Reference: hess-2020-501

"Aquifer recharge in the Piedmont Alpine zone: Historical trends and future scenarios"

Reviewer #2

1) *the HESS-manuscript submission "Aquifer recharge in the Piedmont Alpine zone: Historical trends and future scenarios" by Brussolo et al. addresses the impacts of climate change on the components of the water balance in northwestern Italy. Overall, the manuscript is well written and structured.*

We thank the reviewer for this positive feedback.

2) *Generally, the paper could be shortened by omitting repetitions; Tables could be prepared as illustrations or moved to the supplementary information;*

We have welcomed the reviewer's suggestion and added a "supplementary Information" file where all the tables that summarize the main results discussed in the paper are included.

3) *Figures 1 & 2 could be merged.*

Figures 1 and 2 have been merged in the new paper version, as suggested by the reviewer. Thank you.

4) *At several locations (indicated in the annotated manuscript) specification would help.*

Details have been added at the points indicated by the reviewer in the annotated pdf..

5) *As the main topic is "aquifer recharge", the description of different groundwater recharge comes a little bit short. E.g. provide details on interaction processes of groundwater resources and surface waters (in- & exfitlration, etc.). Likewise, the whole link to groundwater (residual term of the water balance) and temperature imprinting is weak, resulting in a more qualitative assessment concerning the main topic "aquifer recharge".*

In order to address the reviewer comments and provide more details on the main topic of the paper, additional information was added in the introduction and in the methodology section (in the paragraph entitled "Water balance terms"). In particular, the Introduction has been extended as follows:

"Water is a crucial resource, intrinsically linked to society and culture development, food and energy security, well-being, environmental sustainability and poverty reduction. However, several factors, including urbanization, population growth, land use and soil consumption, industrial and agricultural development, endanger water resource sustainability in terms of availability, quality, management and demand (IPCC, 2014; WWAP, 2015). Groundwater resources represent about 97% of liquid freshwater resources on Earth (WHO, 2006; Healy, 2010) and play a key role in water supply and proper ecosystems preservation (WWAP, 2015). Groundwater resources help to maintain river discharges and, together with surface freshwaters, are accounted for in water budget considerations at the river basin scale (Rumsey et al., 2015). The hydrological connection between groundwater and surface water is primarily controlled by: (1) the driving force generated by the hydraulic gradient between groundwater and surface water, (2) the permeability degree of the aquifer in comparison to a streambed (i.e. different hydraulic conductivity) due to the geological context (Lasagna et al., 2016; Epting et al., 2018). Groundwater and surface water interaction is influenced by both local and regional regimes (Epting et al., 2018). Local interaction could be very complex and different methods were developed to quantify this interaction in different locations (Bertrand et al., 2014; Kalbus et al., 2006). Groundwater resources are of utmost importance for their mitigation effects during dry periods and their reduction can impact the whole hydrological cycle. Groundwater is a fundamental natural resource that acts as a reservoir from which good quality water can be collected for drinking purposes, requiring few purifying treatments compared to surface water. Climate change influences several components of the water cycle, including groundwater resources, causing a lowering of piezometric levels due to discharge modifications as a result of snow retention reduction, changes in precipitation regimes and potential evapotranspiration that increases linearly according to temperature increase. In Alpine regions, shorter and thinner snow pack will decrease late spring flows, while the air temperature rise will increase stream flows in fall and winter due to trading of snowfall for rainfall (Confortola et al., 2013), leading to a shift of groundwater recharge from summer to winter, as evaluated by CH2018-Project-Team (2018) and Epting et al. (2021) in Switzerland.

Surface water and pollutants infiltration together with over-exploitation of wells can further deplete groundwater resources, triggering the competition between irrigation and potable uses. Though the degradation of water quality mostly depends on land use and saltwater intrusions into coastal groundwater (Jiménez Cisneros et al., 2014), climate change will affect, either directly or indirectly, also the quality of groundwater resources. Temperature impacts on biological, chemical and physical properties of groundwater resources (Epting et al., 2021), despite the increase of air temperature is not necessary directly correlated with groundwater temperature increase, depending on the intrinsic properties of aquifers (e.g. groundwater in plain aquifers responds to climate change with relatively long response times, in contrast to spring waters), on local and regional spatiotemporal scales and different anthropic inputs (Epting et al., 2021; Bastiancich et al., 2021). Moreover, the interaction between surface water and groundwater flow systems influences the water chemistry (Lasagna et al., 2016), since in areas where rainfall intensity is expected to increase pollutants will be increasingly washed from soils to water bodies (Parry et al., 2007). Finally, water-level changes are a key indicator that flow patterns are changing and that low-quality water may be mobilized (Moench et al., 2003)."

Beside annotated manuscript here some more specific comments:

1. *68: Recharge (for the sake of simplicity here defined as the difference between precipitation and actual evapotranspiration);even though maybe appropriate for the investigations this must be justified in more detail.*

As in our reply to reviewer 1, we revised the Introduction to include a background about previous studies, by adding new references (Smerdon 2017; Epting et al., 2021; Li et al., 2015, Taylor et al. 2013) which justify using precipitation as the largest source of recharge variability, the importance of the spatial and temporal variability in recharge-related studies and illustrate how groundwater recharge projections are related to precipitation, irrigation and snowpack reduction projections.

The temporal variations can be quantified for precipitation and actual evapotranspiration (heavily impacted by air temperature and, in this area, by irrigation). The other terms of the water balance equation are affected by higher uncertainty and their impact is smaller: soil water storage is small, river runoff has scattered measurements and complex process modelling, subsurface flow always shows large uncertainties associated with its estimation (Healy, 2010 p.35). Our paper addresses the calculation of the temporal variations of precipitation and evapotranspiration also in the historical data, confirming other studies focused on precipitation in the Italian territory (e.e. Libertino et al., 2019). These considerations are already discussed in the introduction of the original manuscript.

2. *96 – 103: move to methods section?*

Done.

3. *138: The difference between surface and subsurface catchments at least should be discussed to justify this assumption.*

Surface and subsurface catchments are assumed to be coincident as they are bounded by the border mountain divide, as considered in De Luca et al., 2020. We now specify this in the introduction and in the methodology.

4. *“not shown here”: Maybe include in supplementary material?*

We have added this information in previous Table 4 of the paper, now Table S1 of the Supplementary Information file (which also includes Tables 5-9 of the previous paper version, now Tables S2-S6). Table S1 quantifies the interannual variability as the standard deviation of the detrended timeseries.

Finally, we thank the reviewer for all his/her remarks appearing in the annotated pdf which were considered in the revised manuscript.
