Reply to Referee #2

Dear Referee,
We appreciate the efforts you have invested on our manuscript. In the following, we listed your comments in black font together with our point-by-point response to each in blue color. In addition, we explained how each of the comments will be addressed in the revised manuscript.

Sincerely,
Nariman Mahmoodi, Jens Kiesel, Paul D. Wagner, Nicola Fohrer

GENERAL COMMENTS:

The topic covered fully corresponds to the aims and scope of the Hydrology and Earth System Sciences. Moreover, it covers aspects of hydrology and management. Though, the manuscript, in its present form, has a few weaknesses. Appropriate revisions to the following points should be undertaken to improve the readability and increase the interest for a general audience.

The title should better describe the study. Sustainable water use is not the subject of this study. I would rather say potential future climate impacts on water resources. At the end of the introduction provide a statement on the novelty of the study. At the moment it is not clear enough. Two sections of the manuscript need improvements. More specifically 2.2 Hydrological model and 2.3 Future climate change simulation sections. These two sections are parts of previously published work and they are confusing in relation to this research effort. Authors should better justify the selection of the G-RCM. I strongly recommend a flow chart of the methodology followed. Please provide as supplementary table the IHA Non-Parametric RVA Scorecard. Methodology limitations should be mentioned.

We appreciate the very insightful evaluation. The title is changed to "Spatially distributed impacts of climate change and ground water demand on the water resources in a Wadi system". The introduction is revised and novelty of the research is stressed. A novel aspect of our study is that while climate change impacts on water resources are well understood, the combined effects of climate change and population growth / water demand on water resources are rarely analyzed in a spatially distributed way. The methodology of the research is illustrated using a flow chart which will be added to the revised manuscript.

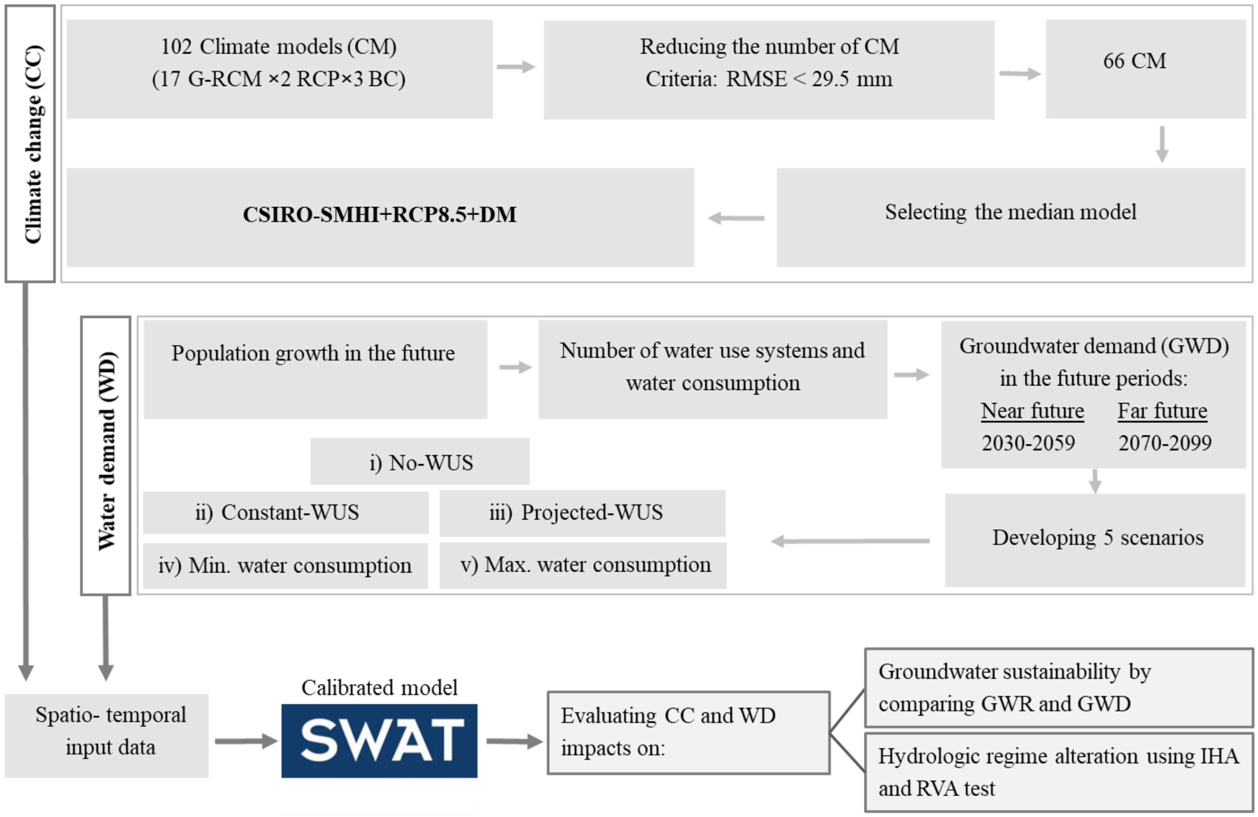

Figure1: Flow chart of the methodology employed.

The non-parametric IHA scorecard will be provided for the model setup and the future periods under different WUS scenarios (Table 1). These results will be added to the supplementary document with further explanation on the scorecard.

Table 1: Non-parametric IHA scorecard for the model setup and the future periods under the three WUS-scenarios.

	Baseline period	*Future period 1*			*Future period 2*		
		No-WUS	Constant-WUS	Projected-WUs	No-WUS	Constant-WUS	Projected-WUs
Normalization Factor	1	1	1	1	1	1	1
Mean annual flow ($m^3 s^{-1}$)	12.13	10.66	9.94	9.23	6.13	5.84	5.5
Non-Normalized Mean ($m^3 s^{-1}$) Flow	12.13	10.66	9.94	9.23	6.13	5.84	5.5
Annual C. V.	2.99	4.39	4.5	4.63	4.76	4.9	5.06
Flow predictability	0.28	0.32	0.34	0.34	0.43	0.44	0.44
Constancy/predictability	0.54	0.60	0.62	0.62	0.71	0.70	0.70
% of floods in 60d period	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Flood-free season	10	48	48	48	124	124	124

Discussion section should be extended, as this is the main contribution to future researchers. Explain and discuss why the streamflow time series was generated for the period from 1993 to 2009 and 1979-2009. The presented results are influenced by this choice and it should be motivated. Moreover, at least a minimal discussion should be provided on expected differences (if any) when using different reference periods. Please contrast your own findings with those of previous literature about hydrological studies and climate change in the area (e.g. https://doi.org/10.1029/2008WR007615; https://doi.org/10.1186/s40068-019-0135-3; https://doi.org/10.1007/s10666-019-09665-x). Uncertainty of the model outputs should be also in discussion.

The time period of observed data does not match in terms of hydrologic and climatic input data in the study area, i.e., from 1993-2009 for streamflow and from 1979 to 2009 for climate components (precipitation, temperature, relative humidity, solar radiation, and wind speed). Therefore, the observed streamflow data from 1993 to 2009 is used to calibrate the model, then the calibrated model is run to simulate streamflow for the whole period (1979-2009) using the observed climate data. Due to these data availability constraints, we cannot provide an analysis of the impact of different reference periods. We will however include a short discussion referring to other studies (such as e.g. Kiesel et al. (2019) where the impact of two different reference period lengths were evaluated). Thank you also for providing these additional references, which we will include in our discussion and relate to our results.

Reference:

Kiesel, J., Gericke, A., Rathjens, H., Wetzig, A., Kakouei, K., Jähnig, S.C. and Fohrer, N., 2019. Climate change impacts on ecologically relevant hydrological indicators in three catchments in three European ecoregions. Ecological engineering, 127, pp.404-416.

Specific Comments

All of the following minor comments regarding typos, rephrasing of sentences or adding of additional information on the model performance will be addressed in the revised manuscript.

Comment 1

Page 1, Line 11-13"A hydrologic model is used to assess streamflow and groundwater recharge of the Halilrood Basin on a daily time step under different scenarios over a model setup period (1979-2009) and for two future scenario periods (near future: 2030–2059 and far future: 2070-2099)." Please specify the number of the different scenarios.

We considered five different scenarios in this study. The information will be added to the abstract.

Comment 2

Page 3, Line 92-94"Based on representative climatic conditions, an eight-year period was used for model calibration (1995-2003) and a six-year period for validation (2004–2009)." Please specify which are the representative climatic conditions. Are these observations? If yes please provide the reference and the source of the data.

The model is calibrated using observed data provided by Iran Water & Power Resources Development Company (IWPCO). The calibration and validation periods are based on an equal distribution of dry years (total precipitation<200 mm), wet years (total precipitation>270 mm) and average year (200–270 mm annual precipitation) in the study area. Both periods are composed of almost 1/3 dry, wet, and normal years, respectively. This information will be added to the revised version.

Comment 3

Page 3, Line 88-89:"The Soil and Water Assessment Tool (SWAT, Arnold et al., 1998; Arnold et al., 2012) was used to simulate the streamflow of Halilrood River between 1993 and 2009 on a daily time step." Perhaps, authors mean that the outputs of the SWAT model were used in this study. This description is poor and confusing. Most of the work presented in this section, has been carried out in Mahmoodi et al. (2020a). Please consider to rewrite this section by clarifying the work you did for this research effort. Moreover, please specify if SWAT parametrization using the representative climatic conditions is sufficient when using the CSIRO-SMHI. In Mahmoodi et al. (2020b) it is mentioned that "Further details on model parameterization and performance are available in Mahmoodi et al. (2020)". I couldn't find this study on the internet. Mahmoodi N., Kiesel J., Wagner D. P. & Fohrer N. 2020 Integrating water use systems and soil and water conservation methods in a hydrological model of an Iranian Wadi system. J. Arid Land. 12 (4), 1–16

Indeed, we set up the model in a previous research effort and applied the model here to simulate different scenarios. We agree that it would be beneficial to add an overview of the model setup and calibration efforts to provide confidence in the model performance. We will modify this section and formulate more precisely. Running scenarios with a model calibrated for baseline conditions, is a common procedure in hydrologic impact assessments. The climatic conditions of the used and downscaled climate scenario CSIRO-SMHI are mostly within the range of conditions of the past (Figure 2). The driest future years which projected to occur more frequently are already included in the baseline years. Beyond that, SWAT is a process-based hydrological model that, unlike data-driven models, should be suitable for depicting the same processes under different (hotter and drier) boundary conditions (Zhu et al., 2016).

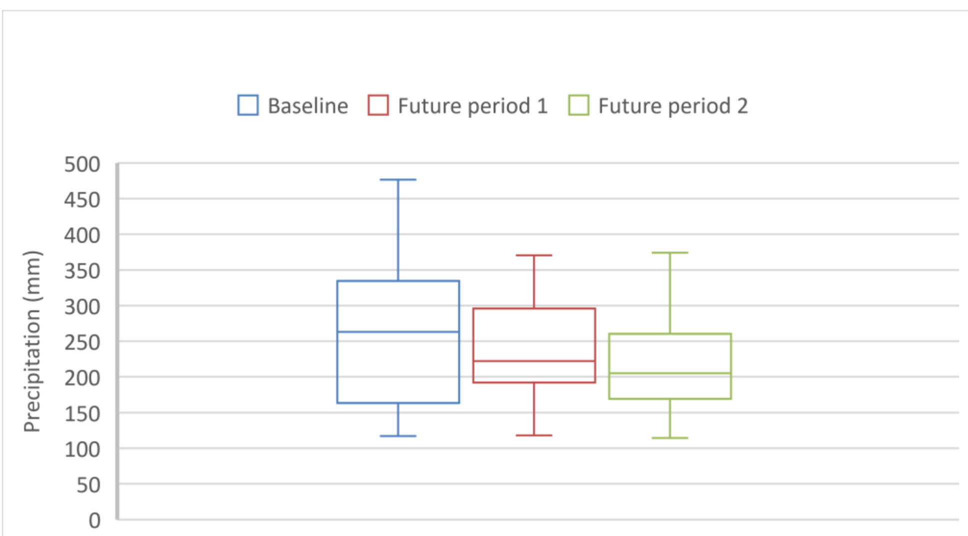

Figure 2: Annual precipitation ranges for the baseline (1993-2009) and the future periods

We are therefore confident that the model can sufficiently represent the future climate conditions. We are sorry to hear that the paper was not found and apologize for the inconvenience. Please find the paper following the link below (open access). https://doi.org/10.1007/s40333-020-0125-3

Reference:

Zhu, Q., Zhang, X., Ma, C., Gao, C. and Xu, Y.P., 2016. Investigating the uncertainty and transferability of parameters in SWAT model under climate change. Hydrological Sciences Journal, 61(5), pp.914-930.

Comment 4

Page 4, Line 110-112: "The calibrated and validated SWAT model was run with this climate model output to simulate groundwater recharge and streamflow for the model setup period (1979-2009) and two future periods (near future: 2030-2059 and far future: 2070-2099)". SWAT model was run in previous work (Mahmoodi et al., 2020b). Please, provide more information about the model outputs. Perhaps a table with descriptive statistical analysis of the observational streamflow data, together with the model outputs (e.g. streamflow for the three different periods) would help readers to follow the logic of the paper.

In the previous paper, we only simulated streamflow in the future. In this research, we combine a water demand scenario with a climate scenario. In addition, streamflow is simulated under pristine conditions. We will add a descriptive table to the revised manuscript, showing basic statistical analysis of streamflow at the basin outlet for baseline and scenario conditions (median, min-, and max- climate models).

Table 2: Statistical analysis of annual streamflow (m^3 s^{-1}) simulated for the model setup period (1979-2009) and two future periods (2030-2059 and 2070-2099) under Constant-WUS scenario for the median, max (wettest) and min (driest) climate models.

			Median climate model		**Max climate model**		**Min climate model**	
	Observations (1993-2009)	model setup period (1979-2009)	Future period 1 (2030-2059)	Future period 2 (2070-2099)	Future period 1 (2030-2059)	Future period 2 (2070-2099)	Future period 1 (2030-2059)	Future period 2 (2070-2099)
Mean	7.66	13.31	9.93	5.84	11.62	15.11	2.85	2.13
Max	33.21	39.79	38.75	20.78	48.59	76.97	6.74	5.72
Min	0.43	1.56	0.53	0.85	0.34	0.21	0.77	0.3
Median	3.42	11.73	6.67	3.74	5.84	10.34	2.34	1.51
STDEV	8.20	10.27	9.77	5.34	13.58	17.20	1.72	1.48
SKEW	1.88	0.98	1.50	1.55	1.52	1.94	0.76	0.99

Comment 5

Page 4, Line 104-107"For the present impact study, following the argumentation that errors level out and a projection can be better represented through averaging, i.e., taking the mean, median, or weighting (Tebaldi and Knutti 2007, Thober and Samaniego, 2014), from the RCP8.5 and distribution mapping-adjusted ensemble, one global-regional climate model was selected."

This sentence is a too long and it is confusing. Could you please explain further? Please also specify why you didn't use climate change projections from RCP 4.5.

We will modify the above sentences and clarify this statement in the revised version of the manuscript. We only used the RCP8.5 as one instructive and worst-case scenario. In addition, actual green-house gas emissions of the last decade have followed the RCP85 trajectory closer than the RCP45 scenario (Sanford et al., 2014). We will add these explanations to the revised version.

Reference:

Sanford, T., Frumhoff, P.C., Luers, A. and Gulledge, J., 2014. The climate policy narrative for a dangerously warming world. Nature Climate Change, 4(3), pp.164-166.

Comment 6

Page 4, Lines 107-108:"This selection was conducted according to the model democracy approach, which treats all climate models equally and the median model of the model ensemble is selected (IPCC, 2013)." What is the model democracy approach? In the IPCC 2013 there is no mention about it. Moreover, please fix the references according to the journal's requirements and in respect to the report's recommendations (see below). IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G. K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

The democracy approach is a synonym for the "ensemble of opportunity", a term which is used in the IPCC 2013 (chapter 11 and 12): It means that all models available define the ensemble and that each model has the same 'weight' or 'importance' (hence: democracy). From this full ensemble, the median model which is representing the median simulations for the hydrological components in the future periods (2030-2059 and 2070-2099) is selected for further investigation.

Thank you for providing the citation. It is modified accordingly in the reference list.

Comment 7

Page 4, Lines 108-110: "The G-RCM CSIRO-SMHI was chosen since it represented the median model of the major hydrological components (Mahmoodi et al., 2020b)." A model and its collection of runs is referred to as an ensemble. Please specify what do you mean as median model. If this ensemble selection influences the hydrological components in a major way, authors should add additional discussion in case of a different selection.

We believe that the focus on one climate model is instructive to discuss possible future impacts and the interaction of climate change impacts with the impacts of growing groundwater demand. We therefore determined a median model using the following procedure: Among the ensemble climate models, one climate model that is representing the median for most of the simulated hydrological components is selected for our current research. In our previous study, we addressed the inherent uncertainties in climate change assessment studies, using 11 climate models, 2 RCPs, and 2 bias correction methods in addition to the raw climate model data. Different climate models and projections will possibly lead to different results, as variability is shown in Figure 3 for each hydrological component under the ensemble of climate projections (Mahmoodi et al, 2020). We therefore can understand the concern that a different selection of a climate model may influence the study’s results and we will add an additional analysis of the full range of the climate model ensemble to the manuscript by showing the results for the min and max climate models.

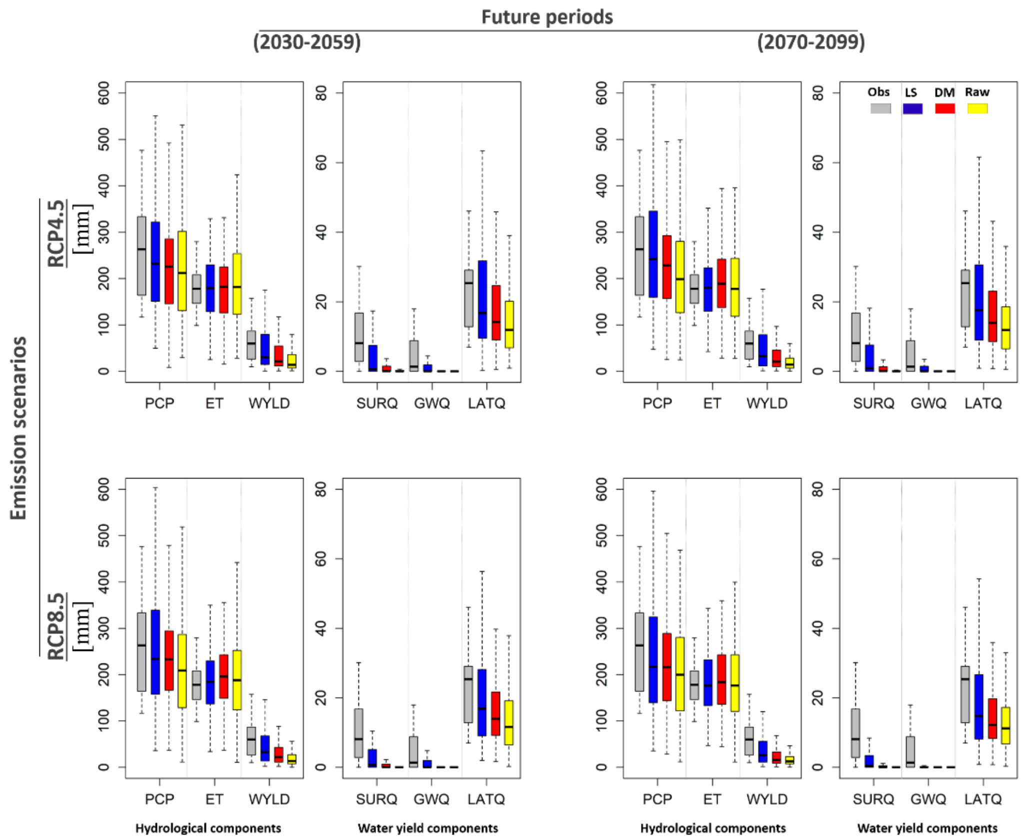

Figure 3: Variability of hydrological components in the future under climate scenarios for the bias corrected—(LS: linear scaling in blue and DM: distribution mapping in red) and the raw data (Raw in yellow) compared to the historical period in gray (1979-2011). PCP: precipitation, ET: actual evapotranspiration, WYLD: water yield, SURQ: surface runoff, GWQ: groundwater flow, LATQ: lateral flow (Mahmoodi et al, 2020).

<u>Reference:</u>

Mahmoodi, N., Wagner, P.D., Kiesel, J. and Fohrer, N., 2020. Modeling the impact of climate change on streamflow and major hydrological components of an Iranian Wadi system. Journal of Water and Climate Change.

Comment 8

Page 4, Lines 117-119: “The population growth rate suggested by presidency of I.R.I, Plan and Budget Organization (2019) was applied on the 2017 population data to estimate the population of the basin for the years 2045 and 2085, representative for the near and far future periods respectively (Table 1)."

If your analysis was made based on 2017 population data, why data relative to 2011 population are presented in tables (table 1 etc.)? If you didn't use these data please remove them.

The number of water use systems are reported until 2011. Therefore, we used the population growth rate between 2011 and 2017 to determine the number of WUS in 2017. We will correct this in the revision.

Comment 9

Page 4, Lines 123-124: "(i): To meet the future domestic, agricultural and industrial water demand, increases in the number of wells and qanats are linearly extrapolated with the estimated increases in the population of Halilrood Basin as follows:" Linear extrapolation should be discussed in the discussion and conclusion sections. Why authors decided to use this method?

Population growth is the main factor to predict the water consumption in Iran, as Keshavarz et al. (2006), reported a significant correlation between water consumption and population/size of households in Fars province with dry climate. In addition, the water consumption data reported for three provinces i.e., Azarbaijan, Khuzestan, Isfahan during the period 2001-2010 shows that the consumption rate is increasing linearly with population growth (Mombeni et al., 2013). Since the population and population growth rate are available for the study area, we assume that the current trend of population growth (current childbirth rate) will remain constant in the future. We believe that linking this increase (which probably overestimates future population) linearly with water demand, provides a rather conservative estimate of future water demand (we will discuss our results with reference to the population growth in Iran suggested by Presidency of I.R.I, Plan and Budget Organization). Therefore, using linear extrapolation is an applicable way to estimate the number of wells and qanats and water consumption in the future. We agree that other assumptions on population growth would lead to a different water demand.

References:

Keshavarzi, A.R., Sharifzadeh, M., Haghighi, A.K., Amin, S., Keshtkar, S. and Bamdad, A., 2006. Rural domestic water consumption behavior: A case study in Ramjerd area, Fars province, IR Iran. Water research, 40(6), pp.1173-1178.

Mombeni, H.A., Rezaei, S., Nadarajah, S. and Emami, M., 2013. Estimation of water demand in Iran based on SARIMA models. Environmental Modeling & Assessment, 18(5), pp.559-565.

Comment 10

Page 7, Lines 186-187:"The direction of change is shown by positive RVA, where the indicator becomes more stable within the RVA targets and negative RVA, where the indicator is moving towards an upper or lower alternative state." Please explain what do you mean "the indicator becomes more stable".

To evaluate the probable alteration through the RVA test, two targets, lower and upper, are considered. Stable situation is estimated for the indicator, whose variations stay within the targets. The phrase "becomes more stable" might be confusing; therefore, it will be changed to "where the indicator remains stable within the upper and lower bounds within the RVA targets and negative RVA, where the indicator is moving outside the upper or lower bounds to an alternative state."

Comment 11

Page 1, Line 42-42; Page 7, Line 203-204; Page 8, Line 225-226; Page 11, Line 287-288: "In Iran, the scarcity of rainfall, combined with climate change and population growth over the last decades, has resulted in higher groundwater extraction rates (Izady et al., 2015; Rafiei Emam et al., 2015; Mahmoudpour et al., 2016)." "As shown in Figure 2c and e, the GWW/GWR ratio is higher in the near and far future if the two stressors climate change and population growth are considered simultaneously (Projected-WUS)." "This might be due to the higher reduction in projected winter precipitation (Mahmoodi et al., 2020b). "This could lead to a higher groundwater withdrawal in summer season when the surface water does not meet the rising demand." Higher than what?

Thank you for pointing this out. We will modify those sentences in the revised version as follows:

"In Iran, groundwater extraction rates have increased over the last decades due to the scarcity of rainfall, combined with climate change and population growth (Izady et al., 2015; Rafiei Emam et al., 2015; Mahmoudpour et al., 2016)."

"As shown in Figure 2c and e, where the two stressors climate change and population growth are considered simultaneously (Projected-WUS), the GWW/GWR ratios in the near and far future are higher than the ratio during the model setup period."

"This might be due to the higher reduction in projected winter precipitation compared to the observations (Mahmoodi et al., 2020b)."

"This could lead to a higher groundwater demand in summer season as compared to the other seasons when the surface water does not meet the rising demand."

Comment 12

Page 5, Lines 135-136 "To disentangle the impacts of climate change and population growth and its combined effects on future aquifer condition and hydrologic regime, five scenarios were developed (Table 4)" I only see 4 scenarios in table 4. Please fix the table and also explain the symbol *.

Sorry for the confusion. "*" will be replaced by "✓" in the revised manuscript. The explanation for "✓" will be added below the table. "✓"addresses the scenario/s considered for each analysis. The table got accidentally truncated. We will make sure the size of the table matches so that all five scenarios fit on one page.

Comment 13

Page 9, Lines 236-237 "Although annual extreme flows mainly experience a lower degree of change in the near and far future (Figure 3 and 4),.." Should there be figure 4?

Thank you very much for spotting this. This should refer to Figure 3.

Comment 14

Table 8. Please write the relative years under each of the two future periods. Comment 15 Figure 3.

The relevant years will be added.