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Rainfall–runoff modelling for estimating Latonyanda River flow contributions to Luvuvhu River downstream of Albasini Dam

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ABSTRACT

Rainfall–runoff modelling was conducted to estimate the flows that Latonyanda River contribute to Luvuvhu River downstream of Albasini Dam. The confluence of Latonyanda and Luvuvhu Rivers is ungauged. The contributed flows compensate for upstream water abstractions and periodic lack of releases from Albasini Dam. The flow contributions from tributaries to Luvuvhu River are important for ecosystem sustenance, meeting downstream domestic and agricultural water demand and ecological water requirements particularly in Kruger National Park. The upper Latonyanda River Quaternary Catchment (LRQC), with streamflow gauging station number A9H027 was delineated and used for rainfall–runoff modelling. The simulation was done using Mike 11 NAM rainfall–runoff model. Calibration and verification runs of Mike 11 NAM rainfall–runoff model were carried out using data for periods of 4 and 2 years, respectively. The model was calibrated using shuffled complex evolution optimizer. The model efficiency was tested using coefficient of determination (R^2), root mean square error (RMSE), overall water balance error (OWBE) and percentage bias (PBIAS). The model parameters obtained from the upper LRQC were transferred and used together with rainfall and evaporation data for 40 years period in the simulation of runoff for the LRQC. The flows that Latonyanda River contribute to Luvuvhu River were computed by subtracting irrigation abstractions and runoff drained to Tshakhuma Dam from the simulated runoff time series of the LRQC. The observed and the simulated runoff showed similar trends and measures of performances for both calibration and verification runs fell within acceptable ranges. The pairs of values obtained for R^2, RMSE, OWBE and PBIAS for calibration and verification were 0.86 and 0.73, 0.21 and 0.2, 2.1 and 1.3, and 4.1 and 3.4, respectively. The simulated runoff for LRQC correlated well with the areal rainfall showing that the results are reasonable. The mean and maximum daily flow contributions from the Latonyanda River are 0.91 and 49 m^3/s respectively. The estimation of these ungauged flows makes it possible to plan and manage the water requirements for the downstream users.

1. Introduction

The majority of watersheds that act as tributaries to mainstem rivers are ungauged for streamflow, particularly in semi-arid areas (Aragón et al., 2006). These tributaries contribute flows to main stem rivers. Tributary flow contributions are essential for ecological functioning of the main stem rivers, decision making in water resources allocation, planning and management, and flood studies. Tributaries contribute flows which augment main river flows during dry periods and also increase total river discharge during high rainfall periods associated with flooding. In regulated river systems, influxes from unregulated tributaries may mitigate the downstream impacts of dams on thermal and hydrologic regimes, sediment processes and aquatic biota (Dye, 2010). Lack of knowledge on actual flows contributed by tributaries may result in wrong decisions in terms of water supply, and this often leads to over abstraction of water from rivers resulting in their depletion and river ecology stress downstream. Oliver (1973) pointed out that extreme variation in the patterns of river discharges creates enormous problems in the management of water resources and often result in high financial losses; the case become worse where the variation in river flow patterns is not known. In many cases losses are associated with high rainfall resulting in floods and severe droughts which cause disastrous and serious adverse impacts on the economy, mainly through failure in agricultural production of regions. In view of these, studies on estimating tributary flows contributions are of paramount importance in addressing the problems associated with the flows of these rivers.

To capture the effects of tributary influences on flow regulated river, Svendsen et al. (2009), used long-term discharge and cross-sectional data to assess the geomorphic and hydrologic impacts of impoundment. The results show that tributaries are impacting on the flow-regulated mainstem and that these impacts are

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reflected in the benthic community structure and in the 7 Be activity of transitional bed load sediment. Soenksen et al. (2010) showed that tributary inflows were the main source of flow increases between 1980 and 2009 for the main-stem Niobrara River located in Nebraska, United States of America (USA). The Centre of Excellence in Natural Resource Management (2004) used observed data to estimate tributary flow contribution as part of ecological water requirements assessment study of Blackwood River in Australia. Stravs and Brilly (2009) used observed streamflow data to study the contributions of tributaries of the Sava River located in Slovenia to its mean daily flow at the time of hydrological drought. The Department of Natural Resources (2010) used observed data to assess the relative contribution of the Upper Otter Tail River watershed lakes region to the peak flood flows on the Red River in the USA. The current literature review did not find any documented studies that have been done on tributary flow contributions in South Africa.

Though methods/models for runoff estimation in ungauged catchments have widely been developed, limited studies linking them to applications of estimating flow contributions of ungauged tributaries have been done. Singer and Dunne (2004) developed an empirical-stochastic, event-based program to simulate inflow to a large river from a network of tributaries. Preliminary verification of the program was done by comparing the frequency of various hydrograph characteristics from the simulated series with those from historical records at main stem gauging points for pre-dam and post-dam flow scenarios. Chrinnarasri et al. (2004) used Mike 11 NAM to determine the tributaries contributions to Mun River, in Ubon Ratchathani Province, Thailand. The study showed that tributaries influence most of the floods occurring in the Mun River. Chibanga et al. (2001) used Artificial Neural Networks (ANNs) to model the ungauged tributary flow contribution at Kafue River sub-catchment in Zambia. Using data from the Kafue River sub-catchment in Zambia and a simple reservoir routing model, an estimate of the flow contribution from the ungauged sections is derived (Chibanga et al., 2001). The study found that selected best performing ANNs give accurate and more robust forecasts over long term than the best performing ARMAXs. Aragón et al. (2006) used GIS and dynamics system to model ungauged flow contribution of tributaries. The study combined GIS tools with a dynamic watershed model to create maps depicting an estimate of the contributions of ungauged semi-arid Rio Salado tributary located within the middle Rio Grande sub-basin in New Mexico.

The South African State of Rivers Report (2001) indicated that the Latonyanda River contributes flows to the Luvuvhu River, which help to compensate for the lack of releases from Albasini Dam. These flows are essential for ecosystem sustenance, meeting downstream domestic and agricultural water demand and ecological water requirements particularly in Kruger National Park. The amount of flow contributed is, however, unknown. This study is therefore aimed at estimating the flows that Latonyanda River contributes to Luvuvhu River, downstream of Albasini Dam, shown in Fig. 1. This will help in controlling abstractions from these rivers and also help maintain flows necessary for river ecology. Luvuvhu River flows into the Kruger National Park where meeting the ecological water requirements is of vital importance to both the aquatic species and animals in the park. There are four instreamflow requirements (IFRs) sites located downstream of Albasini Dam along the Luvuvhu River (Hughes et al., 1997a,b) which monitor the flows required to sustain the riverine ecosystem and downstream users including the Kruger National Park. Thus, this study will aid in knowing the quantity of water that supplements the flows to the IFRs sites.

Mike 11 NAM model has been selected for rainfall–runoff modelling in the current study because it has low data requirement, it is user friendly and easy to set up. It has been accepted worldwide especially for water resources modelling and it has the ability to simulate the watershed physical processes in more detail (Shamsudin and Hashim, 2002). It also simulates runoff at a daily scale required for near real time modelling. Mike 11 NAM is one of the hydrological modelling tools that have been used worldwide for the simulation of rainfall runoff within catchments of different sizes and in different climatic conditions. Examples of such studies include Refsgaard and Knudsen (1996), Lørup et al. (1997) and Makungo et al. (2010). These studies have shown that traditional hydrological models of the conceptual type are reliable tools in simulating rainfall–runoff, especially in areas where records of data on physical characteristics of the catchment are minimal, and where only short records of meteorological and streamflow data are available. These conditions are common in the southern part of Africa, especially in Limpopo Province of South Africa where streamflow and meteorological data records are often inconsistent with only a few intermittent data values showing consistency.

2. The study area

Latonyanda River is a tributary of Luvuvhu River in Limpopo Province, South Africa (Figs. 1 and 2). It joins the upper part of the Luvuvhu River downstream of Albasini Dam. Latonyanda River is located in quaternary catchment A91D of the Luvuvhu River Catchment. A quaternary catchment is a fourth order catchment in a hierarchical classification system in which a primary catchment is the major unit (DWA, 2010). It is used as the basic unit for water resource management in South Africa. The major tributary of Latonyanda River is the Livhungwa River. The Latonyanda River Quaternary Catchment (LRQC) is located between latitudes 22°59′12″S and 23°05′56″S and longitudes 30°09′58″E and 30°21′58″E (Fig. 1) and has a catchment area of approximately 132.4 km^2. The mean annual rainfall, runoff and evaporation are 1287, 377 and 1200–1600 mm, respectively. Rainfall is strongly seasonal and occurs mainly during the summer months (i.e. October to March) and is strongly influenced by the Soutpansberg Mountains. Temperature varies from 2 to 34 °C with the mean annual value of 18 °C. The catchment is dominated by sandy clay loam. Land use activities in the catchment mainly include forestry and agriculture in the upper reaches, and rural settlements downstream. The study area is characterized by thicket bushland, forest plantations, cultivated commercial dry lands and cultivated temporary semi-commercial/subsistence dry land.

3. Methodology

3.1. Data requirements and sources

Data was required to simulate flow at the ungauged outlet of the LRQC (its confluence with the Luvuvhu River). Daily rainfall, streamflow and evaporation data were the main inputs into the Mike 11 NAM rainfall–runoff (RR) model. Rainfall data for two stations (i.e. 0723363 and 0723485) were obtained from the South African Weather Services. Rainfall data was subjected to consistency test using double mass analysis. Less than 0.05% of rainfall data within the verification period was patched using the arithmetic mean method. There is no evaporation station in the LRQC. The nearest evaporation station (station number A9E002) is located in quaternary catchment A91C, which is the nearest neighbour to quaternary catchment A91D (Fig. 1). The two quaternary catchments have approximately similar land use and hydrological characteristics. They are also located within the same altitude range of 600–1400 m above mean sea level. The number of sunshine hours and solar radiation controlling the temperature, estimated based on the equation in Allen et al. (1998), are the same in each of the

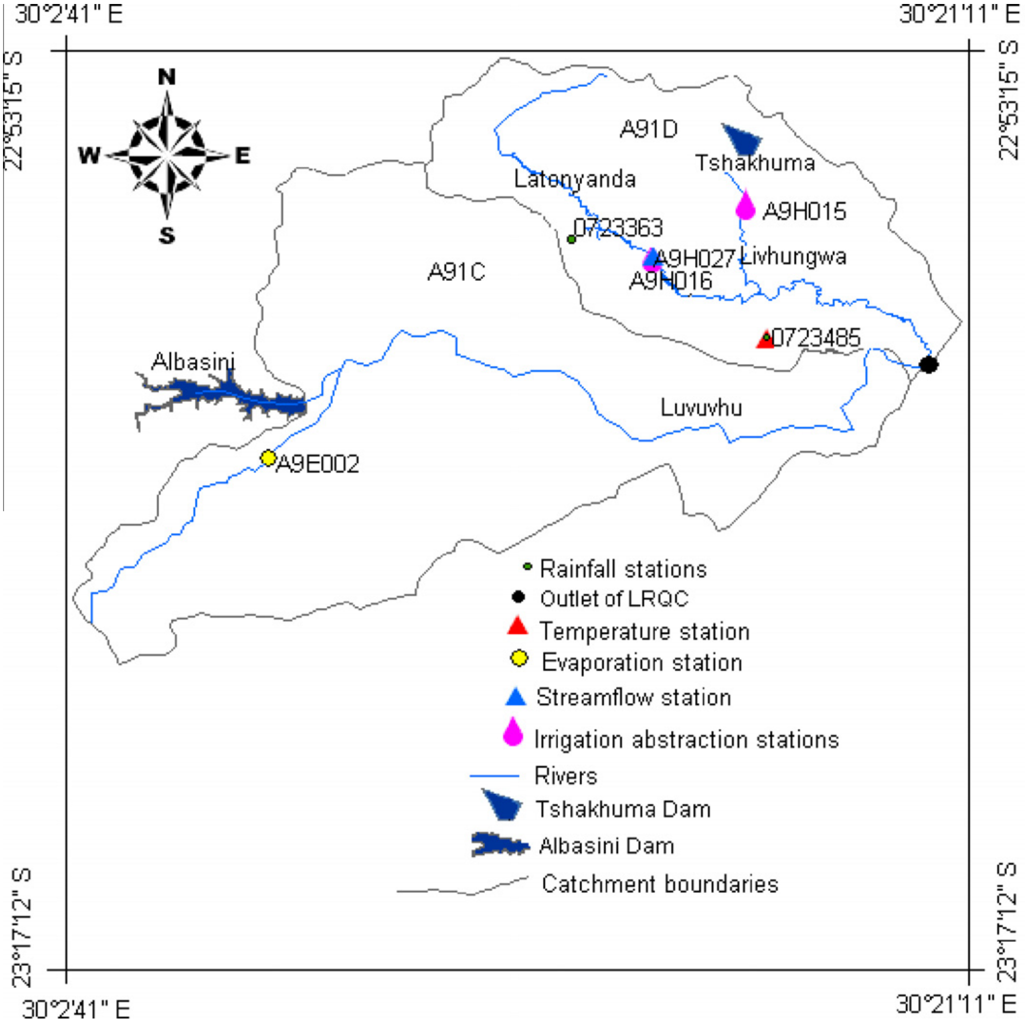

Fig. 1. Locations of rainfall, temperature, evaporation, streamflow and irrigation abstraction stations.

quaternary catchments. Thus, their evaporation rates are likely to be the same. Extended and patched evaporation data from station number A9E002 was obtained from Phangisa (2010).

Streamflow and evaporation data for station numbers A9H027 and A9E002, respectively, and irrigation abstractions data for station numbers A9H015 (Livhungwa River canal) and A9H016 (Latonyanda River canal) were obtained from the Department of Water Affairs (DWA). Tshakhuma Dam is the only dam located within the LRQC but it is disconnected from the Latonyanda River (Fig. 1). This dam supplies water to Tshakhuma Water Treatment Plant. Information obtained from the Tshakhuma Treatment plant operators shows the dam is fed by runoff from the Soutpansberg Mountains surrounding it and groundwater that seeps into the surface. The runoff drained into the Tshakhuma Dam was estimated to obtain the runoff volume that does not reach the confluence of Latonyanda and Luvuvhu Rivers. It was therefore not necessary to obtain water abstractions from the Tshakhuma Water Treatment Plant, as they are accounted for in the runoff volume that does not reach the river. Irrigation abstractions and runoff into Tshakhuma Dam were crucial in estimating the total streamflows that Latonyanda River contributes to Luvuvhu River. The locations of the rainfall, streamflow, evaporation, and temperature including irrigation abstractions stations and Tshakhuma Dam are shown in Fig. 1.

3.2. Data analysis methods

Mike 11 NAM RR model was used to simulate runoff at the outlet of the LRQC. Due to the lack of streamflow data at the outlet to calibrate the model, runoff simulation was performed for the upper LRQC to obtain the parameter values. The upper part of the LRQC, up to the point where there is a streamflow gauging station, was delineated using ArcGIS 9.2 to form the upper Latonyanda River sub-quaternary catchment (LRSQC). The sub-quaternary catchment area, rainfall data for station number 0723363, evaporation and streamflow data were used in the model set up for the upper LRSQC. These data were input into the model and used in the calibration and verification. The simulation was carried out based on daily data set for a 6 year period (2002/10/24–2008/10/24). The daily data for a period of 4 years (2002/10/24–2006/10/24) and a period of 2 years (2006/10/25–2008/10/24) were used for model calibration and verification respectively. A minimum of 3 years including periods of above-average precipitation is recommended for Mike 11 NAM calibration (DHI, 2009).

Auto-calibration was performed using the Shuffled Complex Evolution (SCE) algorithm which is in-built within the Mike 11 NAM model. Detailed description of the Mike 11 NAM model structure is found in Makungo et al. (2010). The root mean square error (RMSE) and overall water balance error (OWBE) were used as

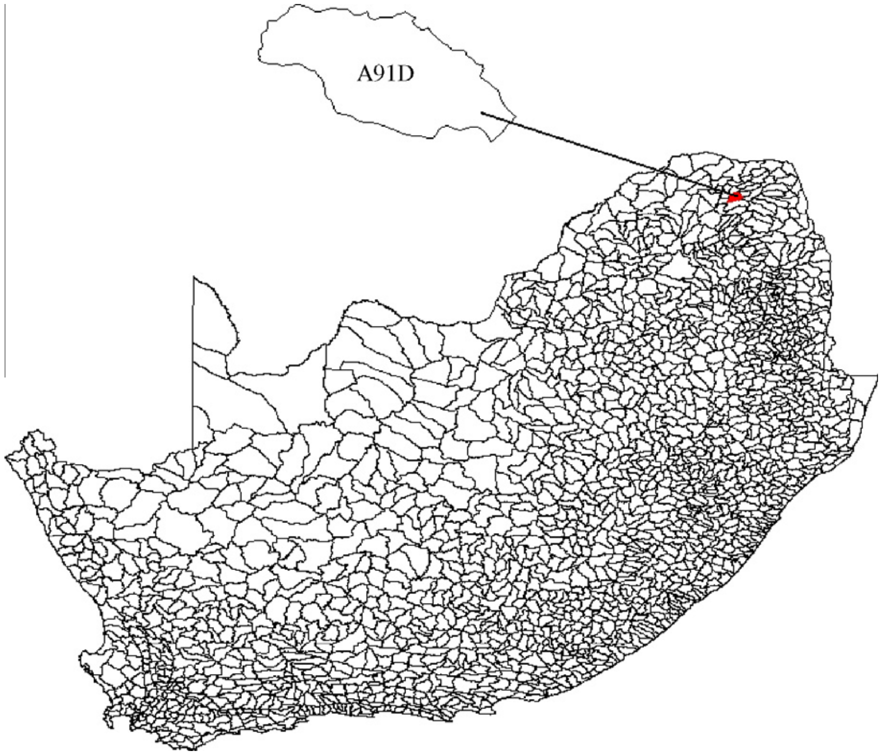

Fig. 2. Location of the study area in South Africa.

calibration objective functions. The OWBE gives the percentage difference between the observed and simulated values. The verification run was performed to assess whether the calibrated model parameter values can be used successfully to estimate discharge for an independent test period which was not used to calibrate the model. The coefficient of determination (R^2), percentage bias (PBIAS), RMSE and OWBE were used as performance measures. The model parameters obtained from the upper LRSQC were transferred to the entire LRQC and used together with weighted areal rainfall and evaporation in the simulation of runoff for the outlet of LRQC using Mike 11 NAM for the period 1970/10/01–2008/10/24. The daily time series data sets required for Mike 11 NAM RR modelling and irrigation abstractions were available for this period. The weighted areal rainfall was computed using Thiessen's polygon method based on weighting factors of 0.51 and 0.49 for stations 0723363 and 0723485, respectively.

Simulated runoff for the LRQC, estimated runoff drained into Tshakhuma Dam and irrigation abstraction data for the period 1970/10/01–2008/10/24 were used in the estimation of the flows that Latonyanda River contribute to Luvuvhu River. This was computed using the following equation:

$$Q_{contr(i)} = Q_{sim(i)} - Q_{irr(i)} - Q_{tsh(i)} \tag{1}$$

where $Q_{contr(i)}$ is the total flow contributions, $Q_{sim(i)}$ is the simulated flows for the entire LRQC, $Q_{irr(i)}$ is the irrigation abstractions, and $Q_{tsh(i)}$ is the runoff drained into Tshakhuma Dam and i is the daily time step.

4. Results and discussion

4.1. Rainfall–runoff modelling for the upper Latonyanda SQC

The delineated upper and lower LRSQCs are shown in Fig. 3. Their estimated areas are 64.72 and 67.68 km^2, respectively, giving a total area of 132.4 km^2. This area is similar to that quoted in the South African State of Rivers Report (2001) and GRDM software, showing that it was delineated accurately.

Table 1 shows the parameter values obtained from the model auto-calibration, and their upper and lower limits (default values). The modelled parameter values fall within the acceptable limits i.e. lower and upper limits of the given individual parameter ranges. Model parameters such as CK1, 2, TOF, TIF do not have much influence on the total runoff volume (Keskin et al., 2007). Keskin et al. (2007) and Makungo et al. (2010) have shown that the most effective model parameters are $L_{\max}$, $U_{\max}$, CQOF and CKIF which also define the base flow in the basin. However, CKIF is not usually a very important parameter since interflow is not the dominant streamflow component (Arcelus, 2000). $U_{\max}$ and $L_{\max}$ are the primary parameters to be changed in order to adjust the water balance in the simulations (DHI, 2009). $L_{\max}$ is important for describing seasonal water balance, especially for evaporation during dry periods, and the distribution of rainfall to evaporation, direct runoff and groundwater (Joynes, 2009). Physically, in a lumped manner, CQOF reflects the infiltration and also to some extent the recharge conditions (DHI, 2009). $U_{\max}$ has moderate effect on the peak flow and accumulated water volume (Zou, 2002). Accurate determination of these parameters results in accurate simulation of runoff. Since the modelled parameter values are within acceptable ranges, it is expected that the model will reasonably simulate runoff in the study area. This ensures reasonable/acceptable model performance which mostly defines the relationship between the observed and simulated runoff.

The comparisons of simulated and observed streamflows, for the calibration and verification runs are shown in Figs. 4 and 5, respectively. For both calibration and verification runs the Mike 11 NAM RR model underestimated relatively high peak flows (>4 m^3/s) (Figs. 4 and 5). However, the simulated peak flow hydrographs follow the trend of the measured flows. Relatively low peaks (<4 m^3/s) particularly in the verification run were over

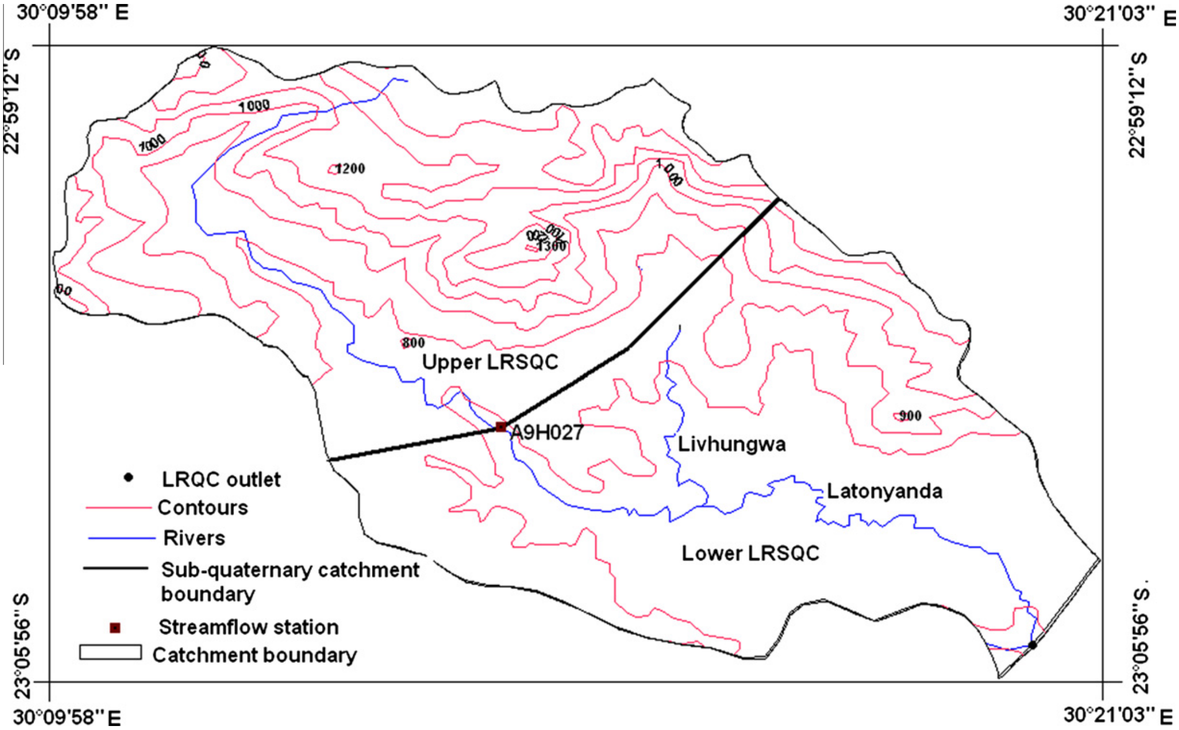

Fig. 3. Upper and lower Latonyanda River sub-quaternary catchments.

Table 1
Parameter values resulting from auto-calibration of Mike 11 NAM and default values.

Parameter	Description	Lower limit	Upper limit	Modelled value
U_{max} (mm)	Maximum water content in the surface storage. This storage can be interpreted as including the water content in the interception storage, in surface depression storages, and in the uppermost few centimeters of the soil	5	35	20
L_{max} (mm)	Maximum water content in the lower storage zone. L_{max} can be interpreted as the maximum soil water content in the root zone available for the vegetative transpiration	50	400	298
CQOF (–)	Overland flow runoff coefficient	0	1	0.214
CKIF (h)	Time constant for interflow from the surface storage	200	2000	917.6
$CK^{1,2}$ (h)	Time constant for overland flow and interflow routing	3	372	33.2
TOF (–)	Threshold value for overland flow	0	0.9	0.111
TIF (–)	Threshold value for interflow	0	0.9	0.328
TG (–)	Threshold value for recharge	0	0.9	0.255
CK_{BF} (h)	Time constant for routing baseflow	500	5000	3942

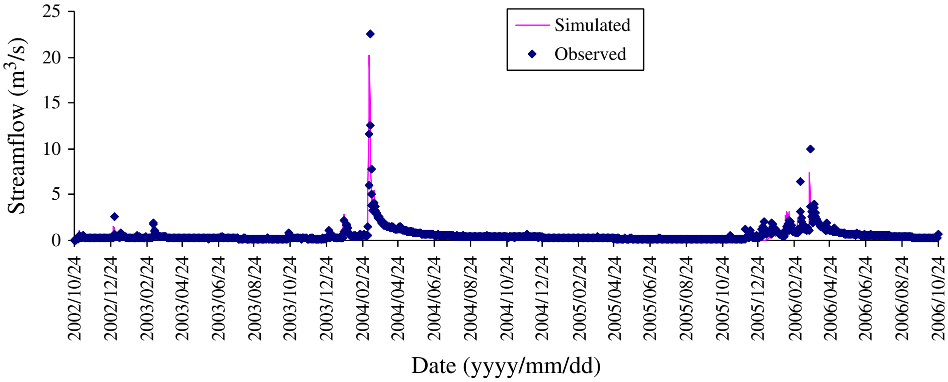

Fig. 4. Simulated and observed streamflows for the calibration run of the Mike 11 NAM RR model for the upper Latonyanda River SQC.

predicted. Low flows were well predicted and only under predicted in isolated cases particularly during verification (Fig. 5). Makungo et al. (2010) also underestimated a few low flows particularly in the verification run using Mike 11 NAM. Mismatch in low flow hydrographs for the verification run occurred between the period 2006/10/28–2006/12/30 and 2007/10/12–2007/12/15 (Fig. 5). This

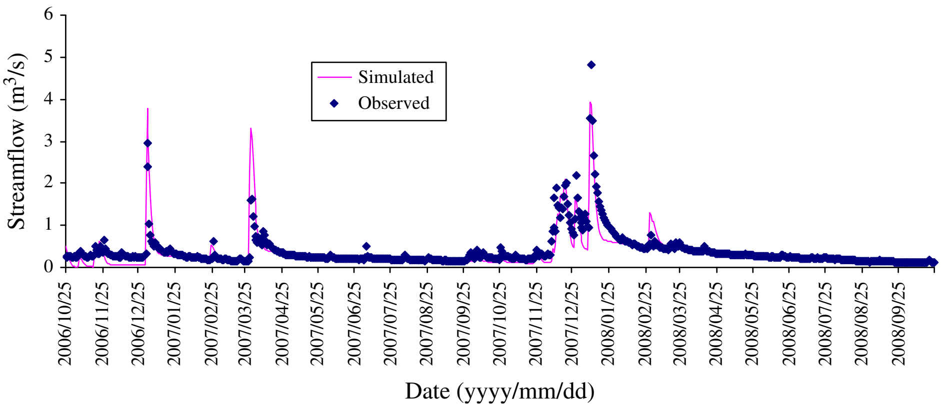

Fig. 5. Simulated and observed streamflows for the verification run of the Mike 11 NAM RR model for the upper Latonyanda River SQC.

together with the few over-predictions of small peaks in almost the same period might be due to the fact that rainfall data series showed some inconsistencies (uncertainties) and gaps from 2006 towards 2008. Makungo et al. (2010) noted that Mike 11 NAM has generally been known to underestimate peak flows because hydrological phenomena during high flow periods are too complex for rainfall–runoff models to predict accurately. The simulation results of the current study are generally comparable to those of Makungo et al. (2010), except for the few cases of overestimation of peak flows in the verification run. This may be due to illegal abstractions upstream of the gauging station A9H027. This is likely to have affected to some extent the estimation of the model parameters and simulated runoff and hence model performance. The link between model parameters and catchment characteristics and the implication on statistical performance have been explained in the preceding paragraph.

Underestimation of peak discharges and some of the low flows may also be due to a limited number of rainfall gauging stations in the study area resulting in poor representative areal rainfall. Vaitieknūienė (2005) reported that it is important to capture the spatial variability of rainfall in modelled catchments, since this may lead to serious errors in predicted runoff. Technical errors such as wrong and altered calibration standards of recording devices, observational errors, and the inherent nature of the model including the errors associated with irrigation abstractions measurements might have individually or collectively resulted in the underestimation of contributed flows.

The flow durations curves (FDCs) for observed and simulated flows for the calibration and verification runs are provided in Figs. 6 and 7. The flows that were equalled or exceeded 35–100% were well predicted while there were slight deviations between observed and simulated flows equalled or exceeded 0–35% (Figs. 6 and 7). The FDCs confirm the underestimation of peak flows in the calibration and verification runs, and slight over-prediction of relatively low flows particularly in the verification run. They also confirm that very low flows were generally well predicted. The low flow statistic which is the flow equalled or exceeded 95% of the time (Q_{95}) for the calibration and verification runs (Table 3) are comparable showing reasonable prediction of low flows. The minimum flow ($Q_{\min}$) values are greater than zero showing that there were no zero flows within the period of study.

All the performance measures for both calibration and verification runs fall within acceptable ranges, and are comparable with the ones obtained in other studies (Table 2). Thus, the model simulated the runoff of the upper Latonyanda River sub-quaternary catchment reasonably. A minimum of 3 years including periods of above-average precipitation is recommended for Mike 11 NAM calibration (DHI, 2009). However, in the current study the calibration was done using data for a period of 4 years which included periods of above-average precipitation. Thus, the relatively longer period will result in more reliable results for the study period as compared to those that can be obtained from the minimum recommended period.

The R^2 for both calibration and verification runs are 0.86 and 0.73, respectively. R^2 is high for calibration compared to verification. This may be due to rainfall measurement errors or missing rainfall data which occurred in the verification period between the years 2006 and 2008, and/or land use changes. Alien invasive

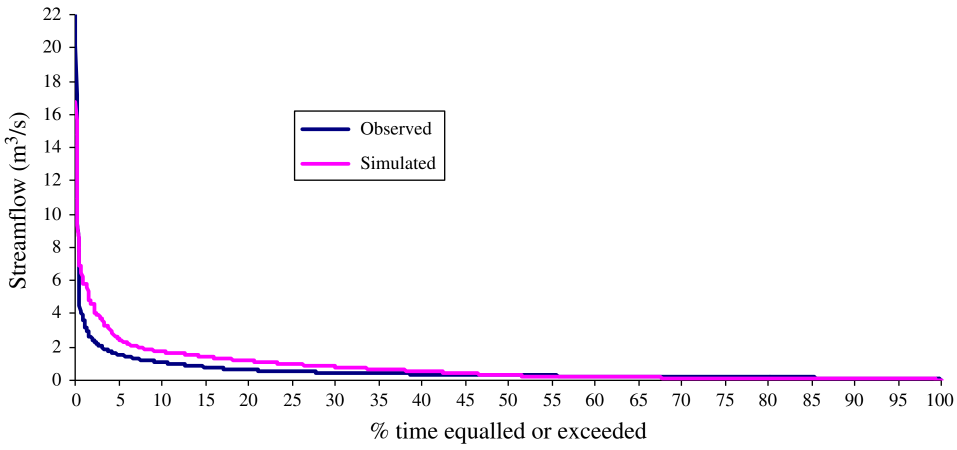

Fig. 6. FDCs for observed and simulated flows for the calibration run.

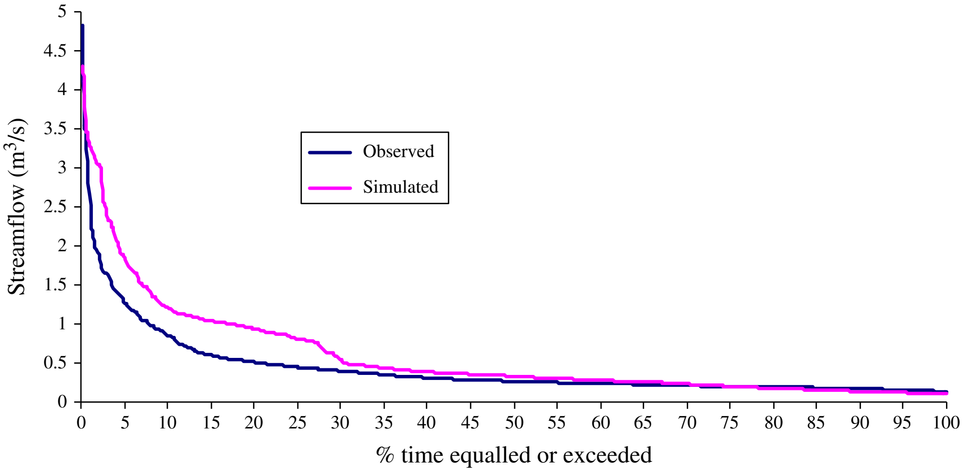

Fig. 7. FDCs for observed and simulated flows for the verification run.

Table 2
Summary of Mike 11 NAM model performances.

Performance measure	Calibration	Verification	
Coefficient of determination (R^2)	0.86	0.73	>0.5–1 – Acceptable[a]
Correlation coefficient (R)	0.93	0.85	>0.5 – Acceptable[b]
Root mean square error (RMSE) (m^3/s)	0.21	0.2	0 = perfect[c]
Overall water balance error (OWBE) (%)	2.1	1.3	±5–10% – Acceptable[d]
Percentage bias (PBIAS) (%)	4.1	3.4	±25% – Acceptable[e]

[a] Moriasi et al. (2007).
[b] Van Liew et al. (2007).
[c] Shamsudin and Hashim (2002).
[d] Madsen et al. (2002).
[e] Yapo et al. (1996).

Table 3
Comparison of low flow statics for calibration and verification runs.

Period	Q_{95} (m^3/s)	Q_{min} (m^3/s)
Calibration		
Observed	0.13	0.05
Simulated	0.09	0.03
Verification		
Observed	0.15	0.13
Simulated	0.12	0.11

vegetation is a problem in A91D quaternary catchment which reduces flows (DWAF, 2004). R^2 values for both the runs fall within the acceptable range given in Moriasi et al. (2007) (see Table 2). These values are comparable or better than those of Shamsudin and Hashim (2002), Vaitieknūienė (2005) and Makungo et al. (2010). Shamsudin and Hashim (2002) and Vaitieknūienė (2005) obtained 0.75 and 0.66–0.82 for calibration, respectively; whereas Makungo et al. (2010) obtained R^2 values of 0.67 and 0.74 for both calibration and verification, respectively. The high value of R^2 for calibration is an indication of good model parameters estimation. The computed RMSE for both calibration and verification runs are 0.21 and 0.2 m^3/s respectively. The RMSE values computed in this study are comparable or better than those of studies by Madsen (2000) and Madsen et al. (2002), which obtained RMSE values of 0.6 and 0.62, and 0.091–0.67 respectively.

The OWBE (in %) for both calibration and verification runs are 2.1% and 1.3%, respectively (Table 2). As shown in Table 2 the OWBE values fall within acceptable range. These values are better than those obtained from other studies, such as Makungo et al. (2010), where the OWBE values obtained ranged from 9.89 and 9.13 for calibration and verification runs, respectively. The improvements of the OWBE values obtained in this study imply that the model performed reasonably well and the results are acceptable.

The computed PBIAS for both calibration and verification runs are 4.1% and 3.4%, respectively. The PBIAS values obtained in the calibration and verification runs fall within the acceptable range of ±25% as recommended by Moriasi et al. (2007). This shows that the values obtained in this study are acceptable. The PBIAS values obtained in this study are comparable or better than those obtained in studies such as, Gautam and Holz (2001) and Makungo et al. (2010), where PBIAS values ranging from −0.10% to 17.99% and −10.45% to −10.09%, respectively, were obtained. The overall model performance in this study compared to other earlier studies indicates that the findings are reasonable. Since the modelled parameter values and performance measures in the current study fell within the acceptable ranges Mike 11 NAM was able to reasonably represent the catchment characteristics that influence runoff generation in the study area.

4.2. Estimated runoff hydrograph for the Latonyanda River Quaternary Catchment

Fig. 8 shows the correlation of simulated runoff and weighted areal rainfall to determine the reasonableness of the simulated runoff. Makungo et al. (2010) used the same criterion to determine the reasonableness of Mike 11 NAM and AWBM runoff simulations. It is important to note that the first 6 months of the Mike 11 NAM simulation results were discarded to avoid errors linked to initial conditions as recommended by DHI (2009). Fig. 8 shows a good correlation between major areal rainfall peaks and simulated runoffs. The observed lag between runoff and areal rainfall is an expected behaviour, partly because the initial conditions are first met before rainfall generates runoff. This correlation confirms suitability of Mike 11 NAM model in simulating runoff of the Latonyanda quaternary catchment for the current study period. Further verification will be essential once more data becomes available. The high peak runoff that occurred in the year 2004/03/06 may be due to the fact that the soil was already saturated from the previous rainfall events.

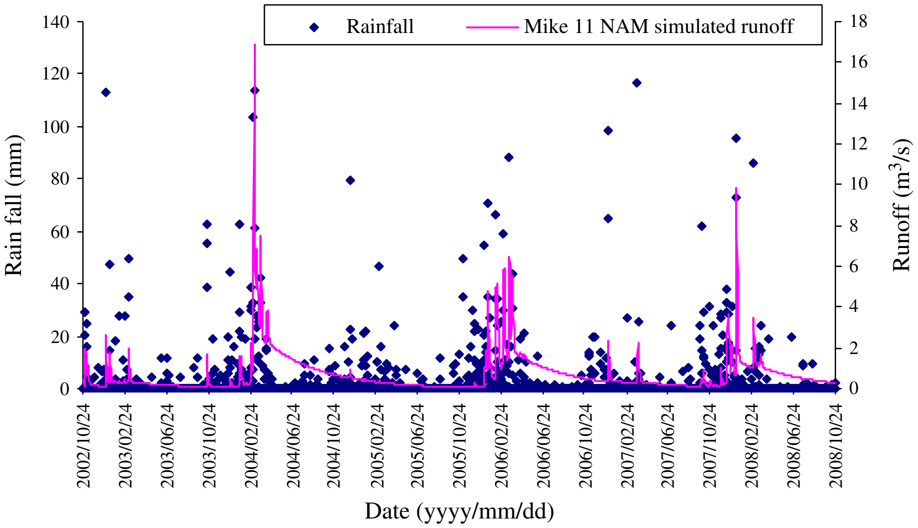

Fig. 8. Simulated runoff hydrograph for the Latonyanda River Quaternary Catchment.

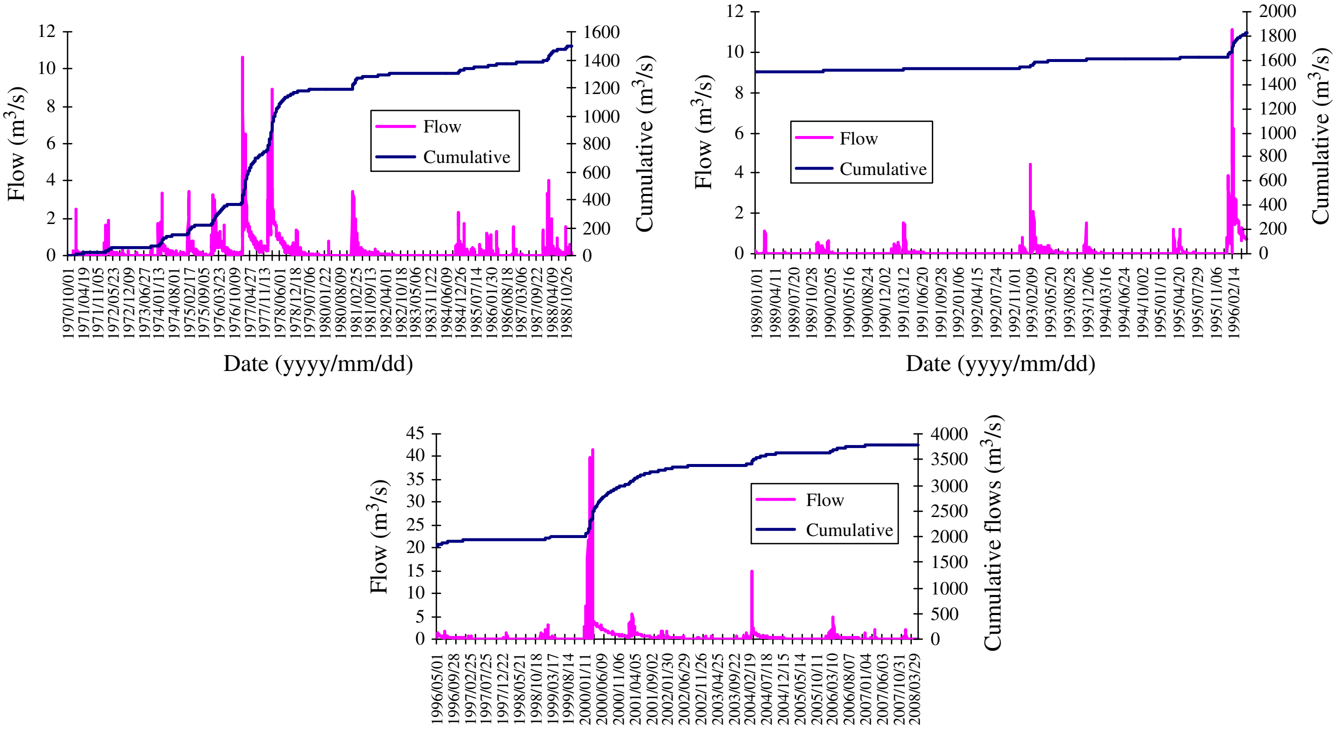

Fig. 9. Latonyanda River flow contribution to Luvuvhu River.

4.3. Estimated flows contribution of Latonyanda River into Luvuvhu River

Fig. 9 shows the estimated flows that Latonyanda River contributes to Luvuvhu River, downstream of Albasini Dam including the accumulated flows. Latonyanda River contributed high flows during wet seasons and low flows during dry seasons. Significant peak flows occurred on the 1977/02/08, 1978/02/25, 1996/02/11, 2000/02/26 and 2004/03/04 (Fig. 9). Examples of periods with low flow contributions include 2003/05/24–2004/01/20; 2004/04/14–2005/02/08 (Fig. 9). Examples of periods with no flow contributions include 1982/10/01–1984/04/05, 1991/12/18–1992/11/08 and 2005/04/30–2006/01/12 (Fig. 9). Periods with no flow contributions correspond to periods with no rainfall or when flows were blocked from the Latonyanda River. Information obtained from the officials of the Department of Water Affairs, Levuvhu branch revealed that during periods of low flows farmers divert the flows from Latonyanda River immediately after station A9H016 to the irrigation canal. This results in no flow contributions during such periods. Low flows occurring during wet seasons may be due to hydrological drought, when the rainfall received might have not generated sufficient runoff to replenish streamflow. However, the general behaviour of the estimated flow time series that Latonyanda River contributes to Luvuvhu River shows the shape of a typical flow hydrograph.

The IFRs for Luvuvhu River IFR site 1 for maintenance and drought flows estimated by Hughes et al. (1997a) range from 0.6

to >10 m^3/s and 0.2 to 10 m^3/s, respectively. Thus, the flows contributed by Latonyanda River during wet and dry seasons are significant for maintenance of IFRs in Luvuvhu River IFR site 1.The findings of this study are in agreement with those of similar studies conducted in other countries, for example, Stravs and Brilly (2009) found that tributaries contributed significant flows into Sava River during hydrological drought periods, and Chrinnarasri et al. (2004) found that tributaries influenced most of the floods that occurred in the Mun River. This underscores the significance of this study.

5. Conclusion

Mike 11 NAM RR model was set up, calibrated and verified for the upper LRSQC to obtain model parameters for simulating runoff for an ungauged outlet of the Latonyanda River. The simulated runoff was used to estimate the Latonyanda River flow contributions to the Luvuvhu River downstream of Albasini Dam. The Luvuvhu River flows into the Kruger National Park where meeting the ecological water requirements is of vital importance to both the aquatic species and animals in the park, making proper management of such flows essential. The observed and the simulated runoff for the upper LRSQC correlated well except for under-prediction of peak events and a few low flows, in addition to a few over predictions that can be explained in terms of inherent uncertainty in the model and the data. Illegal irrigation abstractions could be responsible for over predictions as they reduce the observed values. However, measures of performances for both calibration and verification runs fell within acceptable ranges. The study explained the link between model parameters and catchment characteristics and the implication on statistical performance.

The simulated runoff for the LRQC correlated well with areal rainfall showing that the results are reasonable. The study concluded that flows contributed during wet and dry seasons are significant for the maintenance of environmental functions downstream of the Luvuvhu River particularly in the Kruger National Park.

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