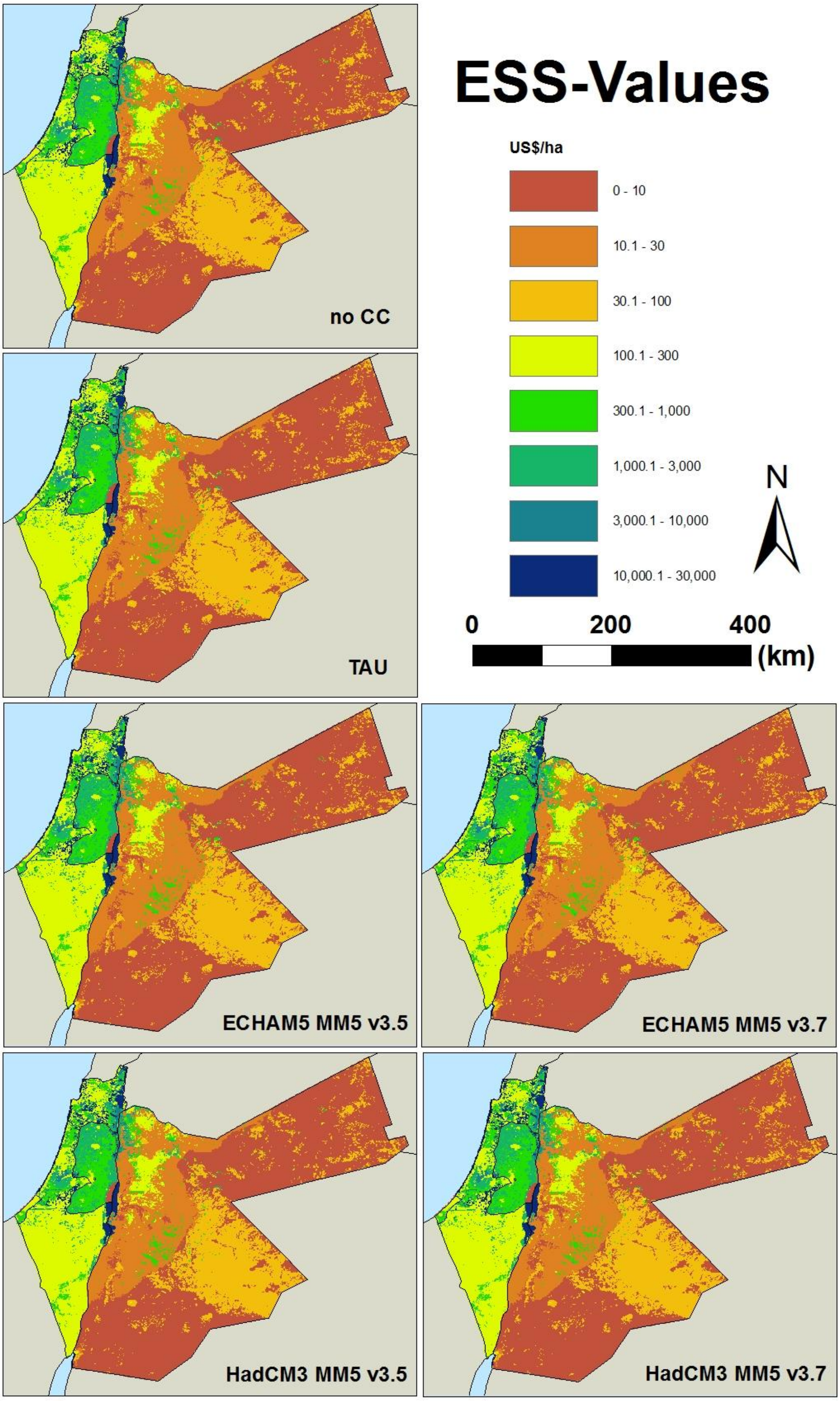

Figure 34: ESS-value maps in 2025 with six different climates and the Modest Hopes scenario

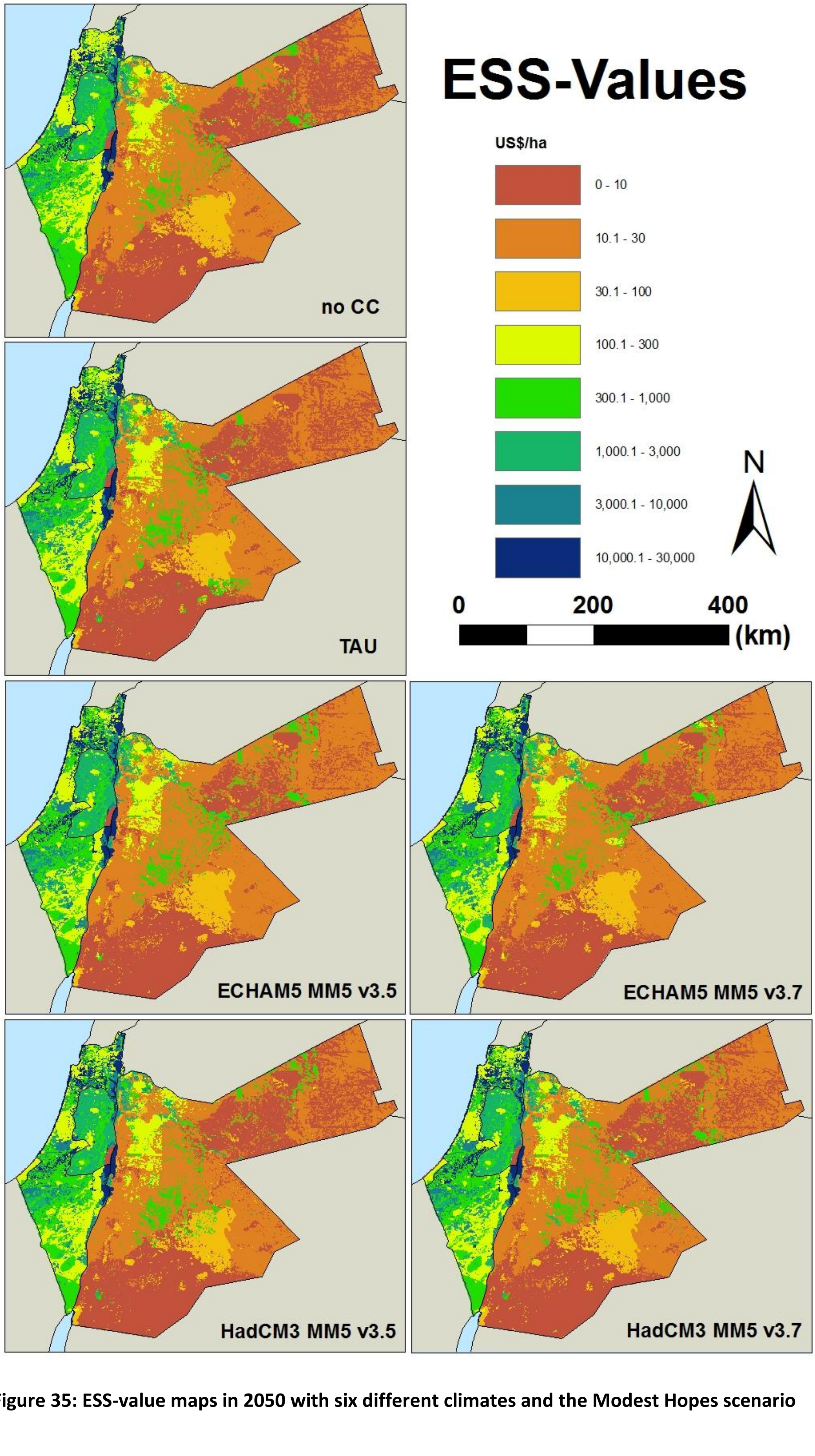

Figure 35: ESS-value maps in 2050 with six different climates and the Modest Hopes scenario

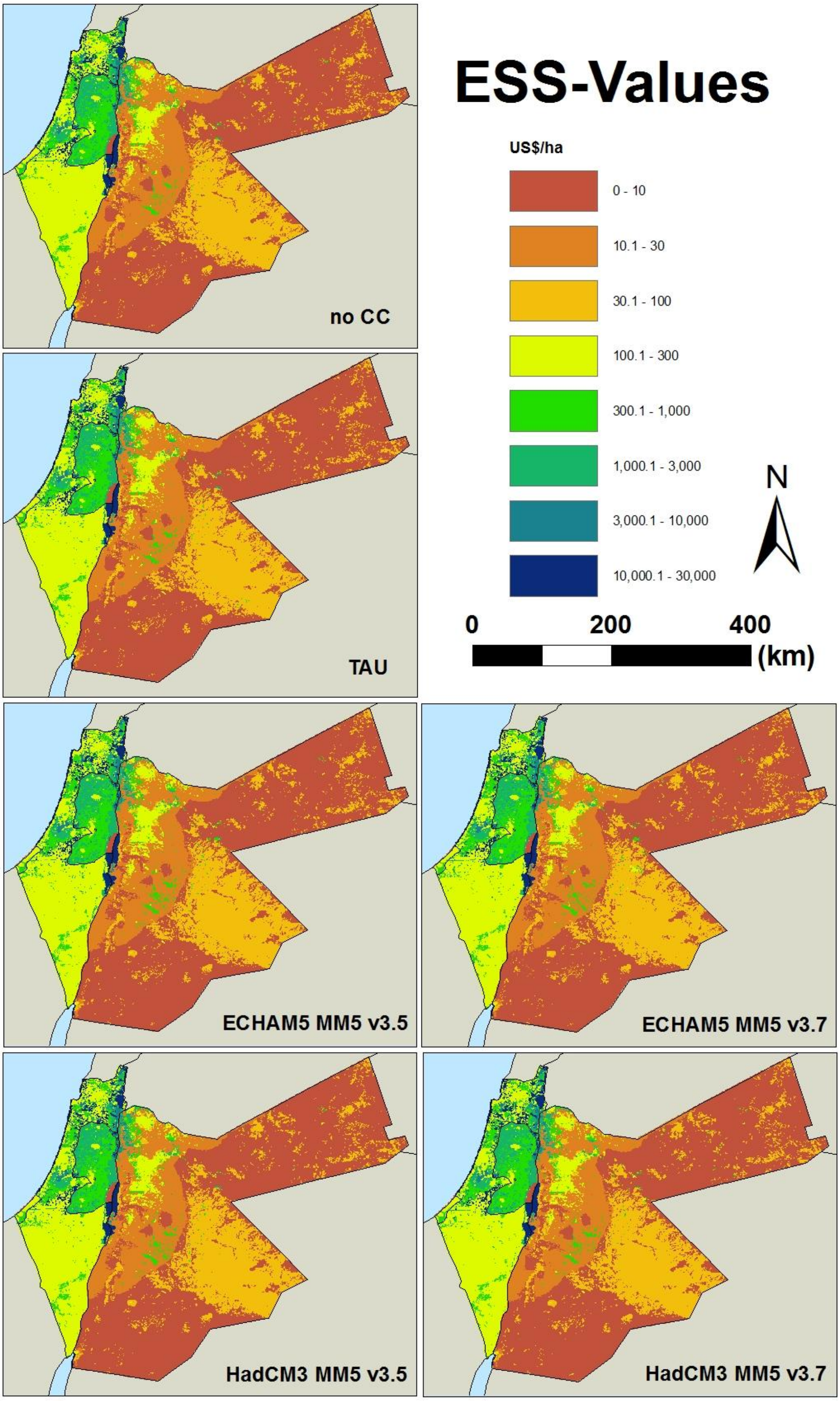

Figure 36: ESS-value maps in 2025 with six different climates and the Poverty & Peace scenario

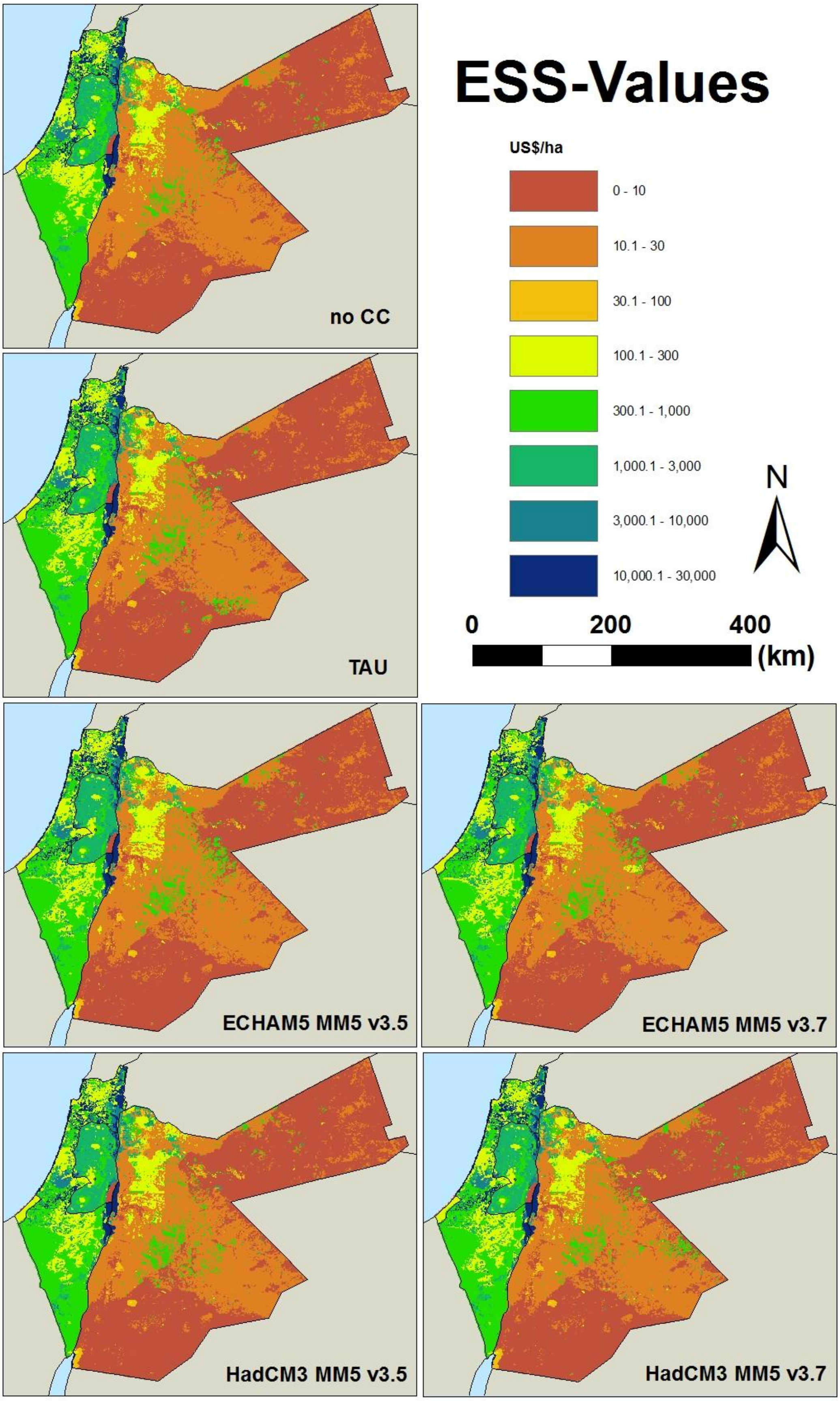

Figure 37: ESS-value maps in 2050 with six different climates and the Poverty & Peace scenario

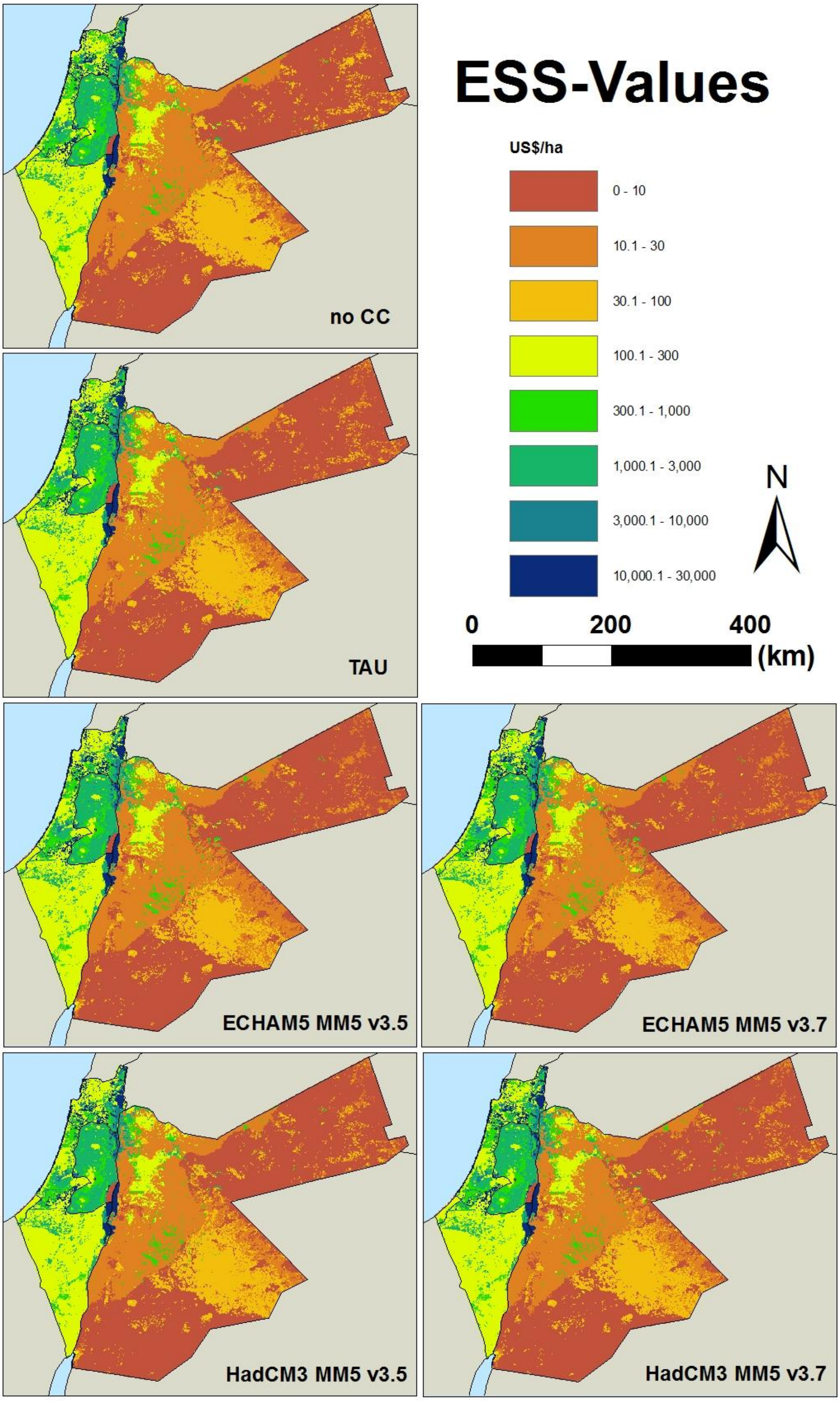

Figure 38: ESS-value maps in 2025 with six different climates and the Willingness & Ability scenario

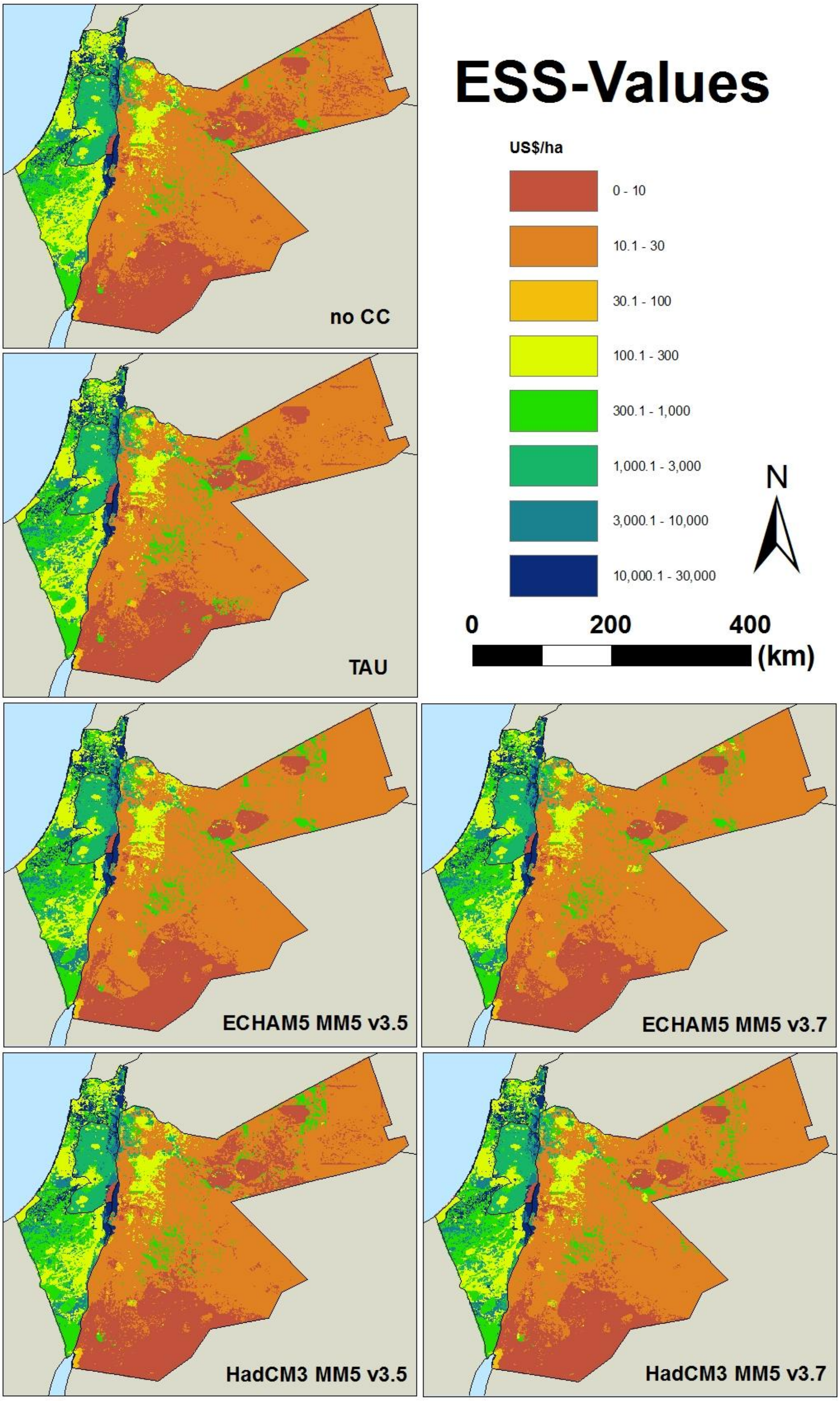

Figure 39: ESS-value maps in 2050 with six different climates and the Willingness & Ability scenario

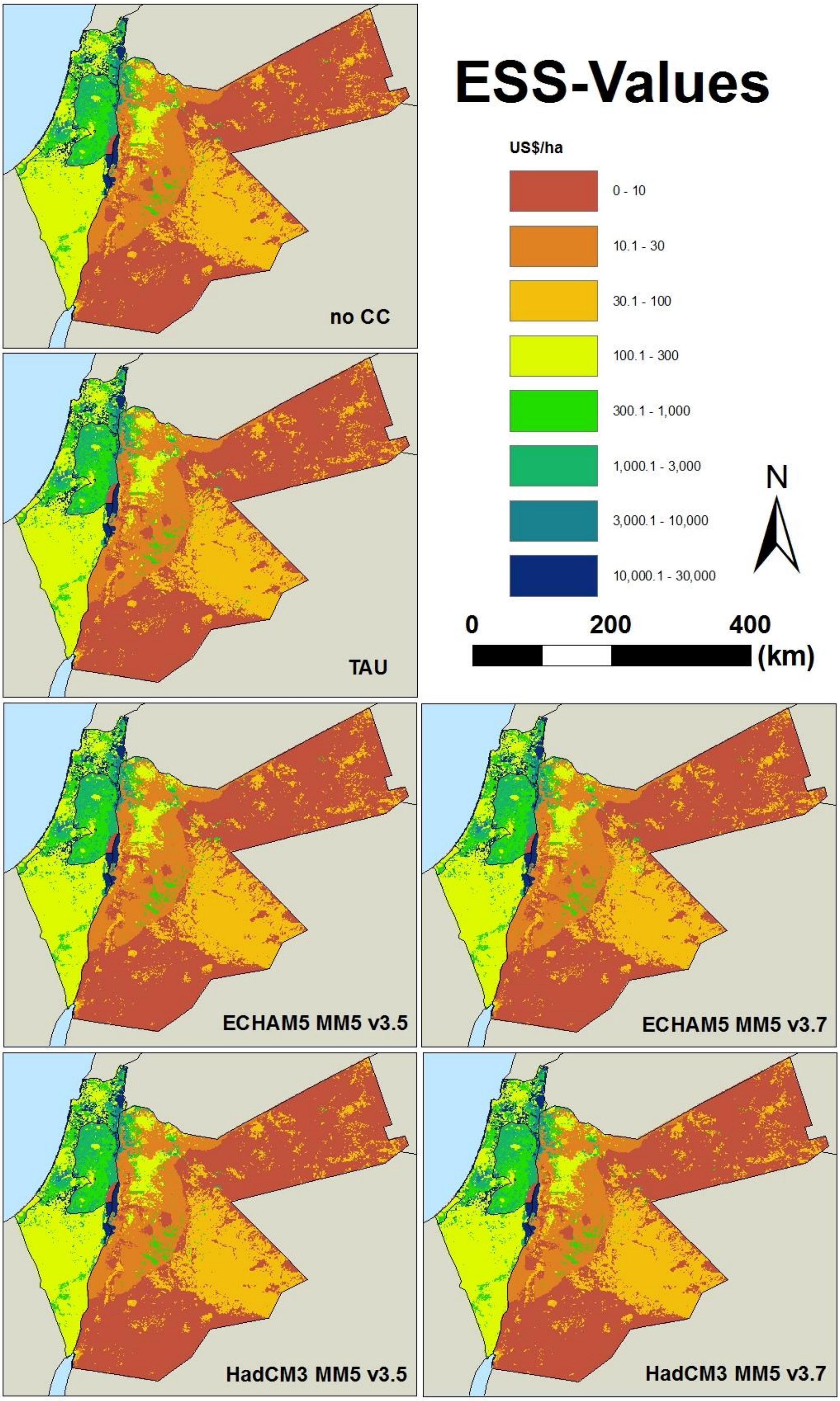

Figure 40: ESS-value maps in 2025 with six different climates and the Suffering of the Weak & Environment scenario

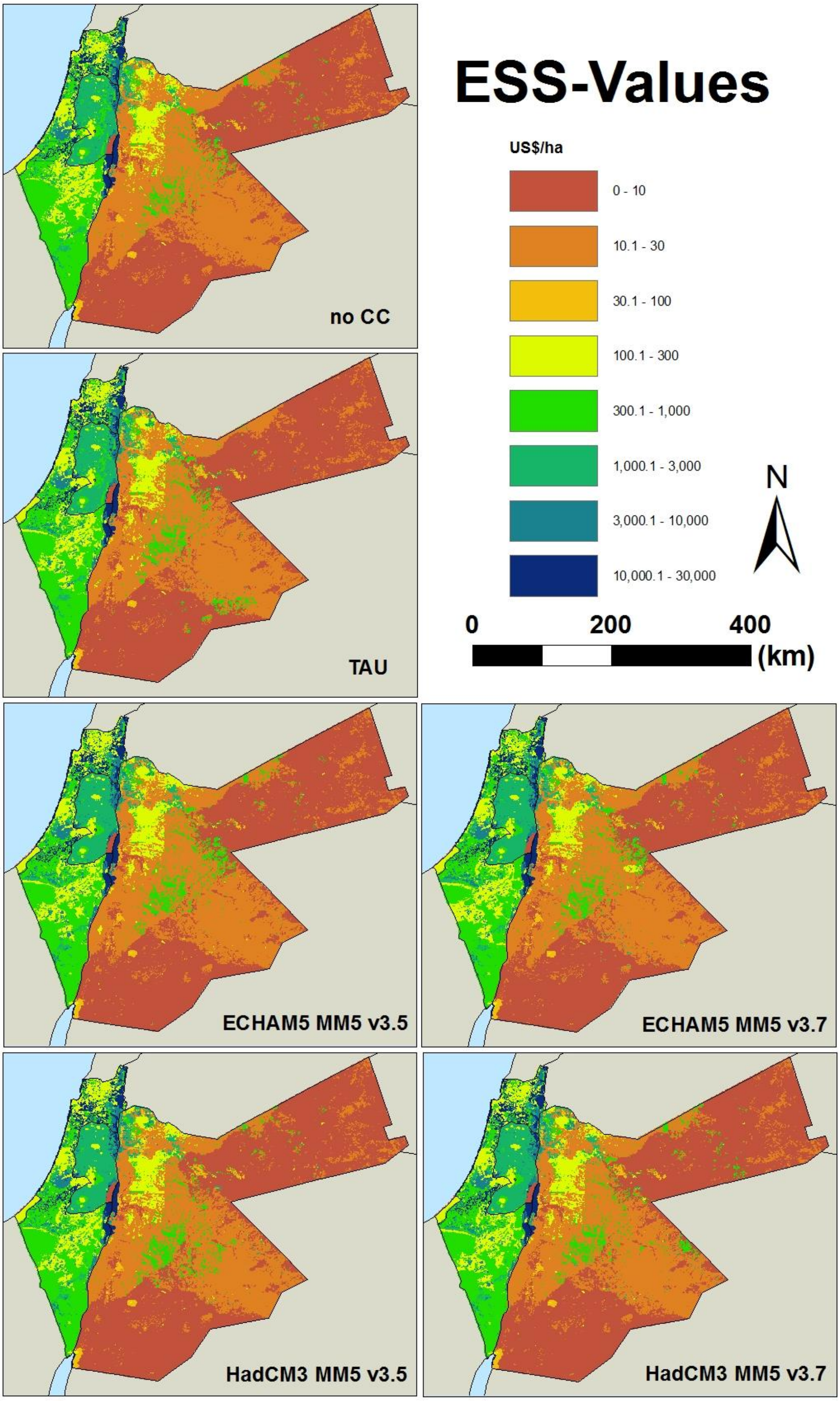

Figure 41: ESS-value maps in 2050 with six different climates and the Suffering of the Weak & Environment scenario

Annex 4: Population density maps

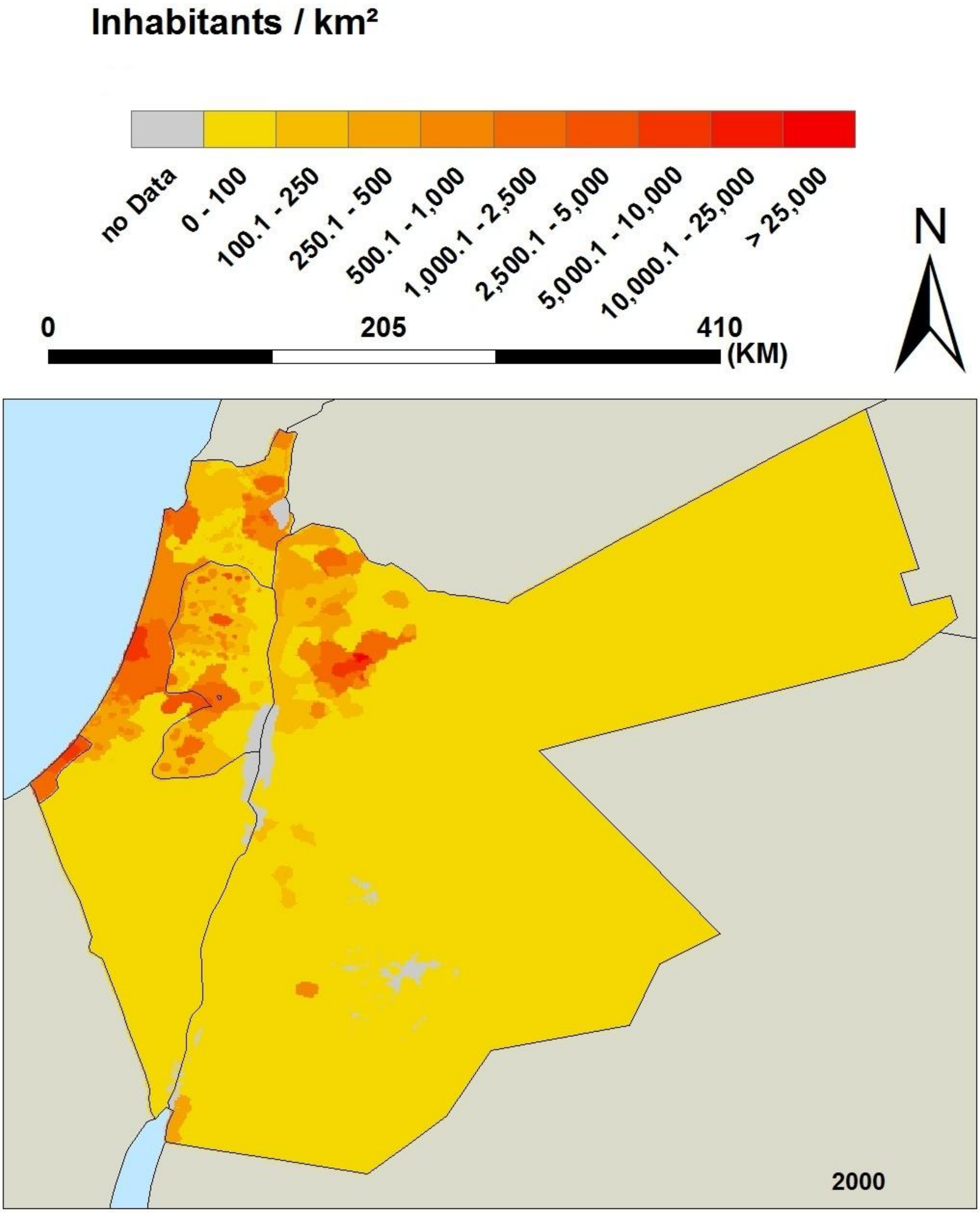

Figure 42: Population density in the GLOWA Jordan River region in 2000

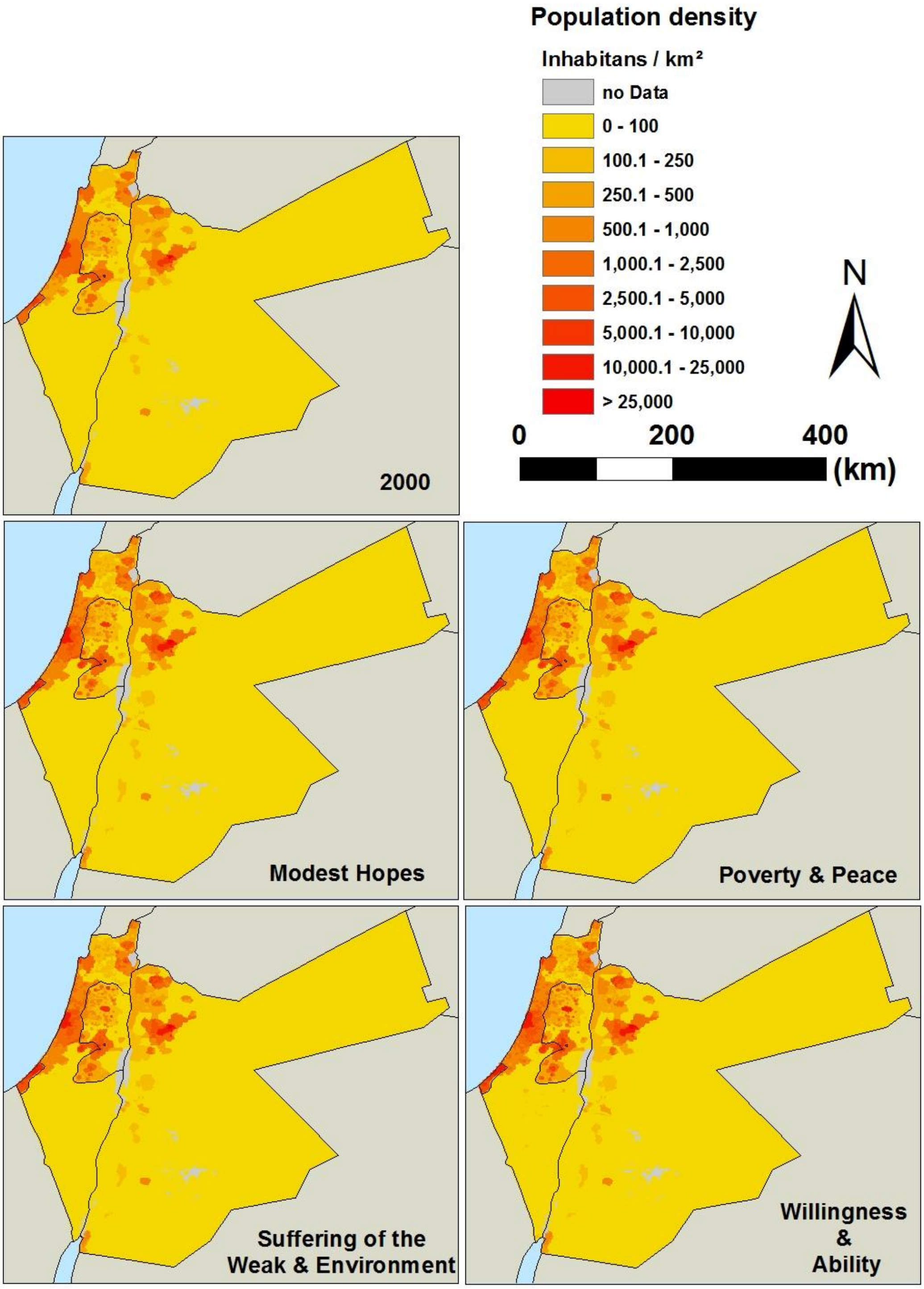

Figure 43: Population density maps for GLOWA Jordan River in 2025 with the four GLOWA scenarios

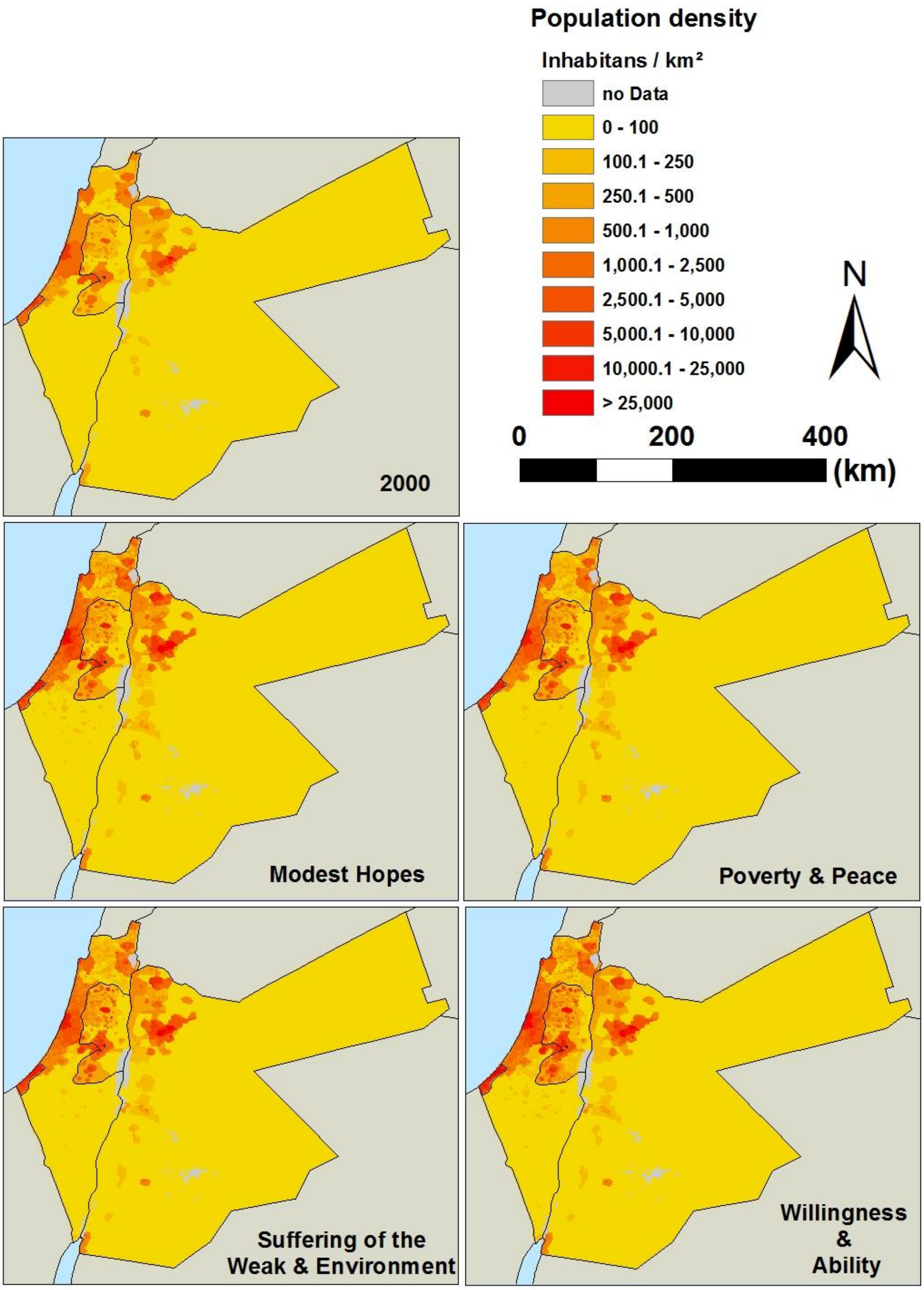

Figure 44: Population density maps for GLOWA Jordan River in 2050 with the four GLOWA scenarios

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