RUNOFF ESTIMATION FOR NZOIA BASIN USING NASA'S GEOS-5 SATELLITE DATA

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Abstract

With the climate fluctuating at the present era, it makes sense to constantly seek to improve our climate change resilience. This involves researching into how the weather develops climate-related risks, and taking steps aimed at coping with these risks. In Kenya, flooding is the most acute event associated with climate change resilience. Flooding occurs due to excessive runoff from a catchment area. Therefore, identifying watersheds and studying their runoff characteristics would provide valuable information to use in improving our climate change resilience. Nzoia basin exhibits temporal and spatial scarcity of rainfall and temperature data available; both for satellite and observed data. Data from rain gauge networks is insufficient at a temporal scale, and would pose challenges when used in runoff estimation. National Aeronautics and Space Administration (NASA) manages the Goddard Earth Observing System model version 5 (GEOS-5) satellites. Satellites by nature are however poor on a spatial scale and therefore need area-specific calibration and validation due to the indirect nature of radiation measurements. This study aimed at improving data available from GEOS-5 satellite for use in runoff studies. By carrying out statistical analyses on temperature and rainfall data from the satellite, it is possible to calibrate this data and analyze its effectiveness in runoff estimation. With the reference being observed runoff, use of calibrated data for runoff estimation improved R-square coefficient from 0.6 to 0.9. This proves the feasibility of the study.

Keywords: Climate, Runoff, Temporal, Spatial, Calibration.

1 Introduction

Climate resilience defines the capacity of a socio-ecological system to absorb stresses and maintain function in the face of external stresses imposed on it by climate change. It also defines the subsequent process of adapting, reorganizing and evolving into more desirable configurations that improve the sustainability of the system, leaving us better prepared for future climate change impacts. There are three concepts to climate resilience; absorptive, adaptive and transformative strategies. To be effectively prepared, sufficient data on the behavior of the climate parameter in question is paramount. This need is further compounded by the fact that fluctuations of the climate in the current era are becoming more severe and frequent. Research on how weather develops climate-related risks and taking steps aimed at coping with these risks is getting more urgent every day.

In Kenya, flooding is the most dramatic and devastating event associated with climate change resilience. Floods occur when runoff in a catchment area is excessive, causing inundation of land above the expected limits of a water channel. The identification of watersheds and the study of their runoff characteristics is probably the most important step in improving our resilience to flooding. Nzoia basin provides a good representative of a typical flood prone basin in Kenya. It continuously exhibits an iterative increase in the number of flood related disasters.

Nzoia basin exhibits temporal and spatial scarcity of rainfall and temperature data available; both for satellite and observed data. Data from rain gauge networks is insufficient at a temporal scale, and would pose challenges when used in runoff estimation. Of the 113 stations with observed rainfall data, only 19 stations had satisfied 80% completeness of data recorded from 1982-2009. This means that less than 0.2% of weather stations in Nzoia basin provide enough data to meet the lowest limit required for use of a dataset in further analysis. For the considered temporal range (1/1/1982 to 12/31/2009), quite a number of stations were even observed to have zero recorded data. In fact, most stations available for Nzoia basin have their percentage completeness for rainfall data below 50% for the considered time period. These missing values are unsuitable for hydrological analysis, including use in runoff estimation.

National Aeronautics and Space Administration (NASA) manages the Goddard Earth Observing System model version 5 (GEOS-5) satellites. Satellites by nature are however poor on a spatial scale (ranging from 100x100km 250x250 km and 250x375km etc.) They also exhibit errors due to uncertainties involved with remote sensing and indirect nature of radar measurement.

Therefore, for satisfactory use in hydrological analysis, satellites need area-specific calibration and validation due to the indirect nature of radiation measurements.

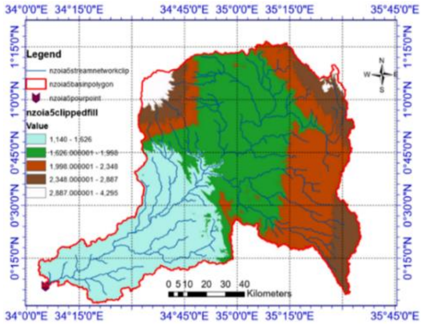

Figure 1: Nzoia basin

Main Objective

The main objective of this study was to improve NASA's GEOS-5 meteorological data available for Nzoia basin for runoff estimation.

Specific Objectives

1. To carry out statistical analysis of observed and GEOS-5 satellite data.
2. To calibrate GEOS-5 satellite data with weather station data.
3. To setup and calibrate a rainfall-runoff model for the basin.
4. To determine the performance of calibrated GEOS-5 satellite data for runoff estimation in Nzoia basin.5

2 Methodology

On collection, both NASA satellite data and weather station data (rainfall and temperature) were to be checked for quality by statistical analysis. Then, the data was calibrated by regression analysis (RA). A runoff model was then to be used to estimate runoff for Nzoia basin.
Below are the procedures employed:

2.1 Catchment Delineation

Catchment delineation was to be achieved in order to give an overview of the catchment and its parameters. These were helpful in runoff estimation for the basin. For instance, catchment area is an important requirement in the runoff model. Delineation was also particularly useful in the choice of stations since it gave the spatial distribution of the stations with respect to the basin. The Arc map software from ArcGIS software were used to process the basin at this stage.

2.2 Statistical Analysis

Statistical analysis was a very vital and core part of the project. It not only enabled quality control of the input and output data obtained, but it also enabled the simplification of the data for easy and accurate analysis. It was not only used as a measure to ensure quality control, but was also a means of organizing, sorting, analyzing and testing the viability of the data at every step throughout the process. In essence, statistical analysis is a tool with which manipulation of the data, quality control and organization was carried out.

2.3 Calibration of Rainfall and Temperature Data

In the project, data for each station was simplified into monthly values. Comparing monthly satellite and weather station data for instance, gave the factors required to bring the satellite data to weather station limits. From this, analysis of the range between the two sources was carried out and calibration of the data was possible. Finally, the factors acquired were applied into the satellite data to give the calibrated output as desired.

2.4 Runoff modelling

For the limited information available to the researcher, use of one dimensional (1D) unsteady flow hydrodynamic runoff model was advised, preferably one using Saint-Venant equations. Mike 11 model from the Danish Hydraulic Institute meets the above criteria (Danish Hydraulic Institute, 2007). NAM mike 11 software was therefore used in analysis. It makes use of the NAM model. The NAM model is a deterministic, lumped and conceptual rainfall-runoff model accounting for water storage in up to 4 different storages.

NAM mike 11 model balances inputs and storages of a basin to determine runoff in a basin. Basically, it takes into account the assumptions made by the hydrological balance assumption. It considers the theory that the basin is made up of various storage units. Until these units are full, there is no runoff observed from the basin.

By varying the sizes of these storages until a suitable estimate is found, it is possible to provide the runoff estimates of the basin in consideration.

Thus, the only major inputs and outputs of the model are rainfall (input), evaporation (output) and runoff (output). In the project, rainfall was already determined, and evaporation can be determined from maximum and minimum temperatures. Thus, NAM mike 11 provided a suitable model for the project as its input data was what was easily available to the researcher.

NAM mike11 involves three basic steps that each represents a stage in the process;

1. Time series

This is where the data is added. As required, you add the rainfall, evaporation and observed discharge for the basin.

2. Rainfall Runoff Parameters

Here, the catchment and catchment areas are adjusted. In addition, the parameters that represent the storage parameters exist in this folder and are to be edited and saved accordingly. Editing and saving the parameters until runoff simulated closely resembles the observed runoff constitutes the calibration of the runoff model.

3. Simulation

This involves the use of catchment parameters into the time series to simulate the runoff from the basin.

3 Results and Discussion

3.1 Introduction

The data available to the researcher covering both the satellite and observed values was from 1982 to 2009. This was considered as the time period for the study.

Choosing rainfall stations was based on the percentage completeness. Complete stations lead to more accurate results due to the availability of data. They are also easy to interpolate since only few values are to be determined. The stations that were 90% complete provided a suitable spatial distribution for most of the basin, apart from in the North West part. Therefore, Keiyo-Marakwet rainfall station at 80% completeness limit was added to the stations used in the study to provide an even spatial distribution.

For temperature data, only three stations were available to the researcher and thus they were adopted.

The spatial distribution of temperature and rainfall stations within Nzoia basin is described in the figure below;

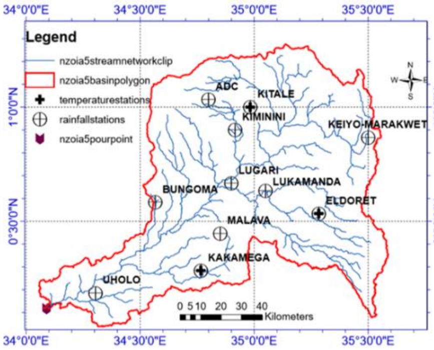

Figure 2: Stations chosen for the study

3.2 Calibration of the Runoff Model

This generally involved changing of the parameters for Nzoia basin till the output that is simulated is similar to the observed discharge.

By changing parameters iteratively, it was possible to obtain the best or optimum parameters. The best parameters are those that give the least root mean square error with the following conditions met:

a. You do not exceed the maximum range of the considered parameters

b. The water balance lies within 0.95 and 1.05, i.e. the difference between the simulated and observed values does not stray to more than five percent.

The time period chosen for calibration of the rainfall-runoff model was 1982 – 1990. Leaving out a warm up of two years, the calibration of the runoff model began in 1984 and then the validation period followed the calibration period.

3.3.1 Simulated Data – Calibration

The following were the results obtained from the optimum parameters;

Water balance = Simulated /Observed = 0.98

R square coefficient = 0.91

The following represents the data as obtained. Note how the missing values in 1985 observed data causes errors in accurate runoff estimation. This is because missing values force the runoff model to estimate zero runoffs that do not exist, which leads to errors in runoff estimation.

The optimal calibration is represented in the figure below;

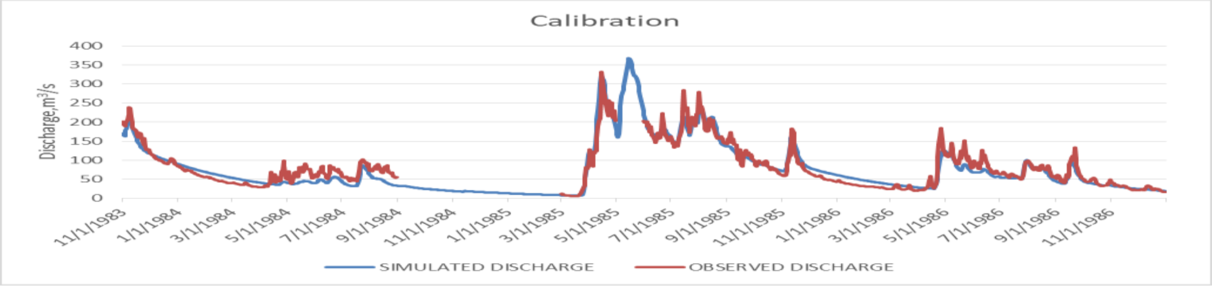

Figure 3: Calibration discharges; Simulated and Observed

From the figure above, it is noted that simulation using the identified parameters provide a good estimate of observed discharge. Therefore, the parameters provided are suitable.

However, it is important to note the negative influence of the missing values on the efficiency of the data calibration carried out.

3.3.3 Validation of the Runoff

It was concluded from validation that the parameters provided a reasonable estimate of the data considered. With an r-square coefficient of 0.8 in comparison to observed values, this provides a reasonable estimate of the data.

The figure below represents the simulated and observed discharge for the runoff period;

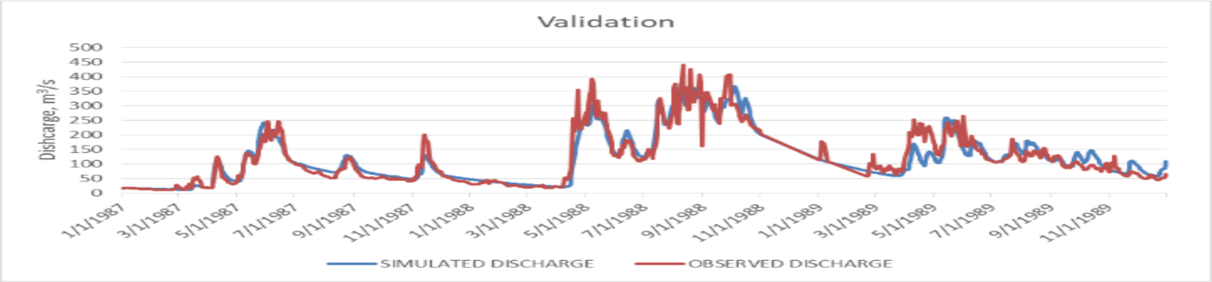

Figure 4: Validation discharges; Simulated and Observed

However, the assumptions were not exact due to one or a combination of the following reasons (model errors):

a. Shift in the days.

b. Record errors. Those recording discharge are humans and as is the norm, they are prone to making mistakes.

c. Missing values make it particularly difficult to accurately calibrate the simulated discharge to the observed discharge.

d. Change in land use land cover characteristics through the years may render the parameters less accurate.

3.4 Runoff Estimation for Nzoia Basin

It was found that runoff estimation using calibrated data provided a good estimate to determine runoff.

The figures below represent typical results obtained comparing discharge obtained from runoff on a daily basis, discharge obtained from satellite data and discharge obtained from calibrated data.

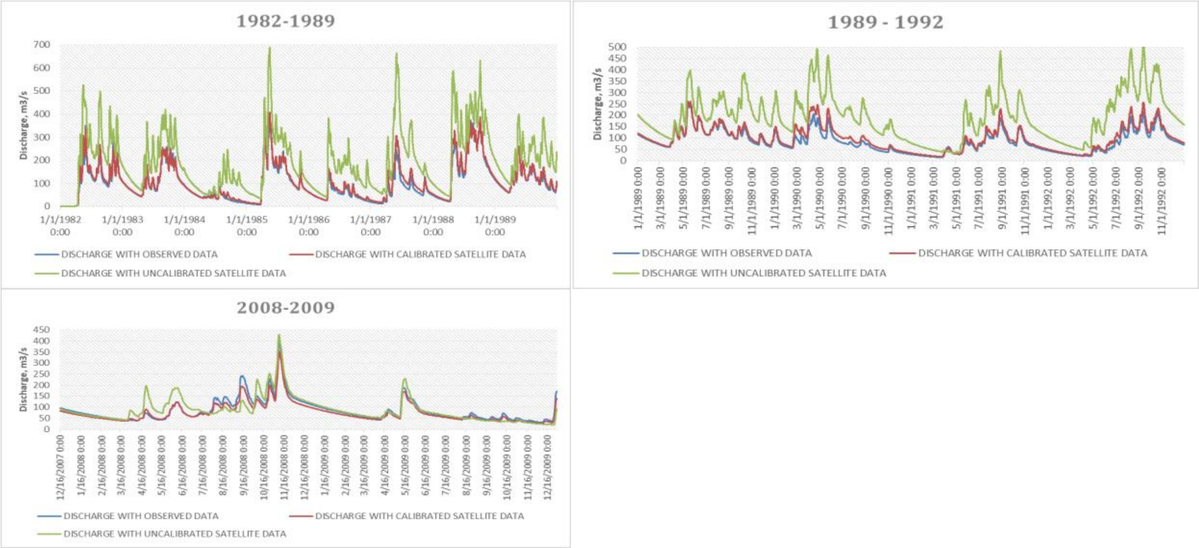

Figure 5: Simulated discharge - daily

From the figure, it is found that satellite data greatly overestimates the discharge. This is especially true at the peaks, for instance in 1990 and 1986. Calibrated data seems to take care of this overestimation, and provides a close estimate of the actual runoff data. Though not an exact estimate, the results provided are better and are very close to observed data.

Note what appears to be the failure of the calibrated data from 2008 to 2009. This is not the case. It is important to remember that 2008 to 2009 represent the period of inadequate observed weather parameters. Some periods even have entire years of data missing. This ultimately leads to calibrated data resembling satellite data more closely than it resembles observed data. Therefore, the importance of availability of data in calibration of data is realized.

The r-squared for the daily runoff data can be represented as below;

Table 1: R-squared comparing calibrated and satellite runoff to observed runoff

R squared Coefficient from Observed Runoff	
To Calibrated Data	0.96
To Satellite data	0.61

On a daily basis, it is clear that runoff estimation by calibration produces better values than satellite data.

On an annual basis, the following were the observations made;

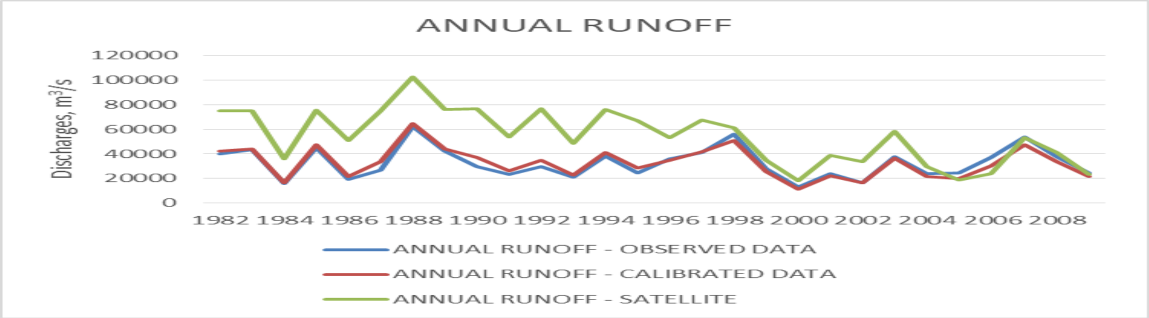

Figure 6: Annual runoff

On an annual basis, satellite data is seen to overestimate. This is a maximum in 1988 at about a difference of 40,000 cubic meters per second. However, from 1998 to 2000 and 2004 to 2009, this overestimation is negligible. However it is important to note that those periods, especially 2009, have limited data available.

It can be concluded that calibration of satellite data for rainfall-runoff analysis is necessary, and provides better estimates of rainfall-runoff relationships compared to use of uncalibrated satellite data alone. Thus, this study was found to be feasible and to provide a reasonable result.

5 Conclusions

In Nzoia basin, monthly rainfall depths for both satellite and observed data are at a maximum at around 250mm. These maximum rainfalls occur mostly in April. On an annual basis, annual averages range from around 1100mm to 1800mm for both datasets. Statistical analysis showed that GEOS-5 data generally tends to overestimate rainfall depths at high values and underestimate them at low values. However, in mid-ranges, at a probability of exceedance of about 0.2, these inaccuracies are observed to be minimized. Overestimations are generally observed to occur around April. On average, this overestimation varied at about 15% above observed data. For maximum temperatures, satellite data shows a tendency to overestimate data. This overestimation is generally observed to be a maximum from February to April, and is at a value of about 2^oC. On average, general maximum overestimations occur specifically in March and provide about 2^oC temperature differences. Any underestimations that exist are observed to be minimal. Maximum general underestimations occur in July at a 0.5^oC temperature difference. For minimum temperatures, satellite data overestimates values throughout the year. This overestimation is a constant for most of the year, and it varies minimally. In general, this overestimation is observed to be about 3^oC, occurring in August.

Use of rainfall-runoff models was found to be suitable for Nzoia basin, with r-squared between daily simulated runoff data model and observed weather station data meeting the threshold (0.7). R-squared values comparing simulated data with observed discharge for the calibration period was found to be 0.9 for daily data. For the validation period, it was found to be 0.8 for daily data. The optimal runoff model parameters observed were 12.7 for Umax, 136 for Lmax, 0.2 for CQOF, 1100 for CKIF, 62 for CK 1, 2, 0.25 for TOF, 0.2 for TIF, 0.05 for TG and 2825 for CKBF. These gave a water balance of about 0.98 and root mean square error of about 460. This proves that the model parameters that gave the above results were suitably accurate. However, one on one correlation could not be achieved due to the various model errors and uncertainties.

Calibrated GEOS-5 data performed reasonably well in runoff estimation for Nzoia basin. While satellite data was poor with an r-squared of 0.6 in relation to runoff observed from simulated discharge with observed parameters, calibrated data performed way better with an r-squared of 0.96 for daily values. For annual discharges, satellite derived runoff was found to provide overestimations. This was especially observable at peak discharges. Overestimations in annual discharges were observed from 1982 to 1998 and 2000 to 2003. Maximum overestimation was observed in 1988 and was at 40,000; ranging from about 100,000 for satellite discharge and 60,000 for observed and calibrated scenarios. It is important to note that the maximum overestimation occurred at the point of maximum annual runoff discharge.

In conclusion therefore, this study was able to improve NASA's GEOS-5 meteorological data available for Nzoia basin for runoff estimation.

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