

**Integrated Water Resources Management
in the Lower Jordan Rift Valley**

**Sustainable Management of Available
Water Resources with Innovative Technologies**



BMBF IWRM R&D Programme

Funding No.: FKZ 02WM1079

SMART – IWRM

Deliverable No. 413

**Report on impact of climate change
on local and regional water resources**

F. Ries

December 2013

Principal Investigator:

Dipl. Hydrologist Fabian Ries

Albert-Ludwigs-Universität Freiburg

Chair of Hydrology

Fahnenbergplatz

79098 Freiburg

Germany

fabian.ries@hydrology.uni-freiburg.de

Georg-August-Universität Göttingen

Department of Applied Geology

Goldschmidtstraße 3

37077 Göttingen

Germany

1. Introduction

The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) predicts a further global warming for the 21st century in addition to the already measured global surface temperature increase of the last decades (0.64 °C for the period of 1956–2005). While global trends in temperature may be clearly detectable, the significance of precipitation trends are difficult to proof with available data records. Nevertheless for the subtropics and especially the Mediterranean region the IPCC predicts an decrease of precipitation with high certainty in addition to an increase of droughts in terms of frequency and intensity (IPCC, 2013).

Due to the close linkage between the energy and the water cycle, an increase of global surface temperature is expected to have multiple effects on water balance components. General circulation models (GCM) calculate complex interactions between the atmosphere and the land surface on a coarse spatial resolution, taking into account only major differences of land surface characteristics. Therefore hydrological models, capable to reflect the effects of a changing environment on the water cycle and the dominant hydrological processes at the crucial scale are required. This is a complex task because of the often observed unknown feedback mechanisms of environmental systems and the scale difference between climate and hydrological models. It remains a major challenge in hydrology to provide reliable estimations on the effect of climatic changes on the regional and local water balance and related water availability.

2. Climate change in the Eastern Mediterranean

The earth's climate is not constant but rather changing continuously. This is shown by numerous studies about paleoclimatology using climate proxies such as tree rings, pollen analysis and cores of ice as well as lake and ocean sediments (e.g. Jones and Mann 2004, Zachos et al. 2001, Royer et al. 2004). Time series of direct measured variables are often too short to show a clearly detectable trend of climate variables. Global and regional climate models are nowadays well established methods to simulate the complex interrelationships between earth's surface and the atmosphere. Nevertheless a reduction in uncertainty of their predictions under different emission scenarios require further research and a continuous improvement of GCMs.

2.1. Observed trends in climate variables in the Eastern Mediterranean

Climatological and hydrological variables are in constant change due to (i) their short-term and seasonal variability, (ii) natural long-term changes of climatic conditions and processes (e.g. orbital position of the earth, solar variability and plate tectonics) and (iii) anthropogenic climate change due to massive emission of greenhouse gases and the modification of the earth's surface primarily by land cover change. Detecting trends in available long climatological or hydrological time series is of high importance in order to investigate the fundamental reasons of changes in water resources availability and to make assumptions of probable changes in the future. Most of the trend studies for the Eastern Mediterranean come to the conclusion that there is a significant positive trend of temperature while the positive trend of precipitation is (still) not statistically

significant (see Table 6 in the Appendix for detailed results of selected studies). The latter is explained by Shohami et al. (2011) through the high natural variance of precipitation making the detection of a clear trend difficult over shorter time periods. Additional difficulties arise through the increasing evidence that precipitation change in the Eastern Mediterranean is connected to and affected by changes and periodicities of large scale atmospheric circulations such as the Arctic Oscillation (Givati & Rosenfeld, 2013) and the North Atlantic Oscillation (Xoplaki et al. 2004) and the East Atlantic/West Russian Oscillation (Krichak et al., 2002). Further research on precipitation trends and interdependencies on changes of large scale atmospheric circulations are needed.

2.2. Expected climate change in the Eastern Mediterranean

The Mediterranean region is one of the hot spots of expected climate change in the world (Giorgi, 2006). While the projections of GCMs differ often in severity and sometimes even direction of their predicted change of climatic variables, the global climate model ensemble CMIP5 show a high degree of consistency for the Mediterranean region (Diffenbaugh & Giorgi 2012). The IPCC (2007) report that nearly all models project decreasing precipitation in southern Europe and Mediterranean Africa (Figure 1).

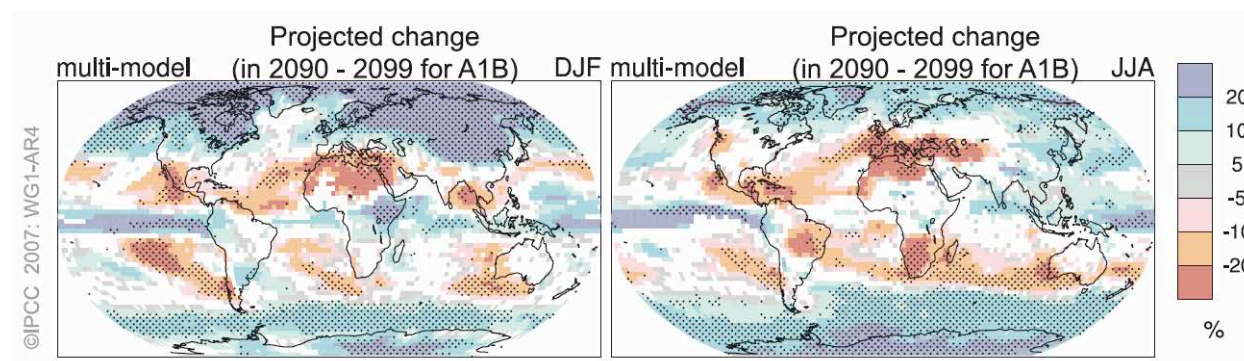


Figure 1: Projected change of precipitation by the period of 2090-2099 relative to 1990-1999 by multi model ensemble for the A1B scenario. Areas where less than 66% of the models agree on the sign of change are left white. Dotted areas indicate an agreement of more than 90% on the sign of change (IPCC, 2007).

The quality and performance of climate models can be tested by simulating historic climate and comparing the model results with paleoclimatologic data. Luterbacher et al. (2012) simulated the climate of the last 2000 years with five GCMs and report high discrepancies concerning precipitation on a annual and seasonal basis between the single model results and the paleoclimatic data. They state that regional climate models (RCMs) can in contrast to GCMs simulate atmospheric processes on a regional scale by representation of topography, coast lines and land cover and thus could contribute to overcome some of the GCM's problems.

Regional climate model were compared by Smiatek et al. (2011). They applied a transient dynamical downscaling approach with the regional climate model MM5 (Dudhia, 1993) and different soil vegetation atmosphere schemes under the boundary conditions of the GCM's ECHAM5 (realization 1 and 3) and HadCM3 for the emission scenario A1B. The RCM's were

able to reproduce observed precipitation patterns but had problems in the simulation of precipitation seasonality. The projection for the near future (2021–2051) show large variability in simulated rainfall changes among the RCMs but consistent negative trends for the end of the 21st century (period 2068-2098). Additional detailed information on the results of RCMs for the Near East are given in Smiatek et al. (2011) and Heckl (2011).

Heckl (2011) analysed RCM model results for four regions along the Upper and Lower Jordan River under the assumptions of emission scenario A2 (regionally oriented economic development) and B2 (local environmental sustainability). Model results for the region A (Sea of Galilee area) are given in Table 6. The spatial distribution of change in temperature and precipitation for the Near East is shown in Figure 5 in the Appendix.

Table 1: Change of mean quaterly temperature and mean seasonal rainfall for the region A (Sea of Galilee area) for the near and far future on the basis of the emission scenarios A2 and B2 as predicted by RCM's. Relative changes related to the period 1961-1989 are given in K and % (adapted from Hackl, 2011).

	Scenario	A2					B2				
		MAM	JJA	SON	DJF	Year	MAM	JJA	SON	DJF	Year
Temperature	Mean 1961-1989 (°C)	15.4	22.8	19	10.6	17	15.4	22.8	19	10.6	17
	Mean 2021-2050 (°C)	16.6	24.4	20.9	11.3	18.3	16.7	24.8	20.7	11.9	18.5
	Mean 2070-2099 (°C)	18.1	27	23.2	13.6	20.5	17.7	26.2	22.3	13	19.8
	ΔT 2021-2050 (K)	1.2	1.6	1.9	0.7	1.3	1.3	2	1.7	1.3	1.6
	ΔT 2070-2099 (K)	2.7	4.2	4.2	2.9	3.5	2.4	3.4	3.3	2.4	2.8
Precipitation	Mean 1961-1989 (mm)					710.8					710.8
	Mean 2021-2050 (mm)					683.9					658.1
	Mean 2070-2099 (mm)					531					569.9
	ΔT 2021-2050 (%)					-3.8					-7.4
	ΔT 2070-2099 (%)					-25.3					-19.9

2.3. Effect of climate change on water balance components in the Eastern Mediterranean

Given the fact that there is high confidence of a changed climate in the future and considering the already scarce water resources in the Middle East, the question emerges on how water resources availability will develop in the future. Several studies are dealing with this issue. Chenoweth et al. (2010) studied the development of future water resources using high-resolution regional climate models in the Mediterranean and the Middle East. For the Jordan River basin they predict a decline of available water resources of 22% by the mid century and 30% until the end of the 21st century due to a decrease in precipitation of 13% respectively 19%. Rimmer et al. (2011) studied future water and solute budgets for Lake Kinneret/Israel by coupling a GCM and different RCMs with a lake evaporation and salinity model. They report that some models

predict an decrease of precipitation ($0.8\% \text{ year}^{-1}$) and a increase of lake evaporation ($0.1\text{-}0.25\% \text{ year}^{-1}$) and a almost doubled salinity while other model predict less or no changes. The authors conclude that human impact on the lake during the last 50 years are larger than the predicted trend from climate change. Climate change impacts on the Jordan River discharge until 2060 were studied by Samuels et al. (2010). Their conceptual hydrological model show a 5% increase in potential evapotranspiration and a reduction of 10-11% of daily mean base flow and 17% of surface flow as a reaction on a precipitation decrease of 10% for the remote future. They emphasize that in addition to uncertainty of climate models, the effect of increased CO_2 concentration and climate change on plant evaporation and vegetation cover on the hydrological cycle are difficult to predict and not taken into account. Hartman et al. (2012) modelled spring discharge of a large karst spring in the West Bank with a set of conceptual hydrological models. The results for modelled water balance components show strong uncertainty for the near future (2021-2051) due to heterogeneous model inputs from RCMs and a decline of spring discharge up to 30% by the end of the century.

3. Case studies

Possible effects of climate change on water balance components are shown in this report by the mean of two case studies - Wadi Auja and Wadi Kafrein (Figure 6). Both catchments are located within the SMART project region and were investigated in detail during the first and second phase of the SMART project. Detailed information on the applied hydrological model Train-Zin and its parametrization are given in Alkhoury (2011) and Ries (2013).

3.1. Case study: Wadi Auja

The study area of Wadi Auja is located at the eastern slopes of the western escarpment of the Jordan Valley draining to the Dead Sea. A steep relief gradient and a high rainfall gradient is characteristic for the area. The surface catchment of Wadi Auja consists of two tributaries. With the purpose of water balance and surface runoff assessment, the hydrological model Train-Zin was applied on three consecutive years (2010-2013) to the surface water catchment of the northern branch of Wadi Auja (55 km^2), where a gauging station permits quantification of total wadi flow. The modelled water balance components for the three years with available runoff data are given in Table 2.

Table 2: Modelled water balance components of Wadi Auja for the period of 2010-2013 (Ries, 2013)

Hydrological year	Rainfall		Evapotransp.		Recharge		Runoff	
	MCM	mm	MCM	mm	MCM	mm	MCM	mm
2010/2011	16	290	14.7	268	1.2	22	0	0
2011/2012	26.7	486	16.9	308	9.4	170	0.3	6
2012/2013*	22	400	14.2	259	7.4	135	0.4	6.9

* hydrological year 2012/2013 modelled until 01.05.2013

The modelled surface runoff show an overall good representation of measured temporal patterns and volumes. Nash-Sutcliffe efficiencies for the modelled discharge are between 0.59 (2012/2013) and 0.92 (2011/2012).

The three years with high temporal and spatial rainfall and runoff data include a dry (2010/2011) an average (2012/2013) and a wet year (2011/2012) with different precipitation amount and distribution over the course of the winter season. The effect of the expected change in rainfall and temperature on water balance components were tested by running the hydrological model of the three seasons with a relative change in temperature and rainfall as predicted by Heckl (2001) for the A2 scenario until 2070-2099 (compare Table 1). Predicted changes in temperature and rainfall show a relatively homogeneous pattern (Figure 5). Hence for the Wadi Auja catchment the same changes of temperature (2.7-4.2 K depending on the season) and precipitation (25,3%) as for the Sea of Galilee region were assumed. Measured and spatially interpolated temperature and rainfall data for the years 2010-2013 were modified by these relative changes. In order to identify the effect of changes in rainfall and temperature separated, nine different model runs were realized as listed in Table 2. Spatial distribution of measured and projected temperature and rainfall in the study area of Wadi Auja is shown in Figure 7 and Figure 8 in the Appendix.

Table 3: Climatic scenarios for Wadi Auja area under predicted temperature and rainfall change

Characteristic of hydrological year	Changed climatic variable
Wet year (based on 2011/2012)	Temperature
	Rainfall
	Temperature and rainfall
Average year (based on 2012/2013)	Temperature
	Rainfall
	Temperature and rainfall
Dry year (based on 2010/2011)	Temperature
	Rainfall
	Temperature and rainfall

3.2. Case study: Wadi Kafrein

Wadi Kafrein is a catchment on the eastern side of the Jordan Valley draining 161 km² from the city of Amman until the Kafrein reservoir constructed in the 1960s were collected runoff is used for irrigation purposes. Alkhoury (2011) parameterized and applied the spatially distributed hydrological model Train-Zin on a three years time series (2007–2010). The model represented properly the runoff generation of Wadi Kafrein with root mean square errors for 5 runoff events between 0.03 and 1.2 m³s⁻¹. The modelled water balance components for the three years with available runoff data are given in Table 4.

Table 4: Modelled water balance components of Wadi Kafrein for the time period of 2007-2010 (adopted Alkhoury, 2011)

Hydrological year	Rainfall		Evapotransp.		Recharge		Runoff		Soil storage	
	mm	MCM	%	MCM	%	MCM	%	MCM	%	MCM
2007/2008	167	26.9	90.6	24.4	7.7	2.1	3.8	1	0.3	0.07
2008/2009	250	40.3	77	31.1	18	7.2	5	2	0.2	0.1
2009/2010*	128	20.7	45.6	9.5	7.1	1.5	3.3	0.7	44.4	9.2

* hydrological year 2009-2010 modelled until 23.12.2009

In order to study the impact of temperature change as well as variations in rainfall amount and intensity on water balance components for Wadi Kafrein, Alkhoury (2011) developed a set of scenarios. Using the temporal and spatial high resolution rainfall measurements 2007-2009 for downscaling, 15 different rainfall scenarios with variations in rainfall amount and intensity were developed (Table 5).

Table 5: Climatic scenarios based on rainfall amount and intensity distribution (adopted Alkhoury, 2011)

Annual	Daily	5 minutes
High total amount	High rainfall depth (HH)	High intensity scenario (HIS)
		Medium intensity scenario (SWS)
		Low intensity scenario (LIS)
	Low rainfall depth (HS)	High intensity scenario (HIS)
		Medium intensity scenario (SWS)
		Low intensity scenario (LIS)
Average total amount	Average rainfall depth (Avg)	High intensity scenario (HIS)
		Medium intensity scenario (SWS)
		Low intensity scenario (LIS)
Low total amount	High rainfall depth (LH)	High intensity scenario (HIS)
		Medium intensity scenario (SWS)
		Low intensity scenario (LIS)
	Low rainfall depth (LL)	High intensity scenario (HIS)
		Medium intensity scenario (SWS)
		Low intensity scenario (LIS)

HH = Wet year with high daily rainfall depth; SH = Wet year with low daily rainfall depth; Avg = Average year with average daily rainfall depth; LH = Dry year with high daily rainfall depth; LL = Dry year with low daily rainfall depth

To evaluate the effect of predicted future temperature rise on the water balance of Wadi Kafrein three scenarios with temperature increase between 1 and 3 °C in combination with three rainfall distribution patterns (HIS, SWS, LIS) were modelled.

4. Results

4.1. Wadi Auja case study

Model results of Train-Zin for the surface catchment of Wadi Auja under future climate based on the observation period are shown in Figure 2. For the scenario of an increase of mean daily temperature without change in precipitation amount only minor effects on water balance components are predicted by the model. Evapotranspiration increases depending on the year by 1.3-2.6%, groundwater recharge decreases by 3.6-15.8% and surface runoff decreases by 1.8-8.5%. The scenario of a decrease of precipitation shows in contrast high effects on all modelled water balance components. Evapotranspiration decreases due to reduced available soil moisture by 10 to 25%. Groundwater recharge was reduced to half for the wet and the average year and has dropped to nearly zero for the dry year. Surface runoff is modelled to be most affected by reduced precipitation amount and drops to zero for the average year and to 0.5 mm for the wet year. This could be explained by the strong threshold behaviour of surface runoff generation. Once rainfall amount per time step falls below a certain threshold no surface runoff is generated because the soil zone remains unsaturated or rainfall intensity does not reach the maximum infiltration rate of the soil.

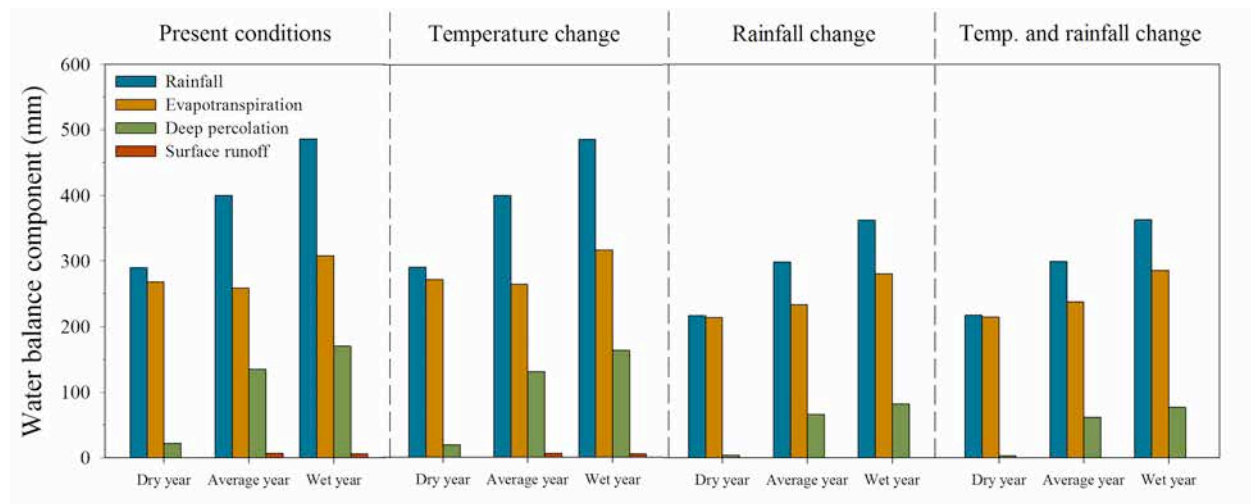


Figure 2: Modelled water balance components under present conditions and three different scenarios for the period 2075–99 with increase only in temperature, decrease only in rainfall and a combined change of temperature and rainfall. The calculations of the future scenarios are based on a simple change of observed temperature and rainfall for the period 2010-2013. All other model parameters were kept constant.

4.2. Wadi Kafrein case study

The application of the hydrological model Train-Zin on Wadi Kafrein catchment under different scenarios of rainfall amount and intensity show the strongest effect on modelled surface runoff and groundwater recharge (Alkhoury, 2011). Surface runoff as fraction of total rainfall amount is lowest for the scenario of a dry year with low daily rainfall depth (LL) with 4.3% and reaches up to 21.2% for the scenario of a wet year with high daily rainfall depth (Figure 3).

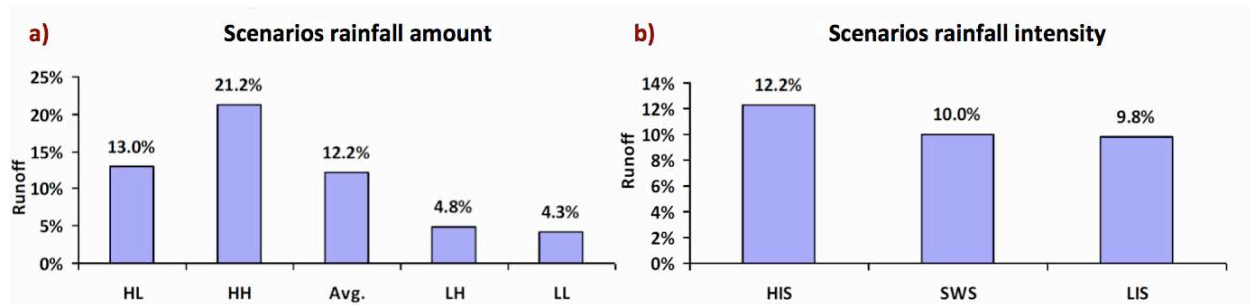


Figure 3: Modelled surface runoff as fraction of rainfall for different scenarios of a) rainfall amount and b) rainfall intensity (average rainfall depth scenario) (Alkhoury, 2011).

Application of three different temperature scenarios resulted in a recharge reduction of 1-4% and a decrease of surface runoff between 1 and 2.4% (Figure 4). Temperature change shows less effect on simulated groundwater recharge and runoff than a change in rainfall intensity.

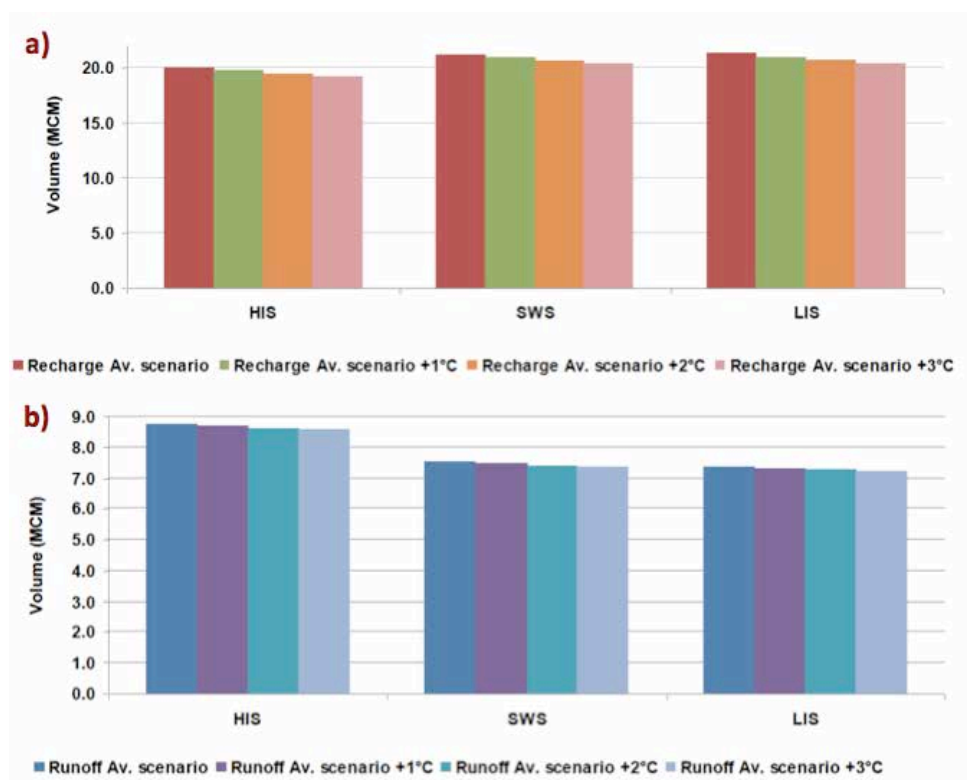


Figure 4: Modelled groundwater recharge volumes (a) and surface runoff volumes (b) in million cubic meter (MCM) for different rainfall intensity scenarios (HIS, SWS, LIS) (Alkhoury, 2011).

In addition to climate scenarios Alkhoury (2011) developed scenarios of landuse use change due to urbanization expansion as it is expected because of high population growth in Jordan. The modelled effect on the water balance of Wadi Kafrein are clearly visible with a strong reduction of recharge and significant increase of surface runoff.

5. Conclusions

Reliable estimations of future changes in water resources availability in the Middle East are of high importance to improve sustainability of integrated water resources management solutions. Numerous studies report clear positive temperature trends for the last decades all around the Mediterranean area. Negative precipitation trends are still not significant presumably because they are masked by high annual variability (Shohami et al., 2011). Climate models and climate change projections have shown important improvements since the third assessment report in 2001 (IPCC, 2007). Global and regional climate models show a high agreement concerning future climate conditions especially in the Mediterranean. The IPCC (2007) states “The decrease is considered especially robust, and very likely to occur, in annual precipitation in European and African regions bordering the Mediterranean...”. For the Eastern Mediterranean, RCMs predict a clear increase of temperature (at least 3 K) and decrease in precipitation (at least 19%) depending on the emission scenario (Heckl, 2011). The occurrence of precipitation extremes is expected to increase coming along with longer dry spells and shorter wet spells (Samuels et al., 2011). As a effect of global warming many studies found reasonable evidence for a reduced water availability on a global (e.g. Milly et al., 2005) and regional scale (in the Mediterranean e.g. Chenoweth et al., 2010; Samuels et al., 2010 and Hartmann et al., 2012).

The possible effects of predicted climate change on water balance components were modelled in two catchments in the Lower Jordan region. Model results show low sensitivity of the model on temperature changes in the future while precipitation changes have high impact on groundwater recharge and surface runoff generation. Assuming reduced rainfall amounts under future climate, groundwater recharge decreases significantly. Surface runoff generation show in the case of Wadi Auja a strong dependency on rainfall thresholds. Assuming a simple decrease of rainfall over the entire rainy season, surface runoff is almost reduced to zero even for relatively wet years. Assuming an increase in extreme precipitation despite the general decrease of rainfall amount in the future could have a contrary effect on surface runoff generation. Predictions on changes in water balance components due to changes in rainfall amount remains uncertain unless there is more reliable information on rainfall distribution and intensity changes in the future.

Alkhoury (2011) emphasized that the effect of land use changes and urbanization could have a higher impact on available water resources than climate change. Chenoweth et al. (2011) remark that climate is only one of many expected changes with potential impact on water availability in the future. The effect of climate change on water availability in the Mediterranean continues to be a topic for further research. Better knowledge of future water availability can contribute to a more efficient and sustainable way of water resources planning.

6. References

- Alkhoury, W. (2011): Hydrological modelling in the meso scale semiarid region of Wadi Kafrein / Jordan – The use of innovative techniques under data scarcity. Doctoral thesis, Universität of Göttingen, Germany, p. 242. <http://ediss.uni-goettingen.de/handle/11858/00-1735-0000-0006-B2FB-6>
- Alpert, P., Ben-Gai, T., Baharad, A., Benjamini, Y., Yekutieli, D., Colacino, M., Diodato, L., Ramis, C., Homar, V., Romero, R., Michaelides, S., & Manes, A. (2002): The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophysical Research Letters*, 29(11), 31-1.
- Ben-Gai, T., Bitan, A., Manes, A., Alpert, P., & Rubin, S. (1998): Spatial and temporal changes in rainfall frequency distribution patterns in Israel. *Theoretical and Applied Climatology*, 61(3-4), 177-190.
- Chenoweth, J., Hadjinicolaou, P., Bruggeman, A., Lelieveld, J., Levin, Z., Lange, M. A., Xoplaki, E. & Hadjikakou, M. (2011): Impact of climate change on the water resources of the eastern Mediterranean and Middle East region: modeled 21st century changes and implications. *Water Resources Research*, 47(6).
- Diffenbaugh, N. S., & Giorgi, F. (2012): Climate change hotspots in the CMIP5 global climate model ensemble. *Climatic change*, 114(3-4), 813-822.
- Dudhia, J. (1993): A nonhydrostatic version of the Penn State-NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and cold front. *Monthly Weather Review*, 121(5), 1493-1513.
- Giorgi, F. (2006). Climate change hot-spots. *Geophysical Research Letters*, 33(8), L08707.
- Hartmann, A., Lange, J., Vivó Aguado, À., Mizyed, N., Smiatek, G., & Kunstmann, H. (2012): A multi-model approach for improved simulations of future water availability at a large Eastern Mediterranean karst spring. *Journal of Hydrology*, 468, 130-138.
- Heckl, A. (2011). Impact of climate change on the water availability in the near east and the upper Jordan River catchment. Doctoral thesis at the University of Augsburg, Germany, p. 194. <http://opus.bibliothek.uni-augsburg.de/opus4/frontdoor/index/index/docId/1603>
- IPCC (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
- IPCC (2013): Preliminary version of the fifth assessment report of the Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/>
- Jones, P. D. & Mann, M. E. (2004): Climate over past millennia. *Reviews of Geophysics*, 42(2), RG2002.
- Kafle, H. K., & Bruins, H. J. (2009). Climatic trends in Israel 1970–2002: warmer and increasing aridity inland. *Climatic Change*, 96(1-2), 63-77.
- Krichak, S. O., Kishcha, P., & Alpert, P. (2002): Decadal trends of main Eurasian oscillations and the Eastern Mediterranean precipitation. *Theoretical and Applied Climatology*, 72(3-4), 209-220.
- Luterbacher, J., García-Herrera, R., Allan, A. R., Alvarez-Castro, B. G., Benito, G., Booth, J., ... &

- Zorita, E. (2012): A review of 2000 years of paleoclimatic evidence in the Mediterranean. The Climate of the Mediterranean Region From the past to the future, P. Lionello (Ed.), ElServier, Amsterdam, 87-185.
- Milly, P. C., Dunne, K. A., & Vecchia, A. V. (2005): Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, 438(7066), 347-350.
- Ries, F. (2013): Local hydrological models and quantification of runoff for sub-basin Auja. In: Rahman, M.A. (Ed.), Deliverable 405 - Local hydrological models and quantification of runoff. Unpublished report, Sustainable Management of Available Water Resources with Innovative Technologies - BMBF IWRM R&D Programme, pp. 318.
- Rimmer, A., Givati, A., Samuels, R., & Alpert, P. (2011): Using ensemble of climate models to evaluate future water and solutes budgets in Lake Kinneret, Israel. *Journal of Hydrology*, 410(3), 248-259.
- Royer, D. L., Berner, R. A., Montañez, I. P., Tabor, N. J., & Beerling, D. J. (2004): CO₂ as a primary driver of Phanerozoic climate. *GSA today*, 14(3), 4-10.
- Samuels, R., Rimmer, A., Hartmann, A., Krichak, S., & Alpert, P. (2010): Climate change impacts on Jordan River flow: downscaling application from a regional climate model. *Journal of Hydrometeorology*, 11(4), 860-879.
- Samuels, R., Smiatek, G., Krichak, S., Kunstmann, H., & Alpert, P. (2011): Extreme value indicators in highly resolved climate change simulations for the Jordan River area. *Journal of geophysical research*, 116(D24).
- Sarris, D., Christodoulakis, D., & Koerner, C. (2007): Recent decline in precipitation and tree growth in the eastern Mediterranean. *Global Change Biology*, 13(6), 1187-1200.
- Shohami, D., Dayan, U., & Morin, E. (2011): Warming and drying of the eastern Mediterranean: Additional evidence from trend analysis. *Journal of Geophysical Research: Atmospheres* (1984–2012), 116(D22).
- Smiatek, G., Kunstmann, H., & Heckl, A. (2011): High resolution climate change simulations for the Jordan River area. *Journal of Geophysical Research: Atmospheres* (1984–2012), 116(D16).
- Stanhill, G., & Ianetz, A. (1997): Long-term trends in, and the spatial variation of, global irradiance in Israel. *Tellus B*, 49(1), 112-122.
- Steinberger, E. H., & Gazit-Yaari, N. (1996). Recent changes in the spatial distribution of annual precipitation in Israel. *Journal of Climate*, 9(12).
- Xoplaki, E., Gonzalez-Rouco, J. F., Luterbacher, J., & Wanner, H. (2004): Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. *Climate Dynamics*, 23(1), 63-78.
- Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K. (2001): Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science*, 292(5517), 686-693.

7. Appendix

Table 6: Summary of studies about trends of climatic variables in the Eastern Mediterranean.

Climate variable	Study	Study area	Observed period	Method	Detected trends	Conclusion
Temperature, rainfall and atmospheric patterns	Shohami et al. 2011	Israel	1964-2003	Trend analysis using non-parametric Mann-Kendall test and Sen slope	Temperature: significant positive trend of 0.1-1 °C/decade Rainfall: Negative trend not yet statistically significant	Climatic conditions in the Eastern Mediterranean become drier and warmer due to a reduction of cyclogenesis and specific humidity
Precipitation	Steinberger & Gazit-Yaari 1996	Israel	1960-1990	Trend analysis of 99 rainfall stations	Decrease of precipitation in central and northern coast and in northern mountain area (up to 1% of annual rainfall per year) and increase at the southern coast and western slopes of the central mountain range. No significant trends detected in the rest of the study area.	Different trends with variable confidence detected. Authors explain changes by a shift of cyclone tracks
Temperature, Precipitation and aridity index P/PET	Kafle & Bruins 2009	Israel (Coastal plains, Negev, North Israel)	1970-2002	Time series analysis on 12 selected meteorological stations	Temperature: Significant warming Precipitation: Increase along coastal plain and decrease in other parts (not significant) Aridity index: Increase but not significant along coastal plains	Climate in Israel has become more arid except for the coastal plain

Precipitation amount and daily extremes	Alpert et al. 2002	Mediterranean	1951-1995	Trend analysis on 265 Mediterranean rainfall stations in Spain, Italy, Cyprus and Israel	Significant increase of rainfall extremes and decrease in overall amount in Spain and Italy No significant trends in Israel and Cyprus	Increase of daily rainfall extremes and decrease in rainfall amount
Global irradiance	Stanhill & Ianetz 1997	Israel	1954-1990	Trend analysis of 130 station years	Significant decrease of 20% within 40 years	Decrease of global irradiance probably due to atmospheric transmissivity and air pollution
Precipitation	Sarris et al. 2007	Samos island (eastern Aegean Sea)	1931-2000 (precipitation) Up 150 years of tree rings	Trend analysis of precipitation records and of pine tree rings	Precipitation: Negative trend for 1931 – 1978 (3.8 mm/year) with breakpoint and accelerated but still not significant decline from 1978 on Tree rings: Negative trend of tree ring width during the last decades of the 20 th century. High correlation between tree ring width and 2- and 5-year precipitation sums	Drying in the eastern Mediterranean with the lowest annual stem radiation increment of the last decades within the 20 th century
Precipitation distribution	Ben-Gai et al. 1998	Israel	1931-1990	Analysis on parameter of annual rainfall distribution functions of 60 rainfall stations	Significant temporal and spatial changes of the parameters of the fitted gamma distribution function. Strongest changes in October/ November and March.	Temporal and spatial changes of rainfall distribution with contrasting trends between north and south

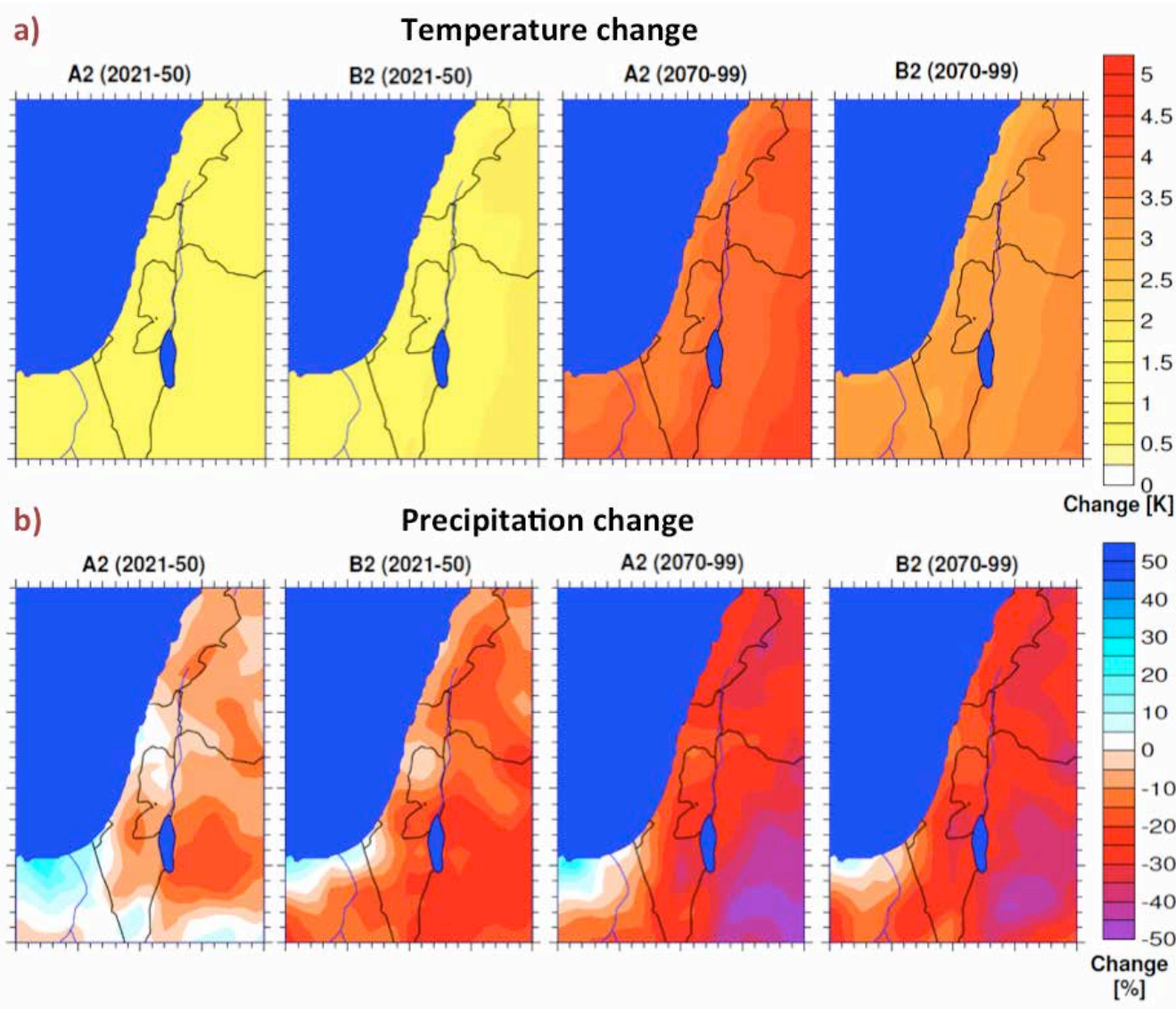


Figure 5: Mean change of temperature (a) and precipitation (b) predicted by RCMs for the emission scenarios A2 and B2 and the period 2021-2025 (near future) and 2070-2099 (far future) relative to the reference period 1961-1989 (Heckl, 2011)

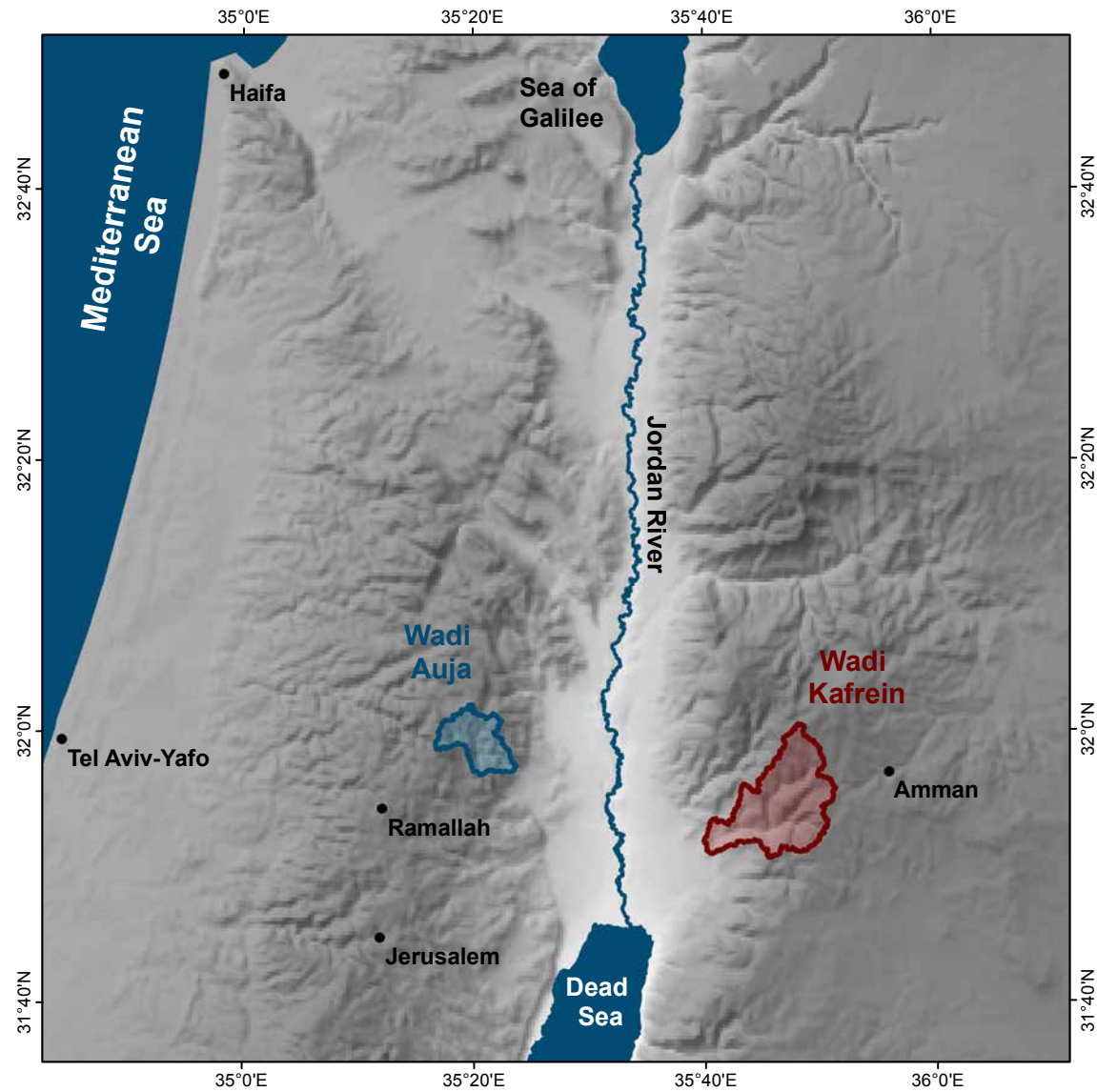


Figure 6: Case study area

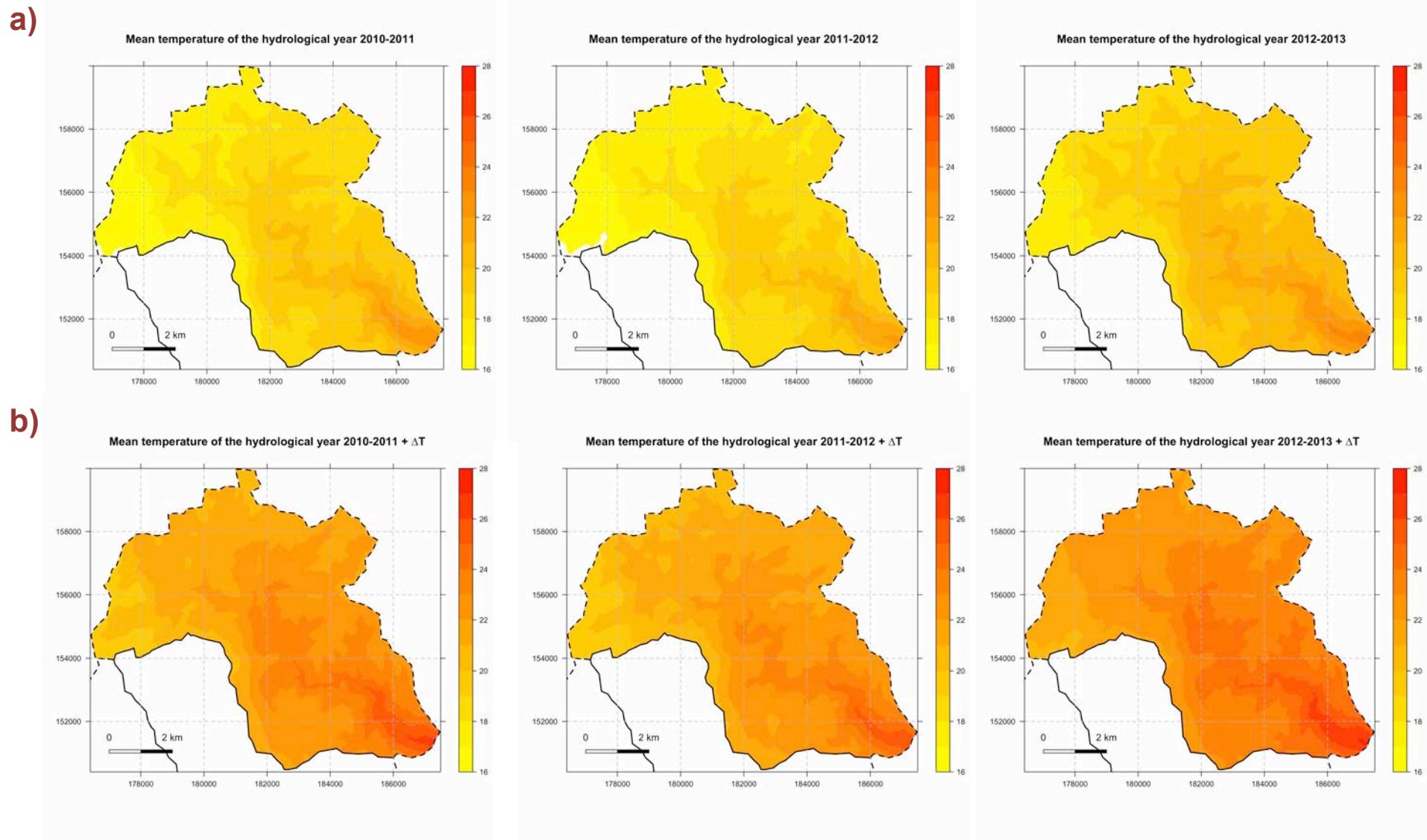


Figure 7: Spatial distribution of mean annual air temperature of the hydrological years (October - September) 2011-2013 (a) and future projections for 2070-2099 (b) derived by a simple delta temperature approach.

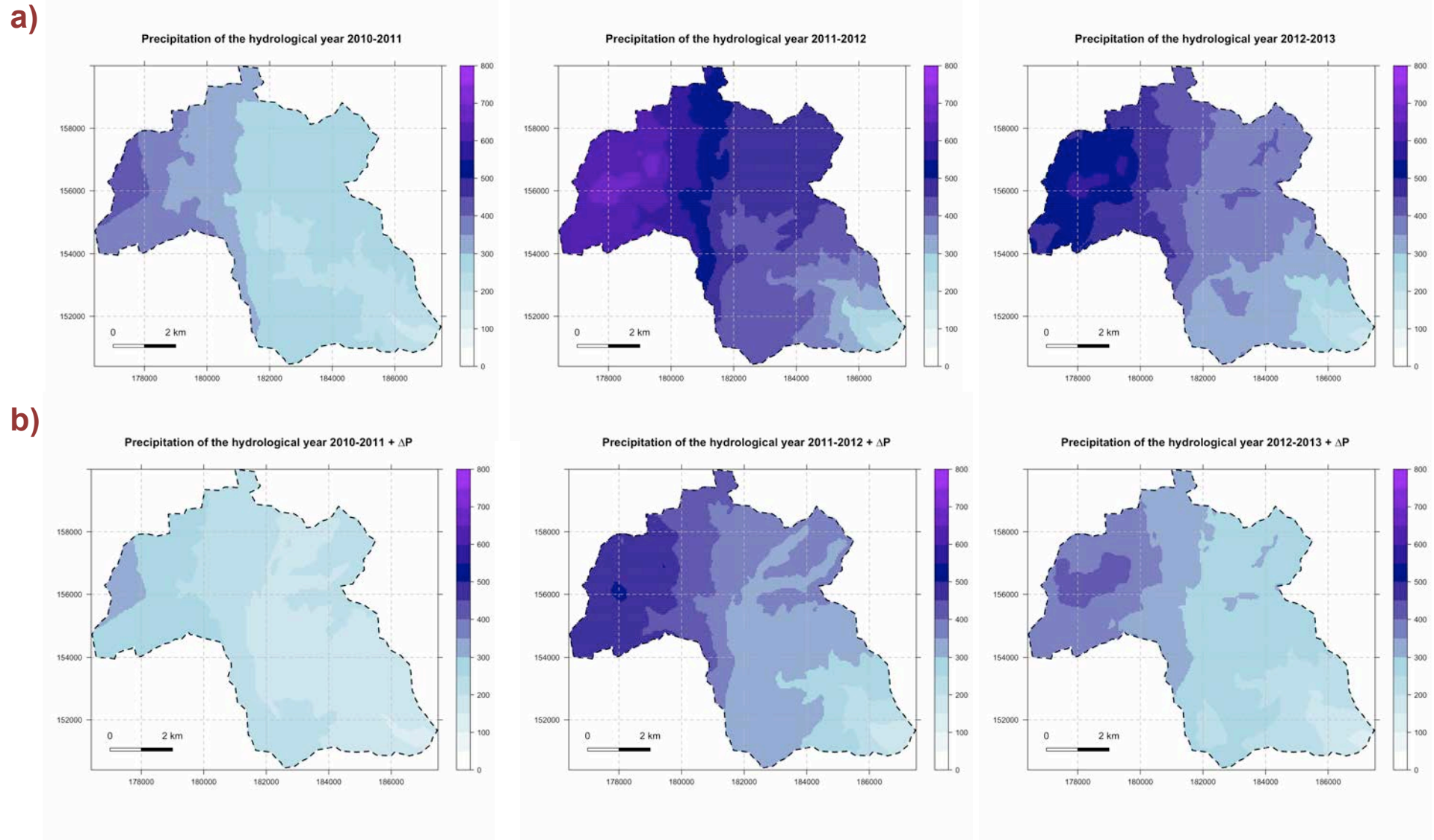


Figure 8: Spatial distribution of precipitation of the hydrological years (October - September) 2011-2013 (a) and future projections for 2070-2099 (b) derived by a simple delta precipitation approach.