# Prospect for Developing Water Storage through Analysis of Runoff and Storage Capacity of Limpopo and Luvuvhu-Letaba Water Management Areas of South Africa

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## Abstract

*The study investigated the prospects for developing water storage based on comparison of existing runoff with storage capacity of river catchments and of municipalities in Limpopo and Luvuvhu-Letaba Water Management Areas (WMAs). Ten municipalities were sampled for the study, namely: Makhado, Musina, Lephalale, Polokwane, and Aganang (Limpopo WMA) and Letaba, Thulamela, Tzaneen, Giyani and Mutale (Luvuvhu-Letaba WMA). The mean annual runoff (MAR) was 985.9 million $m^3$ for Limpopo WMA and 1 183.9 million $m^3$ for Luvuvhu-Letaba WMA. Total storage capacity was 325.2 million $m^3$ for Limpopo WMA and 759.6 million $m^3$ for Luvuvhu-Letaba WMA. A MAR of 611.4 million $m^3$ for Limpopo WMA and 365.2 million $m^3$ for Luvuvhu-Letaba WMA was available for additional storage. Combined municipal MAR of 380.6 million $m^3$ for Limpopo WMA and 155.2 million $m^3$ for Luvuvhu-Letaba WMA was available for additional storage. The Limpopo WMA should be prioritised for building of additional dams.*

**Keywords:** Water management area, catchment, municipality, runoff, storage capacity

## *1. Introduction*

The supply of water in an area is dependent on the quantity of runoff and this is in turn influenced by rainfall. The importance of rainfall was stated by Schulze (1995) who described it as the fundamental driving force and important input behind most hydrological processes. Occurrence of low rainfall and subsequent runoff in an area results in water shortage described in terms of resource stress or scarcity. An area is water stressed when annual supplies per capita drop below 1 700 $m^3$, is water scarce when the supplies decrease below 1 000 $m^3$ and has absolute scarcity when the supplies are below 500 $m^3$ (FAO, 2007).

The rainfall of an area is influenced by the climatic region in which the area is located. Three climatic regimes were identified in Africa, namely: the low rainfall areas, those of intermediate range and the high rainfall areas (de Wit and Stankiewicz, 2006). South Africa is located in a predominantly low rainfall area. The climate is relatively arid in the west and humid in the east. The average annual rainfall is 450mm, and is well below the world average of about 860mm (DWAF, 2004a). Accordingly, the Limpopo Province is also situated in a low rainfall area with lesser rainfall recorded in the western located Limpopo WMA compared to that received by the eastern located Luvuvhu-Letaba WMA (DWAF, 2003; DWAF, 2004b). The river catchments and the municipalities located in these WMAs are therefore affected by the water scarcity.

To mitigate against the challenge of scarcity, water resources should be more efficiently managed, and this should begin with an assessment of the amount of runoff in a specific area. Runoff was described as the water yield from a given area and consists of mainly stormflow and baseflow, and is in fact the water that can be seen on land surfaces and can potentially be stored for use (Schulze, 1995; DWAF, 2004a). Stormflow is the water that is generated on or near the surface of a catchment from the occurrence of rainfall and contributes to flow in the streams within that catchment (Schulze, 1995). On the other hand, baseflow is regarded as water from previous rainfall events that has percolated through the soil horizons into the intermediate and groundwater zones and then contributes to the streams within a catchment as a delayed flow (Schulze, 1995; Fargo, 2002; Webb, 2005).
In addition to the amount of runoff, the amount of water supply depends on the availability of storage infrastructure such as dams (Mostert, 2008). Water is stored in dams during high rainfall seasons when and where the economic value of the resource is low and is reallocated to times and places when and where its economic value is high. The concept of 'economic value' includes both the social and environmental value of water (Keller *et al.,* 2000). The dam storage capacity of a river catchment refers to the quantity of water that can be stored in man-made dams in that catchment and availed for different uses.

The objective of this study was to investigate the prospects of developing water storage through analysis of current runoff and storage capacity relationships of river catchments and municipalities in the Limpopo and Luvuvhu-Letaba WMAs. The water storage capacity within the area was compared to the runoff to assess the prospects of constructing new dams in some catchments and of implementing new strategic water projects such as rain water harvesting in municipalities.

## *2. Methodology*

### 2.1 Study area

The study was based in two WMAs located in the Limpopo Province of South Africa. The WMAs selected for the study are administered by the Limpopo Regional Office of Department of Water Affairs and Forestry (DWAF), namely: Limpopo WMA and Luvuvhu-Letaba WMA (Figure 1).

Ten municipalities under the two WMAs were sampled for the study, five from each WMA. The five municipalities sampled from the Limpopo WMA include three which are fully contained in the WMA, namely: Musina, Aganang, and Lephalale and two which have a large part of their land area located in the WMA, namely: Makhado and Polokwane. As for the Luvuvhu-Letaba WMA, the five municipalities sampled were the Letaba and Giyani which are fully contained and Mutale, Thulamela and Tzaneen with larger part of their land areas located in the WMA.

### 2.2 Sampling procedure

Sampling was done using the multistage approach for WMAs and municipalities (Leedy and Ormrod, 2010). Purposive sampling was used to select the Limpopo and Luvuvhu-Letaba WMAs as they are managed by the nearby Limpopo Regional Office of DWAF that is more accessible for information (Welman *et al.,* 2005; Leedy and Ormrod, 2010). All main river catchments for each WMA were included in the study, seven for Limpopo and six for Luvuvhu-Letaba WMA. Informed by the ease of availability of information, 10 municipalities were also purposively chosen, five in each of the WMAs (Figure 1).

### 2.3 Data collection and analysis

Data for runoff and storage capacity of river catchments (1960-1996) was obtained from DWAF (2003) for the Limpopo and from DWAF (2004b) for the Luvuvhu-Letaba WMA. The data for municipal runoff was calculated from that of representative quaternary catchments as presented by Midgley *et al.* (1994). As guided by Leedy and Ormrod (2010), the data was properly organized for ease of analysis by classifying them into main themes covered by the investigation, namely: runoff and storage capacity of the study area. As mentioned earlier, the study area was categorized into WMAs, river catchments and municipalities.

Interpretation was objective and precise to specific situations and generalizations were made only in strict accordance with the data. The data was related to the purpose of the study and pre-existing literature while also determining the practical significance of relationships among variables (Leedy and Ormrod, 2010).

## *3. Results and discussion*

### 3.1 Runoff and storage capacity of river catchments in the study area

The occurrence of runoff determines the extent to which man will access water for various uses, including domestic, industrial and agricultural uses. Several authors highlighted the benefits of practices such as conservation tillage in improving the agricultural productivity of water (Kongo and Jewitt, 2006; Mutiro *et al.*, 2006; Ngigi *et al.*, 2006; Mupangwa *et al.*, 2008; Munodawafa and Zhou, 2008; and Sturm *et al.*, 2009). With conservation tillage, dryland farming is possible without runoff impoundments in reservoirs that tend to be more necessary for irrigated agriculture.

Man can also enhance water productivity by constructing reservoirs such as dams to impound the water (Keller *et al.*, 2000; Muller, 2000). Water storage infrastructure plays a key role in water management (Mostert, 2008), and the ability of a nation to invest in it determines the ability of the nation to develop its water resources. According to Inocencio *et al.* (2003), developing storage infrastructure is an obvious response to the problem of water scarcity. Dams are the common infrastructure for water storage in the study area and were therefore the focus of investigation.

Dams are classified as small or large with small dams characterised by a storage volume generally less than 0.75 million $m^3$ (BOR, 1987; ICOLD, 1998). Although small dams have an advantage of being operationally efficient and being flexible and often closer to the point of use, the high surface area to volume ratio of these small dams leads to high evaporation loss. Small dams lose, on average, 50% of their impoundment to evaporation in arid and semi-arid areas, and this becomes a disadvantage (Gleick, 1993; Sakthivadivel *et al.*, 1997). On the other hand, large dams are costly to build for huge quantities of water to be impounded. Large dams provide larger quantities of water for allocations for different uses and hence play a bigger role in promoting national water security.

#### (a) Runoffs of catchments in the study area

The amount of runoff from a catchment influences the stream flows and hence the sizes of rivers flowing through that catchment. In fact the size of a river at a catchment is determined by runoff from the catchment under consideration plus the runoff contribution from all upstream catchments (Schulze, 1995). Many of the rivers flowing through the study area are permanently flowing at their headwaters and then pass through drier regions and become seasonal rivers due to natural losses as well as abstractions (Gorgens and Boroto, 2003). The mean annual runoff of river catchments of Limpopo WMA and Luvuvhu-Letaba WMA are presented in Figure 2 (DWAF, 2003; DWAF, 2004b).

As shown in Figure 2, the total MAR of river catchments in the Limpopo WMA was 985.9 million $m^3$ while that of the catchments in the Luvuvhu-Letaba WMA was 1 183.9 million $m^3$. Considering MAR, this result indicated that the Luvuvhu-Letaba WMA had more available water than the Limpopo WMA. It would therefore be expected for the Luvuvhu-Letaba WMA to have better prospects for development of dam storage than the Limpopo WMA.

Seven river catchments had enough water to accommodate dams in excess of 100 million $m^3$ storage volume of the resource. The seven river catchments are Mogalakwena with MAR of 268.8 million $m^3$, Lephalale (149.4 million $m^3$) and Mokolo (315.6 million $m^3$) in the Limpopo WMA and the Groot Letaba (380.9 million $m^3$), Middle Letaba (151.9 million $m^3$), Luvuvhu (362.9 million $m^3$) and Mutale (157.1 million $m^3$) in the Luvuvhu-Letaba WMA. Of the seven catchments, three are in the Limpopo WMA and four are in the Luvuvhu-Letaba WMA and this affirms the point that the latter WMA had more available water.

The range of MAR is from 24.5 million $m^3$ for Nwanedi River to 315.6 million $m^3$ for the Mokolo River in the Limpopo WMA and 41.3 million $m^3$ for the Lower Letaba to 380.9 million $m^3$ for the Groot Letaba in the Luvuvhu-Letaba WMA. These wide ranges show a large variation of MAR from one river catchment to the other, thereby revealing large differences in prospects for development of dam storage across the catchments.

#### (b) Water storage capacity of major catchments under study

Keller *et al.* (2000) alluded to the fact that dam storage captures water when and where its marginal value is low and can then reallocate it to times and places when and where its marginal value is high.

For the area under study, the MAR of river catchments varies from one season to the other, and also differs from one catchment to the other (Figure 2) and this necessitates the development of dam storage. The river catchments for the two WMAs under study were semi-closed with larger outflows to the oceans during rainy seasons and less during dry seasons. As a result, dam storage allowed for this scarce resource to be captured during the rainy season when the MAR was high, thereby reducing the amount of water lost to the oceans, and availing it to be stored for the dry season when the MAR is low, thereby increasing the supply during this time of scarcity. The storage capacity for all the dams in each river catchment was added up to obtain the total storage capacity of the catchment, referred to as catchment storage capacity (Table 1).

In order to establish accurate estimates of available catchment MAR for possible development of additional storage, provision was made for the requirements of the ecological reserve. In accordance with the findings by Hughes (2005), this was calculated at 5% of existing catchment MAR.

The total storage capacity of river catchments in the Limpopo WMA was 325.2 million $m^3$ (33% of MAR) while that of the catchments in the Luvuvhu-Letaba WMA was 759.6 million $m^3$ (64.2% of MAR). Four river catchments had a storage capacity > 100 million $m^3$, namely: Mokolo in the Limpopo WMA with a storage capacity of 145.9 million $m^3$ and the Groot Letaba (265.7 million $m^3$), Middle Letaba (250 million $m^3$) and Luvuvhu (240 million $m^3$) in the Luvuvhu-Letaba WMA. The results reveal that more runoff is stored in the Luvuvhu-Letaba WMA compared to that in the Limpopo WMA (Table 1) suggesting that the latter WMA was less developed in terms of water storage infrastructure.

Accordingly, the Limpopo WMA had 611.4 million $m^3$ of available MAR for possible development of new dams compared to only 365.2 million $m^3$ for the Luvuvhu-Letaba WMA. These results show that prospects for development of additional storage infrastructure are more in the Limpopo WMA than in the Luvuvhu-Letaba WMA. Based on these results, the Limpopo WMA should be given more priority for development of new dams than the Luvuvhu-Letaba WMA.

Five river catchments in the study area had available MAR > 100 million $m^3$ for possible development of new dams and should be targeted for this purpose. The five rivers are the Mogalakwena (181.8 million m3), Lephalale (136.7 million $m^3$) and Mokolo (153.9 million $m^3$) in the Limpopo WMA and the Luvuvhu (104.8 million m3) and Mutale (145.3 million $m^3$) in the Luvuvhu-Letaba WMA.

For the Luvuvhu-Letaba WMA, it was revealed that the Middle Letaba catchment had available MAR of -105.7 million $m^3$ for possible development of additional storage. This negative figure occurred as the present storage capacity is larger than the catchment MAR. As revealed by DWAF (2004b), the major contributor to the storage capacity that exceeded the catchment MAR was the 184.2 million $m^3$ Middle Letaba Dam built in a catchment with MAR of 151.9 million $m^3$, with smaller dams in the catchment exacerbating the situation. The situation was reported to have been caused by the misplacement of the dam due to the political situation of the time.

On the contrary, the Mutale catchment had the highest available MAR (145.3 million $m^3$) in the WMA for possible development of new dams as only a small storage capacity of 3.9 million $m^3$ had been developed. It is therefore recommended that priority for development of new dams be given to the Mogalakwena, Lephalale and Mokolo river catchments in the Limpopo WMA and to the Luvuvhu and Mutale catchments in the Luvuvhu-Letaba WMA.

**(c) Influence of catchment runoff on storage capacity**

As stated by Mostert (2008), the degree of water availability depends on the magnitude of storage capacity in addition to the amount of runoff. For water stressed countries, it would be expected that the development of storage infrastructure should be influenced by the amount of runoff, and this would be the situation in the study area (Figure 3).

There was a moderate to strong correlation ($R^2$=0.6752) between runoff and storage capacity of the river catchments in the Limpopo WMA (Figure 3). As revealed by the graph ($Y=0.382x - 7.3388$), an increase in MAR was accompanied by an increase in water storage capacity. The results indicate that more storage infrastructure was developed in catchments with more runoff. Storage infrastructure was therefore properly planned taking catchment runoff into consideration.

A moderate to strong correlation ($R^2$=0.6228) was also recorded between runoff and storage capacity of catchments in the Luvuvhu-Letaba WMA. The graph ($Y=0.7647x – 24.309$) also shows an increase of storage capacity with an increase in catchment runoff. The steeper gradient of the graph for the Luvuvhu-Letaba WMA suggests a larger increase of storage capacity per increase of catchment runoff and is in accordance with the fact that 64.2% of runoff was stored in this WMA compared to only 33% in the Limpopo WMA. Contrary to the picture presented by the Middle Letaba Dam, the rest of the dams in the Luvuvhu-Letaba WMA were well designed with due consideration made of available runoff.

### 3.2 Runoff and storage capacity of municipalities in the study area

The runoff and storage capacity of municipalities are important determinants of their water availability.

#### (a) Runoff of municipalities in the study area

Although water in South Africa is a national resource (RSA, 1998; DWAF, 2004a), analysis of the amount of runoff across the area of a municipality is important. Knowledge of runoff of municipalities assists in identifying those in which municipal strategic water projects could be initiated for developmental activities. The projects would be of economic benefit to municipalities that would otherwise have to be supplied from storage infrastructure that is a long distance away, and this could be costly.

Adoption of rainwater harvesting practices improves water supply for domestic and productive purposes. For instance, on-farm storage ponds and *in situ* rainwater conservation systems such as conservation tillage are possible strategies for upgrading rainfed agriculture in semi-arid environments (Ngigi *et al.*, 2006). The runoffs of study municipalities were calculated from those of quaternary catchments located in the municipalities (Figure 4). The total MAR of the study municipalities in the Limpopo WMA was 602.7 million $m^3$ while that of the study municipalities in the Luvuvhu-Letaba WMA was 898.3 million $m^3$. The MAR of study municipalities in the Luvuvhu-Letaba WMA is larger than that of Limpopo WMA, suggesting that the former had a larger quantity of available water.

Four municipalities had MAR > 100 million $m^3$ and were the locations of the larger quantities of available water. The four municipalities are Makhado (269.2 million $m^3$) and Lephalale (282 million $m^3$) in the Limpopo WMA and Thulamela (359.1 million $m^3$) and Tzaneen (352.3 million $m^3$) in the Luvuvhu-Letaba WMA. Of the four municipalities, the two in the Luvuvhu-Letaba WMA had larger amounts of available water than their counterparts in the Limpopo WMA.

#### (b) Water storage capacity of municipalities under study

The water storage capacity of a municipality determines the available MAR for possible development of municipal strategic water related projects not fed from major impoundments. These strategic water projects would include on-farm ponds and conservation tillage for upgrading rainfed agriculture in semi-arid environments (Ngigi *et al.*, 2006). When more storage capacity is available in a municipality, more MAR is stored and this improves the prospects for development of the municipal strategic water projects.

Dam storage capacity represents the maximum capacity that the dam has to store water. Municipal storage capacity was calculated as the total of the storage capacity of dams in a municipality and therefore represents the maximum capacity that a municipality has to store water (Table 2).

The municipal storage capacity was 192 million $m^3$ (31.9% of municipal MAR) for study municipalities in Limpopo WMA and 698.2 million $m^3$ (78.2% of MAR) for those in Luvuvhu-Letaba WMA (Table 2) implying that municipalities in the latter WMA were more developed in terms of water storage capacity. Four municipalities had storage capacity > 100 million $m^3$, and those were Lephalale (145.9 million $m^3$) in the Limpopo WMA and Thulamela (218.8 million $m^3$), Tzaneen (243.3 million $m^3$) and Giyani (213.5 million $m^3$) in the Luvuvhu-Letaba WMA. The results reveal that municipalities in Luvuvhu-Letaba WMA were more developed in terms of water storage infrastructure compared to those in Limpopo WMA.

The available MAR for possible development of municipal strategic water related projects was 380.6 million $m^3$ (63.1% of total MAR) for study municipalities in Limpopo WMA and 155.2 million $m^3$ (17.3% of total MAR) for those in Luvuvhu-Letaba WMA.

These results imply that municipalities in the Limpopo WMA offer better prospects for development of the strategic water related projects than their counterparts in the Luvuvhu-Letaba WMA. Such water related projects should be prioritized for municipalities with larger available MAR (e.g. those with > 100 milliom $m^3$), namely: Makhado (222.8 million $m^3$) and Lephalale (122.1 million $m^3$) in the Limpopo WMA and Thulamela (122.3 million $m^3$) in the Luvuvhu-Letaba WMA.

The reduction of the available MAR for study municipalities in the Luvuvhu-Letaba WMA was worsened by the anomaly at the Giyani Municipality were storage capacity exceeded MAR, resulting in available MAR for possible development of additional storage being -177.9 million $m^3$. This anomaly was a result of the large Middle Letaba Dam with storage capacity of 184.2 million $m^3$ built in a catchment with a lesser MAR of only 151.9 million $m^3$. In terms of the plan, the dam was to have been built downstream from its current position, and this had to be changed because of lack of political consensus on the original site.

## *4. Conclusions*

The results of the investigation revealed that there is more runoff in the Luvuvhu-Letaba (total MAR=1 183.9 million $m^3$) than in the Limpopo (985.9 million $m^3$) WMA. There was a wide range of MAR from one catchment within a WMA to the other and this indicated large differences in prospects for development of dam storage across the catchments.

The total storage capacity of river catchments in the Limpopo WMA was 33% of MAR while that of the catchments in the Luvuvhu-Letaba WMA was 64.2% of MAR, revealing that the latter WMA had more storage capacity. Accordingly, the Limpopo WMA had a larger available MAR of 611.4 million $m^3$ for possible development of new dams compared to only 365.2 million $m^3$ for the Luvuvhu-Letaba WMA. Also, the municipalities in the Limpopo WMA had a larger available MAR of 380.6 million $m^3$ for implementation of municipal strategic water related projects compared to 155.2 million $m^3$ for those in the Luvuvhu-Letaba WMA.
The results suggest that the Limpopo WMA should be prioritized for development of new dams and strategic water related projects. The development of new dams should prioritize the Mogalakwena, Lephalale and Mokolo river catchments in the Limpopo WMA and the Luvuvhu and Mutale catchments in the Luvuvhu-Letaba WMA. As for municipal strategic water related projects, priority should be given to Makhado and Lephalale municipalities in the Limpopo WMA and Thulamela municipality in the Luvuvhu-Letaba WMA. Although the Limpopo Province is water scarce, adequate runoff still occurs in some catchments to warrant the construction of new dams for increased water storage.

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## *6. List of figures and tables*

### 6.1 Figures

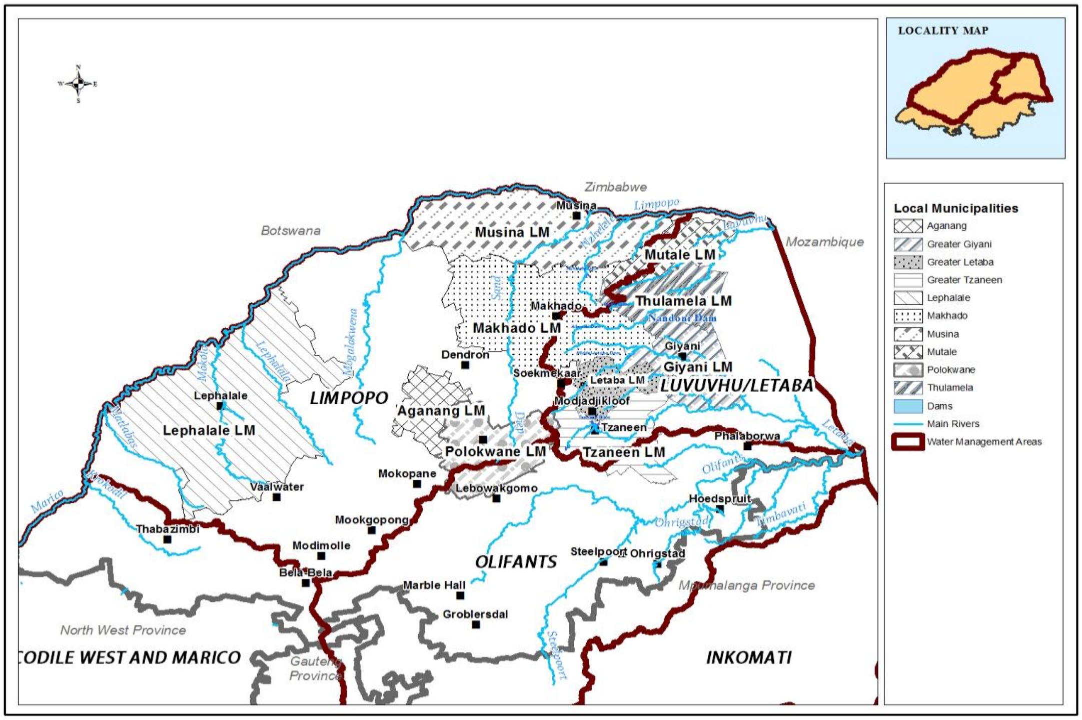


**Figure 1**: Map of the Limpopo Province showing the Limpopo and Luvuvhu-Letaba Water Management Areas (red border line) and the ten municipalities (hatchings) sampled for the study (DWAF, 2004a)

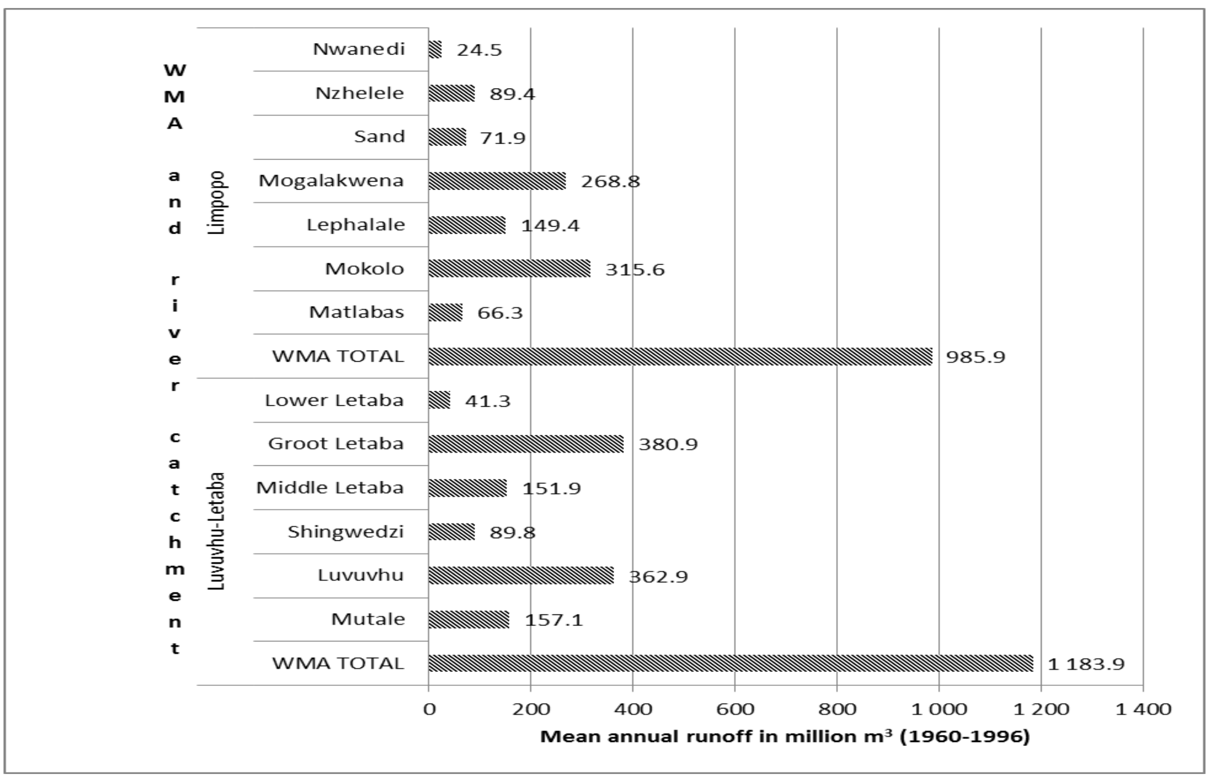


**Figure 2**: Mean annual runoff (MAR) of river catchments of the Limpopo and Luvuvhu-Letaba WMA (DWAF, 2003; DWAF, 2004b)

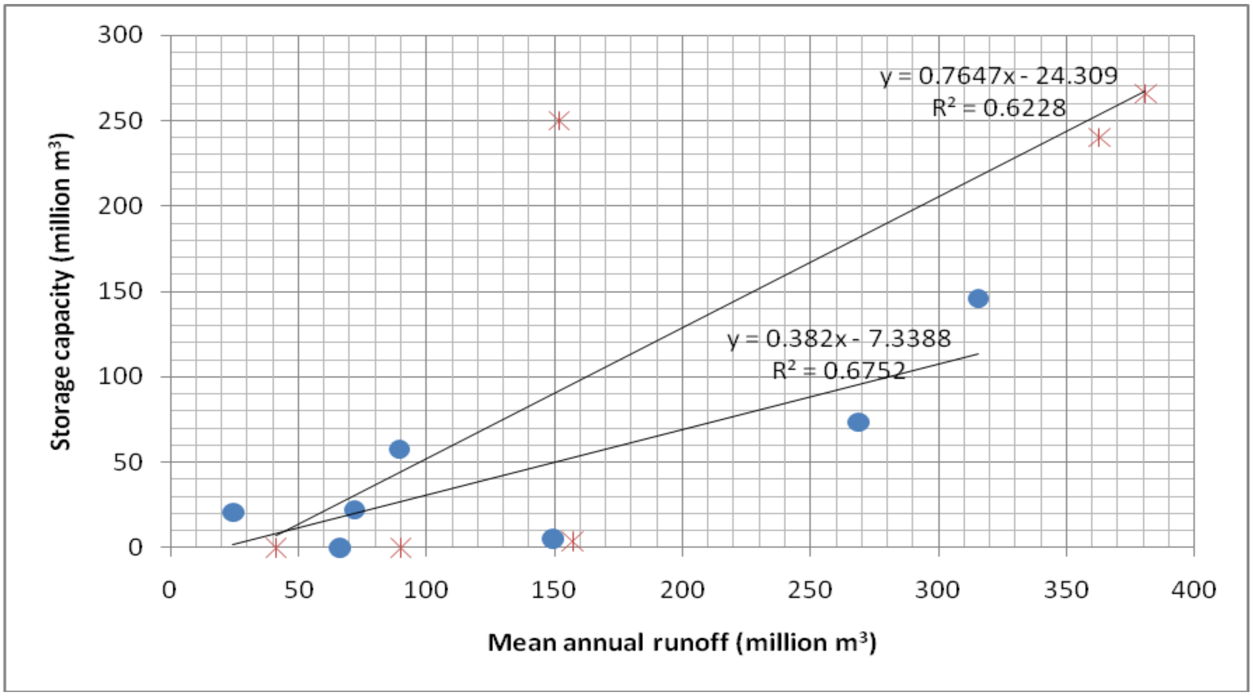


**Figure 3**: Influence of runoff on storage capacity of river catchments of Limpopo and Luvuvhu-Letaba WMAs

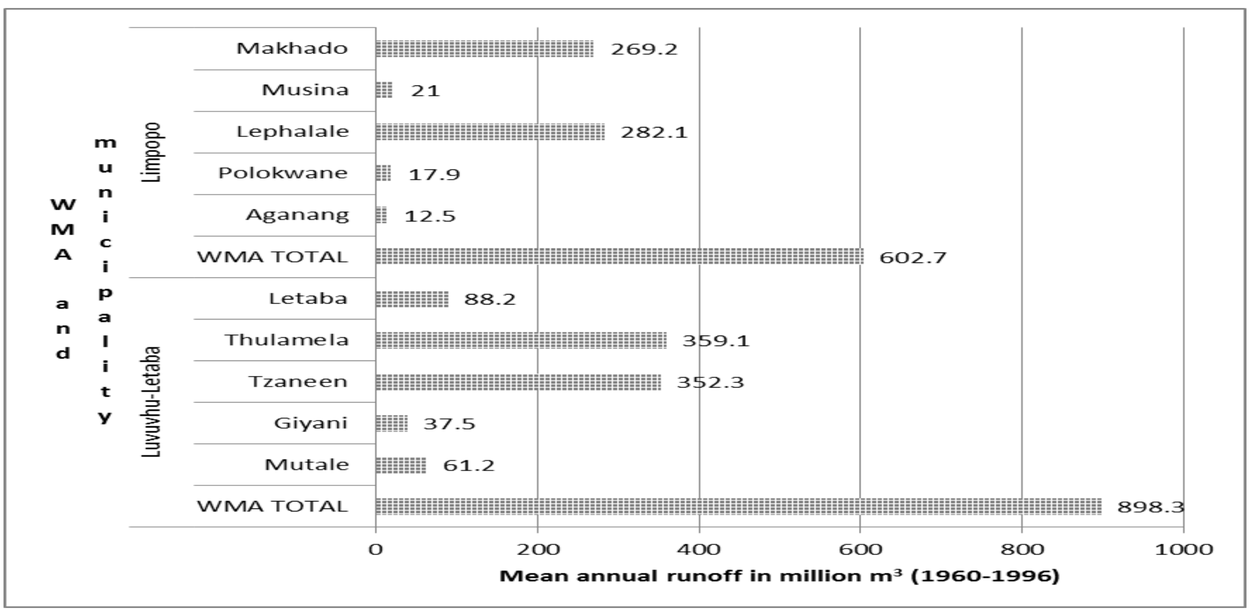


**Figure 4**: Mean annual runoff (MAR) of municipalities of the Limpopo and Luvuvhu-Letaba WMA (Midgley *et al*., 1994)

### 6.2 Tables

**Table 1:** Storage capacity and available MAR for possible development of new dams in river catchments of the Limpopo and Luvuvhu-Letaba WMAs (DWAF, 2003; DWAF, 2004b)

| Water Management Area | Catchment | MAR (million $m^3$) | Storage capacity (million $m^3$) | Storage capacity + 5% MAR for ecological reserve (million $m^3$) | Available MAR for possible development of new dams (million $m^3$) |
|---|---|---|---|---|---|
| **Limpopo** | Nwanedi | 24.5 | 20.6 | 21.8 | 2.7 |
| | Nzhelele | 89.4 | 57.8 | 62.3 | 27.1 |
| | Sand | 71.9 | 22.1 | 25.7 | 46.2 |
| | Mogalakwena | 268.8 | 73.6 | 87.0 | 181.8 |
| | Lephalale | 149.4 | 5.2 | 12.7 | 136.7 |
| | Mokolo | 315.6 | 145.9 | 161.7 | 153.9 |
| | Matlabas | 66.3 | 0 | 3.3 | 63.0 |
| | **WMA total** | **985.9** | **325.2** | **374.5** | **611.4** |
| **Luvuvhu-Letaba** | Lower Letaba | 41.3 | 0.0 | 2.1 | 39.2 |
| | Groot Letaba | 380.9 | 265.7 | 284.7 | 96.2 |
| | Middle Letaba | 151.9 | 250.0 | 257.6 | -105.7 |
| | Shingwedzi | 89.9 | 0.0 | 4.5 | 85.4 |
| | Luvuvhu | 362.9 | 240.0 | 258.1 | 104.8 |
| | Mutale | 157.1 | 3.9 | 11.8 | 145.3 |
| | **WMA total** | **1184** | **759.6** | **818.8** | **365.2** |

**Table 2**: Storage capacity and available MAR for possible strategic water related projects in selected municipalities of the Limpopo and Luvuvhu-Letaba WMAs (DWAF, 2003; DWAF, 2004b)

| Water Management Area | Municipality | MAR (million $m^3$) | Storage capacity (million $m^3$) | Storage capacity with ecological reserve at 5% of MAR (million $m^3$) | Available MAR for possible development of new strategic water projects (million $m^3$) |
|---|---|---|---|---|---|
| **Limpopo** | Makhado | 269.2 | 32.9 | 46.4 | 222.8 |
| | Musina | 21.0 | 0.0 | 1.1 | 20.0 |
| | Lephalale | 282.1 | 145.9 | 160.0 | 122.1 |
| | Polokwane | 17.9 | 13.2 | 14.1 | 3.8 |
| | Aganang | 12.5 | 0.0 | 0.6 | 11.9 |
| | **WMA total** | **602.7** | **192.0** | **222.1** | **380.6** |
| **Luvuvhu-Letaba** | Letaba | 88.2 | 2.0 | 6.4 | 81.8 |
| | Thulamela | 359.1 | 218.8 | 236.8 | 122.3 |
| | Tzaneen | 352.3 | 243.3 | 260.9 | 91.4 |
| | Giyani | 37.5 | 213.5 | 215.4 | -177.9 |
| | Mutale | 61.2 | 20.6 | 23.7 | 37.5 |
| | **WMA total** | **898.3** | **698.2** | **743.1** | **155.2** |