Past and present spatial precipitation variability in the upper middle catchment of the Olifants River basin

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Abstract. Within the context of catchment hydrology, using the Soil and Water Assessment Tool (SWAT) model, this paper attempts to assess the past and present spatial precipitation variability in the upper middle catchment (UMC) of the Olifants River basin. The study shows a strong decreasing trend of east-to-west direction of spatial precipitation with most rainfall concentrated in the eastern part of the area. Within the western part of the UMC, we also noted another decreasing trend of precipitation from south to north with northern areas of the study area receiving the least amount of rainfall. This localized spatial precipitation variability in the area, from past and present, underlines the importance of studies targeting localized areas within a larger and wider river basin like the Olifants where such variations could otherwise been overlooked.

1. Introduction
In general, precipitation and potential evaporation, are the main climatic drivers controlling global freshwater resources.[1] Thus, precipitation is the main input in the hydrological cycle and indeed the main driver of the hydrological systems over land (e.g. streamflow, groundwater recharge, etc). However, in most river basins,[2] precipitation (e.g. rainfall and snowmelt) has a direct effect on our water supplies because it affects not only groundwater recharge but also river baseflow. For example, baseflow feeds into our surface waters through streamflows and eventually our dam reservoirs which happen to be the major sources of water supply in most African countries particularly South Africa. Therefore, any change in precipitation variation, will eventually affect water supply, be it groundwater or surface water. It is therefore important to understand precipitation variability as it affects these water resources not only on global or national level but also at local level where most decisions affecting water resources are based on. In large basins with wider climatic variations, such as the Olifants, the catchment hydrology is characterized by high spatial rainfall variability yet this is rarely noticed. Therefore, this study used the Soil and Water Assessment Tool (SWAT) model to try to assess and understand the extent of spatial precipitation variability between the past and present periods within the upper middle catchment (UMC) of the Olifants River basin.
2. Methodology

2.1. Study area

The study area was the Upper Middle Catchment (UMC) of the Olifants River basin (Figure 1) in South Africa. This area can be located between the following latitudes (24° 38’ 53” S and 26° 37’ 45” S) and longitudes (28° 02’ 56” E and 29° 59’ 22” E). Along the Olifants River, the area stretches from the river source near Trichardt, north of Secunda, in the province of Mpumalanga just to the east of Johannesburg City, all the way passed the Loskop Dam to the confluence with Elands River, just south of the Boshielo Dam (formerly known as Arabie Dam) within the Schuinsdraai Nature Reserve in the Sekhukhune District of the Limpopo Province. In the East-Westwards direction, it covers an area from Belabela (formally known as Warmbaths) near N1 toll-road to the R579 road just before the Steelpoort River in the east. Hydrologically, the UMC is part of the Olifants River catchment, itself a principal sub-catchment of the Limpopo River basin. The UMC covers Secondary Drainage areas, B1, B2 and B3. In total, the study area has 3 Secondary Drainage areas, 5 Tertiary Drainage areas and a total of 43 Quaternary Drainage areas. This part of the Olifants River basin receives precipitation in the range of 600-800 mm per year, with a mean annual precipitation and evaporation of 659 mm and 2103 mm respectively. Most of the rainfall in the area occurs between summer months of December - February. [5] According to the South African Weather Services, [5] South Africa has basically four (4) weather seasons, namely, Spring (September - November), Summer (December - February), Autumn (March – May), and Winter (June – August). These are the same seasons experienced in the UMC.

![Figure 1](image_url). The study area (upper middle catchment) in relation to the entire Olifants River basin in South Africa.

2.2. Model calibration

In this study, the calibration and validation performance of the SWAT model was assessed using the observed discharge (streamflow) values from the B3H001 streamflow gauge at Loskop Noord on the main course of the Olifants River. The calibration process focused on adjusting model-sensitive input parameters determined from the sensitivity analysis performed previously in the basin by [6] and presented in (Table 1). Therefore, using this streamflow data from the B3H001, the SWAT model was calibrated manually with streamflow data from 1991 to 1995 and validated for the period 2002–2006. The first 3 years prior to 1991 were used as a warm up period to mitigate unknown initial conditions.
The manual calibration procedure of the SWAT model has enjoyed wide application from many researchers such as [7], [8], [9].

| Parameter  | Description                                      | Range   | Fitted Value | t-Stat |
|------------|--------------------------------------------------|---------|--------------|--------|
| CN2        | Runoff curve number                              | 35–98   | 65*          | 37.72  |
| ALPHA_BNK  | Base flow alpha factor for bank storage          | 0–1     | 0.39         | 6.97   |
| ESCO       | Soil evaporation compensation factor             | 0–1     | 0.67         | 5.57   |
| SOL_AWC    | Soil available water capacity                     | 0–1     | 0.2          | 4.13   |
| GW_DELAY   | Groundwater delay (days)                          | 0–500   | 345          | 3.02   |
| GW_REVAP   | Groundwater “revap” coefficient                  | 0.02–0.2| 0.15         | 2.34   |

Notes: * Average basin value.

2.3. Data

The digital elevation model (DEM) used in this study came from the NASA Shuttle Radar Topography Mission (SRTM) Version 3.0 Global, in coverage of 1° x 1° tiles at 1 arc second (about 30 meters) resolution, and was obtained from the United States Geological Survey (USGS) database using the EarthExplorer tool. The land use land cover (LULC) maps also were obtained from the same source, then clipped to the study area watershed. The LULC maps used in the study were prepared for two time steps, 2009 map was used for the past period, while the 2014 map was used for the present period. The digital soil map and information on related soil properties for the study area were obtained from the Food and Agriculture Organization (FAO).

The climate data used in this study was obtained from the five weather stations located within and around the study area (Table 2). This climate data was based on the three primary climate variables, i.e. monthly precipitation totals, maximum and minimum monthly temperatures. Since the SWAT model uses daily climate data as its input data, this monthly data was converted into daily data using a program called MODAWEC. [10] After the daily climate data was generated, it was then used in the SWAT model together with the soil data, land-use/cover data and the topographic data (DEM). After all this was done, the SWAT model was run to generate the intended outputs.

3. Results and discussions

3.1. Calibration and validation of the SWAT model

The calibration results generally showed good agreement between simulated and observed runoff (Figure 2(a)), with Root Mean Square Error (RMSE) observations standard deviation ratio (RSR) equal to 0.17, Nash-Sutcliffe model efficiency (NSE) greater than 0.90, and percent bias (PBIAS) being -73%. The coefficient of determination ($R^2$) was 0.51, slightly lower than the recommended value proposed by [11] but then greater than the recommended threshold suggested by. [8] The PBIAS showed a percentage outside the recommended range, thereby, implying that the SWAT model actually overestimated the streamflow of the study area. This may be due to the observed low
streamflows, frequently with zero daily flow during most part of the dry season (June, July and August).

The validation results (Figure 2(b)) also showed a good correlation between the simulated and observed streamflow (runoff). The model goodness-of-fit measure ($R^2$) was above 0.5. The NSE and RSR were 0.9 and 0.16 respectively. However, the model again showed a PBIAS of -70% which was outside the range suggested by [11]. Nevertheless, the validation also showed a good agreement between the simulated and observed daily discharge.

![Figure 2](image2.png)

**Figure 2.** Observed and simulated daily direct runoff for (a) calibration and (b) validation of the SWAT model.

3.2. **Spatio-temporal rainfall variability**

PAST PRECIPITATION (1960 – 2010)  
PRESENT PRECIPITATION (2011 - 2018)

![Figure 3](image3.png)

**Figure 3.** Spatio-temporal variation of precipitation for the study area (mm).
Figure 3 shows a general trend of spatial variation of annual precipitation in the UMC, with most of the precipitation concentrated in the eastern part. It also shows that there is a strong decreasing trend of precipitation from east to west direction for both the past and present period. The western part of the area receives the lowest annual precipitation. However, within the western part of the UMC, it is also noted that the northern part receives less annual precipitation than the south, again indicating another decreasing trend of precipitation in the direction of south-north. This trend seems to be the same for both the past as well as the present period.

It was also noted that between the past and present periods, precipitation has slightly shifted in the study area, with the variations becoming even more pronounced when precipitation is considered on a seasonal or monthly basis, starting from spring all the way through summer to autumn and winter. When compared with the past period, spring precipitation shows an increase of 4.6% while the summer precipitation has dropped by the same amount (-4.6%). The autumn and winter precipitation in the UMC has increased by 8.5% and 5.2% respectively.

4. Conclusions
This study has focused mainly on the spatial variability of precipitation in the upper middle catchment of the Olifants River between the past and present periods. To achieve this, the calibrated version of the SWAT model was used. The hydrological and climate data used in this study has been validated and endorsed in many studies done not only in the Olifants River basin but also elsewhere. From the study, it is noted that precipitation in the UMC does not only vary from east to west but also from south to north directions.

Like other African countries, in South Africa, the economy and livelihood of the people in general is highly correlated with climate (especially precipitation) variability. Compounded with the level of poverty, rapid urbanization, and low level of adaptive capacity and resilience to climate variability, there is now no doubt about the importance of understanding local climate variation both on spatial as well as temporal scales.

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