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ORIGINAL PAPER

Sensitivity exploration of water balance in scenarios of future changes: a case study in an Andean regulated river basin

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Abstract

Effects of climate change on water resources availability have been studied extensively; however, few studies have explored the sensitivity of water to several factors of change. This study aimed to explore the sensitive of water balance in water resources systems due to future changes of climate, land use and water use. Dynamical and statistical downscaling were applied to four global climate models for the projections of precipitation and temperature of two climate scenarios RCP 4.5 and RCP 8.5. Land use projections were carried out through a combination of Markov chains and cellular automata methods. These projections were introduced in a hydrologic model for future water supply evaluation, and its interactions with water use projections derived from a statistical analysis which served to assessment deficits and surplus in water to 2050. This approach was applied in the Machángara river basin located in the Ecuadorian southern Andes. Results showed that the water supply exceeds the water demand in most scenarios; however, taking into account the seasonality, there were months like August and January that would have significant water deficit in joint scenarios in the future. These results could be useful for planners formulating actions to achieve water security for future generations.

1 Introduction

According to Walker and Steffen (1997), the determining factors of global changes are the decline of biodiversity on a global scale, changes in atmospheric composition, changes in land use and land cover (LULC) and climate change (CC) of the planet. Of these factors, CC and LULC change the most important in the Andean basins (Mark et al. 2017; Rolando et al. 2017). They influence the hydrologic cycle and affect water resources, with consequent negative impacts on the population. CC could intensify the stress in the water resources management and generate the need of having strategies to deal with the effect on water availability for human use and natural ecosystems (Kim et al. 2013; Schwank et al. 2014). LULC change severely alters the hydrologic regime in Andean watersheds (Buytaert et al. 2006).

In combination with population growth, this might affect water availability in the future (Kim et al. 2013). The effects of CC imply variations in temperature, changes in precipitation and the water balance will alter (Chavez-Jimenez et al. 2013). These changes impact health, ecology, and economy of a population.

On the other hand, the availability of water is also affected by the LULC change, the replacement of paramo and forests by agricultural and livestock areas causing modifications in hydrological functioning (Hofstede et al. 2014), producing more droughts in summer times and more floods in winter times. The Andean watersheds can be easily disrupted by anthropogenic actions and climatic situations, which could affect the ecosystem and urban, agricultural, industrial, and hydropower sectors benefiting from the water system. This situation is becoming a real challenge for water managers in a basin (Li et al. 2009). Also, there is a need for a scientific basis for the construction of policies concerning water resources management and planning.

The CC and LULC change interactions and its effect on streamflows have been little investigated (Tu 2009; Kim et al. 2013; El-Khoury et al. 2015; Pervez and Henebry 2015; Eum et al. 2016; Shrestha et al. 2017), but these studies have not

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explored the water balance (water supply versus water demand) integrally. However, many studies have studied these two change factors separately. Some studies have shown the impacts produced by climate change in various parts of the world (Fujihara et al. 2008; Nan et al. 2011; Candela et al. 2012; Gao et al. 2012; Koutroulis et al. 2013; Kusangaya et al. 2014; Vargas-Amelin and Pindado 2014; Nam et al. 2015; Vallam and Qin 2016; Wang et al. 2016; Nam et al. 2017; Pieri et al. 2017; Shahid et al. 2017; Zhuang et al. 2017; Sanikhani et al. 2018; Serur and Sarma 2018a, b; Shen et al. 2018), other studies have focused on showing climate change adaptations measures (Charlton and Arnell 2011; Kuhn et al. 2011; Ludwig et al. 2014; Olmstead 2014; Collet et al. 2015; Zhai et al. 2017), while the sensitivity of water resources in watersheds by the dynamics of the use of the land has been studied by some authors (Jewitt et al. 2004; Fohrer et al. 2005; Thanapakpawin et al. 2007; Huisman et al. 2009; Ghaffari et al. 2010; Nie et al. 2011; Baker and Miller 2013; Öztürk et al. 2013; Yan et al. 2013; Rust et al. 2014; Can et al. 2015; Gashaw et al. 2018; Guzha et al. 2018; Mohammady et al. 2018). In high mountains basins, there are few studies (Beniston 2003; Stehr et al. 2010; Vicuña et al. 2011; Schwank et al. 2014; Espinosa and Rivera 2016); however, the influences of the two changes are studied separately. Schwank et al. (2014) show the impact of temperature increment on glaciers melting and on the seasonal river flow increase, moreover the runoff decrease due to reduced precipitation in high mountains of Argentina. Vicuña et al. (2011) show decreases of mean streamflow due to an increment of temperature and a reduction in precipitation in a northern high basin of Chile. Espinoza and Rivera (2016) demonstrate that water vulnerability increases due to changes in paramo areas in an Ecuadorian Andean watershed. And Stehr et al. (2010) show discharge increase due to land use patterns change in a Chile Andean watershed.

This study aimed to analyze the sensitivity of the water balance concerning future scenarios of CC and LULC change in an Andean regulated river basin. This study could be used for watershed planning with a formulation of measures and policies for sustainable water and territorial management.

2 Materials and methods

2.1 Case study

Data of the Machángara river basin, which is situated in Southern Ecuador (Fig. 1), were used to apply the methodology. This basin has an area of 325 km2, and mean elevation of 3400 m.a.s.l. The basin is divided into three sub-basins: Machángara Alto, Chulco, and Machángara Bajo. The upper part basin (Machángara Alto and Chulco rivers sub-basins) contains paramo ecosystem (tussock grasses, mountain forest, wetlands and natural lakes); in the middle part, there are grasslands, mountain forest, and agricultural areas. The lower part has urbanized areas (city of Cuenca). This basin is of vital importance for the population of Cuenca (3rd largest city of Ecuador) for the environmental services offered such as water supply, which are threatened by climate change conditions and the land use change (Celleri et al. 2017). The Machángara river basin has two reservoirs: Chanlud (Machángara Alto river sub-basin) and El Labrado (Chulco river sub-basin), which have a capacity of 16.25 hm^3 and 6.25 hm^3, respectively. Both reservoirs supply water for irrigation, for drinking water systems and are responsible for a small production of hydropower.

For the development of this study, we used monthly hydro-meteorological time series data (1979–2008) of Chanlud and El Labrado stations; these are located in the upper part of the basin. We obtained this information via the National Institute of Meteorology and Hydrology of Ecuador (INAMHI), the Machángara River Basin Council (CBRM), and the Municipal public company of telecommunications, drinking water, sewage, and sanitation of Cuenca (ETAPA).

The basin is lowering its humidity in January. The monthly water demand information was derived from the CBRM. A scheme of the water resources system is shown in Fig. 2. LULC data of the years 1991,2001, and 2010 (spatial resolution of 30 m) was treated by people from the University of Azuay (UDA) and the National Information System of Rural Lands and Technological Infrastructure of the Ministry of Agriculture and Livestock of Ecuador (SIGTIERRAS).

2.2 Water resources system model

The water evaluation and planning model (WEAP) was used to evaluate the water balance of the system (water supply versus water demand). This model provides an integration of both a hydrologic model and a water resources system model that governs the allocation of available water to meet the different water demands (Mounir et al. 2011). It allows multiple scenario analyses, including climate scenarios and land use variations; therefore, it can be applied in different scales from small catchment areas to large basins (Yates et al. 2005).

The rainfall-runoff soil moisture model was used as the conceptual hydrologic model. The hydrological components modeled using WEAP are evapotranspiration, infiltration, surface runoff, sub-surface runoff (i.e., interflow), and baseflow. This conceptual model allows for the characterization of land use specific impacts on runoff. A watershed is first divided into sub-catchments and then further divided into fractional areas, where a water balance is computed for each one of them. Additionally, streamflow data was necessary to be able to compare model results and perform the calibration. It is important to carry out an analysis of water demand to complement the evaluation of the water balance. This analysis

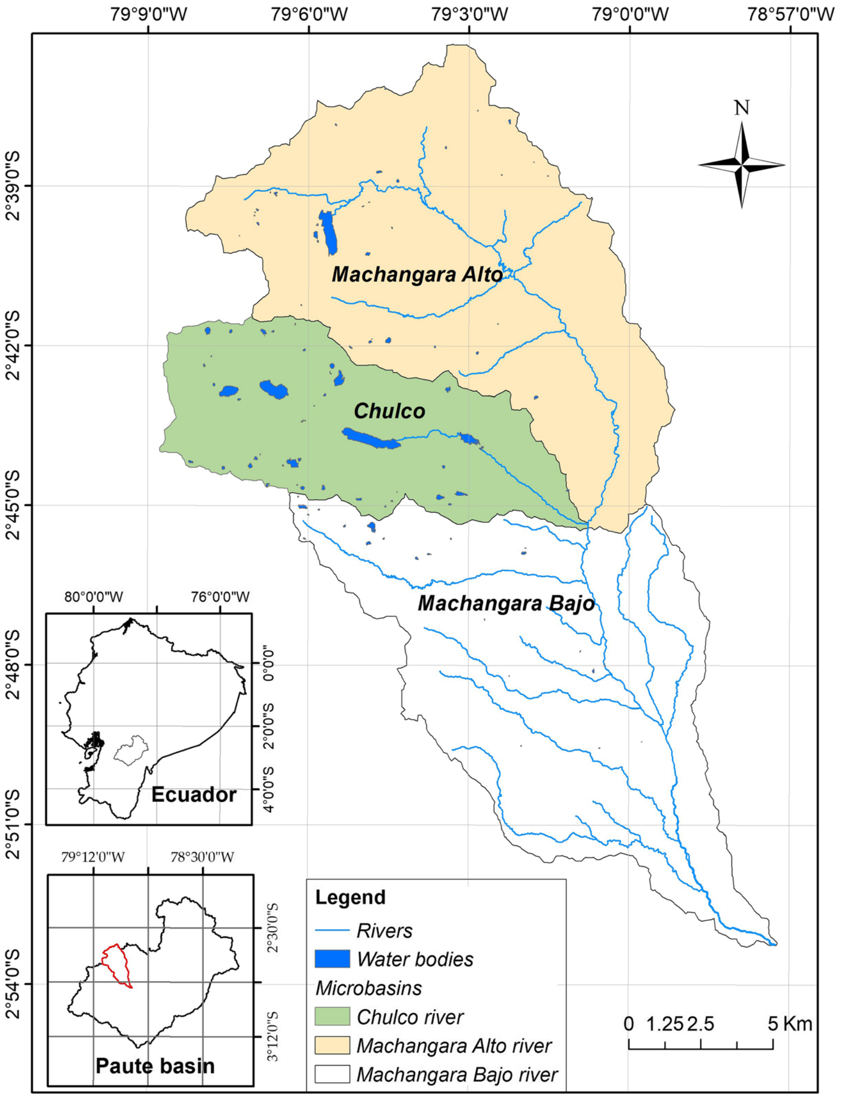

Fig. 1 Location of the Machángara river basin

considers the definition of water consumptions, crops under irrigation, urban demand, and other water needs, for more details; see YATES et al. (2005). The period from 1979 to 1999 was used for the hydrologic model calibration, and the period from 2000 to 2008 was used for the validation of the model. The efficiency criteria which were used were Nash-Sutcliffe (Nash and Sutcliffe 1970) and Nash logarithm (Krause et al. 2005).

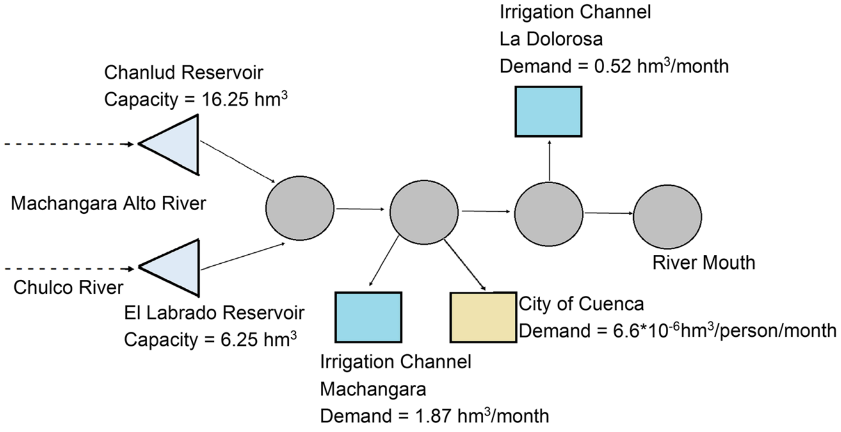

Fig. 2 Scheme of the Water Resources System of Machángara river basin

2.3 Future scenarios

Future scenarios were constructed with a projection from January 2011 to December 2050. Climate, land use, and demand projections were taken into consideration to evaluate water deficits in the future. Two climatic scenarios were considered, and a third scenario was the projection of land use. Demand projections were considered in all scenarios. First, all the scenarios were simulated separately, and then these were combined.

2.3.1 Water use projections

Several parameters were taken into consideration, such as population growth rates, the number of inhabitants, water consumption per capita, and irrigation areas expansion. The population growth rate was based on the average of data obtained from the National Institute of Statistics and Census (INEC - https://www.ecuadorencifras.gob.ec/censo-de-poblacion-y-vivienda) of the last census processes. Agricultural demand was calculated by linear regression of the expansion of irrigation areas of the years 1999, 2001, and 2002.

2.3.2 Climate scenarios

The future climate scenario was obtained from a process of dynamical and statistical downscaling. The dynamical downscaling was developed in the Third National Communication on Climatic Change for Ecuador, developed by the Ministry of the Environment of Ecuador (MAE). The process was carried out with the selection of the sets of 15 global climate models (GCMs) of the Coupled Model Intercomparison Project, Phases 5 (CMIP&5). These models were subjected to a selection, taking as a criterion the proximity to the observed historical data of precipitation and temperature. This procedure resulted in 4 GCMs (IPSL-CM5A-MR, MIROC-ESM, GISS-E2-R, and CSIRO-Mk3-6-0) that are more related to the data observed for Ecuador. A dynamic downscaling process was developed for four GCMs by using the Weather Research and Forecasting model (regional climate model WRF version 3.6.1) reducing the scale to 10 km (Armenta et al. 2016). With the outputs of this process, an additional model (ENSAMBLE) was developed by combining the models using the reliability averaging method (REA) (Giorgi and Mearns 2002).

To downscale the regional climate model (RCM) outputs to a station scale, statistical transformations were used (Gudmundsson et al. 2012). This process was performed for observed data of precipitation and temperature for the Chanlud and El Labrado stations. The methodology consists of an empirical adjustment or bias correction of variables originating from RCMs simulations using quantile mapping with parametric transformations and nonparametric empirical quantiles (Table 1) (Boé et al. 2007; Piani et al. 2010; Dosio and Paruolo 2011; Gudmundsson et al. 2012). These transformations use the nomenclature of Po for observed data and Pm for historical data, and the variables a, b, and c are the parameters that are calculated based on the data used. The Quantile mapping fits a parametric transformation to the quantile-quantile relation of observed and modeled values and then uses the transformations to adjust the distribution of the modeled data to match the distribution of the observations. The Nonparametric quantile mapping using empirical quantiles estimates values of the empirical cumulative distribution function of observed and modeled time series for regularly spaced quantiles, then uses these estimates to perform quantile mapping. The Nonparametric quantile mapping using robust empirical quantiles estimates the values of the quantile-quantile relation of observed and modeled time series for regularly spaced quantiles using local linear least square regression, then performs quantile mapping by interpolating the empirical quantiles.

To determine the best transformation, we compared the observed and modeled data in the reference period (1979–2005) using metrical of goodness of fit such as root mean square error (RMSE) (Wilks 2011), Percent Bias (PBIAS) (Yapo et al. 1996), Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe 1970), coefficient of determination (Wilks 2011), and Kling-Gupta efficiency (KGE) (Gupta et al. 2009). This procedure was applied for precipitation and temperature of each meteorological stations and the outputs of the five RCMs. The best combination of RCMs and statistical transformations were applied to determine the precipitation and temperature projections of two scenarios: RCP 2.6 (very low radiative forcing level) and RCP 8.5 (very high radiative forcing level) (van Vuuren et al. 2011) for the periods 2011–2050.

2.3.3 LULC scenario

The creation of the LULC change scenario was carried out through a combination of Markov chains (MC) and cellular automata (CA) methods. The MC model is based on transition probabilities of the different LULC classes. However, MC cannot provide the spatial distribution of LULC change (Araya and Cabral 2010), which is provided by CA because it gives spatial modeling results, based on the defined transition rules from MC (White and Engelen 2000). CA-MC is a hybrid model, which is capable of modeling and controlling the spatially distributed process based on the transitions probabilities (Guan et al. 2011).

The MC model predicts LULC using the following equation:

$$L_{(t+1)} = P_{ij} * L_t \quad (1)$$

Table 1 Statistical transformations for the quantile mapping downscaling method

Name	Variants	Details
Quantile mapping using parametric transformations	PTFpower	$Po = b * Pm^c$
	PTFlinear	$Po = a + b * Pm$
	PTFexpasympt	$Po = (a + b * Pm) * (1 - \exp(-Pm/\tau))$
	PTFscale	$Po = b * Pm$
	PTFpower.x0	$Po = b * (Pm - x0)^c$
	PTFexpasympt.x0	$Po = (a + b * Pm) * (1 - \exp(-(Pm - x0)/\tau))$
Nonparametric quantile mapping using empirical quantiles	QUANTlinear	This use linear interpolation
	QUANTtricub	This uses monotonic tricubic spline interpolation
Nonparametric quantile mapping using robust empirical quantiles	RQUANTlinear	This use linear interpolation
	RQUANTlinear2	This uses linear interpolation, but for any value of x outside range, the transformation is extrapolated using the slope of the local linear least squares regression at the outer most points
	RQUANTtricub	This use monotonic tricubic spline interpolation

where L_t and $L_{(t+1)}$ are the LULC status at time t and $t+1$, respectively. P_{ij} is the matrix of the transition probability in a certain state. The probability transition matrix determines the probability that a pixel in a ground cover category will change to another one during the period analyzed (Subedi et al. 2013).

A CA is an object that can change its state based upon the application of a rule that relates the new state to its previous state and those of its neighbors, so space and state are discrete. A CA models execution depends on cells, neighborhood, and transition rules. Its basic expression is as follows:

$$S(t, t+1) = f(S(t), N)$$

where S is the state of discrete cellular, t is the actual time, $t+1$ is the future time, N is the cellular field, and f is the transition rule of cellular states in local space (White et al. 2000; Liu 2008).

The projection of LULC was made every 10 years, beginning in the decade 2011–2020 until the decade 2041–2050.

3 Results

3.1 Hydrologic model

Table 2 shows the results of the calibration and validation efficiency indices for the rivers Machángara Alto and Chulco. Figure 3 shows the observed and simulated streamflows in the calibration period.

The calibration process results could be considered very good (Pérez-Sánchez et al. 2017) because the indices Nash-Sutcliffe and Nash-ln are greater than 0.60. However, the Chulco river has better efficiency indices than the Machángara Alto river.

The validation process results indicated an improvement for the Chulco river and a slight reduction in efficiency for the Machángara Alto river; nevertheless, its indices could be considered acceptable.

3.2 Future scenarios

3.2.1 Water use projections

The future water demand for the urban sector was calculated with an annual population growth rate of 2.12 (the population by 2050 would be 811,332 inhabitants) and a rate of water consumption per capita of 220 l per person per day (assuming be constant in future periods).

The future agricultural demand was calculated taking into account the irrigated areas expansion (the irrigated areas by 2050 would be of 14,798 ha for the irrigation channel Machángara and 4111 ha for the irrigation channel La Dolorosa) and the annual water use rate of 3214 m3/ha year;

Table 2 Calibration and validation efficiency indices

River	Calibration		Validation	
	Nash Sutcliffe	Nash logarithm	Nash Sutcliffe	Nash logarithm
Machángara Alto	0.67	0.66	0.74	0.74
Chulco	0.9	0.89	0.88	0.86

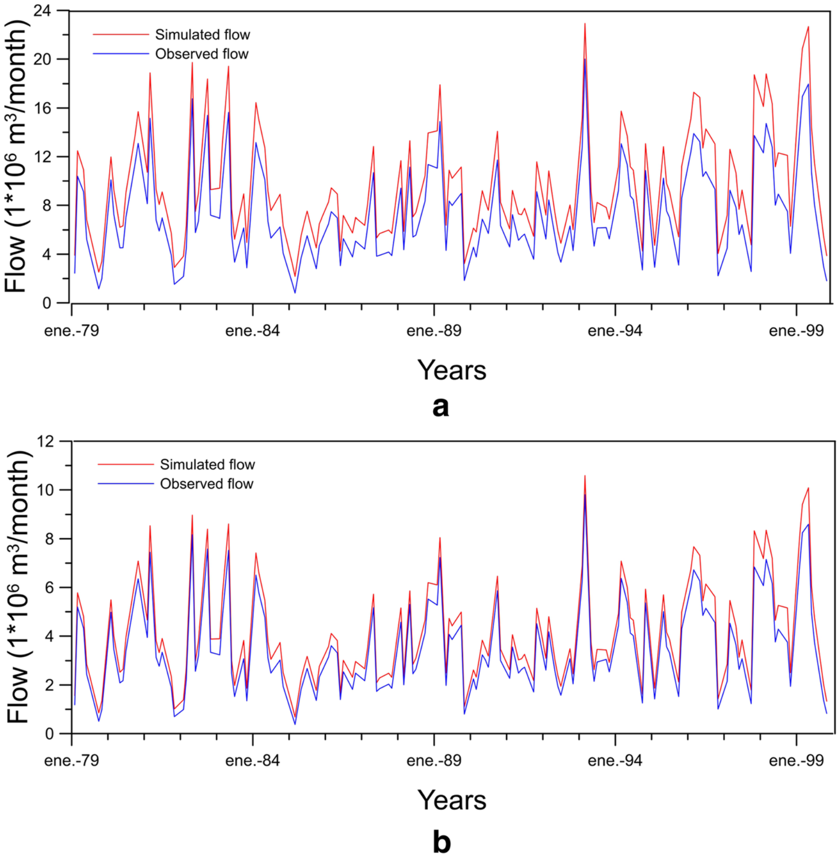

Fig. 3 Observed and simulated streamflows in calibration period of the rivers: **a** Machángara Alto; **b** Chulco

this last one was considered to be constant assuming that the amount of water needed to irrigate 1 ha of crop does not change over time and assuming that crop patterns will not change in the future.

3.2.2 Water balance in the base period

The base period was considered from January 1979 to December 2008. Table 3 shows the monthly average water balance (water supply versus water demand) in this period. It shows that the water supply overcomes the water demand in all months; however, the months of January, August, September, and October display a lower surplus.

3.2.3 Water balance in climate scenarios

The best combination (RCMs and statistical transformations) for Chanlud and El Labrado stations for the projection of the precipitation (2011–2050) was MIROC–PTFexpasympt, while that for the projection of the temperature (2011–2050) was ENSAMBLE-PTFscale. It is indisputable to deny the uncertainty due to the multiple outputs that we could get after downscaling processes of several climate models. However, we selected the combination of parameters that best fit when comparing the observed and historical, and we assumed that this relationship is maintained in the future. The affectation of the climate projections (for two scenarios RCP 4.5 and RCP 8.5) to the future inflows for the reservoirs of Chanlud and El Labrado was evaluated through changing inputs in the hydrologic model. The future changes in the water supply were compared with the water demand in future decades (the first period from 2011 to 2020, the second period 2021 to 2030, the third period from 2031 to 2040, and the fourth period from 2041 to 2050).

The scenario RCP 4.5 projects a rise of the average temperature in all future periods from 0.32 to 1.90 °C, highlighting the maximum increment in the fourth period of 1.90 °C in July. Concerning average precipitation, the scenario RCP 4.5 projects a rise in December, January, February, March, and April, and a decrease of average precipitation in May to

Table 3 Monthly average water balance for base period (%)

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Surplus (+)	36	108	309	426	296	209	113	22	45	49	99	105
Deficit (−)	-	-	-	-	-	-	-	-	-	-	-	-

November. Concerning the base period, February from the fourth period would have the highest rise (42%) and July the lowest decrease (41%). The projections of the scenario RCP 8.5 show a more intense increase of average temperature in all future periods from 0.69 to 2.28 °C, highlighting August with 2.28 °C of increment. The projections of average precipitation in scenario RCP 8.5 show similar behavior to the scenario RCP 4.5, with an increase in December, January, February, March, and April and a decrease in May to November. March would be the month with the highest increase of 44%, and September would have the highest decrease of 41%.

The increase in temperature and precipitation variation in the future periods would change the inflows of the reservoirs that affected water supply and consequently, the water balance. Figure 4 presents the average water volumes of surplus (water supply overcome water demand) and deficit (water demand overcome water supply for the scenarios RCP 4.5 and RCP 8.5). It shows the average water balance for each decade (four future periods) compared with the base period, where the surplus is considered as values greater than zero while the deficit is considered as values less than zero.

The scenarios RCP 4.5 and RCP 8.5 show similar behavior. January, August, September, October, and November would present deficits in some future periods in both scenarios. The deficits of January could be due to the increase in temperature that contributes to higher evapotranspiration, in addition to the increase in demand in the third and fourth future periods compared with the base period. These reasons added to rainfall decrease would also contribute to the existence of deficits in the third and fourth future periods of August, September, October, and November. The largest deficits would occur in January and August with 22% and 25%, respectively, in the future fourth period for the scenario RCP 8.5.

3.2.4 Water balance in LULC change scenario

LULC data of the basin upper part (Machángara Alto and Chulco rivers sub-basins) was classified in seven categories which are the following: water bodies, natural vegetation (native forest and timber forest), paramo, anthropic infrastructure, crops (permanent and semi-permanent), pasture (include herbaceous vegetation, legume and grass vegetation mosaic), and other lands (area without vegetation, stony degraded lands). Figure 5 shows LULC maps of the upper part of the basin (upstream of reservoirs of Chanlud and Labrado) for the years 1991, 2001, and 2010. In 2010, the paramo covered 87% of the area. The natural vegetation, pasture, and other lands cover less than 4% each, the water bodies covers less than 2%, and other types of LULC cover less than 1%.

The LULC change projections of the hybrid model CA-MC are presented in Table 4. A spatial representation of these changes can be seen in Fig. 6. The water bodies remain invariant in all future periods. Crops and anthropic infrastructure would have no change during the last three future periods. This feature is due to Chulco and Machángara Alto sub-basins being located at the highest part of the watershed where anthropic activities are not people's main activity.

Some LULC areas would have an increment in the future such as the pastures, natural vegetation (endemic and introduced species), and other lands. These changes could be due to an increase in livestock activities forest plantation of environmental organizations and forest fires, respectively.

On the other hand, the paramo areas would decrease in the future due to an increase in the area occupied by other categories mainly. Moreover, the spatial distribution of LULC forecast might respond to socioeconomic or biophysical factors that are beyond the scope of this study, but which would be interesting to incorporate in future researches.

The future LULC changes were integrated into the hydrologic model. These changes modified the inflows to the reservoirs, so the water balance was affected. Figure 7 shows the average water volumes of surplus and deficit for the LULC scenario.

January and August in the fourth period would give shortages of 11% and 8%, respectively. The remaining months would present surpluses in future periods; however, January in the third period would have the lowest surplus of 2%. September and November in the fourth period would also have a low surplus of 3% approximately. The deficits and low surplus could be due to some factors such as the decrease of paramo areas, which are considered natural regulators of water resources because of its high water retention capacity (reducing water availability in dry season); the increment of natural vegetation with trees with more water consumption and therefore an increase of evapotranspiration; and the increase of other lands (area without vegetation and degraded lands) and pastures, which may result in less water infiltration and as such a greater surface runoff that flows to the rivers.

3.2.5 Water balance in combined scenarios of climate change and LULC change

Figure 8 displays the average water volumes of surplus and deficit for combined scenarios of climate (RCP 4.5 and RCP 8.5) and LULC. We can observe that both combinations show similar behavior. The combination between future scenarios of climate and LULC showed that January, August, September, October, and November would have deficits in the last future periods. January in the future third period would have a low surplus of 0.5% and 2% for RCP 4.5, LULC, and RCP 8.5, LULC, respectively, but in the future fourth period January would present a deficit of 12% for both scenarios. August would have a deficit of 11% and 16% in the third and fourth future periods respectively for both scenarios. September in the future fourth period

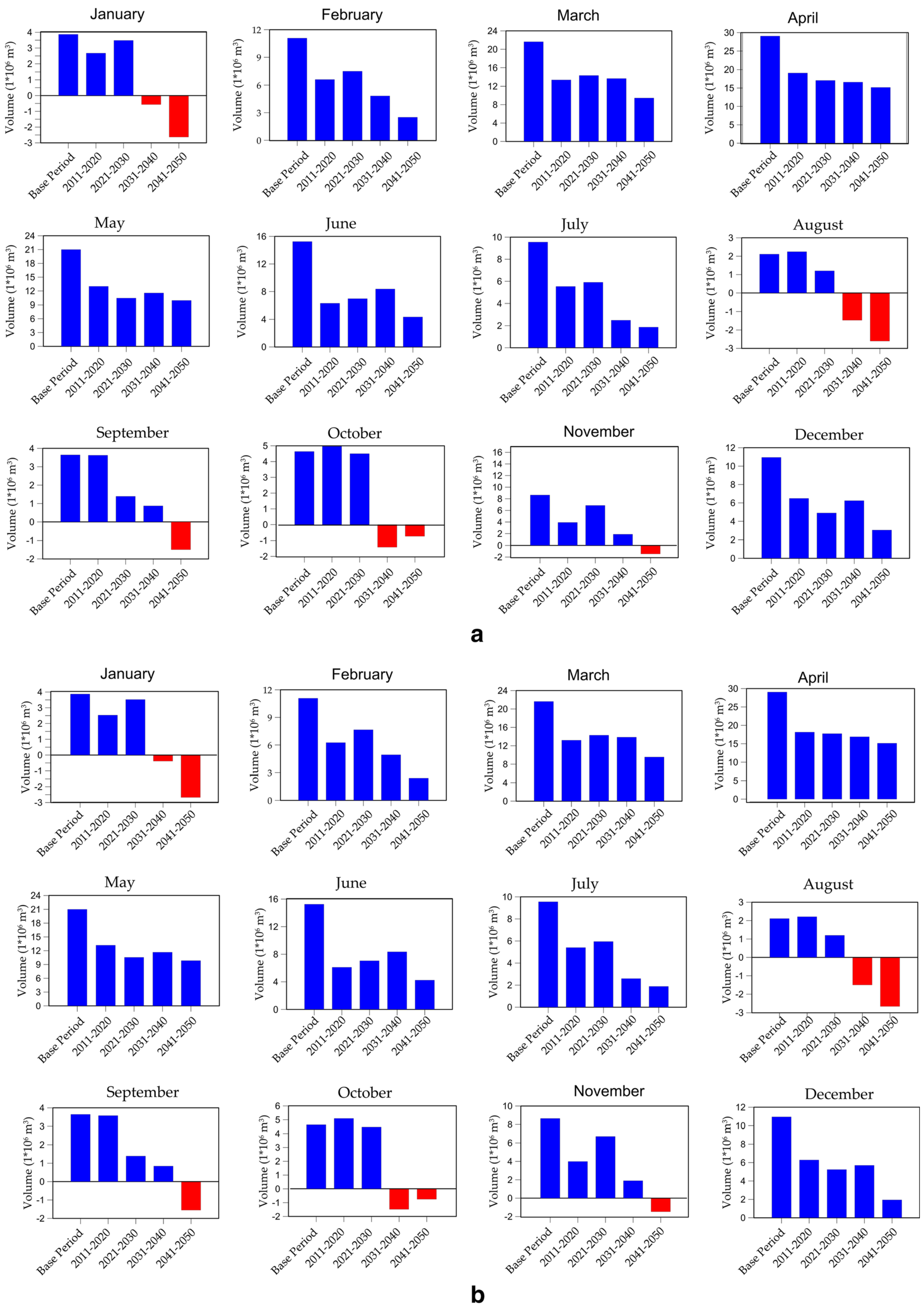

Fig. 4 Average water volumes of surplus (blue) and deficit (red) for the scenarios: **a** RCP 4.5; **b** RCP 8.5

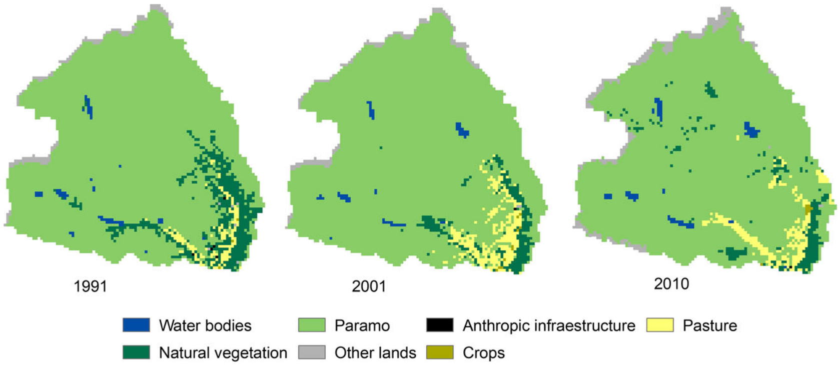

Fig. 5 LULC maps of the upper part of Machángara basin of 1991, 2001, and 2010

Table 4 LULC area (ha) projected from 2010 to 2050

LULC categories	2010	2020	2030	2040	2050
Water bodies	290.12	290.12	290.12	290.12	290.12
Natural vegetation	771.03	1580.96	1520.35	1611.27	1641.58
Paramo	17,296.37	14,921.88	15,012.80	14,921.88	14,891.58
Other lands	768.91	1835.54	1805.23	1865.85	1865.85
Anthropic infrastructure	1.26	3.94	3.94	3.94	3.94
Pasture	706.26	1168.79	1199.09	1138.48	1138.48
Crops	26.84	59.55	29.24	29.24	29.24

would have a deficit of 7% and 8% for RCP 4.5 – LULC and RCP 8.5 – LULC respectively. October in the future third period would have a deficit of 10% for both scenarios. Moreover, it would have a low surplus of 2% and 1% in the future fourth period for RCP 4.5 – LULC and RCP 8.5 – LULC respectively. In the future third period, November would have a deficit of 6% for both scenarios. This analysis shows that January and August would present the largest deficits in the last future periods, however the other months that would have deficits should also be taken into account for future water resources planning and management.

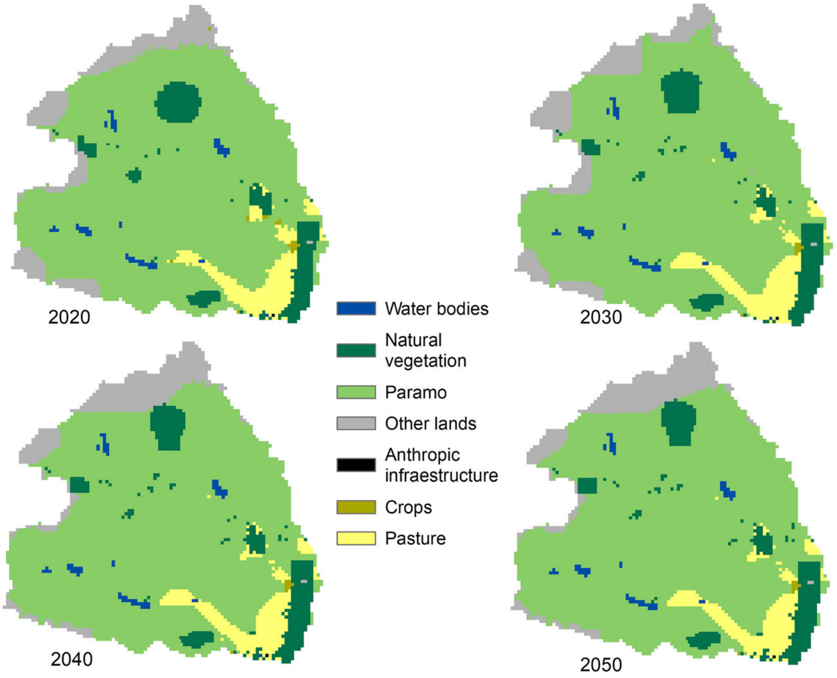

Fig. 6 LULC projections of the upper part of Machángara basin of 2020, 2030, 2040, and 2050

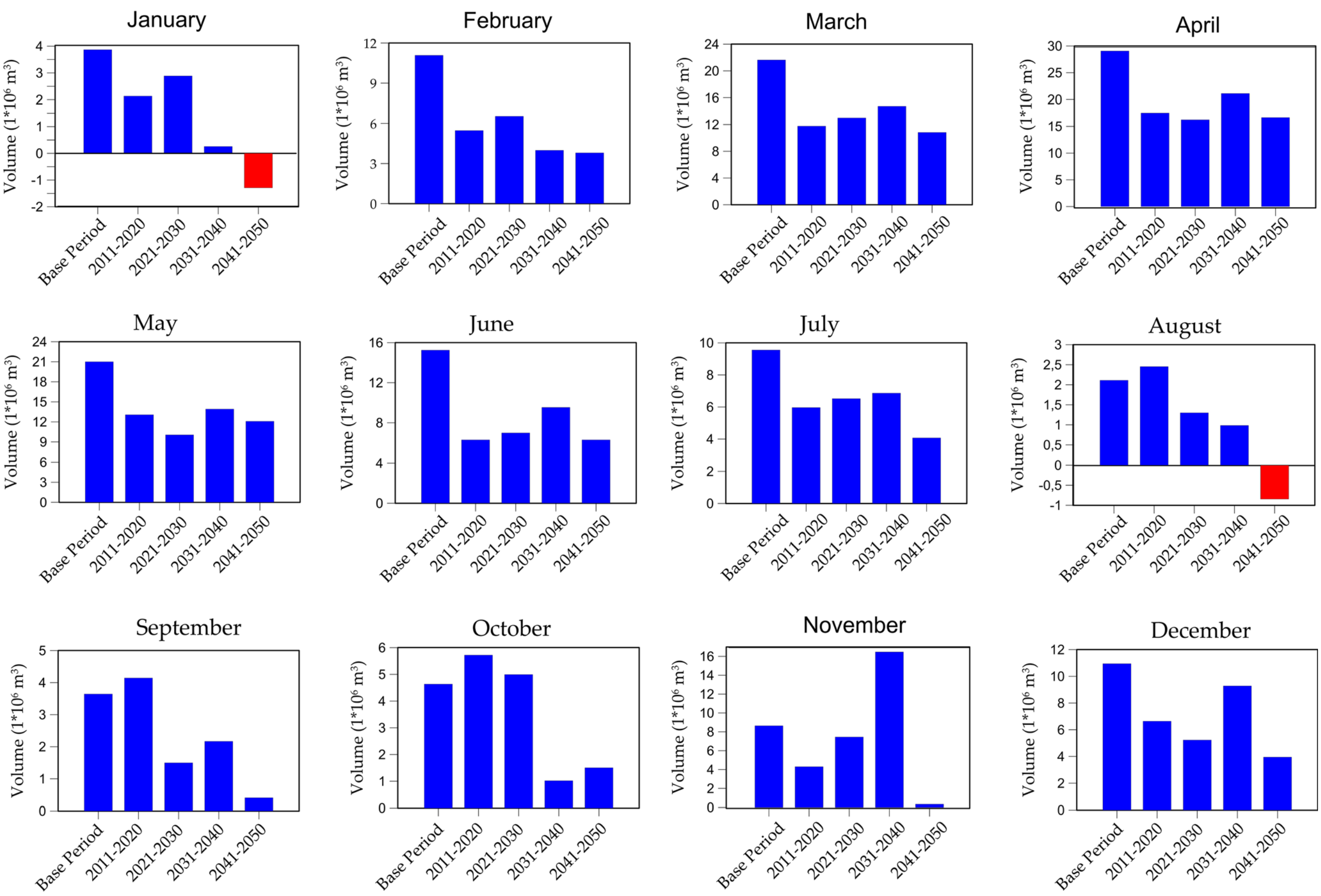

Fig. 7 Average water volumes of surplus (blue) and deficit (red) for the LULC scenario

4 Discussion

The results show that the water balance in the case study is much more sensitive to CC than to LULC change. This finding could be because the watershed upper part has not had an intensive change of LULC. These results agree with some studies such as Kim et al. (2013), who demonstrated that in a basin with more than 60% with mountainous terrain, LULC change had a smaller effect on streamflow compared with CC. Also, Pervez and Henebry (2015) determined that streamflow was more sensitive to changes in precipitation in a basin with almost half of area above 3500 m above sea level (m.a.s.l.).

Further Eum et al. (2016) found that the effect of CC on spring flow was higher than that of LULC change in a basin with significant upland areas.

The results of Tu (2009) also show that streamflow is more affected by CC than by LULC change in the eastern United States. In a Canadian basin, El-Khoury et al. (2015) also state that the CC will mainly drive the changes in streamflow. Shrestha et al. (2017) also indicated that CC has more severe impacts on the hydrology of Australian basins than LULC changes.

Besides, the effects of future changes on the hydrology and water resources of the Machángara river basin were compared with following similar mountain watersheds. Stehr et al. (2010) showed results related to this study. They stated that the replacement of agricultural areas, grassland, and shrubs with introduced forest plantations such as Pines and Eucalyptus in an Andean basin of Chile causes a reduction in the discharge. This study shows that the increase of natural vegetation with trees would roduce an increase of evapotranspiration, so reduce the discharge.

The results of another study conducted by Schwank et al. (2014) in an Argentine mountain basin showed that water availability could be reduced by 12% approximately due to an increase in temperature and a reduction of precipitation. Similar percentages were obtained in this study in months with an intense decrease of precipitation.

In an Ecuadorian basin, Espinosa and Rivera (2016) demonstrated that when paramo areas would reduce, this would affect the flow of rivers due to the loss of water retention capacity from the soil. The results of this study also showed that a decrease of paramo areas reduces water availability in dry seasons because of the loss of the paramo regulation capacity.

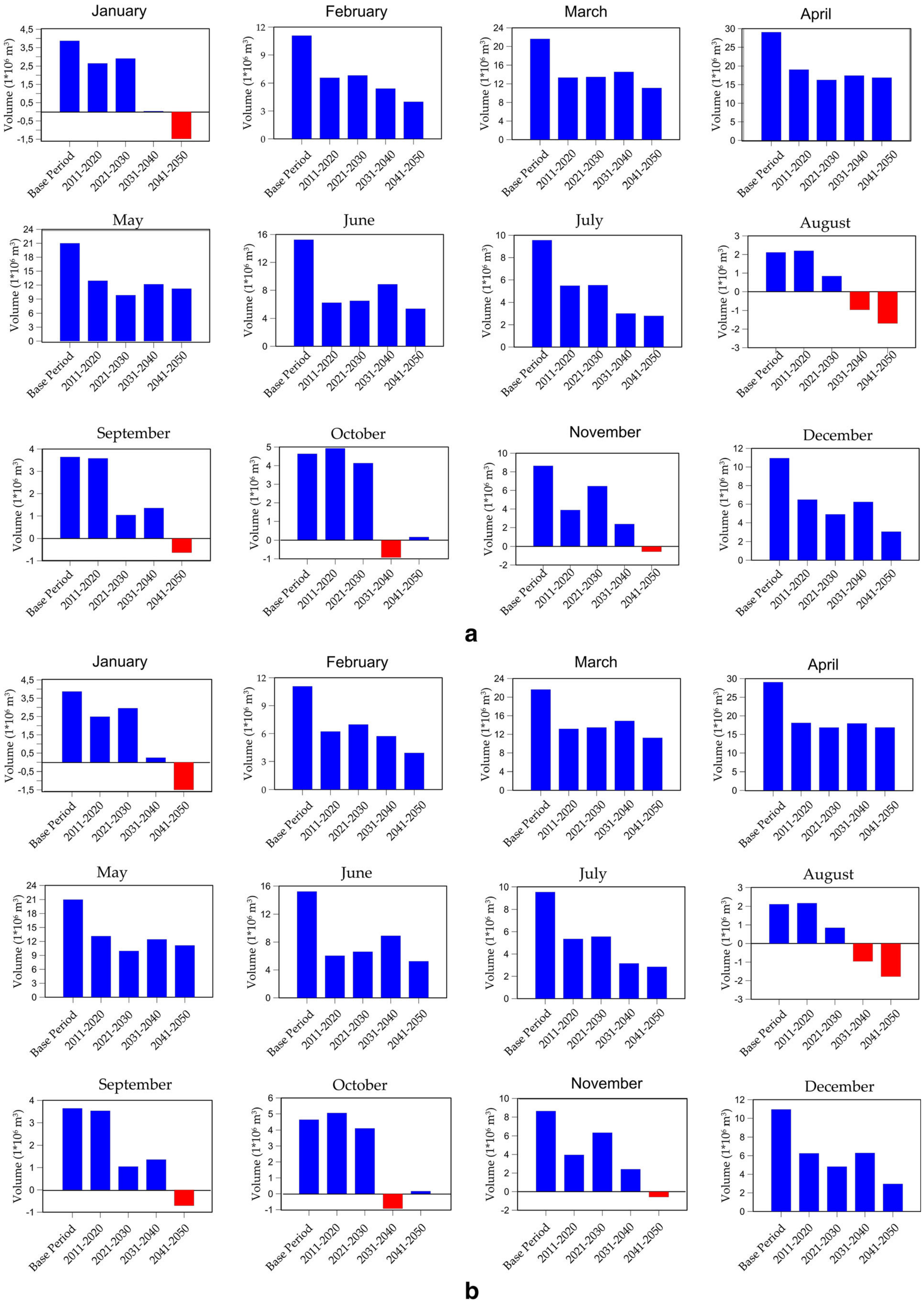

Fig. 8 Average water volumes of surplus (blue) and deficit (red) for combined scenarios: **a** RCP 4.5 and LULC; **b** RCP 8.5 and LULC

In an upper watershed of Chile, Vicuña et al. (2011) showed that in future times an increase in temperature of about 3–4 °C and a reduction in precipitation of 10–30% concerning the base scenario would occur. The climate variation would produce streamflow reduction and a decrease in water availability due to an increase of evapotranspiration and a decrease in rainfall. The positive tendency of temperature agrees with the results of this study; however, it does not agree with the precipitation variations because this study shows seasonal fluctuations with increases and decreases throughout the year.

5 Conclusions

This study developed a sensibility analysis of water balance concerning future changes of climate, land use, and water use. It explored the influence in future surplus and deficit of two CC scenarios, a LULC projection, a water use projection, and all these scenarios combined. Dynamic and statistical tools were used for precipitation and temperature projections. On the other hand, MC and CA methods were used for LULC changes projection. Water use projection was performed with statistical analysis. These future projections were incorporated in a water resources system model to evaluate the water balance until 2050. Applying water supply and demand data and applying the approach described above, the case study of the Machángara river basin was analyzed. Results revealed that the water balance is much more sensitive to CC than to LULC change. This finding is in agreement with some studies. January and August would present the largest deficits in the last future periods; however, other months would have deficits in the last future periods such as September, October, and November. There would be more future periods with surpluses than with deficits, but these few seasonal deficits would be more intense in the last future periods when taking into account the combined scenarios. This methodology could be applied to other similar watersheds, and its results could be useful for planners and policymakers of the Machángara river basin to develop measures to be prepared for any adaptation due to CC and as such formulate territorial planning for LULC management, with the aim of water sustainability in the future.

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Authors' contributions A.A. conceived the initial idea of the study, led the implementation of the methodological steps and drafted and finalized the manuscript. K.P. constructed hydrologic model, simulated the performed of water resources system and developed water use scenarios. J.P and O.D. contributed to the historical analysis of LULC and developed LULC scenarios. S.J. treated the climate models information and provided climate scenarios. D.Z. processed and analyzed the hidrometeorological data and contributed to Figures and Tables editing.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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