RC1: **'Comment on hess-2021-151'**, **M. van Noordwijk**

General

1. The manuscript provides an interesting comparative study of the 'water towers' in East Africa and the change in terms of a simple water balance that can be inferred from a combination of various spatial data sources

We thank the reviewer for the constructive comments. We have considered all comments and suggestions in our revised manuscript.

2. The description of the quantitative framework can be improved, including a more consistent use of acronyms (especially for actual evapotranspiration) and equations

Answer: We thank the reviewer for the feedback. The use of acronyms has been revised to ensure consistency. In the revised Manuscript, the acronym for actual evapotranspiration is ET, potential evapotranspiration is PET, and Water yield is Q.

3. The study relies heavily on the use of a link between NDVI and the omega parameter in the Budyko framework, while the text acknowledges many factors (including soil, topography and seasonality) influence the relationship. At least in the discussion this needs some further work to see how much this could have influenced results and conclusions.

Answer: We thank the reviewer for this comment. We have revised the section that acknowledges many factors such as soil types, topography, seasonality and how they are connected to vegetation signatures in our study and hence our confidence of adopting NDVI-based formulation. We have also incorporated a discussion of uncertainties/limitations in the discussion section. The following are relevant extracts from the revised manuscript:

In the methodology section we have revised the text as follows:

...The ω parameter is the most difficult parameter to estimate in Budyko framework applications (Bai et al., 2019). It reflects the impact of other factors such as land surface characteristics and climate seasonality on water and energy balances (Li et al., 2013). Previous studies have adopted various ways to estimate the ω parameter. Some studies used fitted values based on land-use/cover of the areas under investigation. For instance, Zhang et al. (2012) used values of 2, 0.5, and 1 to represent ω for the forest, grassland and shrubland respectively. Creed et al. (2014) used ω = 2 in forested catchments, ω = 0.5 in grassland or cropland catchments, and ω = 1 in mixed cover catchments. Other studies calibrated it based on historical data (Gunkel and Lange, 2017; Redhead et al., 2016; Yang et al., 2014). However, for data-limited regions, calibration-based estimations are impossible and simpler methods to estimate the ω parameter based on readily available data are desirable. Land surface hydrology varies due to variations in different factors such as vegetation, soil types, topography, and climate seasonality (Li et al., 2013; Yan et al., 2020). Soil texture and topography influence the amount of water available for vegetation – hence the vegetation signatures can reflect the underlying conditions of soil water conditions, topography, seasonality etc. Donohue et al. (2007) argued based on the theory of ecohydrological equilibrium that in water-limited environments, vegetation is the

integrated response to all processes affecting the availability of water. Therefore, vegetation information can serve as a good integrated indicator of these ecohydrological impacts on water and energy balances as it reflects the integrated landscape and climatic features. Using data from 26 major global river basins under a wide range of climate regimes, Li et al. (2013) developed a simple parameterization for Budyko ω parameter based solely on vegetation information as shown in equation 2 (in pre-print version)...

When discussing possible sources of uncertainties in the discussion section, the following text has been included:

...Uncertainties may also arise in the general assumption that estimation of land surface characteristics (ω) based on NDVI formulation provides values that represent integrated conditions for soil, topography, and climate seasonality. Some studies using various hydrological approaches have reported the significance of these factors in influencing catchment hydrology (Kirkby et al., 2002; Troch et al., 2013; Western et al., 2004; Woods, 2002). There is a need for more research to come up with methodological consistency in estimating ω parameters when using the Budyko framework...

4. The eight water towers are most described as 'replicates', rather than each having a specific geographic, ecological and social context: this may be the limit of what is currently possible, but at least some of the contrasts noted call for further analysis and attribution (e.g. in relation to human population density within and surrounding the water tower.

Answer: We completely agree that the eight water towers should not be seen as 'replicates'. We have added Table A2 on 'description of the selected water towers' that gives brief information on geographic, ecological, social context etc of each water tower in the revised manuscript. We have also acknowledged the relevance of local context and the need for ground research for understanding the forest-water-people nexus in the discussion section. See the following relevant extract from the revised manuscript:

...The anthropogenic presence both inside and outside the forested water towers indicates the relevance of local context, and ground research for understanding forest-water-people nexus (Noordwijk et al., 2020) is recommended. This will help in understanding in detail the dynamics and co-evolution of coupled human-forest-water systems...

5. It would help the paper if sharper questions would be formulated at the end of the introduction that gives structure to the subsequent discussion.

Answer: We thank the reviewer for the remark. We have now constructed the research question as follows:

"What are the effects of climate and land-use changes on water yield for the selected forested water towers?"

We hypothesized that, in areas considered as pristine or protected zones (i.e. high elevated forested areas), with AI≥0.65, changes in water yield would majorly be attributed to climate changes and negligibly due to land use/cover changes. The high elevated forested areas would then be expected to fall on the reference Budyko curve over the study period.

6. Beyond the supply of blue water to downstream parts of the watershed, the high actual evapotranspiration in water towers plays a role in regional rainfall recycling -- at least some discussion of this aspect would be relevant.

Answer: We thank the reviewer for bringing this relevant issue to our attention. We have included this point in our revised discussion, i.e. the importance of high elevated forested areas in maintaining high actual evapotranspiration – a key component in regional rainfall recycling. The following is the relevant extract from the revised manuscript:

...Our study offers important findings on the sensitivity of water yield to climate and land-use changes and the importance of these water towers in the generation and supply of blue water to adjacent lowland areas. These results can be used by decision-makers, policymakers, stakeholders, and scientists to emphasize the need to protect and conserve the high elevated forested areas in the region, particularly forest ecosystems above 2000 m a.s.l – where there is a surplus of blue water. The Budyko framework provides primary results that can inform detail hydrological assessments. For instance, our findings show that elevated forested water towers are important areas for maintaining high ET in the region. This finding can be explored further by studying the role of water towers in the supply of green water in the region (i.e. the role of water towers in regional rainfall/moisture recycling) (Ellison et al., 2017; Keys et al., 2014) - including the effect of mountain rain shadows on water yield (Van den Hende et al., 2021)...

Minor

p1, Line 17 Mention 'steady state' assumption of Budyko framework at an annual time scale

Answer: This has been corrected in the revised manuscript.

p1, Line 24 'non-resilient' suggests a binary classification, is there a more gradual description on the degree of resilience

Answer: We thank the reviewer for this remark. The resilience/non-resilience of the water towers is based on Budyko metrics elasticity (e) values as discussed in (Creed et al., 2014; Helman et al., 2017; Sinha et al., 2018) and calculated as a ratio of DI ranges to EI ranges (as shown in Eq 6). For simplicity, the terms low and high elasticity values were used in our study to represent the minimum empirical e value and maximum e value respectively for the different water towers. Elastic catchments (i.e. high elasticity) are expected to plot along the Budyko curve (i.e. resilient to climate changes) while inelastic catchments (i.e. low elasticity) (non-resilience to climate changes) would deviate from the Budyko curve.

p1, Line 29 but mountains also cause 'rainshadows' that don't get the rainfall they might have had without the presence of a mountain...

Answer: We thank the reviewer for this comment. In the revised manuscript we have recognized the effect as an area that requires further investigations. See the relevant extract below:

...This finding can be explored further by studying the role of water towers in the supply of green water in the region (i.e. the role of water towers in regional rainfall/moisture recycling) - including the effect of mountain rain shadows on water yield...

p1, Line 31 more quantitative criteria are needed to get the type of delineation that you use here

Answer: We thank the reviewer for this comment. More information regarding the criteria we used in definition of water towers has been added in the introduction section. The following is the relevant extract from the revised manuscript:

...The selection of water towers was based on aridity index (AI), high elevation, and continuous forest block. The selected water towers have AI≥0.65 (i.e humid), located in high elevated areas under a continuous forest block from the footslope contour to the peak.

The montane forests are the three major forest ecosystems defined and delineated by (EAC et al., 2016; UNEP, 2010), and they include the Albertine Rift, the Kenyan Highlands, and the Ethiopian Highlands. They were defined and delineated based on major rivers in the region. All the selected water towers in this study fall in the three forest ecosystems....

p1, Line 34 in glaciated mountain chains water flow depends primarily on temperature, without ice cap on recent rainfall -- so the temporal variability will differ and dependence on land cover increase

Answer: We thank the reviewer for this remark. This important point '*temperature is a key factor in determining water flows from glaciated mountain chains'* has been included in our revised manuscript.

p1, Line 35 'receive' is a rather passive description -- isn't it 'convert atmospheric moisture into rainfall'
Answer: We thank the reviewer for the remark. This has been revised to '*maintain significantly more precipitation than adjacent lowlands....'*

The intention is to introduce a reasoning that elevated forested areas record higher rainfall compared to lower slopes – an imporatnt source of water resources, especially for drier lowlands.

p1, Line 37 Some reference to Africa as geologically old shield, but rift valley plate tectonics are associated with younger and higher mountains

Answer: We thank the reviewer for the remark. This has been added in the revised manuscript.

...It is also paramount to mention that the East-African rift system has extensive plate tectonics that are considered relatively recent (Dawson, 2008)...

p1, Line 39-40 If you introduce more quantitative P/Epot criteria in line 31, this discussion on E African water towers becomes more meaningful, as it relates to both the P and the Epot side of the ratio.

Answer: We thank the reviewer for this comment. We have provided a clear definition of the water towers including quantitative P/Epot criteria.

...The selected water towers have AI≥0.65 (i.e humid), located in high elevated areas under a continuous forest block from the footslope contour to the highest point...

p1, Line 41 rainfall distribution is meager? what do you mean

Answer: We thank the reviewer for this comment. The intention is to describe that there is a high dependency on rainfall in the East African region, but rainfall distribution is insufficient/scanty. We have replaced the word 'meager' with 'insufficient'

p1, Line 42 Early work on rainfall in Sudan (El Tom, 1972) showed that the standard deviation of annual rainfall is nearly independent of mean annual value, showing that dry areas are highly variable in relative terms, with decadal variation super-imposed (Hulme, 1990) and not easily distinguishable from trended global climate change.

Answer: We thank the reviewer for the remark. We have expanded the text by acknowledging the information from these early works of El Tom, 1972 and Hulme 1990.

...El Tom (1972) tested the reliability of rainfall and showed that in the dry areas, the rainfall is highly variable and nearly independent of the mean annual value – affecting rainfed agriculture in the region. Fluctuations of rainfall are evident in both seasonal and decadal time series mainly in the semi-arid zones (Hulme, 1990)...

p2, Line 5 Please unpack the sentence

Answer: We thank the reviewer for this comment. We have revised the sentence as shown in the following extract:

...Understanding historical climate and human-induced land-use changes and their impacts on streamflow can explain some of the hydrological events experienced in the adjacent lowlands. This can help inform the role of forested water towers in observed extremities in the lowlands such as floods and hydrological droughts...

p2. Line 6 Possibly relevant: ET estimates for SS Africa

Answer: We thank the reviewer for this comment. However, we suspect SS Africa refers to Sub-Saharan Africa, but the comment is not clear to us when we connect it to Page 2, line 6. We had sent an email seeking clarification but had not received a reply by the time of posting our responses. Nevertheless, based on the preceding comment, we have unpacked the sentence as shown in the above response.

p2, Line 8 For corrections on common deforestation discourses, see Aleman et al. 2018

Answer: We thank the reviewer for sharing this important reference, we reviewed the publication added the reference in the revised manuscript. See the following extract from the revised manuscript:

...To our knowledge, there are no studies that have focused on the East-African forested water towers and their ability to generate streamflow under a changing climate and land-use in the East-African region. At the regional scale, studies in the region either focus on studying forest trends/deforestation (Aleman et al., 2018) or the effects of land-use changes on climate (Otieno and Anyah, 2012). At the river basin scale, studies in the region focus on hydrological responses (Gabiri et al., 2020; Hyandye et al., 2018; Mango et al., 2011)...

p2, Line 16 The methods of Ma et al. 2010, 2014 combine these two categories by running rainfall statistics and recorded land-use change patterns in reverse order in calibrated process-based models

Answer: We thank the reviewer for the remark. The reference has been acknowledged in the revised manuscript. The following is the relevant extract from the revised manuscript:

...Various approaches have been used for studying the effects of climate and land-use changes on streamflow. Jiang et al. (2015) categorized such methods into two: (a) deterministic rainfall-runoff models and (b) statistical methods. Ma et al. (2014) combined the two categories by running rainfall statistics and recorded land-use change patterns in reverse order in calibrated process-based models. Dey and Mishra (2017) reviewed the existing approaches and categorized these approaches into four categories; (i) experimental approach e.g. paired catchment method...

P2 Line 22 Maybe mention the steady-state assumptions at annual time-scale upfront. A simple equation might help here.

Answer: We thank the reviewer for the remark. This has been revised accordingly in the revised manuscript. A simple water balance equation has also been included as P=ET+Q under steady-state conditions (as Equation 1 in the revised manuscript):

...A steady-state is reached when the total input (i.e., precipitation) equals the total output (i.e., evapotranspiration and water yield) (Han et al., 2020) and changes in soil water storage are zero (Donohue et al., 2007). Hence a simple water balance equation assuming steady-state conditions can be written as:

$$P = ET + Q \quad (1)$$

where P is precipitation, ET is actual evapotranspiration and Q is water yield...

p2 Line 26 It would help the subsequent discussion if you formulate some clear questions here that you try to answer in the results section

Answer: We thank the reviewer for this comment. We have now constructed the research question as follows:

"What are the effects of climate and land-use changes on water yield for the selected forested water towers?"

We hypothesized that, in areas considered as pristine or protected zones (i.e. high elevated forested areas), with AI≥0.65, changes in water yield would majorly be attributed to climate changes and negligibly due to land use/cover changes. The high elevated forested areas would then be expected to fall on the reference Budyko curve over the study period.

P2 line 30 if you want to avoid use of 'we', please find a less abstract passive formulation...

Answer: We thank the reviewer for the remark. This has been revised accordingly and adopted the use of 'we'.

Fig. 1 As 'montane forests' and 'water towers' only partially overlap, please give the quantitative definitions of both;

Answer: We thank the reviewer for this comment. The definition of the water towers is now included in the revised manuscript as:

...The selection of water towers was based on aridity index (AI), high elevation, and continuous forest block. The selected water towers have AI≥0.65 (i.e humid), located in high elevated areas under a continuous forest block from the footslope contour to the peak...

The definition of the montane forests is given as:

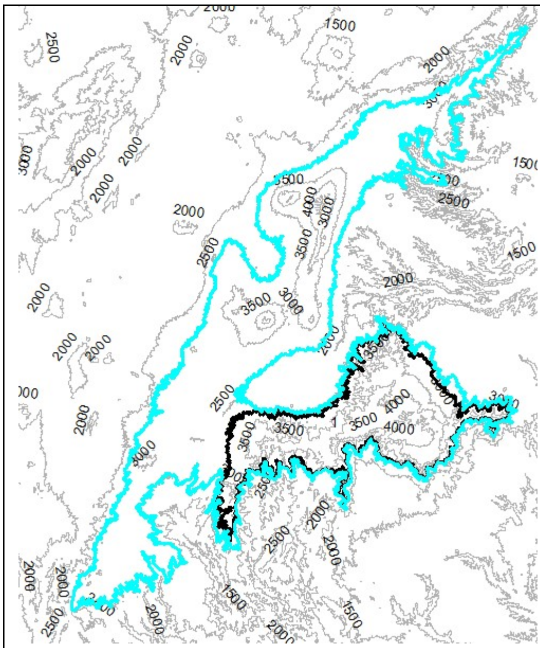
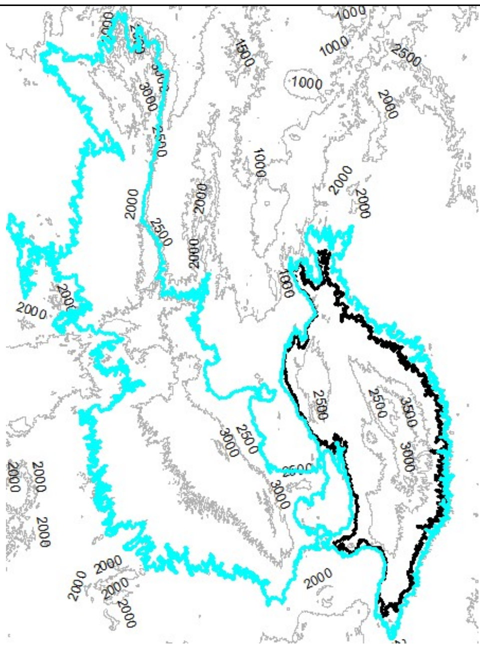
...The montane forests are the three major forest ecosystems defined and delineated by (EAC et al., 2016; UNEP, 2010), and they include the Albertine Rift, the Kenyan Highlands, and the Ethiopian Highlands. They were defined and delineated based on major rivers in the region. All the selected water towers in this study fall in the three forest ecosystems...

Public discussion on the Mau forests in Kenya described these as 'water towers', you don't; again clarifying the quantitative criteria can help

Answer: We thank the reviewer for this comment. You are right, Mau Water Tower is the largest 'water tower' in East Africa (EAC et al., 2016; Odawa and Seo, 2019). We selected a few of the water towers based on elevated forest areas (highest land areas) under one continuous forest block. MAU Forest complex did not meet our criteria as its highest pick is relatively low compared to (Mt Kenya, Aberdare ranges, Mt Elgon etc). It is also made up 22 distinct forest blocks with other types of Land uses in between (including urban areas) – which could not meet our pristine assumption. Again, the idea was to sample a few water towers from each country. In Kenya, 2 water towers were considered sufficient (Mt Kenya, Aberdare ranges and part of Mt Elgon).

Table 1 In the Dewi et al. water tower delineation no fixed contour was used for the delineation, but one relative to the watershed as a whole. Please clarify your choice here, esp regarding the two (Aberdare and Bale) that were adjusted to the surrounding areas...

Answer: We thank the reviewer for this comment. As explained in the above response, the choice of contour delineation was expected to give us a continuous forest block from the selected footslope contour to the highest peak. The adjustment was done upwards and not downwards. Bale mountains rises from 2,500 m a.s.l. (Hillman, 1988). We adjusted upwards to 2,600 m a.s.l to ensure we capture majorly the elevated forested areas presumably under pristine conditions. We could not settle for the administrative boundary at 2,500 m a.s.l as it was capturing more of the surrounding areas. A similar approach was also applied for Aberdare ranges as shown below:

 **Bale mountains:** When the official forest boundary was selected (i.e. 2,500 m a.s.l - cyan blue contour), large surrounding areas were captured – an adjustment to 2,600 m a.s.l (black contour) gave a continuous forest block up to the peak of 4,337 a.s.l.	 **Aberdare ranges**: Similarly, when the 2,000 m contour was selected (cyan blue contour), large areas were captured, hence an upward adjustment to 2,100 m a.s.l (black contour)

p3 Line 11 Here you seem to shift from PET to ET or ETa -- the preceding paragraph only mentions Epot.

Answer. We thank the reviewer for this comment. The potential evapotranspiration mentioned in the preceding is as part of global datasets used in the study. The PET together with P and NDVI datasets were used to calculate actual evapotranspiration (ET) using the Budyko equation (i.e. we used PET to calculate ET).

p3 Line 14 This section may be clearer if you first present a water balance equation...
Answer: We thank the reviewer for this comment. A simple water balance equation has been included as P=ET+Q under steady-state conditions.

p3 Line 17 Deserts tend to have wadi's -- even in zones with low average rainfall, runoff occurs and rainfall intensity exceeds instantaneous infiltration capacity. Your Budyko-based description here needs some empirical adjustment (and scale considerations)

Answer: We thank the reviewer for the remark. In the discussion section and especially when discussing the potential sources of uncertainties, we have acknowledged the lack of empirical adjustment of the Budyko framework to capture special features in the lowland areas such as desert wardis:

...Although the focus of the study was in the elevated forested areas, empirical adjustment of the Budyko model may be needed to capture special features such as desert wadis in the application of the Budyko equation in the lowland areas...

p3 Line 17 Not only under very dry conditions... About 50% of tropics has a P/PET ratio below 0.65; only a quarter has P/PET above 1.0

Answer: We thank the reviewer for this comment. We have added a reference and related information in our revised manuscript:

...About 60% of the world's land surface is considered an arid area (i.e. P/PET ratio also know as aridity index (AI) of below 0.65 (Convention on Biological Diversity, 2001)...

p3 line 31 Fu in stead of FU

Answer: This has been corrected.

p3 Equation 1 -- please specify the time step (1 year?)
Answer: We thank the reviewer for this comment. The time step has been included. The time step is 10 years between 1981 and 2010 and 9 years between 2011 and 2019.

Wouldn't it be better to include a DeltaS storage term, and then make explicit that you assume this is zero at the time scale of your analysis (but this is a considerable source of uncertainty and error...)
Answer: We thank the reviewer for this comment. This has been revised. The ΔS has been included in the equation.

Fig 1A please settle on a single acronym for AET = ETa = ET
Answer: We thank the reviewer for this comment. This has been corrected: Actual evapotranspiration now represented with an acronym ET

p3 Line 37 The seasonality effect is linked to the DeltaS term that you're hiding...

Answer: We thank the reviewer for this comment. The ΔS is now acknowledged and shown in the revised equation:

$$Q = P - ET + \Delta S$$

p4 line 6 As this is an empirical result, please describe the data set on which it was calibrated (from which it was derived)

Answer: We thank the reviewer for this comment. We have now mentioned the kind of datasets used in the revised manuscript.

...Li et al. (2013) used data from 26 major global river basins under a wide range of climate regimes to come up with a simple parameterization for Budyko ω parameter based solely on vegetation information...

p4 Line 8 So what about other influences on omega (soil types, and topography, climate seasonality, ...) that you just mentioned? You assume that these are at the average values in the Li et al. dataset? This will require some further justification, especially as you operate in the relatively rare bimodal rainfall part of the world.

Answer: We thank the reviewer for this comment. We have revised the text on estimations and key assumptions around Budyko ω parameter in our study. The following is the relevant extract from the revised manuscript:

...The ω parameter is the most difficult parameter to estimate in Budyko framework applications (Bai et al., 2019). It reflects the impact of other factors such as land surface characteristics and climate seasonality on water and energy balances (Li et al., 2013). Previous studies have adopted various ways to estimate the ω parameter. Some studies used fitted values based on land-use/cover of the areas under investigation. For instance, Zhang et al. (2012) used values of 2, 0.5, and 1 to represent ω for the forest, grassland and shrubland respectively. Creed et al. (2014) used ω = 2 in forested catchments, ω = 0.5 in grassland or cropland catchments, and ω = 1 in mixed cover catchments. Other studies calibrated it based on historical data (Gunkel and Lange, 2017; Redhead et al., 2016; Yang et al., 2014). However, for data-limited regions, calibration-based estimations are impossible and simpler methods to estimate the ω parameter based on readily available data are desirable. Land surface hydrology varies due to variations in different factors such as vegetation, soil types, topography, and climate seasonality (Li et al., 2013; Yan et al., 2020). Soil texture and topography influence the amount of water available for vegetation – hence the vegetation signatures can reflect the underlying conditions of soil water conditions, topography, seasonality etc. Donohue et al. (2007) argued based on the theory of ecohydrological equilibrium that in water-limited environments, vegetation is the integrated response to all processes affecting the availability of water. Therefore, vegetation information can serve as ***a good integrated indicator*** *of these ecohydrological impacts on water and energy balances as it reflects the integrated landscape and climatic features. Using data from 26 major global river basins under a wide range of climate regimes, Li et al. (2013) developed a simple parameterization for Budyko ω parameter based solely on vegetation information as shown in equation 2 (preprint version)...*

p4 Line 17 Please remove ;
Answer: This has been removed.

p4 line 12 Please indicate what you treat as 'known' inputs here and what as parameters to be estimated
Answer: We thank the reviewer for this comment. This has been revised accordingly. Known inputs are P (from datasets) and ET (Estimated through the Budyko model). The parameter to be estimated here is Q

p4 Line 36 So the EIBud is based on the NDVI relationship? It would help if you give more formal definitions of the terms here

Answer: We thank the reviewer for this comment. In this study, the Budyko curve was developed based on 1981-1990 conditions (for each of the water tower). This was assumed to represent the reference condition for the water balance, to effectively assess the trends in the succeeding periods of 1991-2000, 2001-2010, and 2011-2019.

We have added the following information to give more clarity:
...The EI_{Bud} therefore represents the 'theoretical value' (i.e. point on the Budyko curve where the water tower was expected to fall at a particular period. The EI_{Sim} represents the point where the water tower plotted in that period. The difference between the expected/reference point (EI_{Bud}) and the actual point (EI_{Sim}) was then calculated to give the deviation (d) from the Budyko curve...

p4 Line 6 Is the DeltaEI here the same as d in Eq 5?

Answer: We thank the reviewer for this comment. The ΔEI in Equation 6 is not exactly the same as the deviation (*d*) in equation 5. We have added the following text to ensure there is clarity:

...Elasticity (e) was defined as the ratio of interdecadal variation in dryness index (DI) to interdecadal variation in the evaporative index (EI)...

...In our study, the evaporative indices (EI) for the four periods (i.e. 1981-1990, 1991-2000, 2001-2010, and 2011-2019) were calculated (based on averages of ET and P for each period). The range in EI (i.e. ΔEI) is the difference between the reference/baseline EI (of 1981-1990) and succeeding periods of 1991-2000, 2001-2010, and 2011-2019...

For instance:
i. EI of 1991-2000 minus reference EI of 1981-1990 gives the 1st range ΔEI_A
ii. EI of 2001-2010 minus reference EI of 1981-1990 gives the 2nd range ΔEI_B
ii. EI of 2010-2019 minus reference EI of 1981-1990 gives the 3rd range ΔEI_C

The *d* in equation 5 is basically the vertical deviation from the point at which the water tower was expected to fall (EI_{Bud}) i.e. reference point (i.e. determined by the Budyko curve) versus the actual point that was simulated (EI_{Sim}).

p5 Wouldn't it be easier and more informative to present the ETa/PET ratios?

Answer: We thank the reviewer for this comment. Yes, we agree that the ratio of ET/PET can be very informative especially if the focus is on water stress and land-atmosphere interaction rather than water yield. In the end, our goal is water yield (Q), and Et/PET does not provide much additional insight. The ratio is linked to canopy–atmosphere coupling and is very informative as it can characterize how different areas contribute to the 'production of 'green water' – a key component in moisture/rainfall recycling. This ratio is commonly applied together with the ratio of Q/P or P/PET in Turc space illustrations – an alternative framework to using the Budyko framework.

The ratio of ET/PET has been used differently by various studies. For instance, to estimate ET in hydrological models, to estimate irrigation requirements, to monitor crop water stress etc as described in (Peng et al., 2019).

We feel that the ET/PET ratios can be very informative for studies focusing on 'green water', regional rainfall recycling, and soil moisture conditions. Our study focused on the generation and supply of 'blue water' from high elevated forested areas. We feel more comfortable using Fu's equation in our study as the focus is on the sensitivity of 'blue water' from high elevated forested zones. We have, however, acknowledged the 'green water' as the study already shows that water towers are important areas that maintain high ET and further studies on regional rainfall recycling can further improve our results on the importance of water towers in the East African region. See the relevant extract below:

...our findings show that elevated forested water towers are important areas for maintaining high ET in the region. This finding can be explored further by studying the role of water towers in the supply of green water in the region (i.e. the role of water towers in regional rainfall/moisture recycling) - including the effect of mountain rain shadows on water yield...

p7 line 1 where omega values 'observed'? maybe 'derived'

Answer: We thank the reviewer for this comment. This has been noted and replaced 'observed' with 'derived'

Fig 7 How can Q estimates of 1000 mm/year be obtained for places with P hardly above 1000 mm/year?

Answer: We thank the reviewer for this comment. The Q estimates of 1000 mm/year were mainly observed in the western part where a Rainfall of over 2000 mm/year was observed as shown in Fig 2A - also in some parts within the Mt Kilimanjaro where annual Rainfall was of over 2000 mm/year. Our study observed an over-estimation of simulated Q when a comparison with GRDC runoff was done. This is now highlighted in the discussion of uncertainties. The following is the relevant extract from the revised manuscript.

...In this study, the spatial pattern of the simulated streamflow in the Budyko framework closely resembles the pattern observed in the GRDC composite runoff. We however noted overestimation of water yield in the comparison. This type of observation was also reported by (Teng et al., 2012), where the Budyko equation was found to overestimate water yield in drier regions. Moreover, other factors such as soil type, topography, seasonality, water storage, interception, etc were not accounted for in the quantitative framework which can affect the simulations in the selected forested water towers.

Canopy interception, for instance, plays an important role in the water balance of forested ecosystems as noted in several studies (Astuti and Suryatmojo, 2019; Gash et al., 1980; Teuling et al., 2019; Zimmermann et al., 1999). In their study, (Teuling et al., 2019) found many forested points to have average yearly evapotranspiration (ET) that exceeds the average potential evapotranspiration (PET). Van Dijk et al. (2015) opined that this is possible due to underestimation of evapotranspiration which was attributed to evaporation of interception water by energy not captured in the formulation of PET. The forest evapotranspiration paradox is further discussed in (Teuling, 2018). The correction of underestimation in (Teuling et al., 2019) indicates the need for long-term lysimeter observations for studies focussing on forested ecosystems. Availability of meteorological data in the upper slopes of the East African mountains is a big gap as the majority of meteorological observations are conducted below 1500 m a.s.l and most of the upper slopes data rely on extrapolation of hydrological analysis in the lowlands (Røhr and Killingtveit, 2003).

Local-based runoff measurements would have helped to interpret if there is indeed an overestimation in our study. That said, we observed positive KGE which indicates a "good" model performance...

p14 Discussion: A clearer structure of the discussion is needed.

Answer: We thank the reviewer for the comments in the discussion section. The following comments together with related comments from the other referees helped in improving the discussion section.

p14 Line 19 As you used NDVI data, you used land cover rather than land use change as basis...

Answer: We thank the reviewer for this comment. A discussion on uncertainties has now been included. The following is the relevant extract from the revised manuscript:

...Uncertainties may also arise in the general assumption that estimation of land surface characteristics (ω) based on NDVI formulation provides values that represent integrated conditions for soil, topography, and climate seasonality. Some studies using various hydrological approaches have reported the significance of these factors in influencing catchment hydrology (Kirkby et al., 2002; Troch et al., 2013; Western et al., 2004; Woods, 2002). There is a need for more research to come up with methodological consistency in estimating ω parameters when using the Budyko framework...

p14 Line 21 The sensitivity to land cover change reflects the limited degree of actual change (due to existing institutional arrangements) rather than the lack of response if such rules would be relaxed. Please distinguish these two aspects.

Answer: We thank the reviewer for this remark. We have acknowledged the existing institutional arrangements in our discussion. The following is a relevant extract:

...Our results indicate that changes in precipitation and potential evapotranspiration are the major determinants of blue water availability from high elevated forested water towers in the East African region. However, it would also be paramount to point out that lack of evidence of sensitivity to land-use changes within the water towers, may also be due to existing institutional arrangements, hence a limited degree of actual change. We presume that the results would be different if such rules would be relaxed...

p14 line 24. An alternative to describing deviations along the Y axis (vertical) is to attribute them along the X-axis (horizontal): would such an approach be feasible?
Answer: We thank the reviewer for this comment. Yes, this is possible. Actually, we had discussed the horizontal shifts in the pre-print version (p15 line 6-14). The following is the relevant extract from the revised manuscript:

...Further illustrations can be shown in the Budyko space based on the horizontal shifts relative to the dryness index (DI). The horizontal shifts are important indicators of the behavior of the water towers towards warmer or humid conditions. These horizontal deviations reflect a change in the climatic conditions specifically, temperature and precipitation (Creed and Spargo, 2012)*. This study observed that the majority of the water towers (7 out of 9) plotted within humid conditions (i.e. DI <1). On the other hand, two of the water towers (i.e. Mt Meru and Bale mountains) demonstrated warmer conditions (i.e. DI >1). One major observation is that water towers in Eastern Africa seem to shift towards the left, an indication of the increased humid conditions especially in the period of 2011-2019. At the same time, a gradual increase in PET was observed in all the water towers. A climate shift to wetter conditions and simultaneous increases in regional temperatures have also been reported in the East African region and projected to increase by the end of 21st century (Giannini et al., 2018; Niang et al., 2014; Omambia et al., 2012)...*

p14 Discussion: Can you imagine doing the same analysis on the basis of ET/PET ratios attributed to NDVI, rather than the more complex Budyko route that involves P in the estimation of omega?

Answer: We thank the reviewer for the remark. However, we do not see how P can be removed from the estimation of ET. If one would investigate this system only with NDVI as a predictor of ET, then you would miss important changes due to P.

p14 Line 27: what do you mean by naturally occurring oscillations in this context? Does the occurrence of fire (partially anthropogenic) play a role: it changes NDVI for one or more years, increasing water yield; it may be more common on e.g. Mt Kenya and in the Imatong mountains

Answer: We thank the reviewer for this remark. We have removed the term 'naturally occurring oscillations in the revised manuscript. The following is the relevant extract from the revised manuscript:

...The two water towers where no deviations were observed (i.e. Mt Elgon and Imatong mountains) indicate that the hydroclimatic conditions in the study period did not vary much from the reference conditions of 1981-1990 and any changes in water yield in the two water towers can largely be associated with climatic changes in P and PET...

p15 Line 4 Please clarify 'resilience' as bouncing back in relation to 'elasticity' that refers to the degree of initial change, rather than its temporal dimension.

Answer: We thank the reviewer for this comment. Actually, in our calculation of elasticity (see equation 6), all the DI and EI ranges are referenced to the starting period of 1981-1990 to determine the degree of change from initial conditions. The following is the relevant extract from the revised manuscript:

...Moreover, the lack of deviations in the two water towers may indicate the resilience of forested regions (i.e. adaptable nature of forests) as described in (Creed et al., 2014; Helman et al., 2017; Van der Velde et al., 2014). Such resilience (measured as elasticity) could be a key factor in forested water towers indicating their ability to resist change or bouncing back to their initial natural conditions, hence plotting along the reference Budyko curve. Long-term adaptations of forests have been achieved by trees even in the most water-limited forests (Helman et al., 2017). However, our investigations on elasticity (that refers to the degree of initial change using 1981-1990 as the reference period) did not support the above science as lower elasticity values were observed in most of the water towers. Given that low elasticity indicates broad ranges in the evaporative index (EI) compared to the dryness index (DI), this may further indicate the presence of anthropogenic influence within the water towers. According to Creed et al. (2014), elastic catchments are expected to plot along the Budyko curve (i.e. high elasticity = resilient to climate changes) while inelastic catchments (i.e. low elasticity = non-resilience to climate changes) would deviate from the Budyko curve...

p15 line 10 Isn't this a consequence of the way water towers are defined?

Answer: We thank the reviewer for this comment. We have now defined the criteria we applied in our study. The selected water towers followed the criteria where only those forested areas in high elevated areas and have an Aridity (AI) of 0.65 and above (humid) were selected. We assumed that all the selected water towers would possess humidity conditions given the criteria used. We found this an interesting finding where the two water towers (Mt Meru and Bale mountains) demonstrated warmer conditions (i.e. DI >1). We also discovered climatic shifts between warmer and humid conditions. The following is the relevant extract from the revised manuscript:

...Further illustrations can be shown in the Budyko space based on the horizontal shifts relative to the dryness index (DI). The horizontal shifts are important indicators of the behavior of the water towers towards warmer or humid conditions. These horizontal deviations reflect a change in the climatic conditions specifically, temperature and precipitation (Creed and Spargo, 2012)*. This study observed that the majority of the water towers (7 out of 9) plotted within humid conditions (i.e. DI <1). On the other hand, two of the water towers (i.e. Mt Meru and Bale mountains) demonstrated warmer conditions (i.e. DI >1). One major observation is that water towers in Eastern Africa seem to shift towards the left, an indication of the increased humid conditions especially in the period of 2011-2019. At the same time, a gradual increase in PET was observed in all the water towers. A climate shift to wetter conditions and simultaneous increases in regional temperatures have also been reported in the East African region and projected to increase by the end of 21st century (Giannini et al., 2018; Niang et al., 2014; Omambia et al., 2012)...*

...There are chances that the shifts to wetter conditions in the water towers may also be as a result of the extended impact of increasing PET on the El Nino-Southern Oscillation (ENSO), a phenomenon that influences precipitation in the East African region. Li et al. (2016) investigated annual flood frequencies, from 1990 to 2014, and observed upward trends that were linked to the ENSO phenomenon. Additionally, the shifts to wetter conditions also coincide with the recent reports on the 'rising lake levels phenomenon' in the Eastern Africa region (Chebet, 2020; Chepkoech, 2020; Patel, 2020; Wambua, 2020). We however do not believe we have the data to link the climatic shifts and 'swelling' of lakes to ENSO variations in our study which requires detail scientific investigations...

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