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Quantification of water resources uncertainties in the Luvuvhu sub-basin of the Limpopo river basin

N. Oosthuizen[a,b,*], D. Hughes[b], E. Kapangaziwiri[a], J. Mwenge Kahinda[a], V. Mvandaba[a,b]

[a] CSIR – Natural Resources and the Environment, South Africa
[b] Institute for Water Research, Rhodes University, Grahamstown, South Africa

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ABSTRACT

In the absence of historical observed data, models are generally used to describe the different hydrological processes and generate data and information that will inform management and policy decision making. Ideally, any hydrological model should be based on a sound conceptual understanding of the processes in the basin and be backed by quantitative information for the parameterization of the model. However, these data are often inadequate in many sub-basins, necessitating the incorporation of the uncertainty related to the estimation process. This paper reports on the impact of the uncertainty related to the parameterization of the Pitman monthly model and water use data on the estimates of the water resources of the Luvuvhu, a sub-basin of the Limpopo river basin. The study reviews existing information sources associated with the quantification of water balance components and gives an update of water resources of the sub-basin. The flows generated by the model at the outlet of the basin were between 44.03 Mm^3 and 45.48 Mm^3 per month when incorporating +\-20% uncertainty to the main physical runoff generating parameters. The total predictive uncertainty of the model increased when water use data such as small farm and large reservoirs and irrigation were included. The dam capacity data was considered at an average of 62% uncertainty mainly as a result of the large differences between the available information in the national water resources database and that digitised from satellite imagery. Water used by irrigated crops was estimated with an average of about 50% uncertainty. The mean simulated monthly flows were between 38.57 Mm^3 and 54.83 Mm^3 after the water use uncertainty was added. However, it is expected that the uncertainty could be reduced by using higher resolution remote sensing imagery.

1. Introduction

Uncertainty is inherent to all environmental simulation models and their outputs are affected by uncertainty related to hydro-climatic data (Sawunyama and Hughes, 2007), parameter values as well as the model structure (Hughes et al., 2010). Water use data are among the most unreliable sources of information in developing countries due to the lack of observed data. Ignoring the uncertainty in estimating water use data as was done in the previous national water resources assessments such as in 1990 (Midgley et al., 1994), 2005 (Middleton and Bailey, 2009) and 2012 (Baily and Pitman, 2015) in turn impacts the accuracy of the estimates of water resources availability. In this paper an attempt is made to integrate the combined effect of parameter and water use uncertainty within the Luvuvhu sub-basin.

Over the years, the construction of farm dams has increased significantly (Hughes and Mantel, 2010) and irrigation schemes have become larger to continue to supply food to an increasing population. Farm dams play an important role in South Africa because they provide essential water supply for domestic use, small-scale irrigation and livestock. Their basic purpose is to capture and store runoff for later use e.g. for irrigation in months in the dry season. However, even though their impact on the general water resources system could be regarded as insignificant when viewing them as a single entity, their impact as a collective can be dramatic and should therefore be included into water resources planning and management. Small farms dams could impact streamflow connectivity (Callow and Smetten, 2009), catchment yield (Neal et al., 2002) as well as sediment delivery (Verstraeten and Prosser, 2008). The combination of the impact of farm dams on the water distribution amongst others as well as the water demands by crops, especially at times when rainfall is low, should therefore be prioritized in water resources studies as a result of their significant cumulative impact.

* Corresponding author.CSIR – Natural Resources and the Environment, South Africa.
E-mail address: Nadia.Oosthuizen.geo@gmail.com (N. Oosthuizen).

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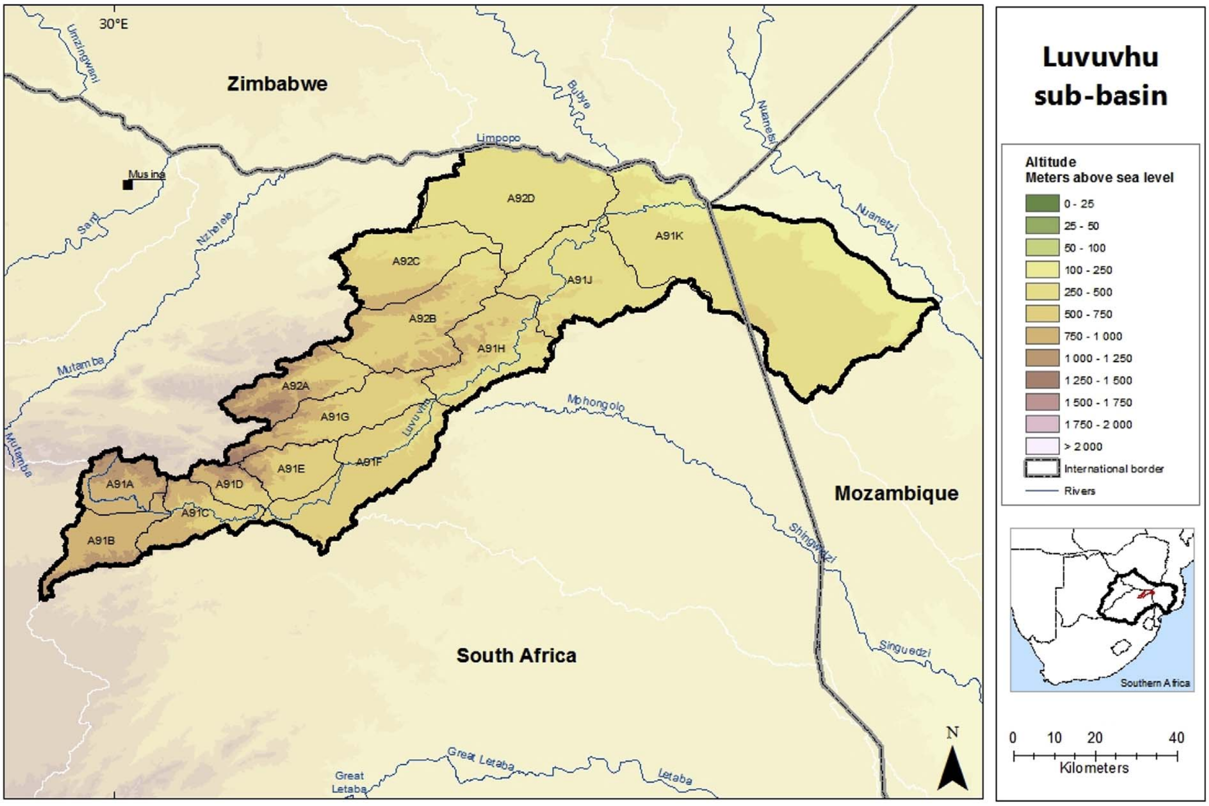

Fig. 1. A map showing the location of the Luvuvhu sub-basin within the Limpopo River Basin.

Table 1
Total farm dam volumes (in Ml) and the range (min and max) of variability (uncertainty) used in the model simulations for each of the quaternary catchments of the Luvuvhu sub-basin.

Catchment	WR2012	Alternative source (e.g. Remote sensing)	Uncertainty %	Min	Max
A91A	0.00	2513.632	100	0	2513.632
A91B	0.00	4710.18	100	0	4710.18
A91C	11128.62	8811.996	21	8791.61	13465.63
A91D	1193.65	6515.89	82	214.86	2172.44
A91E	454.60	72.21282	84	72.74	836.46
A91F	0.00	4530.585	100	0	4530.585
A91G	3706.94	23135.55	84	593.11	6820.77
A91H	0.00	0	0	0	0
A91J	0.00	0	0	0	0
A91K	0.00	0	0	0	0
A92A	0.00	0	0	0	0
A92B	0.00	0	0	0	0
A92C	0.00	128.8763	100	0	128.88
A92D	0.00	60.28	100	0	60.28

2. Study area

The Luvuvhu sub-basin is situated in the northeast of South Africa and drains an area of 5941 km^2 (Nkuna and Odiyo, 2011; Odiyo et al., 2015). However, even though studies suggest that Luvuvhu is located in South Africa (e.g. Hope et al., 2004; Jewitt et al., 2004; Nkuna and Odiyo, 2011; Odiyo et al., 2015), the sub-basin actually extends into Mozambique (Fig. 1). Many people (estimation of some 624,907) depend on the basin for their water needs including irrigation, urban and industrial use, and commercial forestry. However, groundwater resources are over exploited due to irrigation activities, especially in the vicinities of the Albasini Dam and Thohoyandou area (Hope et al., 2004). The soils are sandy loam (Masupha et al., 2016) and soil surveys indicate that 17% of the soil of the basin is potentially suitable for afforestation, but only 14% of this area has been planted. The rainfall constrains and difficulties faced by obtaining a Stream Flow Reduction Activity (SFRA) water use license are identified as the primary reason for this (Hope et al., 2004).

The basin is situated within the humid subtropical climate region (Cwa-Köppen classification) which is characterized by warm summers and dry winters (FAO, 2004). Rainfall occurs in the summer months, from October to April, with the mean annual precipitation ranging from less than 450 mm in the low-lying plains (of the Kruger National Park) and more than 1200 mm in the high altitude areas of the Soutpansberg mountains (ARC, 2015; Odiyo et al., 2015; Masupha et al., 2016). Mean annual runoff is 520 Mm^3 per year (Jewitt et al., 2004; Odiyo et al., 2015). Both rainfall and runoff are greatly influenced by the topography which varies from 200 m to 1500 m. The Luvuvhu sub-basin consists of fourteen so called quaternary catchments in South Africa (A91A - A91K and A92A - A91D), with A91K as the most downstream sub-catchment at the border of South Africa, Zimbabwe and Mozambique where the Luvuvhu River flows into the Limpopo River.

3. Materials and methods

3.1. Data collection and analysis

The Surface Water Resources assessment studies of South Africa have played a major role in providing key hydrological information for all the sub-basins of the country. The first water resources appraisal was produced by Prof. Desmond Midgley in 1952 followed by studies in 1969, 1981, 1990 (in the country commonly known as WR90), 2005 (WR2005) and 2012 (WR2012). The latest national assessment study (the WR2012) did not only focus on updating the previous WR2005 data, but data were re-evaluated, improved, produced new innovative work and developed new tools (Baily and Pitman, 2015). The data can