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Does the Limpopo River Basin have sufficient water for massive irrigation development in the plains of Mozambique?

Pieter van der Zaag [a,b,*], Dinis Juizo [c], Agostinho Vilanculos [d], Alex Bolding [e], Nynke Post Uiterweer [e]

[a] Dept. of Management and Institutions, UNESCO-IHE, Delft, The Netherlands
[b] Water Resources Section, Delft University of Technology, The Netherlands
[c] Dept. of Civil Engineering, Eduardo Mondlane University, Maputo, Mozambique
[d] Ägencia Regional de Agua-Sul (Regional Water Agency–South), Maputo, Mozambique
[e] Irrigation and Water Engineering Group, Wageningen University, The Netherlands

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ABSTRACT

This paper verifies whether the water resources of the transboundary Limpopo River Basin are sufficient for the planned massive irrigation developments in the Mozambique part of this basin, namely 73,000 ha, in addition to existing irrigation (estimated at 9400 ha), and natural growth of common use irrigation (4000 ha). This development includes the expansion of sugar cane production for the production of ethanol as a biofuel. Total additional water requirements may amount to 1.3×10^9 m^3/a or more. A simple river basin simulation model was constructed in order to assess different irrigation development scenarios, and at two storage capacities of the existing Massingir dam.

Many uncertainties surround current and future water availability in the Lower Limpopo River Basin. Discharge measurements are incomplete and sometimes inconsistent, while upstream developments during the last 25 years have been dramatic and future trends are unknown. In Mozambique it is not precisely known how much water is currently consumed, especially by the many small-scale users of surface and shallow alluvial groundwater. Future impacts of climate change increase existing uncertainties.

Model simulations indicate that the Limpopo River does not carry sufficient water for all planned irrigation. A maximum of approx. 58,000 ha of irrigated agriculture can be sustained in the Mozambican part of the basin. This figure assumes that Massingir will be operated at increased reservoir capacity, and implies that only about 44,000 ha of new irrigation can be developed, which is 60% of the envisaged developments. Any additional water use would certainly impact downstream users and thus create tensions.

Some time will elapse before 44,000 ha of new irrigated land will have been developed. This time could be used to improve monitoring networks to decrease current uncertainties. Meanwhile the four riparian Limpopo States are preparing a joint river basin study. In this study a methodology could be developed to estimate and safeguard water availability for those users who under the law do not need registration – but who do need water.

1. Introduction

In the semi-arid tropics, access to productive (blue) water, over and above the normal rainfall (green water), is crucial to insure and "drought-proof" vulnerable rural livelihoods and farming systems against irregular patterns of rainfall and thus against famine and absolute poverty (see for example Hope et al., 2004; Love et al., 2006; Hussain et al., 2007; Senzanje et al., 2008; Hanjra and Gichuki, 2008). Such improvements of rainfed farming systems enhance their resilience to cope with climate shocks and can bring these systems to a fundamentally higher level or state. This affords households a real chance to achieve a higher level of socio-economic development and well-being, and thus provides them with a real option out of the so-called poverty trap (Enfors and Gordon, 2008).

Creating buffers against irregular rainfall patterns, and accessing blue water, either from rivers or from groundwater, requires investments that frequently exceed the financial resources of poor households; hence the relevance of progressive policies that can empower rural households to develop the water resources.

Mozambique, as other Southern African countries, has a bifurcated water sector: highly visible large scale, centralised and state-initiated irrigation schemes, company-initiated irrigation plantation as well as commercial hydropower enterprises live side

* Corresponding author at: Dept. of Management and Institutions, UNESCO-IHE, Delft, The Netherlands. Tel.: +31 15 215 1829; fax: +31 15 212 2921.
E-mail address: p.vanderzaag@unesco-ihe.org (P. van der Zaag).

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by side with small-scale famer-initiated water developments that are often not easily detected, and are scattered in the landscape.

Government policy in Mozambique has focused on state-led irrigation developments, and recently also on facilitating private sector investments in large-scale irrigation ventures. The question that this paper seeks to answer is whether there is sufficient water for the envisaged water developments in the Lower Limpopo River Basin, and to what extent these may curtail existing and future small-scale farmer-managed water initiatives.

Many uncertainties surround current and future water availability in the Mozambican part of the transboundary Limpopo River Basin. Discharge measurements are incomplete and sometimes inconsistent, while upstream developments during the last 25 years have been dramatic and their future trend is unknown. As current water uses in Mozambique are poorly monitored, it is not precisely known how much water is currently consumed, especially by the many small-scale users of surface and shallow alluvial groundwater. Future impacts of climate change increase existing uncertainties.

This paper investigates whether the water resources of the Lower Limpopo River Basin are sufficient for the planned massive irrigation developments, namely 73,000 ha. This development includes the expansion of sugar cane production for the production of ethanol as a biofuel. Total additional "blue" water requirements may amount to approximately 1.3×10^9 m^3/a. A simple river basin simulation model (based on the Waflex approach, see Savenije, 1995) was constructed, based on 39 years of monthly inflow data. Different irrigation development scenarios including two storage capacities for the existing Massingir Dam were assessed using this model.

2. Water requirement

Current water uses in the Lower Limpopo River Basin are relatively small, and mainly include so-called common uses of water for domestic and agricultural purposes in the rural areas, some water supply for cities and small towns, and existing "formal" irrigation mainly centred around Chokwe irrigation scheme. Total current irrigation was thus estimated to be 9400 ha. Furthermore, a minimum flow has been determined for the estuary in order to avoid excessive salt intrusion (7.5 m^3/s, equivalent to about 20×10^6 m^3/month; DNA, 1996, page 172). These uses are summarised in Table 1.

Note that there is a paucity of data on current water uses. A case in point are the common uses, as defined by the 1991 Water Act, which are uses of water for primary requirements for which no water licences are required, and which are therefore often invisible in an administrative sense. We therefore had to make assumptions about the amounts involved. Significant in terms of water consumption are the agricultural common uses: in Mozambique all irrigation smaller than 1 ha per household is considered common use, including irrigation systems where the smallholders irrigate less then 1 ha each. Moreover, also included are the *machongo* cultivation on the peaty soils in the flood plains that use groundwater through natural (capillary rise) and artificial means as well as spring water from the adjacent dunes (*encostas*). Domestic water demand were estimated on the basis of the 1997 population census by the National Institute of Statistics INE (Fig. 1). Livestock water demand was estimated on using the 2009 livestock census by the Provincial Agriculture Directorate of Gaza DPAG (Fig. 2).

Plans for irrigation development in the Mozambican part of the Limpopo basin are summarised in an unpublished document by Mozambique national water department DNA, and amount to some 73,000 ha, in addition to the existing 9400 ha, and the expected natural growth of common use irrigation (4000 ha). It has been estimated by us that this new irrigation may require 1.3×10^9 m^3/a of water. The largest planned development is the ProCana project, just downstream of Massingir dam on the Rio Elefantes (known as the Olifants River in South Africa). It is here assumed that the 37,500 ha of sugarcane envisaged by ProCana will require a gross amount of irrigation water of 555×10^6 m^3/a. This assumption is based on the experience with underground drip irrigation at Mhlume Estate of the Royal Swaziland Sugar Corporation, since ProCana has engaged the same irrigation company to install a similar technology on the core estate (26,500 ha) (data provided by Dr. Leonard Ndlovu; see also Merry, 2001). The ProCana prospectus boasts that it has received a licence from the Mozambican government to withdraw up to 750×10^6 m^3/a (ProCana, 2008). Another large irrigation development is 10,000 ha of sugar cane by CAM, also on the Elefantes downstream of ProCana but upstream of Chokwe irrigation scheme. Plans for Chokwe irrigation scheme, sit-

Table 1
Estimated existing (2009) and planned (2025) water requirements in the Lower Limpopo River Basin.

	ha	mm/a	10^6 m^3/a
Existing uses			
Common uses[a] – agriculture	4000	1500	60
Common uses[a] – domestic + animals			23
Irrigation in Chokwe and elsewhere[b]	5400	2150	116
Estuarine flow requirements			240
Total existing uses	9400		439
Additional requirements from existing uses			
Common uses[a] – agriculture	4000	1500	60
Common uses[a] – domestic + animals			25
Chokwe	16,500	2150	355
Planned new uses			
ProCana drip	26,500	1200	318
ProCana outgrowers	11,000	2150	237
CAM	10,000	2150	215
Xai Xai (Ponela)	9000	2150	194
Total planned additional use by 2025	77,000		1404

[a] Common uses are those uses of water that satisfy primary requirements for which no water licences are required, and which are therefore not registered.
[b] These figures are higher than those provided by ARA-Sul/UGBL in April 2009, when they had on record 4525 ha of formal irrigation, with a planned water demand of 94.6×10^6 m^3/a.

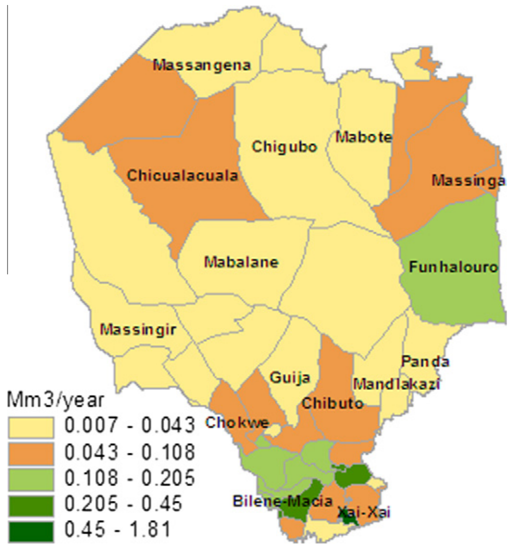

Fig. 1. Estimated future water demand for domestic use in the year 2025 in the Lower Limpopo River Basin, per district.

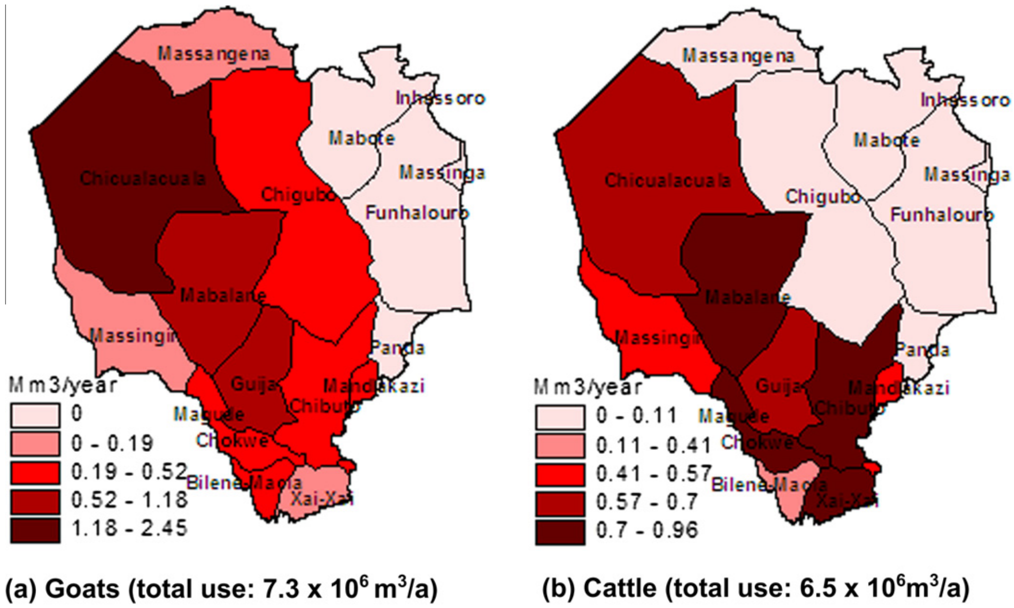

Fig. 2. Estimated current water use of goats and cattle in the Lower Limpopo River Basin, per district, 2009.

uated downstream of the confluence of the Elefantes with the mainstream Limpopo, envisage that the potential command area will effectively be irrigated. Finally, further downstream near Xai Xai a block of 9000 ha of rice is currently being developed.

3. Available water resources

The main sources of blue water in the Lower Limpopo River Basin are the two main branches flowing into Mozambique, namely the Olifants and the main stem Limpopo, as well as some local tributaries, including the Changane and Sangutane rivers. In this paper the local tributaries will be ignored because of lack of stream flow data. The error in the analysis is however small, as these tributaries are ephemeral and contribute relatively little water and during few rainstorms only. Moreover, most of these tributaries do not have storage reservoirs so this water cannot be kept for later use during the dry season.

There are no reliable estimates of current water availability in the Olifants and the main stem Limpopo as they flow into Mozambique. This is mainly due to two factors: (1) discharge measurements in the Mozambican part of both rivers are incomplete and their accuracy is questioned; (2) upstream developments, especially in South Africa since the early 1980s, have resulted in large water withdrawals, but how this has effected water availability in Mozambique is not well understood, nor what the most likely upstream development scenarios will be during the next 10–20 years and how this will effect Mozambique.

The greatest uncertainty surrounds the water discharges in the Olifants River where it flows into Mozambique. This is partly caused by the lack of reliable discharge observations since 1977, when Massingir Dam was constructed and the gauging site submerged. From then on river inflows from the Olifants into Massingir dam were estimated through establishing the water balance of the reservoir, based on observed precipitation, evaporation, discharge and water level.

The monthly discharge data published in DNA (1984), covering the period October 1951–September 1983 are considered the most reliable (Table 2).

Because of the large upstream developments that have become more significant in recent times, as well as the quality of the 1984 document, it was decided to take as the starting point of the analysis the data set presented in the DNA (1984) report. This data set was extended by 7 years to cover a 39 year period (October 1951–September 1990). Such a period was considered sufficient to account for long-term climatic cycles. For the Limpopo River we used data provided by DNA; for the Olifants River we used data from McCartney and Arranz (2007), increasing their 1995 scenario set by 14%.

Future water developments upstream in South Africa influence water availability in Mozambique. McCartney and Arranz (2007) have estimated the most likely development scenarios in the South African part of the Olifants/Elefantes river, upstream of Mozambique (Table 3).[1] Note that the 2025 high growth scenario implies

Table 2
Discharge data based on a series of monthly means, October 1951–September 1983 (DNA, 1984).

	Unit	Limpopo upstream of confluence	Elefantes flowing into Massingir
Average	10^6 m^3/a	3512	1840
Stand. dev.	10^6 m^3/a	3749	1120
Coeff. of var.	–	1.07	0.61

Table 3
Annual average inflow into Massingir (10^6 m^3/a).

	1951–1983 (DNA, 1984)	1951–1983 (McCartney p.c.)	1950–1990 (McCartney p.c.)
Observed	1840		
Modelled – naturalised (zero abstractions in RSA)		2.068	1993
Modelled – with abstractions in RSA as during 1995		1520	1427
Modelled – with abstractions in RSA as projected in 2025 (high growth scenario)		1290	1199

[1] The authors kindly made available the outcomes of their models (McCartney pers. comm., 2008).

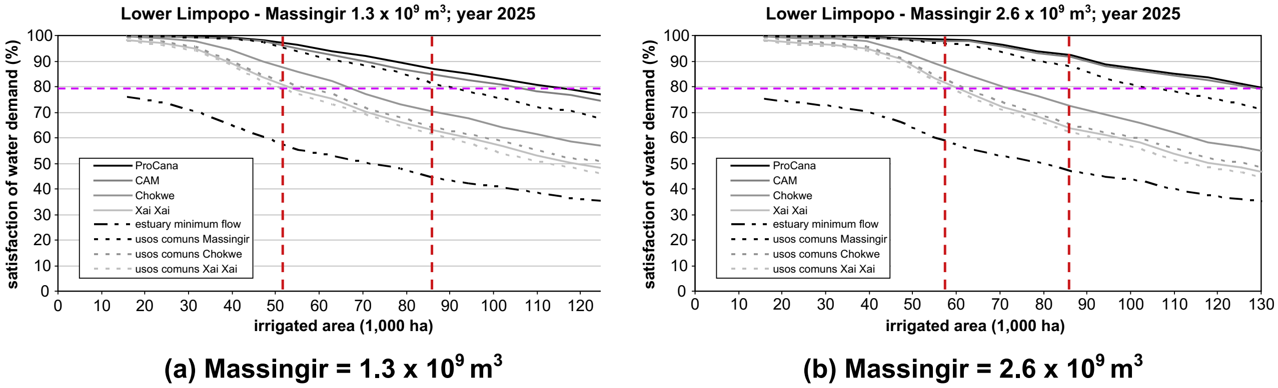

Fig. 3. Satisfaction of water demand as a function of irrigation development, for two reservoir capacities (the right vertical broken line indicates the planned full-scale irrigation development (86,400 ha), the left vertical broken line indicates the maximum development that still achieves 80% satisfaction of demand for all irrigators).

that inflows into Massingir would equal 1290/1840 = 0.70 times the original DNA data set of 1951–1983.

4. Water storage

The only major reservoir in the Lower Limpopo River Basin is Massingir dam on the Elefantes, which was constructed between 1972 and 1977. The design capacity was 2.6×10^9 m^3 but this was never realised because of seepage problems in the dam wall, and in practice its storage capacity was limited to 1.3×10^9 m^3. A rehabilitation project has increased its storage capacity through the construction of additional gates on top of the spillway, allowing the water level to be raised by 10 m, doubling live storage to the original design capacity. However, a disaster struck the dam in May 2008, when the outlet works collapsed as the reservoir was filling over and above historic levels. It therefore remains unsure whether the dam will indeed ever be operated above the historic capacity of 1.3×10^9 m^3.

5. Modelling the Lower Limpopo River Basin

A data set was constructed to reproduce the water availability under the 2025 High Growth scenario as proposed by McCartney and Arranz (2007). Thereto the DNA (1984) data of Elefantes River Basin monthly discharge data were multiplied by a factor 0.70 (i.e. 1290/1840).[2]

As we lack any data on the likely developments upstream in South Africa and Zimbabwe in the catchment area of the Limpopo mainstream, we assumed a significant, but compared to the Elefantes River Basin a slightly less dramatic, abstraction level upstream. The DNA discharge data were therefore multiplied by a factor 0.75. This is an arbitrary assumption but a sensitivity analysis shows that this assumption does not affect the outcomes much: varying this factor between 0.5 and 1.0 improves the satisfaction of demand (the percentage of time the water demand of a user is satisfied) of all users with 3% or less, with the exception of the compliance of the minimum estuary flow, which varies with 8% (at original Massingir capacity).

We expanded the original 1951–1983 data set with data from DNA for the mainstream and McCartney and Arranz (2007) for the Elefantes with 7 years to include the period 1983–1990. Average annual inflow considered by the model to simulate the high growth scenario in 2025 thus amounts to 2.45×10^9 m^3/a for the Limpopo mainstream and 1.22×10^9 m^3/a for the Elefantes, totalling 3.67×10^9 m^3/a.

The model considers net evaporation losses from the Massingir reservoir, which are significant (in the order of 6–11% of inflows into the dam, depending on scenario). The model also assumes that the water requirements of CAM, Chokwe and Xai Xai partly rely on the flows from the unregulated mainstream Limpopo (calculated as half of the flow of the previous time step). The balance of the requirement is requested from Massingir.

The model assumes a worst case institutional situation: any user along the river diverts that water it requires or the amount that is available, which ever is lowest. So there are no assumed efforts for upstream users to let water flow for the benefit of downstream users in case water is insufficient. So, those located nearest to the Massingir dam are first in the "water queue" and will be able to satisfy their demands first, irrespective of whether there is sufficient water for downstream users.

6. Results

Fig. 3 shows the results of the model runs at different levels of irrigation development, with 86,400 ha (9400 + 4000 + 73,000) of irrigation as the target. It is clear that at this target development level only the two large sugar cane developments manage to satisfy their water needs with high reliabilities. The other users, located further downstream, will have a much lower chance to satisfy their water requirements, lower than a generally accepted assurance level of 80% for irrigation (i.e. in 80% of the years the full irrigation requirements will be met). If irrigation water has to be supplied for all users at this reliability (i.e. failing in one of 5 years, on average), a maximum of approximately 58,000 ha can be irrigated with the enlarged Massingir reservoir. This implies that only about 44,000 ha of additional irrigation can be considered, i.e. only 60% of the envisaged 73,000 ha. At the current capacity of Massingir only 52,000 ha can be irrigated at an assurance level of 80%, allowing for only 38,000 ha of new irrigation. Note that at all development levels the minimum flow at the estuary is frequently violated, even despite that in the model Massingir reservoir releases water to (partially) satisfy this minimum flow.

Note that if ProCana would withdraw the amount of water cited in its prospectus (750×10^6 m^3/a) then satisfaction levels of Chokwe drop to 64.7% and of Xai Xai to 59.3% (with an enlarged Massingir).

Evaporation losses from Massingir are relatively large (92×10^6 m^3/year at full development with current dam capacity

[2] In fact, it would be better to multiply the original data by a factor 0.9 and then deduct a value of 39.6×10^6 m^3/month, which returns the correct average discharge but reproduces better the standard deviation of the data set by McCartney and Arranz (2007). However, given the size of Massingir, reducing the fluctuation has hardly any effect on model outcomes; what matters is the average value.

Table 4
Water use for planned and maximum irrigation development (10^6 m^3/a).

Development scenario	Reservoir capacity	Water use	Evaporation from Massingir	Total water use
73,000 ha new irrigation	2.6×10^9 m^3	1277	117	1394
44,000 ha new irrigation	2.6×10^9 m^3	980	133	1113
73,000 ha new irrigation	1.3×10^9 m^3	1204	92	1296
44,000 ha new irrigation	1.3×10^9 m^3	936	106	1042
38,000 ha new irrigation	1.3×10^9 m^3	871	109	979

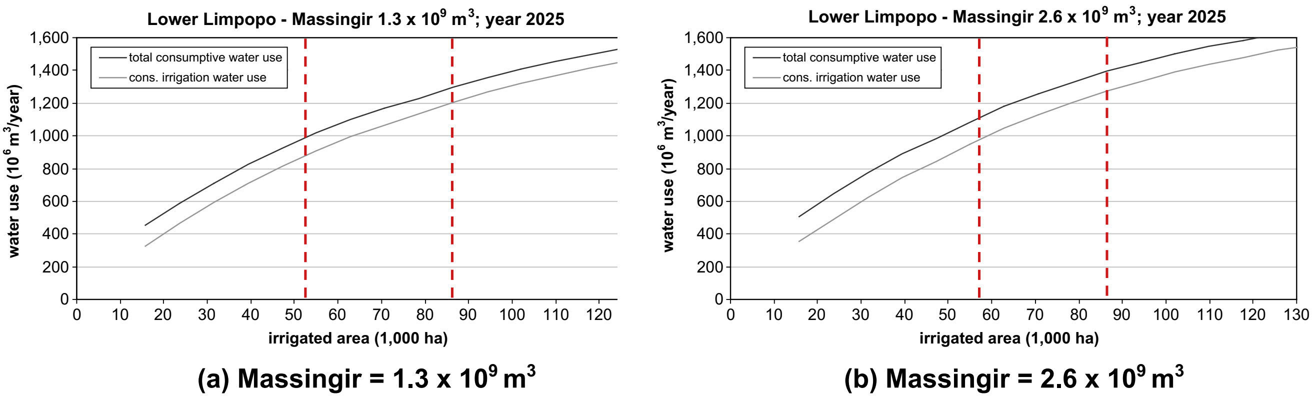

Fig. 4. Total water use (irrigation water use and evaporation losses from Massingir dam) as a function of irrigation development, for two reservoir capacities.

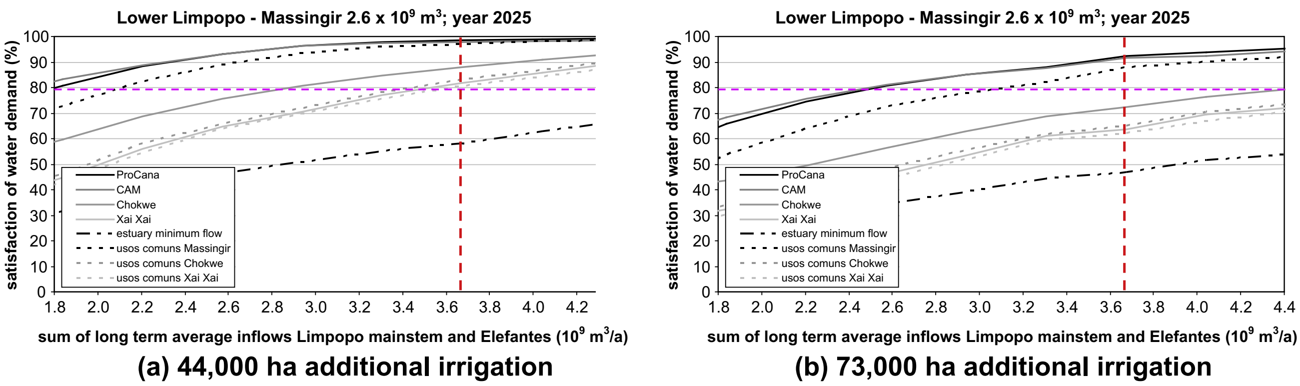

Fig. 5. Sensitivity of satisfaction of demand on water availability, with an enlarged Massingir reservoir. (The vertical red broken line indicates the base value used in the previous analyses.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and 117×10^6 m^3/year with an enlarged Massingir dam, representing 7–8% of total water consumption; Table 4 and Fig. 4).

7. Sensitivity analysis

In order to verify the sensitivity of the outcomes to the assumed total annual inflows from both the Elefantes and the Limpopo, inflows were varied from 0.3 to 1.2 of the base series used, at 3.67×10^9 m^3/a. The results (Fig. 5b) show that if inflows reduce by 10% to 3.31×10^9 m^3/a, Chokwe irrigation scheme will see its satisfaction levels decrease from 73% to 69% at full development, while Xai Xai's will reduce from 64% to 61%. If water availability decreases a further 10% to 2.94×10^9 m^3/a, these values drop to 63% and 54%, respectively. The satisfaction levels of ProCana and CAM only drop below 80% when water availability decreases to below 2.5×10^9 m^3/a. These figures indicate that the modelling results are, predictably, quite sensitive to the water availability. If water availability is less than assumed, then those located further downstream will be first and most severely affected. For adequate planning, it is therefore important to reduce the high level of uncertainty of the inflow data.

8. Conclusion

There are many uncertainties when considering water demand and water availability. On the demand side little is known of current and future water uses for primary purposes, the so-called "*usos comuns*",[3] in particular with respect to small-scale irrigation and wetland cultivation. These uses remain largely invisible, and may be affected by envisaged large-scale irrigation development.

[3] This is in legal terms '*de minimis*' water use (see Hodgson, 2004).

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But even the plans for large-scale irrigation development are surrounded with uncertainty, as a large part of the planned irrigation is for biofuel production, the profitability of which being largely determined by the world market price of oil, which has been volatile during the last few years.

There are many uncertainties related to future water availability in the Lower Limpopo River Basin, also in connection with climate change (Reason et al., 2005; Shongwe et al., 2009; Love et al., 2010). Discharge measurements are incomplete and sometimes inconsistent, while upstream developments during the last 25 years have been significant if not dramatic and their future trend is unknown. This uncertainty seriously complicates the possibility of realistic water resources planning.

Given these limitations, it was decided to model water availability conservatively, basing inflows into Massingir dam on the High Growth scenario in the upstream South African Olifants catchment area for the year 2025, as developed by McCartney and Arranz (2007), and using discharge data of the mainstream Limpopo at 75% of historic data (1951–1983).

Within the confines of the above assumptions it may be concluded that there is sufficient water for the development of 38,000 ha new irrigation in case Massingir dam is operated at current capacity, whereby all uses can achieve 80% assurance of supply (average annual water use is $0.98 \times 10^9\ m^3/a$, of which $0.11 \times 10^9\ m^3/a$ net open water evaporation from the dam itself). If Massingir can be operated at double capacity, a total of 44,000 ha irrigated may be added compared to current use (annual water use would be $1.11 \times 10^9\ m^3/a$, of which $0.13 \times 10^9\ m^3/a$ evaporation from the dam).

The modelling results show that any additional water use would certainly impact downstream users and thus create tensions between water users. Also, the considered irrigation development could impact existing water uses for primary requirements that have not been formally registered (*usos comuns*). Moreover, once the mentioned large-scale developments have materialised, it will be more difficult for new irrigators (e.g. emergent farmers) to access water for productive purposes. Competition over water will be exacerbated by upstream developments in South Africa and Zimbabwe.

These findings mean that that the Lower Limpopo River Basin has insufficient water for all envisaged irrigation developments amounting to 73,000 ha. There is sufficient water for only 60% of that figure. It is evident that if ProCana would use all the water allocated to it as claimed in its prospectus ($750 \times 10^6\ m^3/a$; whereas we used $555 \times 10^6\ m^3/a$ for its full development scenario), then the downstream water users will face water shortages more regularly than modelled here.

It may thus be concluded that all envisaged development plans have to be revisited and reduced. The public water institutions, such as ARA-Sul and the Basin Committee, should decide how best to achieve these required reductions.

Given the historically slow irrigation development in the Lower Limpopo River Basin, despite huge plans ever since the early 1980s, it is expected that some time will elapse before 44,000 ha of new irrigation will have been implemented. This time could be used to improve monitoring networks and consolidate the disparate data sets on river discharge and water use, in order to decrease the high uncertainty of current findings.

Meanwhile the four riparian Limpopo States are currently preparing a joint river basin study. In that study a methodology could be developed to estimate and safeguard water availability for those users who under the law do not need registration – but who do need water. In this context it is important to study the implications of future irrigation development in downstream Mozambique for the entire basin and all users.

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