

Hydrological responses to climate and land use changes: The paradox of regional and local climate effect in the Pra River Basin of Ghana

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ARTICLE INFO

Keywords:

Climate change
InVEST model
Land use land cover change
Pra River Basin
Regional climate models
SDSM-DC
water yield

ABSTRACT

Study Region: Pra River Basin, Ghana.

Study Focus: The study modelled the changes in water yield using regional, sub-regional and local climate conditions from modelling outputs at spatial resolutions of 44 km, 12 km and 0.002 km respectively to drive the Integrated Valuation of Ecosystem Services and Trade-offs model at three time periods of land use land cover (LULC). Changes in historical water yield (simulated for 1986, 2002 & 2018 LULC using the mean climatic parameters from 1981-2010) and future scenario (simulated for 2018 LULC using the mean climatic parameters from 2020-2049) for annual, seasonal and monthly periods were assessed.

New Hydrological Insights for the Region: The results show that future annual water yield could change by -46%, -48%, +44% and -35% under the regional, sub-regional, local and ensemble mean of the climate scenarios respectively. Seasonal water yield from the ensemble mean of the future climate scenario was projected to decrease between 2-16 mm, with a mean decrease of 33.39% during the December–February season. There was no directional effect of spatial resolution on water yield. The future period could be impacted by both drought and flood. We recommend that re/afforestation should be encouraged to improve infiltration and reduce deforestation which was 2.27% per annum in the assessed period to prevent flood causing runoffs, while irrigation technology will help to improve resilience to drought.

1. Introduction

Sustainability of water resources has become a global debate in this era of climate change. Globally, accessible freshwater resources are less than 1% of the global water stock and its uneven spatial and temporal distribution, along with overexploitation of water resources for human activities, which often causes water scarcity (Savenije, 2000; Hoekstra and Mekonnen, 2011).

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<https://doi.org/10.1016/j.ejrh.2019.100654>

Received 7 August 2019; Received in revised form 3 December 2019; Accepted 3 December 2019

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Anthropogenic degradation of watersheds is one of the main direct causes of freshwater scarcity (Murphy and Kapelle, 2014). Water sustainability depends on ecosystem structure and function in a watershed, and a current challenge due to unplanned use resulting from population and economic growth, changes in land use and global dynamics. It is further threatened by climate change at the global, regional and local scale (Enanga et al., 2011; Boon and Ahenkan, 2012; Bangash et al., 2013; Niang et al., 2014; IPCC, 2014; World Bank Group, 2016).

The negative consequences associated with this situation are amplified during the dry season when water resources can usually be insufficient to meet both human and riverine ecosystem needs (Jujnovsky et al., 2010). About 48% of the world's population in 2025 is projected to live in basins that are water-stressed (Bangash et al., 2013). A rising world population is forecast to be 9.7 billion people by 2050, and sub-Saharan Africa which is projected to double by that period could subsequently cause major changes in lifestyle especially in terms of spending and food choices (UN DESA, 2019). Water will be a major resource required to increase food production (approximately 70%) to meet global food needs in 2050 (Steduto et al., 2012).

A potential constraint to food production is the threat of water scarcity (Steduto et al., 2012; Davis et al., 2015). The Intergovernmental Panel on Climate Change (IPCC, 2007) projected 10 – 30% reduction in water availability by 2050 over some dry regions at mid-latitudes and in the dry tropics. This is particularly concerning as some of these locations are currently water-stressed. In Ethiopia, climate change accounted for 70% changes in water resources in comparison with land use change (Abera et al., 2019). Floods and droughts are the notable extreme impacts of climate change, evidenced mostly in Sub-Saharan Africa, causing significant economic losses due to the low resilience capacity of the region resulting from high poverty and political instability (UNEP, 2002; Bo et al., 2004; FAO, 2009; Davis et al., 2015).

Research conducted by the Water Footprint Network (2018) showed that Ghana annually faces blue water (amount of surface or ground water used for the production of a good or service) scarcity during the dry seasons (November – February). Studies show that climate change is expected to further worsen this situation as it may result in erratic rainfall in the tropics which would alter the trend of runoff and river flows (Milly et al., 2005; IPCC, 2007; López-Moreno et al., 2011). The trend of change in water availability is inconsistent in Ghana under different climate models (Kasei, 2009; Obuobie et al., 2012; Nutsukpo et al., 2013; Amisigo et al., 2015). The Pra River Basin, the leading tuber crop production zone of Ghana and a major producer of cocoa (an economic crop in Ghana) has been found to be water-stressed, and projected to undergo water scarcity (681 m³ per capita per year) and absolute scarcity (306 m³ per capita per year) in 2020 and 2050 respectively (Obuobie et al., 2012). These findings, as well as regional and global projections of climate change, could negatively impact on food security and the economy of Ghana. This situation would be critical for the inhabitants of Ghana's Pra River Basin who depend majorly on agriculture for their livelihood and are already facing challenges due to unsustainable management of its watersheds because of intensified human activities (WRC, 2012; Murphy and Kapelle, 2014; Duncan et al., 2019). Amisigo et al. (2015) projected both positive and negative change in runoff in the Pra River Basin for the period 2011 – 2050, whereas Obuobie et al. (2012) projected only negative change for streamflow in the same basin from 2006 - 2065. According to Awotwi et al. (2019) settlement and mining land use classes showed a strong positive correlation with water yield while cropland showed a weak correlation. Therefore, land use expansion into forest reduces the service of vegetation in regulating the amount of water yield. The Pra River Basin is one of the most extensively and intensively used river basins in Ghana in terms of settlements, agriculture, logging and mining, particularly because of its valuable tree species, mineral ore deposits and suitable environment for farming. Therefore, the wide variations in water availability due to climate and anthropogenic activities may have severe local impacts and, hence, further assessment with high-resolution models and a combination of varied resolutions models is needed.

Moreover, quantifying the distribution of water resources at the basin level under both climate and land use change scenarios can help identify vulnerable locations for adequate adaptation planning and implementation. The current challenges in such assessment are the high data requirement, pre-processing of data, and time and training efforts required by traditional hydrological models in achieving the desired goals with broader spatial representation of results to support decision-making process (Vogl et al., 2016; Luke and Hack, 2018).

Furthermore, models that can support hydrological ecosystem service (HES) decisions should be conceptualized to account for changes in land use at the parcel-level (Guswa et al., 2014) which is not adequately represented in traditional hydrological models. Adopting the Integrated Valuation of Ecosystem Service and Trade-offs (InVEST) model, with its minimal application efforts and data requirements, makes it suitable and capable of serving areas with scarce data like Sub-Saharan Africa and the Pra River Basin in particular (Volk, 2014; Ibrahim et al., 2015; Komi et al., 2017). The spatially explicit nature and quick scenario generation of large geographical areas using InVEST could facilitate the decision-making process, protect degrading water resources by highlighting hotspots that would require urgent land management interventions and improve monitoring of hydrological ecosystem services in the long-term at reduced cost (Dimobe et al., 2015; Vogl et al., 2016; Luke and Hack, 2018; Sharp et al., 2018). These strengths make the tool attractive to use as opposed to some of the complex hydrological models such as SWAT (Soil and Water Assessment Tool), FIESTA (Fog Interception for the Enhancement of Streamflow in Tropical Areas) and ARIES (Artificial Intelligence for Ecosystem Services). According to Ochoa and Urbina-Cardona (2017) InVEST was among the most commonly used tools implemented for spatial modelling of HES.

The aim of this study was to therefore assess the variations in the impacts of future regional and local climate simulations and land use change on water yields using a hydrological ecosystem service tool in order to inform water resources management policies in the Pra River Basin of Ghana. The following questions were investigated:

- What was the change in annual water yield based on 1986, 2002 and 2018 LULC?
- What is the expected degree of change in annual water yield under regional and local climate scale scenarios for the future period (2020 – 2049)?

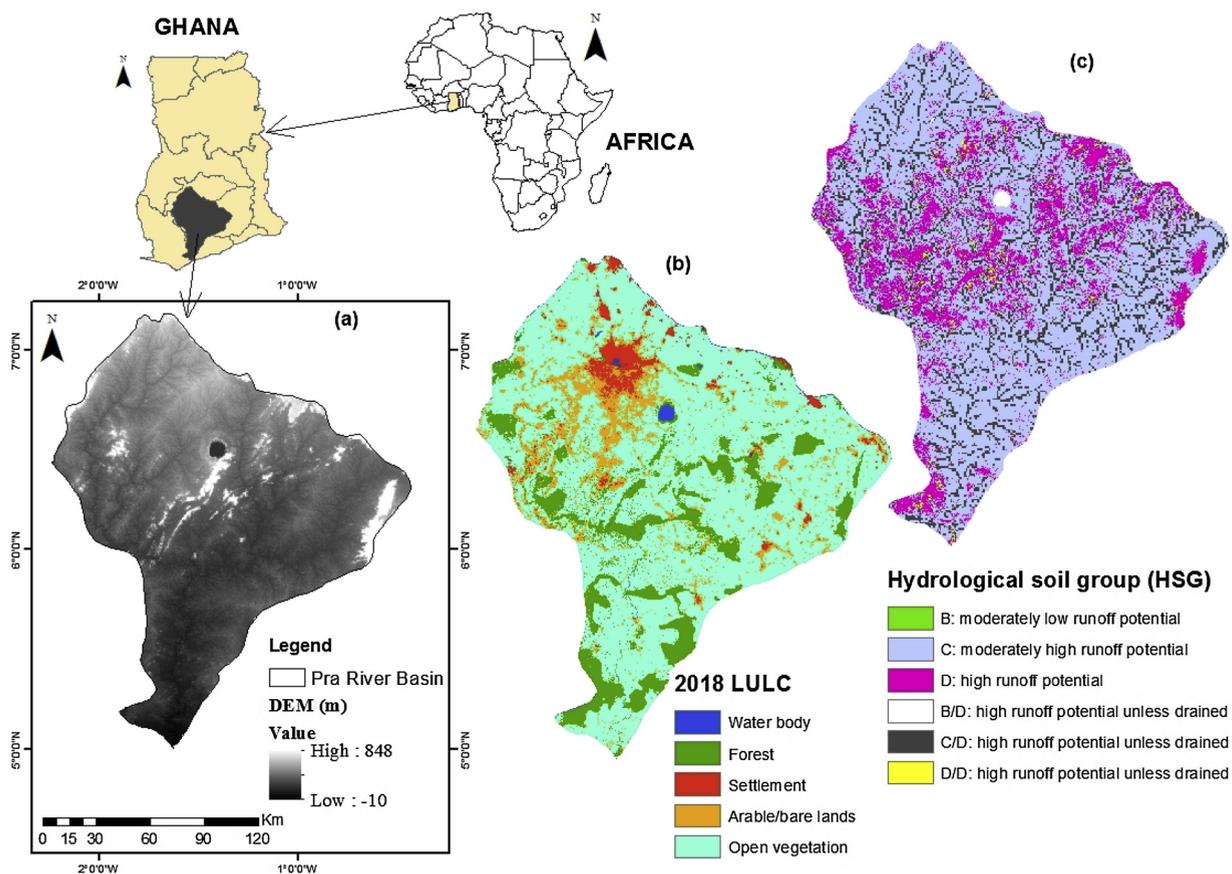


Fig. 1. Map of Pra River Basin showing (a) digital elevation model (DEM) (b) land use land cover (LULC) of 2018 and (c) hydrological soil group. [Source: Produced/prepared by the author(s) with data from (A) NASA earthdata (B) Landsat 8 satellite image and (C) Soilgrids (Hengl et al., 2017)] (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

- What could be the future variations in seasonal water yield in the basin?

2. Materials and methods

2.1. Study location

The Pra River Basin has the highest density of settlements (with over 1300 towns) in Ghana and covers an area of 23,330.70 km², between latitudes 4°58' N and 7°11' N and longitudes 0°25' W and 2°13' W (WRC, 2012). The Pra River Basin is underlain majorly by soil with moderately high runoff potential (Ross et al., 2018) and lies at an elevation range between -10 m and 848 m (Fig. 1a). This makes the low areas of the basin vulnerable to water disasters during extremes rainfall events. The mean annual values of rainfall, minimum and maximum temperatures for the period 1981 – 2010 were 1446 mm, 21.74 °C and 31.6 °C, respectively (Bessah et al., 2018; 2019). The climatic conditions in the basin promote rapid vegetative growth and are conducive for farming (Fig. 1b), especially during the rainy seasons. Furthermore, both large and small-scale mining activities take place in the basin, thereby, creating some intense land use change dynamics. This has resulted in land use competition between farmers and miners especially cocoa farmers and small-scale illegal miners (locally known as *galamsey*) (Dickson and Benneh, 1995; CONIWAS, 2011; Kusimi et al., 2015).

Moreover, water demand for activities in the basin is critical since a population from about 1300 towns in 41 districts in Ghana depends on the basin for their water supply, that is, an estimated population of 5.9 million people in the basin based on a growth rate of 2.2% according to the 2000 census (WRC, 2012; Kusimi et al., 2015). Findings from the IPCC Fifth Assessment Report's 43 global circulation models (GCMs) projected temperature to increase in the range of 1.2 °C – 5.1 °C and rainfall to decrease in the range of 0.88 – 1.66% in the 21st century in the Pra River Basin (IPCC, 2014; Bessah et al., 2018; 2019). However, GCMs at coarse spatial resolution does not provide some of the vital components of the regional and local climate which contribute maximally to the changes observed at a basin level (Wilby and Wigley, 1997; Wilby et al., 2014). This implies that higher spatial resolution climate models (either single or combined) are needed to assess the changes in climate and its impact on water resources to guide the planning of appropriate adaptation measures for the basin's inhabitants.

2.2. Hydrological ecosystem service modelling using InVEST

The HES modelled in this study was water yield which falls under the provisional category of HES. The InVEST seasonal water yield model provides guidance regarding the contribution of land parcels to the generation of both baseflow and quick flow. The baseflow is defined as the generation of streamflow with watershed residence times of months to years, while quick flow represents the generation of streamflow with watershed residence times of hours to days (Sharp et al., 2018). The model computes spatial indices that quantify the relative contribution of a parcel of land to the generation of both baseflow and quick flow. The first approach of the model emphasises the land-use and land-cover (LULC) of a site since the focus is on net generation from the pixel or parcel of land while the second approach represents the actual streamflow generated by a pixel. Since actual streamflow cannot be less than zero, this approach, unlike the first, result in indices that are greater than or equal to zero. The current version of InVEST seasonal water yield model used in this study does not estimate quantitative baseflow but only the relative contributions per pixels. This is a limitation that developers are working on to address in a separate tool in the next version of the InVEST model (Sharp et al., 2018). It is worth stating that the water yield from the InVEST model provides averages and not the extremes, and neglects the interactions between groundwater (surface and deep) in its estimations.

The model was set up by pre-processing the datasets into the same pixel size in a GIS environment before using them in the InVEST model. A combination of raster, vector and CSV data are required with specific naming guidelines for data files. The data used as inputs to the model are presented in Table S1 in the supplementary material. All raster datasets were resampled to a 30 m spatial resolution in ArcGIS 10.3. The resampling was done to maintain consistency with the resolution of the LULC and DEM. Furthermore, raster input datasets of InVEST model are required to have the same spatial resolution. LULC maps of 1986, 2002 and 2018 generated from Landsat images for the study area were used (Fig. S1 in the supplementary material). The random forest algorithm for supervised classification was employed in R software in combination with QGIS for the LULC maps generation and change detection analysis. The InVEST model was not tested for readjustment due to the lack of observed water yield records in the study area. From the land use analysis, forest and open vegetation were reported to approximately decrease by 20% and 3% between 1986 and 2002, while from 2002 - 2018 there was an approximate decrease of 36% and 1% respectively. Settlement and arable/bare lands increased in both periods (1986 - 2002 and 2002 - 2018), water bodies (including all open water such as lakes, rivers and temporarily stored surface water) increased by about 300% in the first period and decreased by 75% in the second period (Figure S1). The West African drought in 1983 was a major reason for the reduced water quantity in the 1986 LULC (Greene et al., 2009). After the drought, the basin recorded an increasing trend in rainfall amount which contributed to the increase in water bodies between 1986 and 2002 (Bessah et al., 2019). On the other hand, galamsey caused the decline in water bodies in the second interval through water diversion to galamsey sites and degradation of water quality to a mud-like water body (Awotwi et al., 2019). The results further showed a continuous decline in natural vegetation at the expense of land use for agriculture and settlement. The biophysical table containing the curve number (CN) was estimated from the Washington State Department of Transportation (WSDOT) highway runoff manual (WSDOT, 2014) and hydrologic soil-cover complexes prepared by Natural Resources Conservation Service and Agricultural Research Service (NRCS, 2017). The monthly crop factor or plant evapotranspiration coefficient (K_c) was sourced from Sharp et al. (2018). Both adopted curve number and crop factor are presented in Table 1.

2.3. Climate input data

Observed climate records from 1981 - 2010 were acquired from the Ghana Meteorological Agency and the simulated future climate scenarios were for the period 2020 - 2049. The regional climate scenario was obtained from the Coordinated Regional Climate Downscaling Experiment (CORDEX). The mean output of the second generation Canadian Earth System Model (CanESM2) by the Canadian Centre for Climate Modeling and Analysis (CCCma), [CCCma-CanESM2] and the mid-resolution model of Institut Pierre Simon Laplace (IPSL), [IPSL-CM5A-MR] at 44 km spatial resolution covering Africa were used. The sub-regional climate scenario was obtained from the Weather Research and Forecasting (WRF) model. The mean output of the General Fluid Dynamics Laboratory's Earth System Model (GFDL-ESM2M) and the Hadley Centre's Global Environment Model (HadGEM2-ES) at 12 km covering West Africa were used (see Table S2 in the supplementary material). The local climate scenario was simulated from a statistical downscaling model (SDSM-DC) at 0.002 km spatial resolution. The ensemble mean of the five models was computed and hereinafter referred to as Ensemble mean and/or Ensemble. Different climate models at varying spatial resolution were used because they have

Table 1
Estimated curve number (CN) and monthly mean crop factor (K_c).

Description	CN_A	CN_B	CN_C	CN_D	K_c
Water	0	100	100	100	1
Forest	0	50	60	65	1
Settlement	0	75	83	86	0.3
Arable/Bare lands	0	68	76	80	0.56
Open vegetation	0	65	77	82	0.74

Note: A, B, C and D are soil hydrological groups (SHG). SHG_A: Low runoff potential; SHG_B: Moderately low runoff potential; SHG_C: Moderately high runoff potential and SHG_D: High runoff potential.

[source: WSDOT, 2014; NRCS, 2017; Sharp et al., 2018].

Table 2
Rainfall events for the observed records and future climate simulations.

Month	Observed	CORDEX-RCA4	WRF	SDSM	Ensemble
January	2	1	4	2	2
February	4	2	6	4	4
March	8	11	16	8	12
April	9	16	24	9	18
May	11	21	25	10	20
June	13	23	23	12	20
July	10	23	21	10	19
August	9	18	18	9	16
September	11	20	21	11	18
October	13	13	25	12	17
November	7	4	17	7	10
December	3	1	7	3	4

Rain event is defined as the number of days in a month with rainfall amounts > 0.1 mm.

different capacity in mimicking local climate. Furthermore, it was done to determine the hydrological response to climate simulations from varying spatial resolution and enhance future projections via the ensembling of the different climate models in this study. The performance of the models in simulating the observed rainfall and temperature were evaluated and those with unacceptable time-series-based-metrics results (Nash–Sutcliffe efficiency, root mean square error and coefficient of determination) were bias-corrected. Details about these climate models and their bias-correction methods (variance scaling method was used for temperature, while linear scaling plus double quantile mapping were used for rainfall) are provided in Bessah et al. (2018); (2019). Therefore, CORDEX-RCA4, WRF and SDSM-DC hereinafter shall be referred to as regional, sub-regional and local climate conditions respectively and interchangeably. The climate models were run under the IPCC's RCP 4.5 emission scenario (Vuuren et al., 2011; IPCC, 2014).

Rain events were the lowest in January for both the observed and the future period from the climate models, whereas the highest rain events varied in months amongst the models (Table 2). The month of June had the highest rain event for the observed, SDSM and CORDEX-RCA4, while May was the highest for WRF model.

The Penman-Monteith evapotranspiration method in Instat v3.36 was used to calculate the reference evapotranspiration (ET₀) (Tables S3–S9 in supplementary material). Average insolation incident on a horizontal surface (MJ m⁻²/day), relative humidity at 2 m above sea level (%), wind speed at 10 m above the surface of the earth (m/s) records, from 1983 – 2010 (1981 – 1982 were missing data) were acquired from NASA Power database (NASA POWER, 2018) to calculate ET₀ with observed mean temperature for the historical period. Wind speed was converted to 2 m above earth surface with a factor of 1.33. Due to the lack of observed insolation, relative humidity (RH) and wind speed data, a five-year record (2012 – 2017) of the acquired three parameters from NASA Power database were replicated six times to cover 30 years and used with the mean temperature of the models from 2020 – 2049 to estimate the future ET₀. We assumed insolation, RH and wind speed for the future period to follow the same cycle every 5 years for a 30-year period, as no modelled records of future variations in these variables were available. This was because the available data after 2010 for a convenient replication was from 2012 – 2017. Secondly, it was done to control the errors or uncertainties in using unverified remotely sensed climate data to bias-correct model simulations.

All maps of monthly precipitation (records presented in tables of the supplementary material) and reference evapotranspiration were created using ordinary kriging interpolation in ArcGIS 10.3. This approach minimises interpolation errors during predictions by the use of semi-variogram models (Isaaks and Srivastava, 1989; Oliver and Webster, 1990). The spherical semivariogram model was based on Eq. 1 (Bohling, 2005):

$$g(h) = \begin{cases} c \cdot \left(1.5 \left(\frac{h}{a} \right) - 0.5 \left(\frac{h}{a} \right)^3 \right) & \text{if } h \leq a \\ c & \text{otherwise} \end{cases} \quad (1)$$

Where h = lag distance, a = range (practical), and c = sill

2.4. Data analysis and presentation

Water yield responses to LULC change were assessed with observed climate data based on LULC maps of 1986, 2002 and 2018, while the impact of climate change was assessed under the regional, sub-regional and local climate scale simulations using LULC map of 2018. The impact of both LULC and climate change was determined between the observed and future yield using climate models. To determine the LULC change impact on water yield, the LULC of 1986, 2002 and 2018 were simulated in combination with the mean climate of the historical period from 1981 to 2010 and pixel-based variation in yield determined for comparison of land use management impact. For the second part of the analyses on the impact of climate change on water yield, historical observed climate (1981 – 2010) and future climate simulations (CORDEX-RCA4, WRF and SDSM) from 2020 – 2049 were simulated in combination with the LULC of 2018 and the output compared. The difference in yield under climate change was calculated by pixel subtraction of historical yield from the three future simulations outputs.

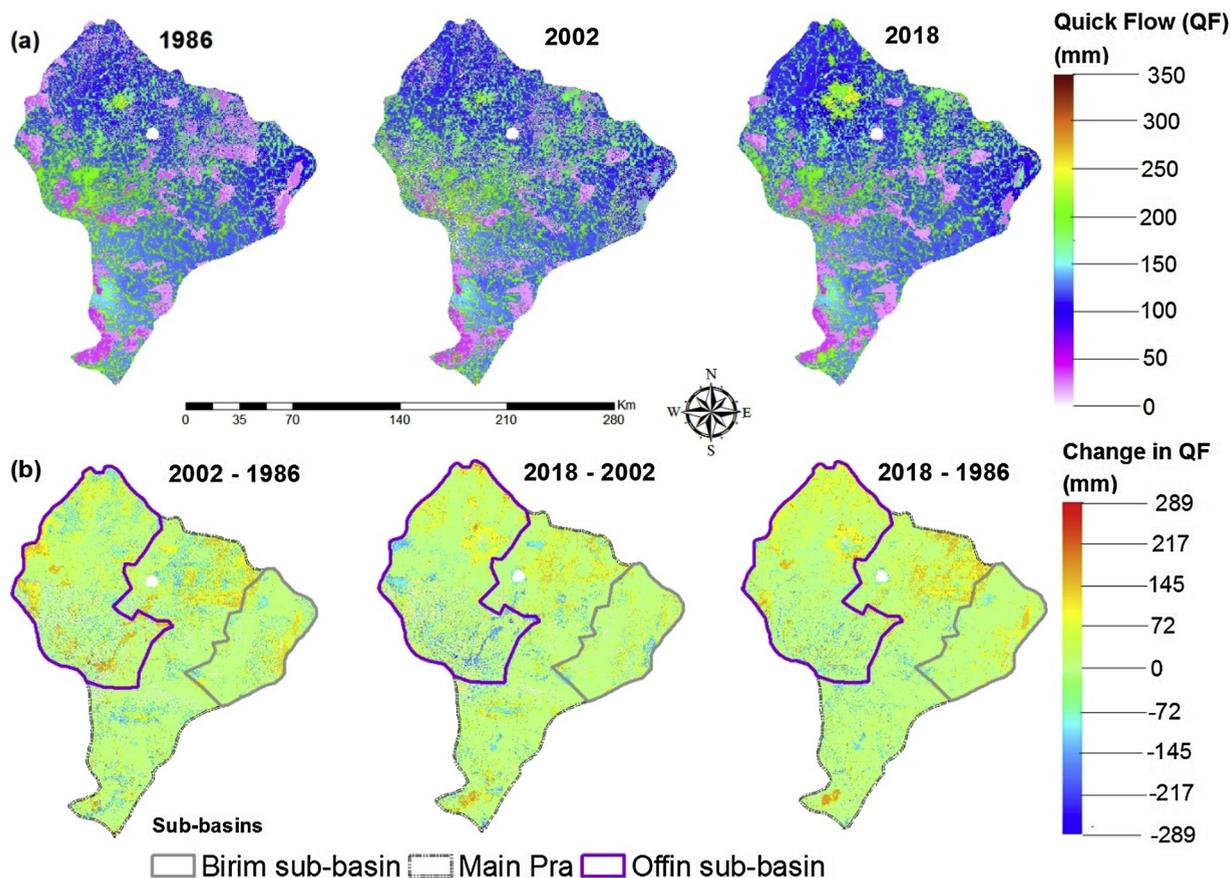


Fig. 2. (a) Historical mean annual water yield and (b) change in yield under LULC change. The simulation was done with the combination of LULC maps of 1986, 2002 and 2018 and the mean observed historical climate from 1981 – 2010.

3. Results

3.1. Water yield from the observed climate period under different LULC

The mean annual water yield for the observed climate period (1981 – 2010) for the years 1986, 2002 and 2018 were very similar in the range of 0 - 336 mm, 0 - 334 mm and 0 - 336 mm respectively (Fig. 2a). This implies that mean annual yield in a land parcel or pixel was directly proportional to climate conditions (especially rainfall). However, the expansion of arable/bare lands and settlement from 1986 - 2018 showed that wide locations of the basin under these two classes had water yield between 100 mm – 200 mm per year. The yield was highest in the settlement land use class and least under forest. Settlement yielded water between 200 mm – 240 mm averagely, while that of forest was less than 40 mm and open vegetation was between 41 – 160 mm (Fig. 2a). Mean annual water yield for each land class over the three LULC periods was not different in depth (mm). This could be due to the fact that yield was assessed under the same climatic condition. The spatial distribution of water yield was according to the locations of land use classes in the assessed years. The 2 mm water yield difference between 2002 and the other two years (1986 and 2018 had the same monthly mean water yield values) was due to the monthly variations in January, March, May, June and July at 0.04, 0.53, 0.21, 0.43 and 0.15 mm respectively (details presented in Figure S2 – S4 in the supplementary material). The difference determined from the highest mean values under land use change was due to the extreme spatial changes in water yield between -287.45 mm and 288.9 mm (Fig. 2b). Land use change between 1986 and 2002 showed more distribution of decreased yield in the Pra main sub-basin in the range of 200 – 288 mm and a concentrated increase of yield in the north of the same sub-basin at an average of 145 mm (Fig. 2b). Generally, Pra main and Offin sub-basins showed the highest distribution of increase (> 140 mm) and decrease (> 200 mm) in the first interval (1986 – 2002) of land use change. Birim sub-basin also experienced an increase in yield at the east end which could have contributed to the flooding of the Birim river during this period (Fig. 2b). In the second interval (2002 – 2018), Offin sub-basin showed the highest decrease in water yield. However, the northern part of the Pra River Basin and a small portion of the south showed an increase in water yield (Fig. 2b). The land use change between 1986 and 2018 spatially showed a smaller decrease in water yield distribution compared to 1986 – 2002 and 2002 – 2018 change. Furthermore, there was a dominant increased distribution in the north and east end of the basin (Fig. 2b). Although InVEST model was limited in accounting for baseflow, LULC change significantly influenced the distribution of water yield (extreme increase and decrease) across the basin.

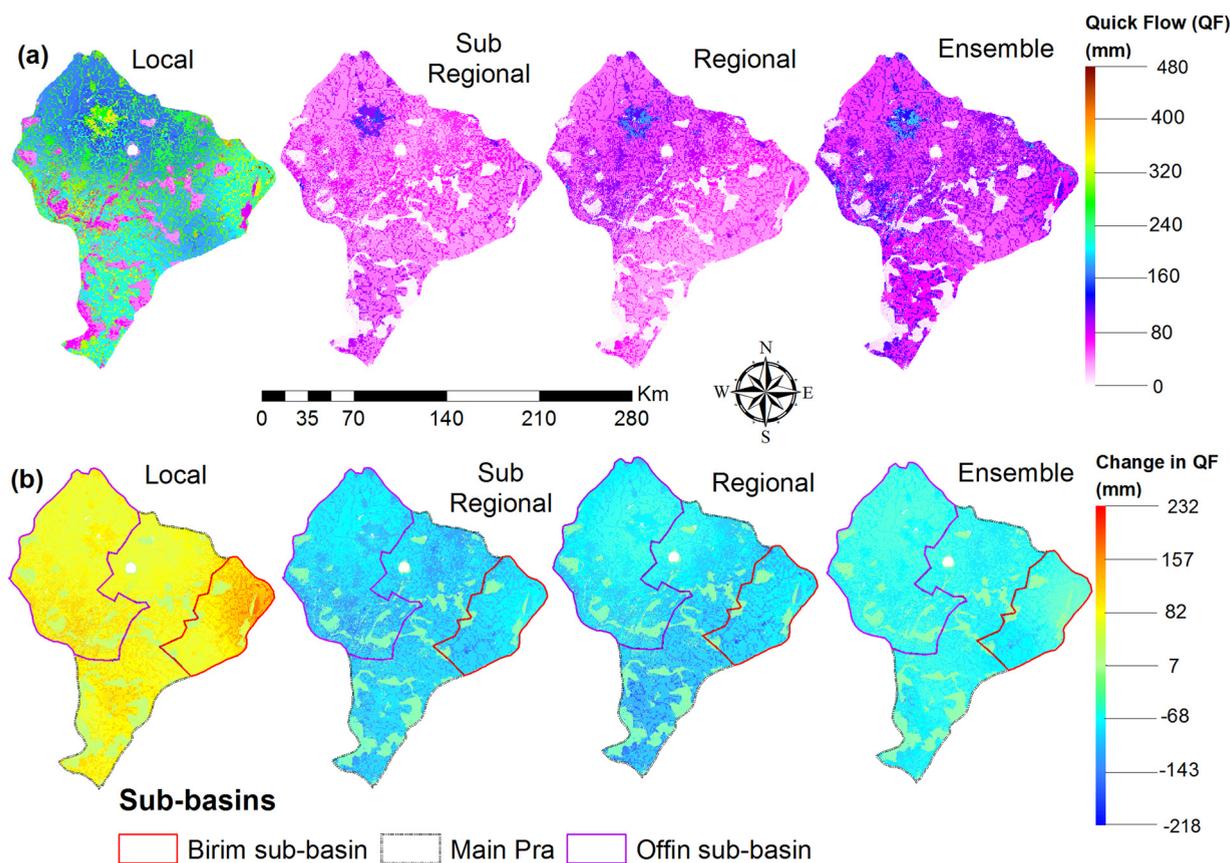


Fig. 3. (a) Future mean annual water yield and (b) change in yield in reference to 2018 simulated yield under mean observed historical climate from 1981 – 2010. The simulation was conducted using the combination of future climate (2020 – 2049) simulations from SDSM (local), WRF (Sub-Regional), CORDEX-RCA4 (Regional) and Ensemble mean of the models and the LULC of 2018.

3.2. Future changes in annual water yield

Water yield was projected to decrease by 46%, 48% and 35% under the regional, sub-regional and ensemble mean climate conditions respectively and to increase by 44% under the local climate conditions (Fig. 3a). The widest coverage of yield for the regional, sub-regional and ensemble mean conditions was at an average of 80 mm, whereas that of the local was about 180 mm (Fig. 3a). The regional climate condition showed a general decreasing pattern of water yield from the north towards the south-east of the Pra River Basin. The Ensemble of the climate models showed a yield that unified the extreme spatial increase and decrease across the basin. The regional and sub-regional climate scenarios generally showed only a decreasing change in yield over the basin, while the Ensemble showed that some locations are expected not to experience any change in water yield, that is, 0 mm change in yield (Fig. 3b). Spatially, regional and sub-regional climate scenarios showed a decrease in the range of 7 – 218 mm and 13 – 179 mm respectively (Fig. 3b). In contrast, the sub-regional simulation showed an even distribution of significant decrease across the basin in the range of 70 – 150 mm, while the regional on the other hand showed a less decrease in the northern part of the basin, especially in the Offin sub-basin in the range of 20 – 70 mm (Fig. 3b). The local climate scenario showed a decrease in water yield in few locations majorly in the Pra main sub-basin and the highest increase in yield in the Birim sub-basin at the east end of the basin (Fig. 3b). The change in water yield under the local climate ranged between –18 mm and +232 mm. Therefore, the 44% increase in yield under the local climate scenario does not cover the whole basin although the majority of the places, especially the Birim and Offin sub-basins, would benefit from such increase in yield.

3.3. Variations in seasonal yield of water

The Ensemble mean of the climate models projected mean water yield to decrease across the four seasons in the year. Mean seasonal water yield was 2, 16, 12 and 9 mm less in the future period of December – February (DJF), March - May (MAM), June – August (JJA) and September – November (SON) seasons respectively (Fig. 4a and 4b). DJF in future had wide coverage of low yield except for the eastern part which was an average of 5 mm (Fig. 4b). Despite the mean decrease in yield in future for DJF, the spatial distribution generally showed an increase in most part of the basin especially in the Birim sub-basin in the range of 1 – 5 mm (Fig. 4c). In MAM, the highest mean of water yield with the widest coverage from the central to the west was about 30 mm and 15 mm in the

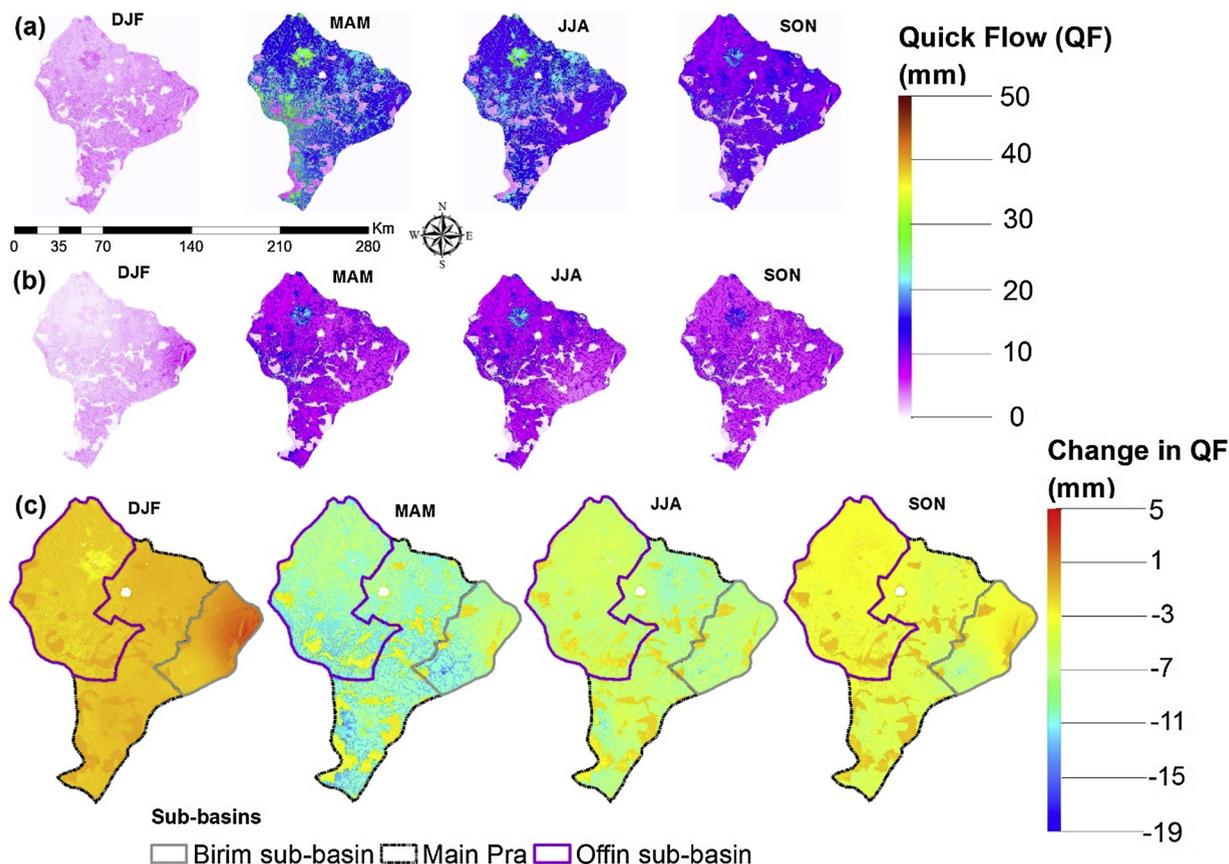


Fig. 4. Seasonal water yield simulated for (a) 2018 (b) Ensemble mean of model for the future (2020 – 2049) and (c) change in the yield between 2018 and Future (Ensemble). Simulation for both 2018 and Ensemble mean was performed with the LULC of 2018 in combination with mean observed historical climate (1981 – 2010) and Ensemble future climate (2020 – 2049) from the models respectively.

historical and future period respectively (Fig. 4a and 4b). The highest seasonal decrease spatially was in MAM. This will affect the major cropping season that is mostly from March to July. Similar spatial variations were observed in JJA and SON seasons. Spatially, the decrease in water yield in JJA and SON was in the north of Pra main sub-basin and south of Birim sub-basin respectively at a mean value of about 10 mm (Fig. 4c). Generally, SON showed a minimal change between -3 mm and 0 mm. This could limit water availability for dry season cropping mostly practised in the basin for the production of vegetables. Details of monthly water yield under the future climate scenarios are presented in the supplementary material (Figs. S5 – S8). Therefore, climate change would impact water yield in all season in the basin with more of a decrease in MAM and increase in DJF spatially (Fig. 4c).

4. Discussion

Land use change influenced water yield in the assessed periods specifically in determining the location and volume of yield, while climate determined its depth. The difference in mean annual water yield under land use change was negligible (about 2 mm) and does not reveal details of the impact. This could be due to the fact that water yield is based on pixels and not necessary a flow as in other traditional hydrological models. The difference in yield at pixel scale showed that land use change had a significant impact on water yield. While some locations experienced an increased above 250 mm, others experienced a decrease beyond the same value. The spatial trend of change in land use also determined which location of the basin could need either flood or drought intervention measures. For instance, the difference between 1986 and 2002 showed more of flood possibility in the Offin sub-basin which changed to the possibility of a drought situation due to the general distribution of decreased yield between 2002 and 2018. This can be attributed to the changes in LULC in the sub-basin between the assessed years. Although forest declined in the first interval and most of the reserves were recovered in the second interval, the conversion to open vegetation in the first interval could contribute to higher water yield in 2002 (Fig. S1 in supplementary material). The conversion from 2002 to 2018 showed an increasing arable/bare lands and settlement taking over open water areas in the earlier LULC map (Fig. S1). Therefore, water yield would negatively be impacted in the second interval (Fig. 2b). Under the same climatic condition, InVEST was capable of determining an amount of yield available per location under the different land use scenarios. The maximum change in annual water yield was a decrease of about 83% and an increase of about 86% based on the mean yield of the assessed years under land use change across the basin. Awotwi et al. (2019) also

reported a marginal decrease in surface water yield (of approximately 3.34 mm) as a result of LULC changes between 1986 and 2000 simulated using the SWAT model in the study area. Their findings relate with the results of this study showing a mean annual yield change of 2 mm between 1986 and 2002. The changes would be largely due to the difference in the model conceptualization and the variation in type of datasets used. For example, Awotwi et al. (2019) used maximum likelihood algorithm for LULC classification while this study employed random forest algorithm. Furthermore, Awotwi et al. (2019) reported a spatial distribution change in water yield between 1986 and 2016 in the range from -13 mm to +69 mm and a baseflow between -79 mm and +73 mm in the study area. The spatial distribution of this study between a similar period (1986 and 2018) showed an extreme change in water yield between -279 mm and +289 mm. Although the different concept of water yield modelling in SWAT and InVEST does not warrant exact value comparison (Luke and Hack, 2018), the variations help to understand some of the processes that could have led to the results. For instance, the current version of InVEST model is limited in the estimation of baseflow (that is, no quantitative estimation) which could increase the amount of water yield (Sharp et al., 2018). Therefore, based on the findings in this study, the InVEST tool was capable of demonstrating the magnitude and distribution of land use change impact on mean annual water yield in the Pra River Basin which are relevant for research and decision making especially in deciding on specific locations that call for immediate land use and management intervention in addressing climate change impact on water resources at the basin scale.

The projected change in mean annual water yield at -46%, -48%, -35%, and +44% by regional, sub-regional, ensemble mean and local climate conditions respectively relate (extreme positive and negative projected changes) with the findings of Amisigo et al. (2015) in the Pra River Basin. According to Amisigo et al. (2015), annual runoff in the study area could change by -12.2%, -34.4%, -25.9% and +60.9% under the Global Wet (NCAR_CCSM3_0 A2), Global Dry (CSIRO_MK3_0 A2), Ghana dry (IPSL_CM4 B1) and wet (NCAR_PCM1 A1b) scenarios, respectively, from 2011 – 2050 in reference to 1950 - 2000. While the A2 scenario represents more of a divided world, the B1 scenario is characterised by a more ecologically friendly world that emphasis on global economic solutions and social and environmental stability (Fenech et al., 2007). The A1b scenario is also of an integrated world with a balanced emphasis on all energy sources. The RCP4.5 used for climate simulations in this study is close in description to emission scenario B1 and A1b (Vuuren et al., 2011) used by Amisigo et al. (2015). A Pearson correlation factor of $R = 0.735$ was found between surface runoff and water yield for the study area (Awotwi et al., 2019). Therefore, projected changes (negative under regional and sub-regional climate scenarios and positive under local climate scenario) in water yield in this study under climate change for the future period (2020 – 2049) relate with the changed pattern of Ghana dry and Ghana wet scenarios reported by Amisigo et al. (2015) for the period 2011 - 2050.

The correlation between rainfall and runoff changes has been found to be at $R = 0.49$ for West Africa (Roudier et al., 2014). Relatively, climate change (more specifically the changes in rainfall patterns) could contribute to approximately 50% of changes in the amount of surface water generation (water yield, runoff, etc.). According to Bessah et al. (2019) change in rainfall was projected by the sub-regional, and local climate scenarios to increase by 10.93% and 13.43% whereas the regional and ensemble mean climate scenarios projected a decrease of 22.08% and 1.77% respectively. Paradoxically, the sub-regional climate scenario projected an increase in rainfall by 10.93% resulting in a decreased water yield by 48% in future. Another paradox was the degree of change in water yield which was higher in the sub-regional than the regional climate conditions despite the opposite projection in change of rainfall. As the local (at 0.002 km) tends towards positive, the sub-regional (at 12 km) condition was higher in the negative than the regional (at 44 km). This implies that the spatial resolution of climate model and their projected change in rainfall could not be used in determining the pattern of change of water yield in the Pra River Basin. Therefore, water yield is not directly proportional to rainfall trend in the basin in this study although it has the highest contribution to water yield (Queensland Government, 2011).

The seasonal changes in future for the ensemble is expected to have a negative impact on crop production. Prolonged dry spells and drought experienced by farmers in the past has resulted in crop failure and increased the vulnerability of the basin to food insecurity (Bessah, 2019 unpublished). Moreover, the decrease in yield by the regional, sub-regional and ensemble mean arouses concerns for the availability of water to run the proposed hydro dam sustainably on the Pra River Basin (Kabo-Bah et al., 2016). Nevertheless, the local climate scenario could increase water yield during all season in the basin. This could create the situation of increased surface water, leading to an opportunity for irrigation crop production during the dry or lean (prolonged dry spells in a rainy season) seasons. On the other hand, it could cause flood disaster especially on farms situated on low lands and close to rivers. Flooding on farms has been a regular occurrence in some communities within the Pra River Basin located close to the three main rivers (Pra, Birim and Offin). Road access to the farms are impossible during such situation and both harvested and maturing crops are usually destroyed, as often frequently observed in the northern part of Ghana (Armah et al., 2010; Akwei, 2017). The spatial distribution is a guide to locations that could be in need of either flood adaptation or drought resilience interventions in all seasons in the future period.

5. Conclusion

Using the InVEST model to assess the hydrological ecosystem services of water yield in the Pra River Basin produced results within ranges of other tools and in-situ data collected in a comparable period. It was shown that changes in land use from 1986 – 2018 had minimal influence on the overall mean annual water yield in the basin although the spatial variation was significant at extreme decreased and increased yield at some specific locations. However, climate showed a significant influence on mean water yield at varying degrees according to the spatial resolution of the climate models but with no particular pattern of change. Apart from the local climate projecting an increase in water yield, all other conditions projected yield to decrease in the coming decades. We recommend that high-resolution climate models capable of capturing the local climate, such as SDSM reported in previous studies in the basin, be compared in climate change impact studies in other sensitive locations, like the Savannah zones of Ghana. It will help to

ascertain the future possible ways to aid in site-specific adaptation planning and policy formulation. Improved satellite and in-situ surveillance systems, agronomical assistance and enforcement of environmental law (e.g. the implementation of the Integrated Water Resources Management Policy and Riparian Buffer policy) could help reduce the impacts of land use change on water yield in the Offin and Pra main sub-basins. Irrigation farming should be encouraged and farmers empowered with knowledge and equipment support for adoption in order to enhance their adaptation to the projected extreme climate events (flood and drought), since the basin contribute significantly to the production of tree crops like cocoa and tuber crops with valuable economic gains to the nation.

Author contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Enoch Bessah. The first draft of the manuscript was written by Enoch Bessah and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

None.

Acknowledgements

This paper was prepared based on the PhD thesis submitted by the first author to the Pan African University Institute of Life and Earth Sciences at the University of Ibadan, Nigeria and funded by the African Union Commission. The research was supported by the International Foundation for Science, Stockholm, Sweden, through a grant to Enoch Bessah [grant number W_6201-1] and by the International Support Network for African Development (ISNAD-Africa). We acknowledge the World Climate Research Programme's Working Group on Regional Climate and the Working Group on Coupled Modeling, the former coordinating body of CORDEX and responsible panel for CMIP5 through which the climate modelling groups made their model output available. We appreciate developers of SDSM-DC and the Natural Capital Project team for making their models free to access. We also thank the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) for making WRF model outputs available. Our sincere gratitude to NASA and the International Soil Reference and Information Centre (ISRIC) for free access to their data. Moreover, we thank Imperial College London for making this publication in open access possible. Finally, we appreciate the editor and the professional work done by the anonymous reviewers which improved the quality of this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.ejrh.2019.100654>.

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