# Modelling the impact of climate variability and land-use changes in the Upper Crocodile River Basin, South Africa

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## Abstract

Improved understanding of the impacts of climatic variability and land-use changes on water resources in the semi-arid part of South Africa is necessary to ensure sustainability in water resources supply. In this study, the Soil and Water Assessment Tool (SWAT) hydrological model was applied in the highly urbanized Upper Crocodile River Basin (UCRB) to evaluate the individual and combined effects of climate and land-use changes on streamflow. The SWAT model was calibrated against four discharge stations from 1998 to 2010 and validated from 2010 to 2016. Successful results regarding the coefficient of determination ($R^2$), percentage bias (PBIAS), and Nash-Sutcliffe efficiency equation (NSE) objective functions proved that streamflow predictions were reliable for analysis under climate and land-use changes. The climate change scenarios, reflecting a 1.5°C temperature increase, and a 20% precipitation decrease, were shown to reduce the antecedent moisture condition of the UCRB. The 5% urban expansion land-use scenario revealed that increasing urbanization enhanced the imperviousness of the basin. Moreover, in the worst-case scenario, incorporating the climate and land-use changes resulted in a 14% average streamflow decrease in the UCRB. Consequently, the UCRB's predicted climate and human activity changes suggest water availability and quality decreases. The deterioration of the surface water quality will be aggravated as there is less natural water for the dilution of effluent loadings, and groundwater quality may be exacerbated by its connection with surface water in the basin. Therefore, improved integrated water management strategies, above those currently considered, is required to ensure the efficient use and sustainability of the UCRB's water resources.

## Introduction

Climate change is regarded as one of the critical factors surrounding the changing distribution and decreased availability of water resources (Kundzewicz et al., 2008). As such, the rapid rise in surface temperatures since 1970, surpassing any 50-year interval over the previous two millennia as recorded by the Intergovernmental Panel on Climate Change (IPCC, 2021), may threaten the future sustainability of global water resources. However, the IPCC noted that present and projected climate changes are attributed to global warming and its related increases in atmospheric greenhouse gas emissions, owing to recent population and economic growth driving changes in human activity (IPCC, 2001; 2007; 2013; 2021). Therefore, understanding the relationship between anthropogenic activities and climate is essential for quantifying and predicting climate change, and thus, its potential impact on water resources.

Human activities contribute to climate change as they play a major role in altering hydrological circulation (Kuchment, 2004) and influence hydro-climatic variables such as precipitation, temperature, and precipitation extremes (Ahn and Merwade, 2014). In turn, Dale (1997) noted that climate change and human activities are interrelated as climate change could alter the politics, social attitudes, and affluence governing the choice over anthropogenic activities. In addition, as water resources are central to the predicted impacts of climate change (IPCC, 2007), streamflow is regarded as one of the most crucial resultants for water resources management (Dey and Mishra, 2017). Given that human activities and climate variability impact streamflow (Zhang *et al*., 2011), their effects need to be delineated and mitigated to ensure water resources sustainability, especially for countries that are vulnerable to climate change impacts such as South Africa.

South Africa is deemed at risk to the projected effects of climate change (Kusangaya *et al*., 2014). Climate change predictions suggest that the country will continue to warm at a rate significantly higher than the 0.15°C per decade observed over the 20th Century (Engelbrecht *et al*., 2015), resulting in temperature rises of 5 to 8°C over the interior parts by the end of the 21st century, with reduced increases occurring over coastal regions (IPCC, 2007). Moreover, South Africa is expected to suffer from reduced rainfall in the future (ASSAf, 2017), which is increasingly worrying given that the 490 mm it already receives is less than half of the global average (WWF-SA, 2016). South Africa's geographic location in the African continent's southern region may further exacerbate its climate change impacts. Africa has experienced surface temperature increases above the global average (IPCC, 2021) and is regarded as one of the most vulnerable continents to climate change due to its low adaptive capacity (IPCC, 2001; Callaway, 2004). Furthermore, southern Africa is considered the most vulnerable region in Africa to climate change impacts (IPCC, 2007) due to large spatial and temporal variability in climate (IPCC, 2007; Gallego-Ayala and Juizo 2011). Subsequently, climate change impacts on southern Africa's water resources are expected to be even more pronounced than previously anticipated (Kusangaya *et al.*, 2014), posing a serious threat to South Africa's water resources, given its climate change outlook (Ziervogel *et al.*, 2014).

The developing trend in South Africa's climate towards lower rainfalls and higher temperatures leads to decreased terrestrial moisture (Graham *et al.*, 2011; Engelbrecht *et al.*, 2015), ultimately affecting streamflow components (Legesse *et al.*, 2010). Precipitation directly affects the quantity of water entering a hydrological system (Trenberth, 1999); therefore, decreases in precipitation has an adverse effect on streamflow. Temperature directly affects the quantity and rate of evaporation (Arnell and Liv, 2001); hence, due to higher temperatures, a rain falling overland may be quickly evaporated back into the atmosphere, subsequently reducing water availability for run-off and infiltration (Gleick, 1989). Interception and water uptake from vegetation further exacerbate water's availability for run-off and infiltration, thereby reducing groundwater recharge (Healy, 2010). Decreases in groundwater recharge translate to lowering of the water table and, hence, reduced subsurface flow into the stream network (Matalas *et al.*, 1998). Consequently, streamflow projections for South Africa indicate a substantial decrease by 2050, compromising access to water for human consumption, socio-economic development, agriculture, and the aquatic environment (Kusangaya *et al.*, 2014).

Human practices may compound South Africa's predicted water availability and accessibility shortages by aggravating the quality of its water resources. Mining, recreational, and agricultural activities, and urban and industrial developments significantly alter the quality of natural flows (Edokpayi *et al.*, 2017). In addition, poor wastewater disposal may amplify this problem as many developing countries such as South Africa do not treat wastewater apart from urban wastewater treatment plants. Wastewater treatment plants often discharge their effluents directly into or nearby streams, which is concerning for South Africa's water resources, given that more than half of its wastewater treatment plants do not treat wastewater to acceptable standards (Edokpayi *et al.*, 2015). Resultantly, the streams draining South Africa's urban settlements are characterized by poor water quality. South Africa's population and industrial growth may intensify this issue as it will likely lead to increased wastewater generation (Edokpayi *et al.*, 2017).

The Upper Crocodile River Basin (Fig. 1a) exemplifies the climatic and anthropogenic factors affecting the current and future sustainability of South Africa's water resources. The basin is characterized as having the greatest human impact in South Africa due to the urban sprawls of northern Johannesburg and southern Pretoria (Tshwane) (Department of Water Affairs and Forestry [DWAF], 2008). As a result, there is a considerable water demand from various economic sectors in the basin (Abiye *et al.*,2015), totalling 556 million $m^3$/year (DWAF, 2008). However, water resources within the UCRB could not meet this demand and it has required enhancement from the neighbouring Vaal River Basin to the south (Abiye *et al.*, 2015; Leketa and Abiye, 2019). The transfer of 550 million $m^3$/year of water from the Vaal Basin subsequently increased wastewater disposal from treatment plants to the rivers draining the UCRB, which is part of the Limpopo River Basin (Leketa and Abiye, 2019), thereby exacerbating the quality of the UCRB's surface water resources (DWAF, 2008). These water quality issues likely most afflict the Hartbeespoort Dam, one of the most severely eutrophicated water bodies in South Africa (Cukic and Venter, 2012), as it is the first restrictive flow body downstream from Johannesburg and Pretoria.

The UCRB is, therefore, expected to be adversely affected by South Africa's envisaged climate and human activity changes. The predicted decrease in rainfall and increase in temperature, coupled with the expected exponential population growth, and associated effluent discharge, pose significant threats to groundwater and surface water availability (Kusangaya *et al.*, 2014). Therefore, managing the UCRB's water resources in response to climate and human activity changes is critical for ensuring water quality and sustainability in the basin.

The Soil and Water Assessment Tool (SWAT) hydrological model has been applied successfully in different regions with variable climatic setting to assess the impacts of changing climates and land-use practices on basin hydrology (Arnold *et al.*, 2012). In South Africa, SWAT has been used extensively to simulate basin hydrology in watersheds with various characteristics and climates (Govender and Everson, 2005; Gyamfi *et al.*, 2016; Thavhana *et al.*, 2018; Mengistu *et al.*, 2019). However, no previous SWAT South African studies have examined SWAT's applicability in simulating streamflow in a large catchment with a pronounced human impact under climate and anthropogenic activity changes. Therefore, this study used the SWAT model to simulate basin hydrology in the UCRB to assess the impact of changing climate and land-use practices on streamflow as a means to justify present and future water resources decision-making in the basin.

# Study Area

The UCRB, covering an area of 6336 km$^2$ between the Gauteng and North-West Provinces, is a catchment that constitutes part of the Crocodile West and Marico Water Management Area as per the Department of Water and Sanitation (DWS) classification. Due to higher elevations in the south of the basin (Fig. 1a), the UCRB is drained in a northerly direction. The confluence of the Jukskei and Hennops Rivers in the eastern part of the basin forms the Crocodile River, which contributes to 90% of the Hartbeespoort Dam's inflow (Leketa *et al.*, 2018), while the Magalies River provides a limited contribution to the Hartbeespoort Dam from the west. The Crocodile River flows northward from the Hartbeespoort Dam into the Roodekoppies Dam before eventually joining the Limpopo River via the Lower Crocodile River Basin (Leketa *et al.*, 2018). Apart from the Hartbeespoort and Roodekoppies Dams, the UCRB contains two other significant water bodies: Rietvlei Dam and Buffelspoort Dam (Fig. 1a) that increased the storage of surface water.

# Climate setting

The UCRB forms part of South Africa's interior and is characterized by a subtropical highland climate (Leketa *et al.*, 2018) with a low yet highly variable mean annual rainfall of 700 mm (Abiye, 2011) and mean annual evapotranspiration of approximately 1700 mm (DWAF, 2008). Plots concerning average monthly precipitation and maximum and minimum surface temperatures for the basin's weather stations (Fig. 1b) indicate a directly proportional relationship between rainfall and temperature. Resultantly, the UCRB experiences cold, dry winters between May and July (Leketa, 2019), with winter temperatures ranging from a minimum of 1°C to a maximum of 20°C between April and September (DWAF, 2004). In contrast, the UCRB generally receives rainfall between the summer months of October and March, which occurs as convective rainfall in the form of afternoon thundershowers and occasional hailstorms (Barnard, 2000; DWAF, 2004; Leketa, 2019). This rainfall is instigated by the hot temperatures experienced during summer, commonly ranging from a minimum of 10°C to a maximum of 30°C (DWAF, 2004).

# Geological and hydrogeological setting

Underlying the UCRB are rocks of the Archean Basement Complex, the Witwatersrand, Ventersdorp, and Transvaal Supergroups, the Bushveld Igneous Complex, and the Karoo Supergroup, which have a general northerly younging direction relative to Johannesburg (Barnard, 2000; Leketa, 2019) (Fig. 2). The Archean Basement Complex is defined by granodiorites, gabbros, granitic gneiss, and serpentinites (McCarthy and Rubidge, 2005) of the Kaapvaal Craton. Uncomformably overlying the Kaapvaal Craton, the Witwatersrand Supergroup is sequentially divided into the West Rand Group, comprising quartzites and ferruginous magnetic shales, and the Central Rand Group, composed of quartzites, shales, and conglomerates (Pretorius, 1976). The Ventersdorp Supergroup overlies the Witwatersrand Supergroup and outcrops as tuffs and andesites which belong to the Klipriviersberg Group (Barnard, 2000) within the UCRB. The Transvaal Supergroup consists of quartzites of the Black Reef Formation and dolomites of the Malmani Subgroup, which comprise the Chuniespoort Group (Eriksson *et al.*, 2006; Leketa, 2019). The Pretoria Group overlies the Chuniespoort Group and is represented by several formations, namely: the Timeball Hill shale and quartzite, Hekpoort andesite, Strubenkop shale, Daspoort sandstone, Silverton lava and shale, Magaliesberg quartzite, and Rayton shale, sandstone, and volcanic rocks (Eriksson et al., 2006). The Bushveld Igneous Complex outcrops in the northern part of the UCRB and consists of gabbros, norites, and anorthosites of the Rustenburg Layered Suite; Nebo-granites of the Lebowa Granite Suite; and granodiorites of the Rashoop Granophyre Suite (Cawthorn, 2006). The Karoo Supergroup that covers the geological sequence is composed of mudstones, sandstones, and tillites of the Dwyka Group and sandstones, shales, and coal of the Ecca Group (Leketa, 2019), which have small outcrops in the eastern part of the basin.

From a structural perspective, the UCRB has undergone deformation resulting in numerous shear zones and strike-slip faults which penetrate different rock units (Abiye, 2011). Barnard (2000) classified the hydrogeological properties of the UCRB into four aquifer types: fractured aquifers, karstic aquifers, intergranular aquifers, and intergranular and fractured aquifers. Fractured aquifers are commonly found in the granitic gneisses of the Archean basement and in the Witwatersrand Supergroup quartzites (Leketa, 2019). In contrast, karstic aquifers are found within the Malmani Subgroup of the UCRB, which Abiye (2011) noted to occur at greater depths and have higher productivity in comparison to fractured aquifer systems within the UCRB. Intergranular aquifers dominate along riverbanks and in the weathered zones of granites, whilst intergranular and fractured aquifers occur in the basement granites and Bushveld Igneous Complex in the UCRB (Barnard, 2000) (Fig. 2).

## Materials And Methods

# Overview of SWAT

SWAT is a continuous-time, deterministic semi-distributed hydrological model that operates on a river basin or watershed scale to predict the impact of land management practices on sediment, water, and agricultural chemical yields for large and intricate watersheds over long periods using readily available data (Neitsch *et al.*, 2011; Arnold *et al.*, 2012). To do so, SWAT operates through several geographic information systems (GIS) interfaces, enabling model parameterization and initialization. Initialization occurs through the sequential input of variables such as topography, land-use/land cover, soils, land management, and climate, which are linked to output variables via regression equations (Neitsch *et al.*, 2011). SWAT utilises topographic data to partition a watershed into numerous sub-basins depending on elevation and further divides sub-basins into hydrological response units (HRUs) using similarities between land-uses, management practices, topography, and soil characteristics (Arnold *et al.*, 2012; Krysanova and Srinivasan, 2015). SWAT simulates the hydrological processes in each HRU using two phases: the land phase and the routing phase, simulating water movement overland towards the main river channel and water movement through the stream network, respectively (Arnold *et al.*, 2012). The deterministic nature of SWAT is beneficial to examine the impact of changing climate and anthropogenic activities on streamflow as deterministic models produce the same outputs for a given set of inputs. Therefore, SWAT isolates the hydrological response to changes in a single variable, e.g., climate and land-use, permitting the quantification of the relative and combined impacts of climate and land-use changes on basin hydrology.

# Construction of the model

For this study, the SWAT2012 model was coupled with the Quantum Geographic Information System (QGIS) (Version 3.10- A Coruña) via an extension to QGIS known as QSWAT 3 (Version 1.1). QSWAT enabled the spatial delineation of the catchment extent and the factors influencing the basin's hydrological properties through a systematic attribute, vector, and raster dataset input to synthesize the SWAT model prior to calibration and validation of the model for the visualization of streamflow results under climate and land-use changes.

# Data preparation

The elevation-related properties of the UCRB, and therefore, the flow routing through the basin, were defined via the input of a digital elevation map (DEM). The 30m- resolution DEM, obtained from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/), along with a river map, sourced from South Africa's Department of Forestry, Fisheries & the Environment (https://egis.environment.gov.za/), delineated the elevation of the stream network and the direction of flow within the UCRB. Adding the positions of the inlets, outlets, and reservoirs along the stream network partitioned the UCRB into 139 sub-basins (Fig. 3a), each containing one tributary or main channel reach (Neitsch *et al.*, 2011). In addition, one point source was added to each sub-basin to account for the artificial inflations to the basin from wastewater treatment plants. South Africa's Department of Water Affairs (DWAF, 2004) identified nine wastewater treatment plants (Table 1) whose daily effluent loadings enhanced streamflow to the UCRB.

Table 1
The locations and effluent loadings from wastewater treatment plants within the UCRB (DWAF, 2004)

| Wastewater Treatment Plant | Latitude | Longitude | Discharge ($m^3$/day) |
|---|---|---|---|
| Oilifantsfontein | 25.942° S | 28.213° E | 38 000 |
| Sunderland Ridge | 25.827° S | 28.106° E | 35 000 |
| Esther Park | 26.101° S | 28.185° E | 400 |
| JHB Northern Works | 25.949° S | 27.990° E | 220 000 |
| AECI | 26.091° S | 27.976° E | 7 000 |
| Modderfontein | 26.092° S | 28.169° E | 16 000 |
| Midrand South | 25.922° S | 28.168° E | 5000 |
| Percy Stewart | 26.081° S | 27.728° E | 25 000 |
| Driefontein | 26.017° S | 27.842° E | 15 000 |

Creating HRUs for the UCRB involved describing combinations of soils and land-use/land cover practices that differ significantly regarding their hydrologic characteristics to cause unique changes in streamflow (Neitsch *et al.*, 2011; Dile *et al.*, 2015). The land-use/land cover practices occurring over the UCRB were obtained from South Africa's Department of Environment, Forestry, and Fisheries, who developed South Africa's Land Cover dataset 2018 (SANLC 2018), describing the land-use practices operating in the country. The SANLC 2018 contained 73 different land-use/land cover classes, of which 58 occurred over the UCRB (Fig. 3b). These land-use practices were integrated into the SWAT model, which utilised 22 different land-use/land cover classes, using a land-use lookup table and appropriate SWAT codes. Soil data for the basin was sourced from the United Nations Food and Agricultural Organization's (FAO) Harmonized World Soil Database (HWSD- Version 1.2) (available at: http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/). The HSWD constituted a raster image (Fig. 3c), which delineated the spatial relations of the soil mapping units, and a database file, detailing the physical and hydrological properties of the soils. The HSWD database file contained the soils' identifier, depth, rooting depth, albedo, bulk density, clay, silt, sand, carbon, and rock fragment content necessary for input into SWAT's usersoil table. However, the hydrological group, available water capacity, hydraulic conductivity, and erodibility of the soils were absent from these records and were, thus, calculated using the Soil-Plant-Air-Water (SPAW) Hydrology program (available at- https://www.ars.usda.gov/research/software/) or appropriate soil equations. The physical properties of the UCRB's soils were outlined in SWAT's usersoil table, which were observed by SWAT via a soil lookup table.

SWAT's reservoir target release approach characterised the dams in the UCRB, where the physical attributes and the monthly target storage (STARG), set for the flooding and non-flood seasons, determined the downstream release rate from each reservoir. The surface areas and volumes of each dam, when filled to the emergency (RES_ESA and RES_EVOL) and principal spillways (RES_PSA and RES_PVOL), and the initial dam volumes (RES_VOL) (Table 2) defined the physical properties of each reservoir and were estimated using historical records from South Africa's Department of Water and Sanitation (DWS). The non-flood season was not selected for the implementation; instead, the flooding season was continuous throughout the year, and the monthly target storage for the flooding season was set to the reservoir principal spillway volume (Table 2). This ensured that the dam outflow reflected the desire to achieve full reservoir operating capacity irrespective of water abundant or strenuous conditions occurring in the UCRB. Lastly, the number of days needed to reach the target storage during the flood season (NDTARGR) were estimated using available daily reservoir releases related to dam storage, obtained from DWS.

Table 2
The target release attributes used for the UCRB’s dam characterization

| Dam | RES_ESA (ha) | RES_EVOL ($10^4$ $m^3$) | RES_PSA (ha) | RES_PVOL ($10^4$ $m^3$) | RES_VOL ($10^4$ $m^3$) | STARG ($10^4$ $m^3$) | NDTARGR (days) |
|---|---|---|---|---|---|---|---|
| Roodekoppies | 1728.1 | 11850 | 1571 | 10300 | 9500 | 10300 | 18 |
| Hartbeespoort | 2271.7 | 21400 | 2065.2 | 18640 | 16000 | 18640 | 16 |
| Rietvlei | 207.9 | 1400 | 189 | 1230 | 950 | 1230 | 6 |
| Buffelspoort | 149.3 | 1200 | 135.7 | 1025.1 | 900 | 1025.1 | 6 |

Climate data for the UCRB was obtained from the South African Weather Service (SAWS), who provided daily records regarding maximum and minimum surface temperatures, precipitation, wind speed, wind direction, relative humidity, and solar radiation for two weather stations found within or proximal to the UCRB from January 1980 to July 2020.

However, the dewpoint temperature was absent from these recordings and was calculated using the dew.exe program (available at: https://swat.tamu.edu/software/) using average humidity and temperature data for the basin. The climate over the UCRB was observed by SWAT using text files containing daily recordings and a weather table (WGEN_user), which described the climate statistics at each weather station. The weather table was composed using the WGNmaker4.xls Excel macro extension and defined monthly averages, standard deviations, skew coefficients, and probabilities for each climatic variable in each weather station.

The SWAT model was run on a monthly basis from January 1998 to December 2016 with five equilibration years (NYSKIP) used to start up the hydrological cycle and improve streamflow quantification in the basin (Neitsch et al., 2011). The accuracy of SWAT's streamflow simulations was assessed in relation to four discharge stations distributed across the UCRB (Fig.3d). The selection of these stations was based on the comprehensive coverage of stream inflow into Hartbeespoort Dam (A2H012, A2H044), stream outflow from the dam (A2H083), and the outflow from the entire UCRB (A2H019) (Fig.3d). Additionally, these recording stations had the most complete records regarding monthly streamflow measurements for accuracy analysis (Table3). As this study aimed to simulate the UCRB's hydrology in response to climate and land-use changes, further calibration and validation of the model were necessary to certify that the model made accurate streamflow predictions from its basin response.

Table 3
Discharge station attributes used for streamflow precision analysis

| Discharge Station | Name | Sub-basin | Latitude | Longitude | Catchment area ($km^2$) | Data availability |
|---|---|---|---|---|---|---|
| **A2H012** | Krokodil River @ Kalkheuwel | **19** | 25.811° S | 27.910° E | 2551 | 1922/10/01 to 2020/09/03 |
| **A2H019** | Krokodil River @ Beestkraal | **3** | 25.404° S | 27.575° E | 6131 | 1951/03/01 to 2016/03/31 |
| **A2H044** | Jukskei River @ Vlakfontein | **26** | 25.896° S | 27.935° E | 798 | 1971/07/18 to 2020/09/03 |
| **A2H083** | Krokodil River @ Hartbeesfontein | **13** | 25.719° S | 27.844° E | 4116 | 1980/03/01 to 2016/02/29 |

# Parameter sensitivity, calibration, and validation

The SWAT Calibration and Uncertainty Program's (SWATCUP) sequential uncertainty fitting (SUFI2) procedure was used to calibrate and validate the UCRB model. SUFI2 is a stochastic approach to model calibration, where the errors and uncertainties in modelling work are acknowledged, owing to the ignorance of the processes occurring in the natural environment (Abbaspour, 2015). As such, parameters used in SUFI2 were expressed as ranges, accounting for all model uncertainties. Propagation of these uncertainties resulted in uncertainties concerning output variables, which SUFI2 expressed as 95% probability distributions and, thus, produced an envelope of model outputs referred to as 95% prediction uncertainty (95 PPU). The parameters used for SUFI2's calibration procedure were delineated through SWATCUP's global sensitivity analysis, and their sensitivities were determined by calculating the multiple regression system (Eq. 1), which regressed the parameters against a function of model accuracy to provide two statistics of parameter sensitivity, namely the t-stat value and the p-value. The t-stat is defined as the coefficient of a parameter (β) divided by its standard error and measures the precision with which the regression coefficient is determined. The p-value is obtained by comparing a parameter's t-stat value with those in the Student's t-distribution table and assesses the null hypothesis that the coefficient is equal to zero. Resultantly, low p-values (< 0.05) and larger absolute values for t-stat indicated increased parameter sensitivity.

$$g = \alpha + \sum_{i=1}^{m} \beta_i b_i \quad (1)$$

SWATCUP implemented two statistics, the p-factor and r-factor, to quantify the fit between the simulation results, expressed as 95 PPU, and the recorded data expressed as a single signal (Abbaspour, 2015). The p-factor defined the percentage of observed data enveloped by modelling result, whereas the r-factor referred to the thickness of the 95 PPU envelope. As a result, larger p-factor (> 0.7) and smaller r-factor values (~ 1) reflected a limited parameter range which was accurate compared to recorded data. In addition, the $R^2$ (Eq. 2), PBIAS (Eq. 3), and NSE (Eq. 4) model performance indicators were used to certify the accuracy of calibration and validation further. The evaluation criteria for these indicators are outlined by Moriasi *et al.*(2007) and are summarized in Table 4, adapted from Moriasi *et al.* (2015).

$$R^2 = \left[ \frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right]^2 \quad (2)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n} O_i} * 100 \quad (3)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (4)$$

$O_i$ = observed discharge, $P_i$ = simulated discharge, $\bar{O}$ = observed average discharge, $\bar{P}$ = simulated average discharge

Table 4
The evaluation criteria for the model performance indicators

| | Performance Evaluation Criteria | | | |
|---|---|---|---|---|
| **Performance Measure** | **Very Good** | **Good** | **Satisfactory** | **Not Satisfactory** |
| **$R^2$** | $R^2 > 0.85$ | $0.75 < R^2 \leq 0.85$ | $0.60 < R^2 \leq 0.75$ | $R^2 \leq 0.60$ |
| **PBIAS (%)** | PBIAS < ± 5 | ± 5 ≤ PBIAS < ± 10 | ± 10 ≤ PBIAS < ± 15 | PBIAS ≥ ± 15 |
| **NSE** | NSE > 0.80 | 0.70 < NSE ≤ 0.80 | 0.50 < NSE ≤ 0.70 | NSE ≤ 0.50 |

# Results And Discussion

## Parameter Sensitivity

Eighteen parameters were identified for sensitivity analysis based on the findings of previous SWAT studies performed in South Africa (Gyamfi *et al.*, 2016; Thavhana *et al.*, 2018; Mengistu *et al.*, 2019) and successful calibrations across Europe (Abbaspour *et al.*, 2015). These parameters (Table 5) covered several aspects governing basin hydrology, such as basin properties (FFCB, SURLAG), HRU properties (SLSUBBSN, OV_N, ESCO, EPCO), soil properties (SOL_K, SOL_AWC), groundwater flow (ALPHA_BF, GW_DELAY, GW_REVAP, GWQMN, REVAPMN, SHALLST), main channel flow (CH_K2, CH_N2, ALPHA_BNK), and management practices (CN2). Global sensitivity results indicated that thirteen parameters were sensitive to streamflow within the UCRB; however, five parameters (ALPHA_BF, SURLAG, GWQMN, GW_REVAP, ESCO) were regarded as less sensitive ($P > 0.05$) and were removed from consideration for calibration.

Table 5
Parameters considered for SWATCUP sensitivity analysis

| Parameter | Description |
|---|---|
| **ALPHA_BF** | Baseflow alpha factor (1/days) |
| **GW_DELAY** | Groundwater delay time (days) |
| **GW_REVAP** | Groundwater percolation coefficient |
| **GWQMN** | Depth of water in the shallow aquifer threshold required for return flow to occur (mm $H_2O$) |
| **REVAPM** | Threshold depth of water in the shallow aquifer for percolation into the deep aquifer to occur (mm $H_2O$) |
| **SHALLST** | Initial depth of water in the shallow aquifer (mm $H_2O$) |
| **SLSUBBSN** | Average slope length (m) |
| **OV_N** | Manning's "n" value for overland flow |
| **ESCO** | Soil evaporation compensation factor |
| **EPCO** | Plant uptake compensation factor |
| **SOL_K** | Saturated hydraulic conductivity of the soil (mm/hr) |
| **SOL_AWC** | Available water capacity of the soil layer (mm $H_2O$/mm soil) |
| **CH_K2** | Effective hydraulic conductivity in main the main channel (mm/hr) |
| **CH_N2** | Manning's "n" value for the main channel |
| **ALPHA_BNK** | Baseflow alpha factor for bank storage (days) |
| **FFCB** | Initial soil water storage as a fraction of field capacity water content |
| **SURLAG** | Surface runoff lag coefficient |
| **CN2** | Initial SCS runoff curve number |

# Calibration

# Calibrated parameters

The UCRB model was calibrated against thirteen years of monthly recorded data, beginning 1 January 1998 to 31 December 2009, using the multi-site approach to calibration. The most sensitive parameters to streamflow in the basin were put into SUFI2 with a broad range for calibration. Performing nine calibration iterations, each containing 500 simulations, subsequently reduced parameter limits and provided a set of parameter ranges (Table 6) that achieved the best efficiency between observed and simulated streamflow within the basin. From these parameters, the soil (SOL_K and SOL_AWC) and run-off parameters (CN2 and OV_N) were the most sensitive to streamflow alterations during calibration. The soil and run-off parameters' increased sensitivity were common across South African comparative studies and indicated that SWAT initially failed to characterise run-off and infiltration processes accurately within the UCRB.

Table 6
SWATCUP sensitivity analysis results for the calibration period

| | Parameter | T-stat | P-value | Parameter identifier | Minimum | Maximum | Fitted Value |
|---|---|---|---|---|---|---|---|
| 1 | **SOL_K** | 17.9368 | 0.0000 | Relative | 0.887951 | 1.43648 | **0.923947** |
| 2 | **CN2** | 9.5273 | 0.0000 | Relative | -0.177476 | -0.013154 | **0.113360** |
| 3 | **SOL_AWC** | 3.1703 | 0.0016 | Relative | 0.627981 | 1.069515 | **0.927783** |
| 4 | **OV_N** | 2.7404 | 0.0064 | Replace | 0.088593 | 0.264253 | **0.236674** |
| 5 | **ALPHA_BNK** | 1.8559 | 0.0641 | Replace | 0.766267 | 1.000000 | **0.986095** |
| 6 | **CH_N2** | 1.6357 | 0.1026 | Replace | 0.400019 | 0.500233 | **0.429582** |
| 7 | **FFCB** | -1.4084 | 0.1596 | Replace | 0.520373 | 0.879171 | **0.633394** |
| 8 | **GW_DELAY** | -1.2740 | 0.2033 | Replace | 5464.796387 | 7703.459473 | **5511.808105** |
| 9 | **CH_K2** | 0.7488 | 0.4543 | Replace | 0.000000 | 17.888680 | **3.738734** |
| 10 | **SLSUBBSN** | -0.6298 | 0.5291 | Replace | 31.843937 | 43.454220 | **37.474922** |
| 11 | **SHALLST** | -0.3402 | 0.7339 | Replace | 5168.109375 | 26675.406250 | **11125.630859** |
| 12 | **REVAPMN** | 0.1544 | 0.8774 | Replace | 12174.837891 | 16815.298828 | **16560.074219** |
| 13 | **EPCO** | 0.1263 | 0.8996 | Replace | 0.809426 | 0.920590 | **0.851779** |

# Model performance

Table 7 shows that the calibrated parameters produced an average r-factor of 1.04, characteristic of a small parameter range. P-factor values of 0.78, 0.72, 0.71, and 0.73, in sub-basins 3, 13, 19, and 26 resulted in a mean p-factor of 0.74, indicating that SUFI2's uncertainty enveloped 74% of recorded data on average, descriptive of good model simulation (Abbaspour, 2015). Analysis of the precision of calibration using the model performance indicators showed that the model simulated an $R^2$ of 0.89, 0.80, 0.78, and 0.77 in sub-basins 3, 13, 19, and 26, respectively. It was thus deduced that sub-basin 3 was characteristic of very good model performance, whereas sub-basins 13, 19, and 26 delineated good model performance. The PBIAS results indicated that calibration resulted in a model which tended to overestimate streamflow in the UCRB, owing to an average PBIAS of -8.71. However, this was due to PBIAS values of -12.49, -16.06, and − 11.21 in sub-basins 3, 13, and 19, as the model generated an underestimation bias of 4.91 in sub-basin 29. The NSE results expressed satisfactory model simulation across all sub-basins, attributed to NSE values of 0.86, 0.77, 0.69, and 0.71 in sub-basins 3, 13, 19, and 26. Resultantly, the calibration hydrographs for each sub-basin (Fig. 4) expressed minor discrepancies between simulated and measured data, with consistency regarding peak flow simulation. Ultimately, therefore, the calibration results specified that the multi-site calibration approach successfully produced accurate streamflow simulations for the UCRB, substantiating Piniewski and Okruszko (2011) results using the same method. Moreover, the success of the UCRB model calibration further corroborated the findings of Piniewski and Okruszko (2011) concerning the superior efficacy of multi-site calibration in generating satisfactory stream discharges in large watersheds with substantial spatial heterogeneity as opposed to smaller watersheds.

Table 7
The calibration results showing the accuracy of simulation in the UCRB

| Sub-basin | Stream Gauge | p-factor | r-factor | NSE | PBIAS | $R^2$ | Observed mean ($m^3/s$) | Simulated mean ($m^3/s$) | Observed σ ($m^3/s$) | Simulated σ ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|---|
| **3** | A2H019 | 0.78 | 1.02 | 0.86 | -12.49 | 0.89 | 7.63 | 8.85 | 14.59 | 15.33 |
| **13** | A2H083 | 0.72 | 1.13 | 0.77 | -16.06 | 0.8 | 7.07 | 8.42 | 9.9 | 8.22 |
| **19** | A2H012 | 0.71 | 1.07 | 0.69 | -11.21 | 0.78 | 10.05 | 11.32 | 6.98 | 7.69 |
| **26** | A2H044 | 0.73 | 0.94 | 0.71 | 4.91 | 0.77 | 5.57 | 5.31 | 4.44 | 4.95 |
| **Average** | | **0.74** | **1.04** | **0.76** | **-8.71** | **0.81** | **7.58** | **8.48** | **8.98** | **9.05** |

σ = standard deviation

# Validation

The validation process was conducted on the data from 1 January 2010 to 31 December 2015. These results indicated that model validation produced similar p-factors and r-factors to calibration (Table 8). The average validation r-factor of 1.08 reflected the reduced parameter range developed during calibration. However, the p-factors of 0.74, 0.68, 0.69, and 0.67, simulated for sub-basins 3, 13, 19, and 26, respectively, showed a decrease in comparison to the calibration period. Consequently, the average p-factor for the sub-basins indicated that the parameter uncertainty encompassed 70% of observed data, which bordered the satisfactory performance threshold. $R^2$ results indicated reductions in the linear correlation with measured data compared to the calibration period across all sub-basins, generating values of 0.78, 0.76, 0.63, and 0.70 in sub-basins 3, 13, 19, and 26, characteristic of satisfactory accordance with measured data. PBIAS analysis showed that validation increased the magnitude of model bias in sub-basins 3, 19, and 26, with values of -14.56, -12.09, and 6.49. However, model validation reduced the bias of sub-basins 13 compared to the calibration period due to a value of -15.26. Therefore, sub-basins 3, 19, and 26 were considered satisfactory concerning their simulation bias, whereas sub-basin 13 bordered the PBIAS satisfactory threshold. The NSE values exhibited decreases in all sub-basins during the validation period compared to calibration, except for sub-basin 19, which expressed a marginal increase from 0.69 to 0.70. However, the model still predicted streamflow above a satisfactory standard in sub-basins 3, 13, and 26, producing values of 0.85, 0.73, and 0.63, respectively. As a result, the model performance indicators expressed that the simulation accuracy during validation was inferior to that of the calibration period, which is portrayed by the increase in discrepancies between simulated and observed data in the validation hydrographs (Fig. 5). The reduced model precision during validation is recurrent in SWAT streamflow studies and was suggestive that the parameters characterising the UCRB's response to streamflow during calibration did not precisely describe the basin response outside the calibration period (Abbaspour, 2015). Nevertheless, the statistical and graphical performance measures showed that the calibrated model was verified to simulate monthly streamflow in the UCRB with adequate precision for assessment under climate and land-use changes.

Table 8
The simulation accuracy in the UCRB for the validation period

| Sub-basin | Stream Gauge | p-factor | r-factor | NSE | PBIAS | $R^2$ | Observed mean ($m^3/s$) | Simulated mean ($m^3/s$) | Observed σ ($m^3/s$) | Simulated σ ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|---|
| **3** | A2H019 | 0.74 | 1.06 | 0.85 | -14.56 | 0.78 | 15.14 | 16.79 | 18.49 | 20.05 |
| **13** | A2H083 | 0.68 | 1.19 | 0.73 | -15.26 | 0.76 | 13.43 | 15.85 | 12.13 | 12.19 |
| **19** | A2H012 | 0.69 | 1.13 | 0.7 | -12.09 | 0.63 | 17.18 | 19.26 | 8.31 | 15.63 |
| **26** | A2H044 | 0.67 | 0.92 | 0.63 | 6.49 | 0.7 | 8.83 | 8.29 | 4.46 | 5.11 |
| **Average** | | **0.70** | **1.08** | **0.73** | **-8.86** | **0.72** | **13.65** | **15.05** | **10.85** | **13.25** |

σ = standard deviation

# Climate change scenarios

Graphs of the annual trend in mean temperature and precipitation were averaged from two weather stations as a means to rationalize climate change scenarios for the UCRB. Their gradients indicate that average surface temperatures have been rising by 0.04°C/year with declining annual precipitations of 1.8 mm/year over the UCRB between 1980 and 2020 (Fig. 6). These climatic trends agreed with southern African climate change studies by Graham *et al.*(2011), Kusangaya *et al.*(2014), and Engelbrecht *et al.*(2015), who suggested that its climate will become hotter and drier in the future. Resultantly, for this study, an increase of 1.5°C in temperature and a decrease of 20% in rainfall were used as the climate change scenarios, in line with the Leketa and Abiye (2019) study. The rainfall scenario was deemed suitable for analysis as it concurred with the ± 20% variability in precipitation projected by the IPCC for the end of the 21st century (IPCC, 2001). Moreover, the IPCC provided a special report delineating the potential impacts of a 1.5°C temperature increase relative to pre-industrial levels in an effort to minimise average temperature rises to 1.5°C by the end of this century. Therefore, the temperature and rainfall scenarios provide a sensible extent to global climate change by the end of the 21st century, and hence, the potential climates influencing the UCRB's streamflow.

The plots in Fig. 7 present the climate change scenarios for each sub-basin and depicts that the rainfall changes directly influenced streamflow in the basin. In contrast, the temperature change had inverse effects on stream discharge. As a result, decreasing precipitation by 20% and increasing temperature by 1.5°C resulted in notable reductions in streamflow across the basin. However, these climatic changes were shown to have no influence on peak and low flow simulation compared to the current simulations, suggesting that the climate changes decreased the antecedent moisture conditions in the UCRB and did not influence its basin response (Roberts and Klingeman, 1970).

# Land-use change scenario

The land-use change used for analysis aimed to consider the social and economic factors driving human activity changes in the UCRB. According to DWAF (2008), population growth within the UCRB will continue to exceed the national average despite the UCRB's birth rate being below the national average due to economic-stimulated migration into the basin. As a result, the UCRB's 5.5 million population in 2005 is expected to increase to between 6.4 and 8.3 million by 2030. In addition, most of this growth is predicted to be in the urban growth centres of Johannesburg, Midrand, and Pretoria (DWAF, 2008). Therefore, given the association of the UCRB with large-scale urbanization (Abiye *et al.*, 2015), a 5% increase in urbanization was used as the land-use change assessment, achieved using SWAT’s land-use update table.

The land-use change hydrographs (Fig. 8) showed that a 5% increase in urbanization in the UCRB inflated streamflow compared to the current simulation in each sub-basin. Moreover, all sub-basins expressed uniformity that the urbanization increased the magnitude of peak flows and advanced peak flow simulation. As a result, the increased urbanization influenced streamflow similarly to previous urbanizations studies (Cheng and Wang, 2002; Moon *et al.*, 2004), suggesting that a 5% urban expansion increased the imperviousness of the UCRB.

# Worst-case scenario

A worst-case scenario was developed for the UCRB to illustrate the impacts of its envisaged climate and anthropogenic activity changes on run-off and infiltration processes, and therefore, water availability using streamflow hydrographs (Fig. 9). These hydrographs were synthesized using the 5% urbanization increase land-use update and the climate changes reflecting a 20% reduction in precipitation and 1.5°C temperature increase. The worst-case scenario hydrographs show similarities to the urbanization scenario regarding the advancement of peak flow occurrence across all sub-basins. In contrast, the worst-case scenario decreased streamflow below the current simulation in each sub-basin, showing substantial reductions in high and low simulation compared to the 5% increase in urbanization, suggesting that the temperature and rainfall changes accompany the worst-case scenario reduced water availability in the UCRB.

# Comparative analysis

For further characterization of the relative and combined impacts of land-use and climate changes in the UCRB, a comparative analysis was performed to quantify the streamflow effects of these changes. The assessment expressed the change in streamflow due to the climate and land-use s scenarios as a percentage difference compared to the current simulation in each sub-basin (Table 9), representing the calibrated model's streamflow response to the realistic climate and human activities occurring over UCRB.

Table 9
The variation in streamflow due to climate and land-use changes

| | **Climate changes** | | | | | |
|---|---|---|---|---|---|---|
| **Sub-basin** | **+ 20% Rainfall** | **-20% Rainfall** | **-1.5°C Temperature** | **+ 1.5°C Temperature** | **+ 5% Urbanization** | **Worst-case scenario** |
| **3** | 53% ↑ | 27% ↓ | 21% ↑ | 28% ↓ | 27% ↑ | 16% ↓ |
| **13** | 45% ↑ | 21% ↓ | 20% ↑ | 26% ↓ | 25% ↑ | 12% ↓ |
| **19** | 48% ↑ | 23% ↓ | 27% ↑ | 30% ↓ | 23% ↑ | 10% ↓ |
| **26** | 49% ↑ | 22% ↓ | 25% ↑ | 28% ↓ | 15% ↑ | 19% ↓ |
| **Average** | **48.75% ↑** | **23.25% ↓** | **23.25% ↑** | **28% ↓** | **22.5% ↑** | **14.25% ↓** |

These results indicate that streamflow was more sensitive to the temperature increase related to climate change than the decrease in precipitation. Reducing rainfall by 20% provided an average streamflow decrease of 23% across all sub-basins. Sub-basins 13, 19, and 26 expressed similar streamflow reductions of 21%, 23%, and 22%, respectively, whereas sub-basin 3 showed a more significant streamflow decrease of 27%. Increasing the temperature in sub-basins 3, 13, 19, and 26 produced streamflow simulation reductions of 26%, 28%, 30%, and 28%, resulting in a mean decrease of 28% across the basin. The 5% increase in urbanization increased streamflow in the UCRB by an average of 22.5%. Sub-basin 26 displayed a minor streamflow increase of 15%, whereas sub-basins 3, 13, and 19 expressed greater streamflow inflations of 27%, 25%, and 23%, respectively. In contrast, the worst-case scenario decreased streamflow in the UCRB by 14% on average, producing streamflow reductions of 16%, 12%, 10%, and 19% in sub-basins 3, 13, 19, and 26, respectively. Moreover, comparing these results to the urbanization scenario indicated that the climatic changes associated with the worst-case scenario subsequently decreased streamflow by 43%, 37%, 33%, and 34% in sub-basins 3, 13, 19, and 26, respectively. Therefore, the results for sub-basin 19 were consistent with the 39% reduction approximated by Leketa and Abiye (2019) using the same climatic changes.

The individual impacts of an increase in temperature and decrease in precipitation and their combined effects, portrayed by the worst-case scenario, were shown to drastically reduce streamflow in each sub-basin. Hence, it was determined that these climatic changes decreased the antecedent moisture conditions, ultimately reducing water availability for run-off and infiltration. Although increasing urbanization inflated streamflow in the basin, its streamflow effects indicated a strengthening of the impervious nature of the UCRB, thereby enhancing run-off and decreasing infiltration. Decreases in infiltration are related to reduced groundwater recharge, and hence, lower baseflow feeding the stream network. Consequently, the UCRB's envisaged climate and land-use changes might have devastating consequences for the quality of its surface water resources as reduced baseflow results in less natural water for dilution of lower quality wastewater in the basin (Leketa and Abiye, 2019). In addition, increasing urbanization is expected to yield larger water surpluses due to inflated return flows in the basin (DWAF, 2004). Therefore, it is predicted to compromise the quality of streams and impoundments in the UCRB, particularly the Hartbeespoort Dam (DWAF, 2008). Groundwater resources may also be negatively influenced by these changes given its connection with surface water in various parts of the basin (Abiye, 2011; Abiye *et al.*, 2011; Abiye, 2014; Abiye *et al.*, 2015). The predicted change towards decreased infiltration will likely reduce recharge and the availability of groundwater resources. In addition, decreasing infiltration may also reduce the abundance of freshwater below the surface, which will mitigate the dilution between fresh and polluted water, adversely affecting the basin's groundwater resources quality.

# Conclusion

This study was aimed to assess the applicability of the SWAT model in simulating the streamflow response of the Upper Crocodile River Basin to land-use and climate changes. The Upper Crocodile River Basin encompassed part of the major cities of Johannesburg and Pretoria and received effluents from numerous wastewater treatment plants, making water quality of primary concern in the basin. In addition, the UCRB's predicted urbanization increases and climate change towards decreased water availability might aggravate its water quality concerns. Therefore, it was necessary to model the impacts of climate, and human activity changes on streamflow in the UCRB to mitigate their potential influence on water resources in the basin. The calibration and validation accuracy analysis using the $R^2$, PBIAS, and NSE performance measures showed that SWAT adequately simulated stream discharge with recorded data across all sub-basins for evaluation under climate and land-use scenarios. The UCRB's envisaged climate change towards hotter and drier conditions, reflected by a 1.5°C increase in temperature and a 20% reduction in rainfall, decreased the low and peak flow simulation, suggesting a decrease in the antecedent moisture condition in the UCRB. The 5% urbanization increase enhanced run-off and peak flow magnitude and reduced the lag time between precipitation and run-off, indicative of a more impervious UCRB. Therefore, the UCRB's predicted climate and land-use changes ultimately reflect lower baseflow contribution to streamflow. Hence, effluent loadings from wastewater treatment plants will likely constitute a more significant portion of stream discharge, reducing water quality in the basin. Moreover, the connection between surface and groundwater suggests that groundwater resources will also be adversely affected by the UCRB's predicted climate and human activity changes. Consistency between the climate and land-use change results for all evaluated sub-basins indicate that decreased water quality and availability will affect the entire UCRB, from the streams draining Johannesburg to the Crocodile River draining the basin through the Hartbeespoort and Roodekoppies Dams. Therefore, improved integrated water resources management, beyond the current developed scope, is necessary to ensure water sustainability in the UCRB.

# Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

The data collection, synthesis, calibration, and validation of the model were performed by Byron M. Fynn. The first draft of the manuscript was written by Byron M. Fynn. Prof. Tamiru A. Abiye assisted in reviewing and analyzing the model and editing the first draft of the manuscript.

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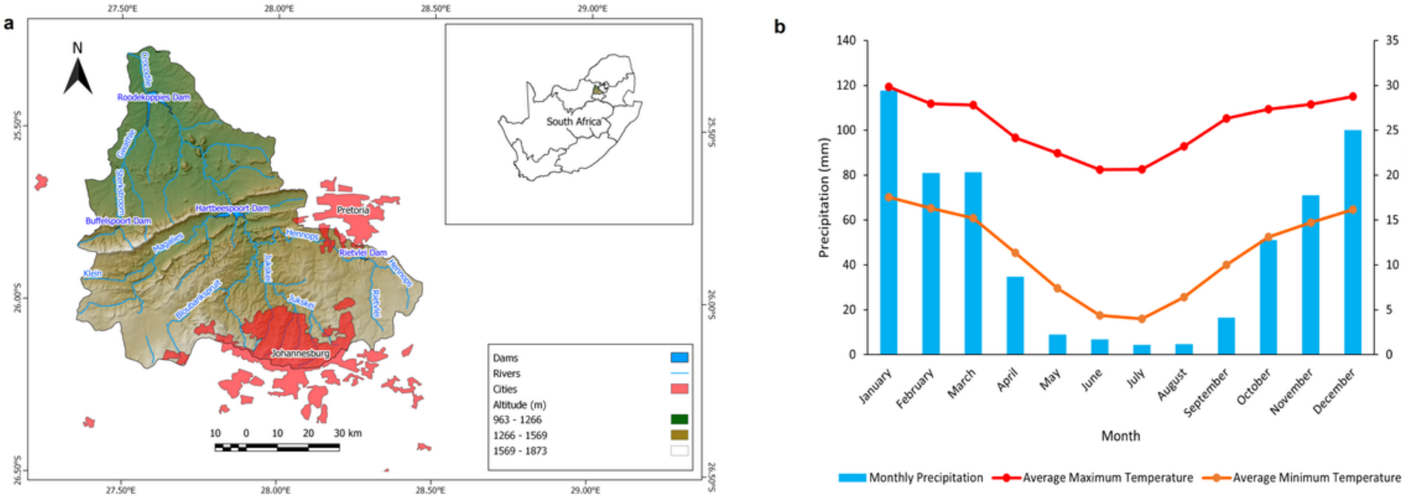
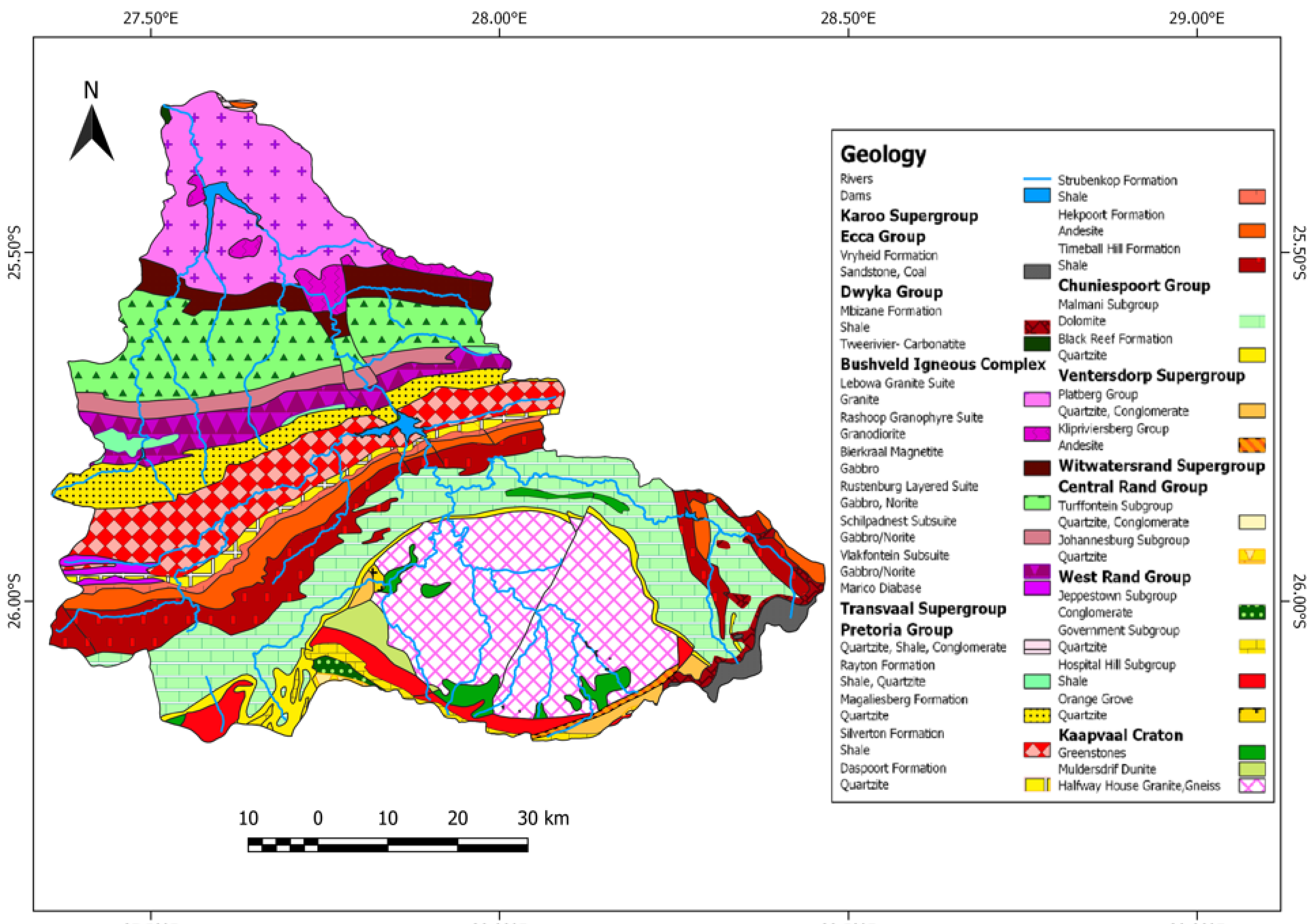
# Figures



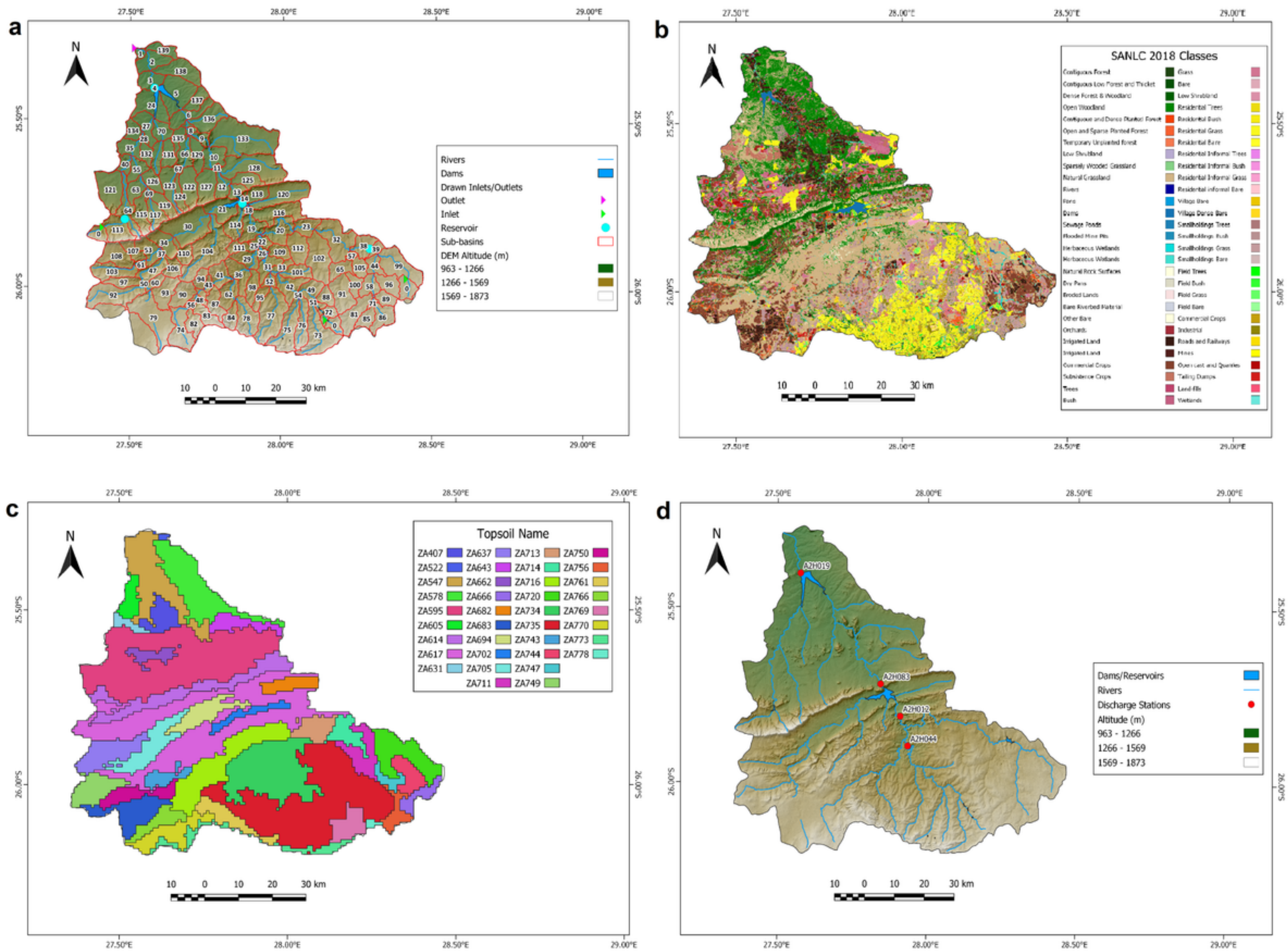

## Figure 1

(a) Locality map of the UCRB (b) The monthly average rainfall, maximum and minimum temperatures for the UCRB's weather stations (1980-2020)



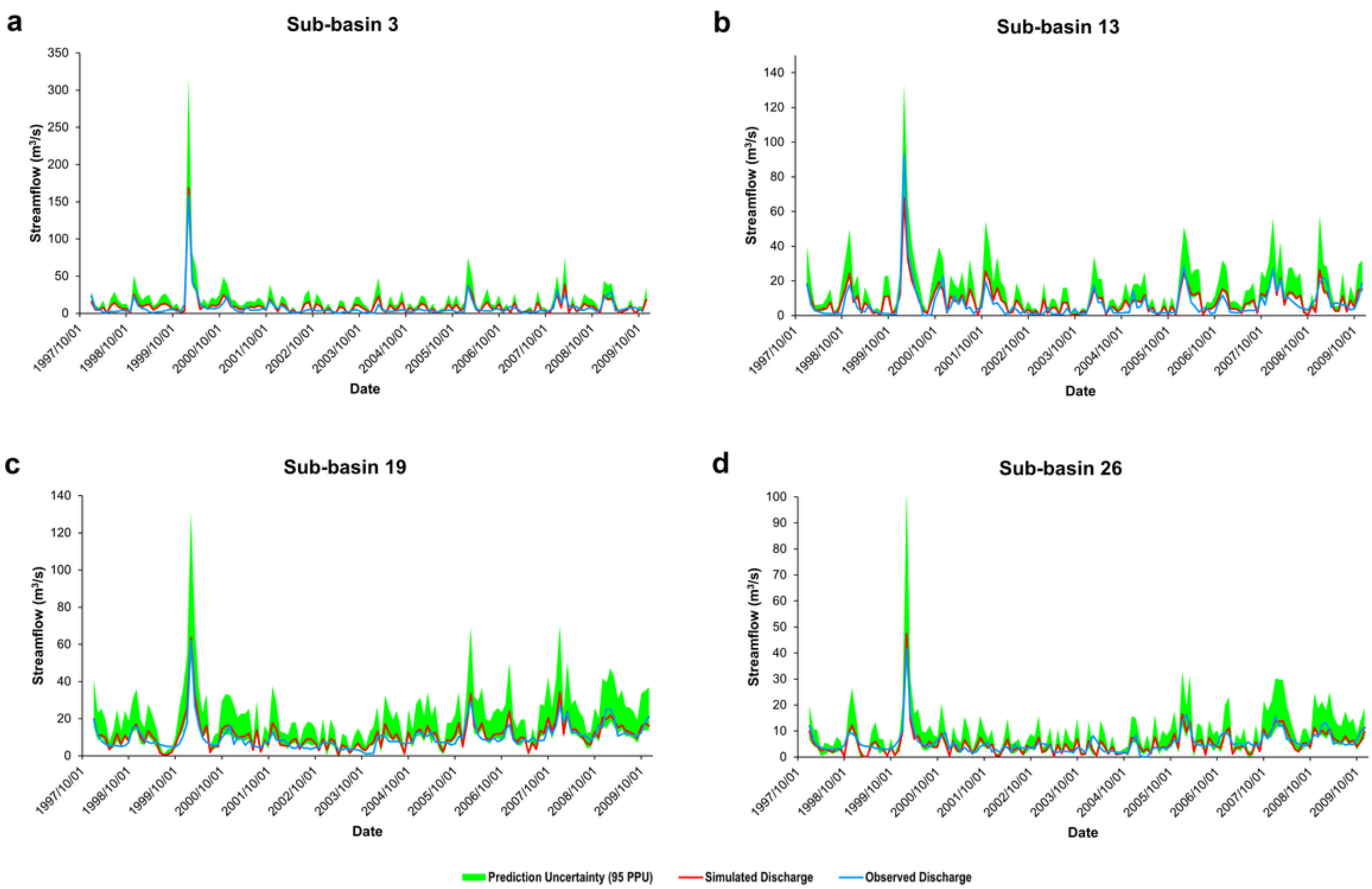
## Figure 2

Geological Map and Lithostratigraphic sequence of the UCRB



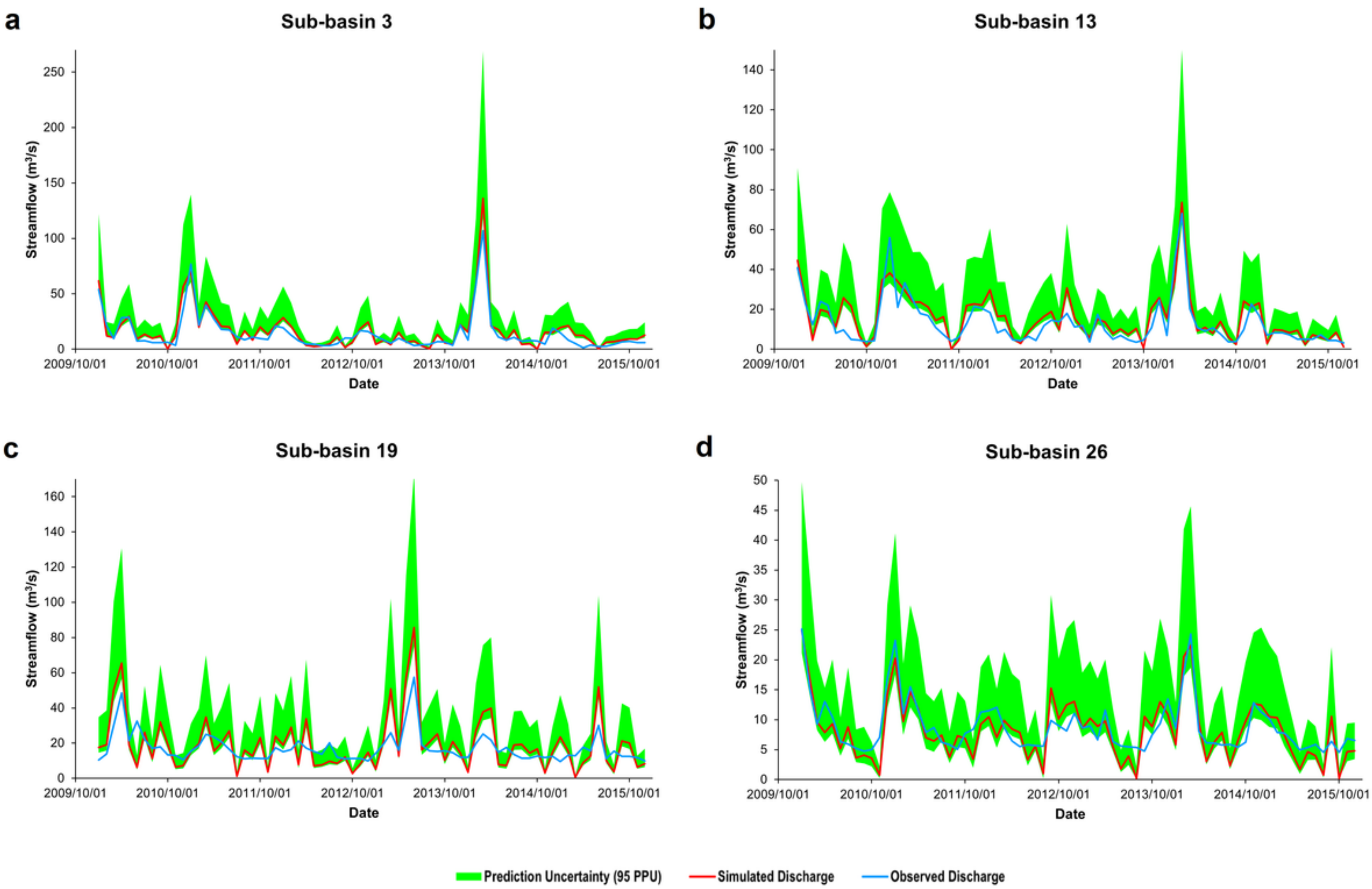

## Figure 3

The (a) sub-basins (b) land-use practices (c) soils and (d) discharge stations used for the development and analysis of the UCRB SWAT model



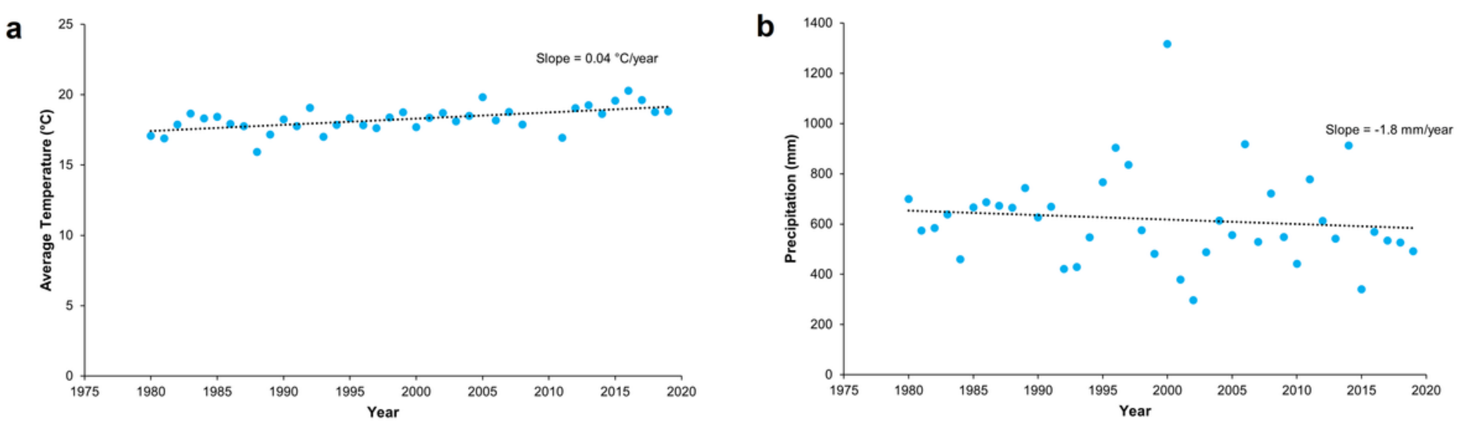

## Figure 4

The calibration hydrographs for the sub-basins containing discharge stations



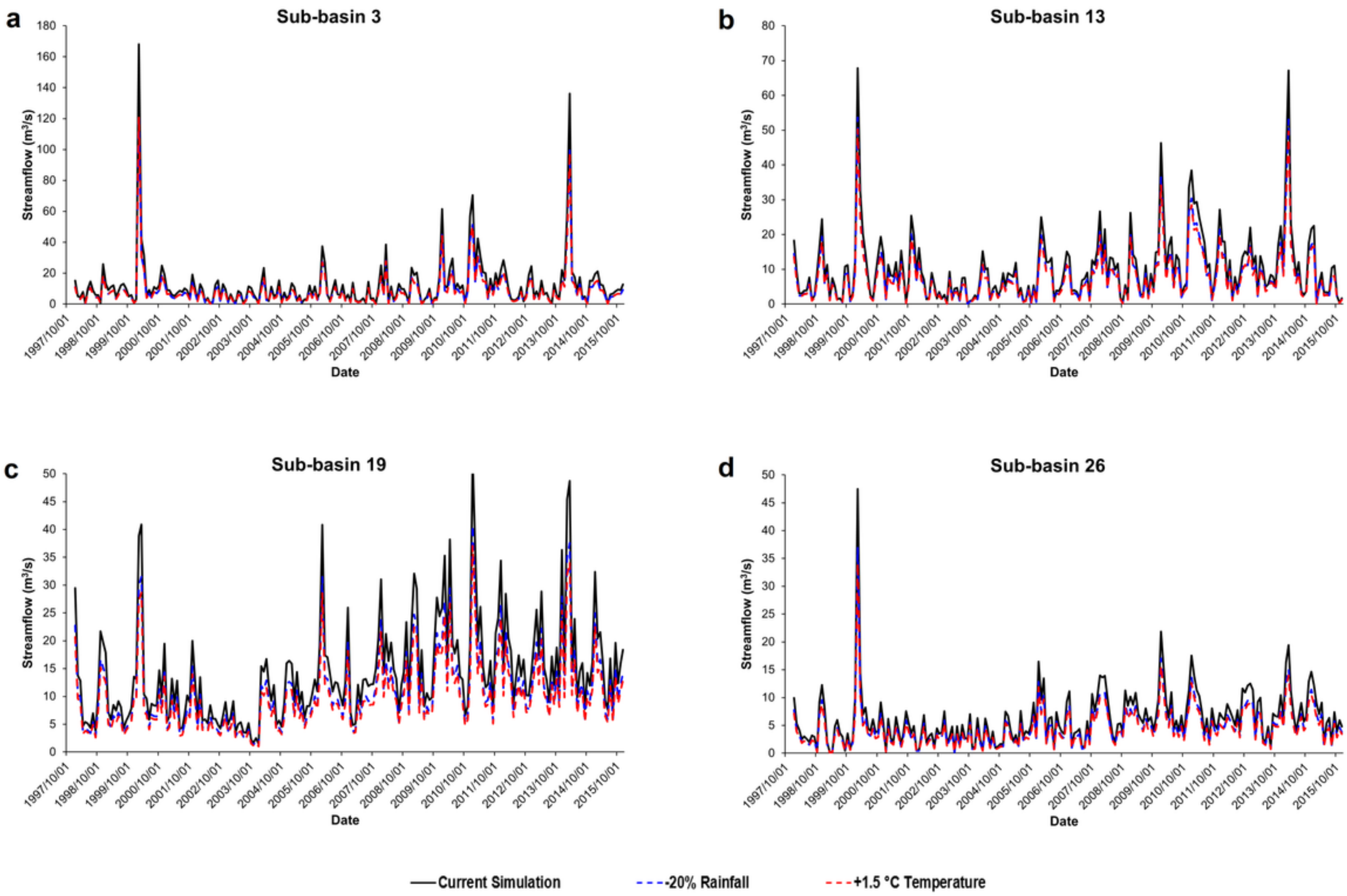

## Figure 5

The validation hydrographs showing the simulation accuracy compared to recorded streamflow



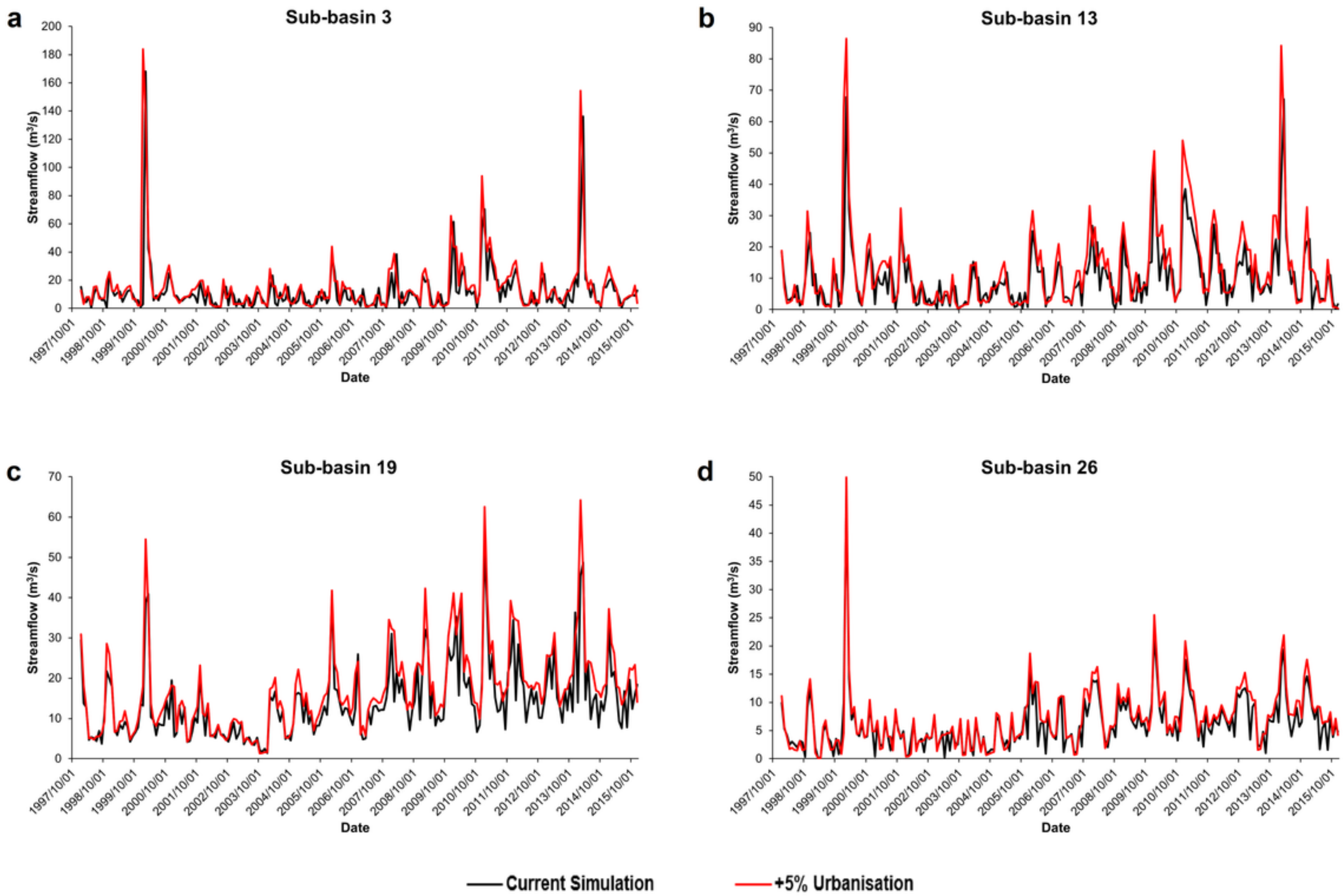

## Figure 6

The annual average (a) temperature and (b) precipitations experienced over the UCRB from 1980 to 2020




## Figure 7

The climate change hydrographs for the UCRB




## Figure 8

The increase in urbanization land-use scenario for the UCRB

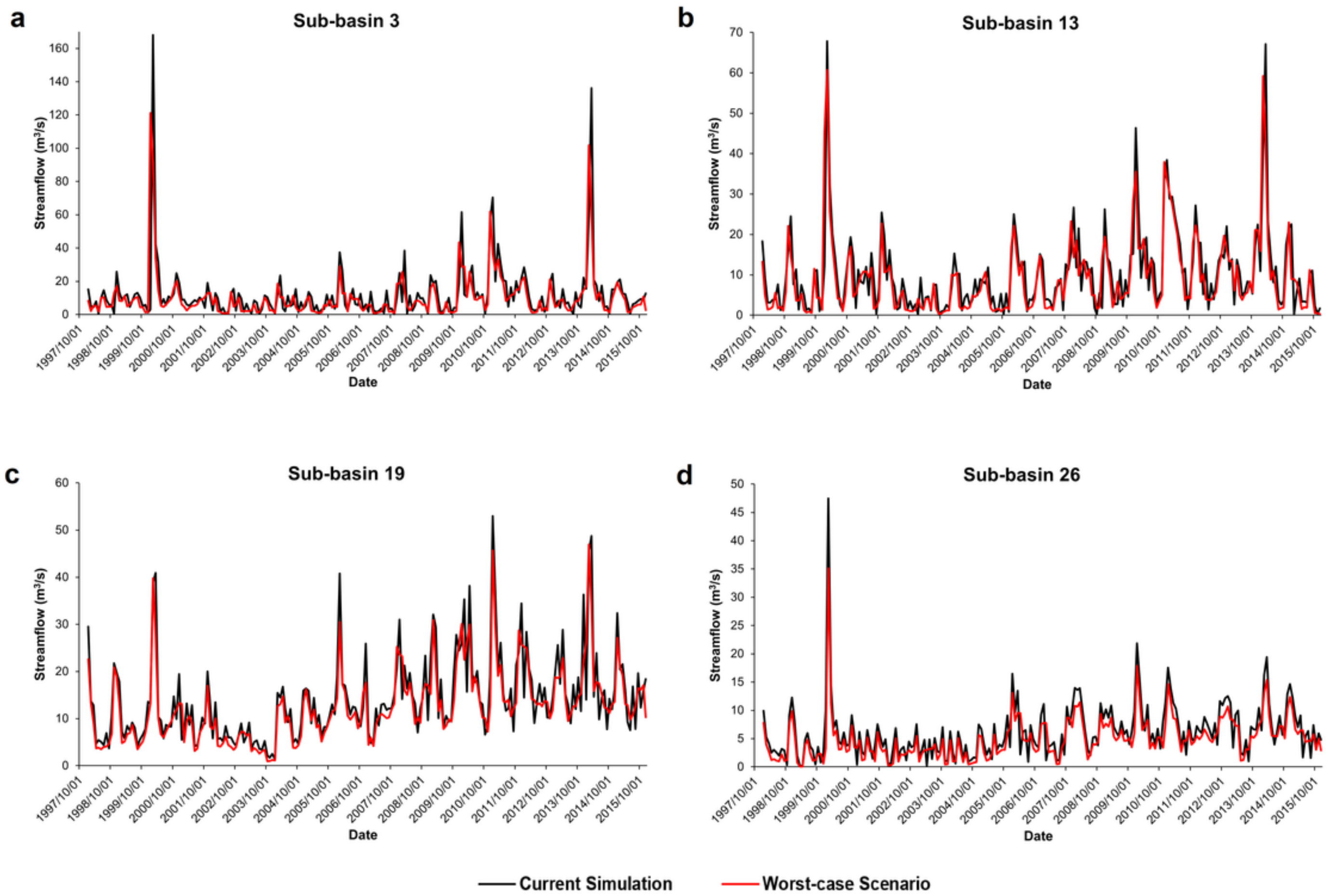



**Figure 9**

Streamflow hydrographs for the worst-case scenario in the UCRB

# Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- A2H012Subbasin19.xlsx
- A2H019Subbasin3.xlsx
- A2H034Subbasin104.xlsx
- A2H044Subbasin26.xlsx
- A2H045Subbasin29.xlsx
- A2H083Subbasin13.xlsx
- Calibratedsensitivitygraph.png
- ConsideredParametersSensitivity.png
- LanduseLookup.csv
- Monthlyflowout13.csv
- Monthlyflowout19.csv

- Monthlyflowout26.csv
- Monthlyflowout3.csv
- Monthlyflowoutvali13.csv
- Monthlyflowoutvali19.csv
- Monthlyflowoutvali26.csv
- Monthlyflowoutvali3.csv
- Pretoriadwp1.txt
- QSWATRef2012.mdb
- RainDecSub13.csv
- RainDecSub19.csv
- RainDecSub26.csv
- RainDecSub3.csv
- RainIncSub13.csv
- RainIncSub19.csv
- RainIncSub26.csv
- RainIncSub3.csv
- Subbasin104Vali.png
- Subbasin13Vali.png
- Subbasin13.png
- Subbasin13.xlsx
- Subbasin19Vali.png
- Subbasin19.png
- Subbasin19.xlsx
- Subbasin26Vali.png
- Subbasin26.png
- Subbasin26.xlsx
- Subbasin29Vali.png
- Subbasin3Vali.png
- Subbasin3.png
- Subbasin3.xlsx
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- Sub13RainInc.png
- Sub13TempDec.png
- Sub13TempInc.png
- Sub13UrbanInc.png
- Sub13WCS.png
- Sub19RainDec.png
- Sub19RainInc.png

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- Sub3RainDec.png
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- UrbanIncSub3.csv
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- UsersoilTable.xlsx
- WCSSub13.csv
- WCSSub19.csv
- WCSSub26.csv
- WCSSub3.csv
- soillookupUCRB.xlsx