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# A study of wetland hydrology and ecosystem service provision: GaMampa wetland, South Africa

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**Abstract** The GaMampa wetland, a palustrine wetland, comprises less than 1% of the catchment but is widely believed to make a significant contribution to dry-season river flow in the Mohlapitsi River, a tributary of the Olifants River, in South Africa. The contribution of the GaMampa wetland to dry-season flow in the Mohlapitsi River and the impact of increasing agriculture on its hydrological functioning were investigated. Economic analyses showed that the net financial value of the wetland was US$ 83 263 of which agriculture comprises 38%. Hydrological analyses indicated that the Mohlapitsi River contributes, on average, 16% of the dry-season flow in the Olifants River. However, the wetland contributes, at most, 12% to the increase in dry-season flow observed over the reach of the river in which the wetland is located. The remainder of the increase originates from groundwater flowing through the wetland. Furthermore, despite the conversion of 50% of the wetland to agriculture since 2001, there has been no statistically significant reduction in dry-season flow in the Mohlapitsi River. These results highlight the importance of understanding the nature of the full suite of services being provided by a wetland in order to make informed decisions for appropriate management.

**Key words** agriculture; ecosystem services; hydrology; livelihoods; South Africa; wetland

## Une étude de l'hydrologie et de la fourniture de services écosystémiques des zones humides: la zone humide de GaMampa, Afrique du Sud

**Résumé** La zone humide de GaMampa, une zone humide palustre, représente moins de 1% du bassin versant auquel elle appartient, mais il est communément admis qu'elle apporte en saison sèche une contribution significative au débit de la rivière Mohlapitsi, affluent de la rivière Olifants, en Afrique du Sud. Nous avons étudié la contribution de la zone humide de GaMampa au débit de la rivière Mohlapitsi en saison sèche et l'impact croissant de l'agriculture sur son fonctionnement hydrologique. Les analyses économiques ont montré que la valeur financière nette de la zone humide était de 83 263 US$ dont 38% correspondent à l'agriculture. Les analyses hydrologiques ont montré que la rivière Mohlapitsi contribue en moyenne pour 16% au débit de la rivière Olifants en saison séche. Cependant, la zone humide contribue à 12% au plus de l'augmentation du débit observé en saison séche sur la portion de la rivière sur laquelle la zone humide est située. Le reste de l'augmentation provient de l'eau souterraine qui coule au travers de la zone humide. Par ailleurs, malgré la conversion de 50% de la zones humide en terres agricoles depuis 2001, il n'y a pas eu de réduction statistiquement significative du débit de saison sèche de la rivière Mohlapitsi. Ces résultats soulignent combien il est important de comprendre la nature de la gamme complète de services fournis par une zone humide, afin de prendre des décisions éclairées pour une gestion appropriée.

**Mots clefs** agriculture; services écosystémiques; hydrologie; moyens de subsistance; Afrique du Sud; zone humide

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## 1 INTRODUCTION

Wetlands play a significant role in the hydrological cycle. Wetland form, function and maintenance are governed to a large extent by the hydrological processes that occur within them, and their interactions with the catchment in which they are located (Mitsch and Gosselinck 2007, Maltby 2009). Patterns of flow and the chemistry of water emanating from wetlands are significantly modified by the complex interaction of these influences, and many ecosystem services are attributable to the manner in which wetlands regulate water fluxes (MEA 2005). In this way, wetlands provide important services, including maintenance of dry-season flows, groundwater recharge and flood mitigation (McCartney and Acreman 2009). However, not all wetlands provide all of these regulatory services. The specific services provided by a particular wetland depend on the type of wetland and its location within a catchment (Bullock and Acreman 2003).

The needs of agriculture for flat, fertile land with a ready supply of water mean that many wetlands in southern Africa are utilized by local communities for agriculture (both cultivation and livestock production) (Rebelo *et al*. 2010). Wetland agriculture makes an important contribution to livelihoods, food security and poverty alleviation for many millions of people (Frenken and Mharapara 2001). However, inappropriate agricultural practices can result in degradation, deleterious environmental impacts and loss of important ecosystem services that, in the worst cases, can threaten agricultural production itself (Falkenmark *et al*. 2007). For example, agricultural activities in the wetlands of the Illubabor Region of Ethiopia, including drainage and the planting of inappropriate crops, have resulted in desiccation of wetlands and loss of soil fertility (Hailu *et al*. 2000). Similarly, in Zimbabwe, colonial farming practices, also including drainage, resulted in desiccation, soil erosion and gullying within wetlands (Whitlow 1992).

Hence, although there is often little understanding of the actual impacts and the trade-offs associated with the agricultural activities, wetland agriculture is widely regarded as a major threat to wetlands (McCartney *et al*. 2010). In some countries in southern Africa, legislation limits wetland agriculture specifically to protect hydrological functions. For example, in Zimbabwe, although enforcement has been variable, both the Water Resources Act of 1927/1976 and the Natural Resources Act of 1941/1975 prohibit the use of wetlands for cultivation (Bell and Roberts 1991, Bullock and McCartney 1996).

Sustainable management of wetlands requires detailed knowledge of both their hydrological functions and the livelihood services they provide. Despite research conducted to date, hydrological processes and mechanisms occurring within many wetlands are not fully understood, and there is a lack of quantitative information relating to fluxes and water balances in general. There is also relatively little information on the value of wetland agriculture to communities and how agricultural practices affect other wetland services. Studies that have investigated both the hydrology and the socio-economic aspects of wetlands are not common. In this paper, we report the findings of an integrated study at the GaMampa wetland in South Africa. The study combined hydrological, land cover and livelihood investigations, as well as economic valuation of the key provisioning services provided by the wetland.

## 2 SITE DESCRIPTION

The GaMampa wetland, a palustrine wetland naturally comprising predominantly reed beds (*Phragmites mauritanus*) and scattered open water, covers an area of approximately 1 km$^2$. It is located in the bottom of a steep-sided valley, adjacent to the Mohlapitsi River, South Africa (Fig. 1). In this respect, it is similar to the majority of wetlands in the Limpopo Basin, with an analysis of the South African National Wetlands Inventory (2002) showing that 99% of the 7921 wetlands in the basin are 1 km$^2$ or less in size. The Mohlapitsi River originates in the Wolkberg Mountains, and is one of the tributaries of the Olifants River, itself a tributary of the Limpopo River. At the confluence with the Olifants, the catchment area is approximately 490 km$^2$. The catchment is predominantly rural. The upper catchment comprises relatively natural grassland vegetation, contained within two nature reserves (Sarron 2005). All villages are located, and agricultural activities occur, close to the valley bottom. The catchment area above the wetland is approximately 263 km$^2$, with a population density of approximately 10.5 persons per km$^2$.

The catchment altitude ranges from 760 to just below 2000 m a.s.l. The geology underlying the catchment is a complex assemblage of compact sedimentary and extrusive rocks of the Godwan and Black Reef formations. In the north and east of the catchment, it comprises lava, tuff, quartzite, shale and

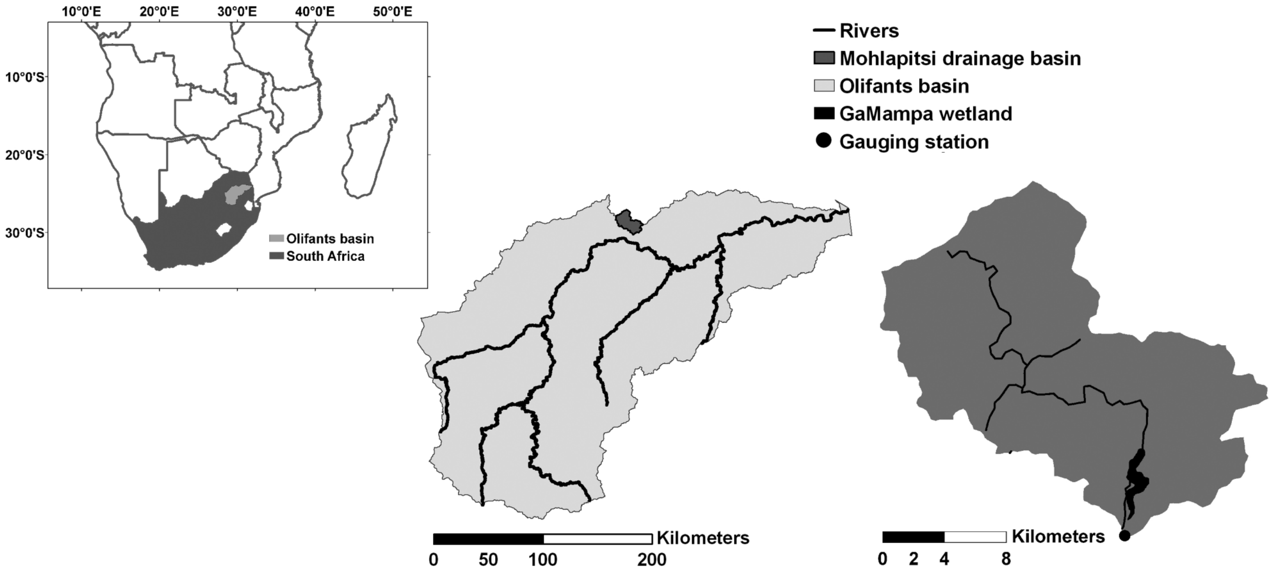


**Fig. 1** Map showing the location in the Olifants catchment, and position of the flow gauging station and wetland in the Mohlapitsi River catchment.

conglomerates. In the south and west, and underlying the wetland, it comprises dolomite, chert and subordinate limestone (Council of Geoscience 2001).

Rainfall is measured at five raingauges located in the catchment, or just outside its boundary. The catchment is characterized by seasonal rainfall that largely occurs during the summer months, from October to April. The mean annual rainfall for the catchment is 771 mm, but varies significantly with altitude and aspect. Mean annual rainfall in the higher parts of the catchment exceeds 1000 mm (with a maximum of 1433 mm). In the valley bottom, where the wetland is located, rainfall is typically 500–600 mm. Averaged across the catchment, mean annual potential evapotranspiration (computed using the Penman-Monteith equation and gridded climate data provided in Schultze *et al*. 1997) is 1428 mm (McCartney 2006).

The Mohlapitsi is a perennial river, with peak flows generated during the rainy season between December and April. The river flow is monitored just below the GaMampa wetland, at the Department of Water Affairs (DWA) gauging station, B7H013. The flow shows both seasonal and inter-annual variation, with a mean annual flow (1970–2005) of 37.96 $hm^3$, equating to about 144 mm of runoff (McCartney 2006). The highest mean monthly flow is recorded in February (7.64 $hm^3$) and the lowest in October (1.23 $hm^3$). The 95 percentile flow (i.e. *Q*95, the average daily flow that is exceeded 95% of the time) is 0.184 $m^3\ s^{-1}$ and the 5 percentile flow (i.e. *Q*5, the average daily flow that is exceeded 5% of the time) is 4.373 $m^3\ s^{-1}$.

A hydrological function commonly attributed to wetlands in southern Africa is that they act as regulators of flow by storing water in the wet season and releasing it slowly during the dry season (Mackel 1974, Perera 1982). Although the generality of this phenomenon has been questioned in recent years (Bullock 1992, McCartney and Neal 1999), it remains a widely-held perception of stakeholders, outside the communities living in the Mohlapitsi valley (Darradi *et al.* 2006).

Based on maps produced as part of the National Wetlands Inventory in 1998, the GaMampa wetland occurs along the valley floor, extending about 4 km along both sides of the river, with a variable width of up to about 800 m (Fig. 2). The soils in the wetland are a mix of fine-textured, poorly-drained soils away from the river channel, and less extensive sandy soils located close to the channel. Most of the organic soils are elevated well above the main channel and, even in major floods, are not inundated by the river. There are a number of springs in the wetland that continue to flow in the dry season (Kotze 2005).

There are five villages located in the valley bottom close to the GaMampa wetland, namely GaMampa, Manthlane, Mapagane, Mashushu and GaMoila. The villages are part of ward 24 of Mafefe in the Lepelle-Nkumpi Municipality, Capricorn District of the Limpopo Province, and contain 391 households and about 18% of the population in

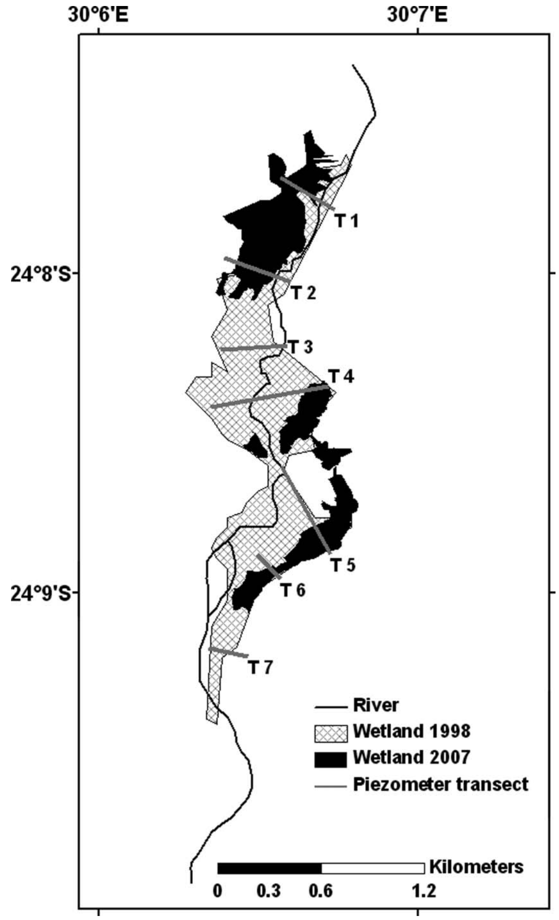


**Fig. 2** Wetland extent in 1998 (source: South Africa National Wetlands Map 2002), and 2007 from ground surveys showing location of dip well transects.

the ward. The size of individual households varies from one to 10 people, with an average of seven. Based on the classification provided by Statistics South Africa (2000) and the 2001 Census (Statistics South Africa 2001), about 90% of households are classified as very poor (spend the equivalent of US$ 93 or less a month), poor (spend the equivalent of US$ 93–155 a month) and vulnerable (spend the equivalent of US$ 155–279 a month).

Most of the households have access to piped water for drinking and sanitation facilities, and many have small gardens and kraals in which they keep small numbers of livestock. Livelihood activities are centred on small-scale agriculture, mainly practiced by old and mature men and women. Unemployment is high, and many men between the ages of 25 and 65 migrate to neighbouring towns and mines in Limpopo Province to seek work. Engagement in subsistence farming is not considered employment. Local job opportunities come mainly from government programmes (e.g. the building of schools, road construction, a sanitation project, and construction of a tourism centre), but are limited. Many households depend for their livelihoods on social transfers in the form of old peoples' pensions and government grants for child welfare (Tinguery 2006).

The wetland provides important ecosystem services, including the provision of natural resources (grass for livestock grazing and reeds for making crafts), provision of water, and carbon storage (Kotze 2005). Cultivation within the wetland, although initiated several decades ago, expanded after 2000 following severe floods that damaged the small-scale irrigation infrastructure on which local people depended, and slightly modified the drainage within the wetland, making agriculture more feasible (i.e. as a result of scouring and a slight shift in the riverbed) (Murgue 2010). The Fertilis irrigation system, which is located to the north and west of the wetland and takes water from the Mohlapitsi upstream of it, was repaired in 2006. However, in the intervening years, the wetland was increasingly utilized for agriculture. An analysis of four Landsat ETM images (2 July 1996, 8 July 1998, 10 September 2001 and 24 July 2004), indicated that the area of natural wetland vegetation declined from 0.96 km$^2$ in 1996 (approximately the same area as given in the National Wetland Inventory) to 0.43 km$^2$ in 2004 (i.e. a reduction of 52.2%) (Troy *et al*. 2007). As the crops grown in the wetland (predominantly maize and coriander) do not do well in saturated conditions, farmers have dug a large number of channels in an attempt to drain the wetland soils. Livestock grazing takes place in the areas of natural vegetation, some of which are subject to moderately heavy grazing (Kotze 2005).

## 3 METHODS

The study conducted at GaMampa was part of a larger project investigating options and opportunities for sustainable development of wetlands in eight countries in southern Africa (Rebelo *et al*. 2010). Investigations at GaMampa comprised analyses of land cover and hydrology in conjunction with livelihood assessment and economic valuation of the key provisioning services provided by the wetland.

### 3.1 Land cover and hydrological investigations

A field survey was conducted in February 2007 to assess the ground cover in the wetland, to record the boundaries of the reed beds, and to identify the main plant species in the wetland. Areas of remaining natural vegetation were mapped with a GPS.

To investigate the contribution of the Mohlapitsi catchment to the flow of the Olifants River, flow measured at the B7H013 gauging station was compared with that measured at the most immediate downstream gauge on the main river (i.e. DWA gauging station B7H009). The catchment area at B7H013 is 263 km$^2$ and that at B7H009 is 42 472 km$^2$. For the analyses, observed mean daily flow data for the period of common observation (i.e. 1971–1996) at both stations were used. The percentage contribution of average monthly flow from the Mohlapitsi to the Olifants was calculated from the gauged data. Flow duration curves, which show the relationship between any given discharge and the percentage of time that discharge is equalled or exceeded (Shaw 1984), were also derived. The baseflow index (BFI) (i.e. the ratio of the baseflow volume to the total flow volume from a catchment) (Gustard *et al*. 1992) was calculated for both stations using a technique of hydrograph separation, based on turning points identified from flow minima derived from average daily flow data divided into non-overlapping 5-day blocks.

To gain insight into hydrological processes within the wetland and its contribution to river flow, hydrometric instruments were installed within the wetland. These included a network of dip wells, installed in seven transects perpendicular to the river (Fig. 2). The depth of the dip wells was determined by the occurrence of an impermeable layer with none being more than 3.5 m deep. Dip wells were located typically 50–100 m apart, with a lateral distance between transects of approximately 500 m. The number of dip wells in each transect varied from three to seven. The location and elevation of all dip wells was determined through a survey using a theodolite. A dip meter (Eijkelkamp, The Netherlands), was used to measure the depth to the water table on a daily basis following rainfall, and every second day during dry periods and during the dry season. Monitoring of the water table started in November 2005 and continued until July 2007.

Discharge measurements were made immediately upstream of the wetland during the period July–August 2006 for the purpose of calibrating a weir. However, the weir was washed away and not replaced. Consequently the gauging was stopped and never continued. Over the two months, 14 spot measurements were made using a C2 current meter (OTT Messtechnik, Germany) with flows calculated using the velocity–area method (Shaw 1984). The volume of water that might have drained from the wetland over the same time period was calculated using the water table measurements and the typical physical characteristics of the soils in the wetland derived from the literature (Table 1). Over the two-month period, the maximum possible and minimum possible values for the volume of water that may have drained from the wetland were estimated as the difference between porosity and the drained upper limit multiplied by the area and the average water-level change across the wetland for each soil type. This was compared with the observed change in flow to determine if the wetland was the source of the additional water supplied to the river during the dry season. Similarly, the maximum and minimum volume of water from the wetland that may have contributed to evapotranspiration was estimated as the difference between the drained upper limit and the permanent wilting point multiplied by the average water level change across the wetland for each soil type. Hence, the drop in water table was effectively separated into a volume of water contributing to drainage and a volume of water contributing to evapotranspiration. The soil moisture in the unsaturated zone of the wetland was not measured, and was assumed to be negligible in comparison to storage changes arising from fluctuations in the water table.

The principal fluxes in the water budget of the GaMampa wetland were assumed to be:

$$\Delta \mathrm{Sw} = P + \mathrm{GW}_i + \mathrm{SW}_i - E - \mathrm{SW}_o - \mathrm{GW}_o \quad (1)$$

where $\Delta$Sw is change in storage in the wetland; $P$ is rainfall; GW$_i$ is groundwater inflow from the

**Table 1** Typical physical characteristics of the soils found in the GaMampa wetland (data source: Richardson and Vepraskas 2001).

| Soil class | Porosity (cm$^3$ cm$^{-3}$) | DUL (cm$^3$ cm$^{-3}$) | PWP (cm$^3$ cm$^{-3}$) | DW (cm$^3$ cm$^{-3}$) | PAW (cm$^3$ cm$^{-3}$) |
|---|---|---|---|---|---|
| Organic | 0.80 | 0.50 | 0.40 | 0.30 | 0.10 |
| Sandy loam | 0.30 | 0.20 | 0.10 | 0.10 | 0.10 |

Porosity: the amount of water held in the soil when it is saturated; DUL: drained upper limit (often called “field capacity”, this is the soil water condition reached when water has been allowed to percolate naturally from the soil until drainage ceases and the water remaining is held by capillary forces that are great enough to resist gravity); PWP: permanent wilting point (the lower limit of water available to plants; at the permanent wilting point the difference in plant suction and matric potential is so low that no water is available for transpiration); DW: drainage water (= Porosity – DUL); PAW: plant available water (i.e. evapotranspiration) (= DUL – PWP).

surrounding catchment; $SW_i$ is surface water inflow from the hill slopes or river; $E$ is evapotranspiration (crop and wetland vegetation); $SW_o$ is surface water outflow; and $GW_o$ is groundwater flow to the river.

The water balance was determined for the period July–August 2006, the only period for which flow data upstream of the wetland were available. The wetland area was taken to be 1.0 km$^2$, comprising both the cultivated and natural areas. As there was no rainfall throughout this period, the observable flows in the wetland were confined to the drains, and so assumed to be groundwater rather than surface water. Evapotranspiration, averaged across both the natural vegetation and the agricultural crops, was assumed to lie somewhere between 50 and 100% of the potential evapotranspiration (i.e. between 177 and 89 mm). The calculation to estimate the groundwater inflow into the wetland was done twice: first, assuming evapotranspiration equalled 177 mm based on groundwater-level changes (see above) with the smallest possible contribution from the wetland to both evapotranspiration and drainage to the river; and second, assuming evapotranspiration equalled 89 mm, again based on groundwater-level changes (see above), with the greatest possible contribution from the wetland to both evapotranspiration and drainage to the river. Hence, an estimate was derived for both the likely maximum and minimum volume of groundwater inflow into the wetland from the surrounding catchment.

### 3.2 Livelihood analysis and economic valuation

The livelihood analysis was undertaken using the Sustainable Livelihood Approach (Chambers and Conway 1992, DFID 1999). Data were collected through a mix of participatory tools (key informant interviews, focus group discussion and resource mapping exercises) and a more formal household survey using interviews. A total of 143 households were interviewed in two phases in May and October 2006. The sample was stratified into two clusters of wetland cultivators and non-cultivators. Interviewed households were chosen through a process of systematic random sampling. The questionnaire focused primarily on the provisioning services provided by the wetland and included questions on: household demographics; asset endowment (physical domestic and productive, natural); use of wetland resources; crop and livestock production activities and practices; access to services and participation in social networks; sources of income; household budget; sources of food; and food security. A commitment was made by the researchers to the interviewees not to publish individual personal data.

**Table 2** Economic indicators derived from the household survey (elaborated from Adekola 2007).

| Indicator | Method of derivation |
|---|---|
| Total annual production or harvest | Based on percentage of households involved in the activity estimated from the survey sample and average quantity collected per each of these households |
| Gross annual financial value | Total annual production × price (maximum, minimum and average) |
| Annual cash income | Average quantity sold × average selling price from survey |
| Net annual financial value | Gross financial value – (fixed + variable costs). Cost of implements was calculated using straight line depreciation and corrected for inflation |

A wealth index was constructed as a linear combination of household assets using principal component analysis (Campbell *et al.* 2002). The asset variables used for constructing the wealth index were: housing type; farm assets; domestic assets; transport equipment; livestock number; and land area. Univariate, bivariate and multivariate analyses (multiple correspondence analysis and cluster analysis) were used to categorize households according to the way they used the wetland. Using data from the household survey, several economic indicators were calculated for the valuation of wetland provisioning services (Table 2) (Adekola *et al*. 2008). A multinomial logit model (see Greene 2003) was used to investigate the probability of households undertaking a range of wetland activities (Jogo *et al*. 2008). A Tobit model (see Tobin 1958) was then applied to determine the total value of products collected from the wetland as a fraction of annual household income.

## 4 RESULTS

### 4.1 Land cover and hydrology

The GPS mapping showed that, in February 2007, a total wetland area of 45.4 ha, dominated by the reed *Phragmites mauritanus,* remained (Fig. 2). This is slightly greater than the area identified using satellite images from 2004 (Troy *et al*. 2007). The difference is likely to be a feature of the different data sources and methods used in the mapping (i.e. satellite images with a resolution of 30 m and GPS-based ground survey), rather than an actual increase in wetland extent. The key point is that, in contrast to the preceding years, there was no major change in the extent of the wetland between 2004 and 2007.

The hydrological analyses confirm that the Mohlapitsi catchment contributed significantly more to the flow of the Olifants River than was anticipated from its size (Fig. 3(b)). Although the catchment represented just 0.6% of the total area to B7H009, it contributed 3.9% of the mean annual flow and approximately 16% of the average flow at the end of the dry season (i.e. in August and September). Over the period of joint observation, mean annual runoff to B7H013 is equal to 103 mm, whilst to B7H009 it is just 20 mm. Figure 3(a) shows the time series of the percentage contribution of the Mohlapitsi to the Olifants River. The estimated percentage contribution of the Mohlapitsi varies considerably from 0.80 to 172.7% Although there are missing data, particularly in the early years, there is a slight upward trend in the contribution from the Mohlapitsi over time, though it is not statistically significant. By far the largest percentage contributions were in September 1986, September 1993 and September 1995, all end of dry-season months in which the flow in the Olifants was extremely low (i.e. between 4 and 11% of the mean monthly value).

For the Mohlapitsi catchment, the BFI was 0.80 compared to 0.51 for the Olifants catchment at B7H009. Hence, it is greater despite the fact that there are several large dams in the catchment to

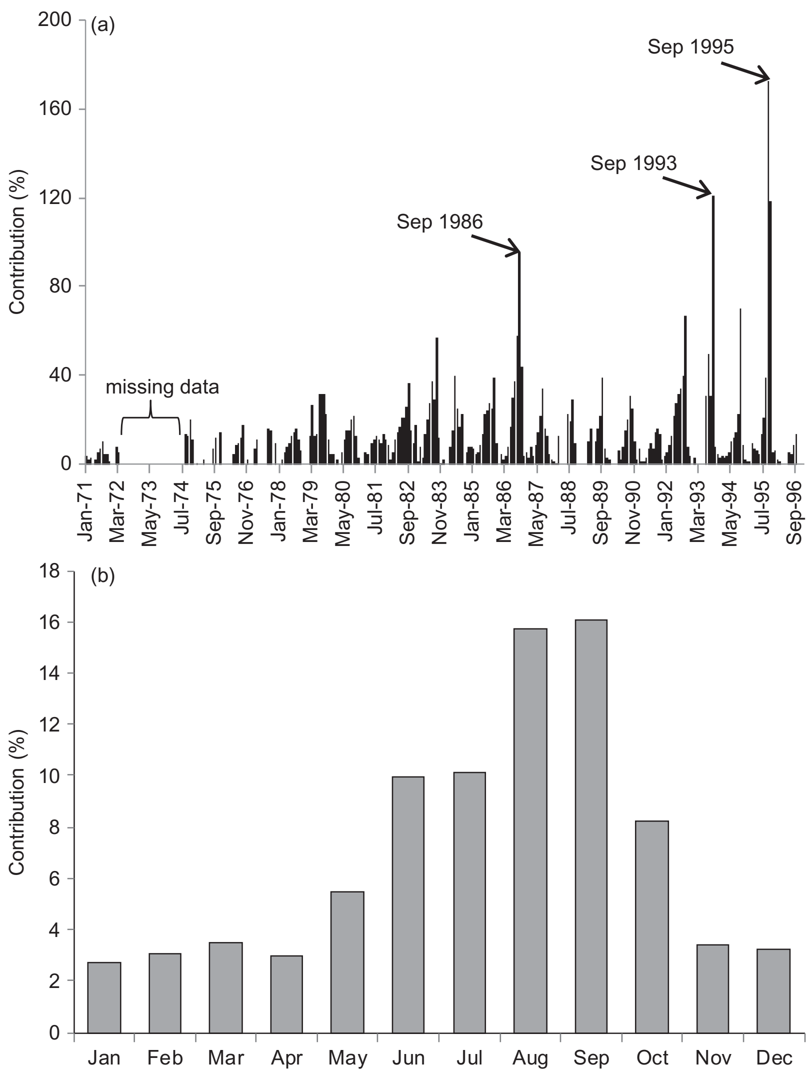


**Fig. 3** (a) Time series showing the percentage contribution of flow from the Mohlapitsi River (gauge B7H013) to the Olifants River (gauge B7H009). (b) Percentage contribution of flow (i.e. average monthly) from the Mohlapitsi River (B7H013) to the Olifants River (gauge B7H009).

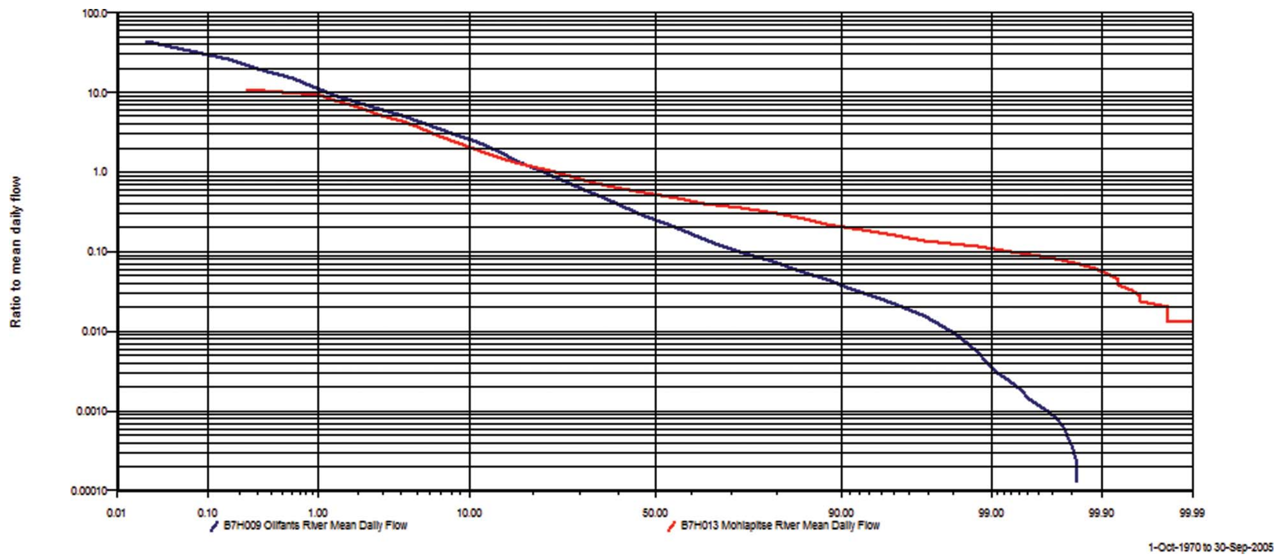


**Fig. 4** Flow duration curves (presented as ratio to mean daily) for both B7H013 (red line) and B7H009 (blue line).

B7H009 that regulate flows and, so tend to increase BFI. Figure 4 shows the calculated flow duration curves for both B7H013 and B7H009. In order to enable direct comparison, the flow duration curves have been normalized using the mean annual flow for each catchment. The shape of the flow duration curve is a good indicator of a catchment's characteristic response to its average rainfall history, with a steeply sloped curve resulting from a very variable discharge, usually from small catchments with little storage where the streamflow directly reflects the rainfall pattern, and less steep curves indicating less variation in the flow regime, as a result of the dampening effects of either surface or groundwater storage within the catchment. Despite the fact that it is a much smaller catchment, with no reservoirs, the flow duration curve for the Mohlapitsi catchment is much less steep than that for the Olifants River as a whole (Fig. 4).

Figure 5(a) shows the time series of flow measured at B7H013. There is no obvious difference in the flow before and after 2001, when significant cultivation commenced in the wetland. Figure 5(b) presents a comparison of the mean monthly flows measured at B7H013 for the period 1970–2000 with those for the period 2001–2009 (i.e. before and after the main period of wetland cultivation). The graph indicates an increase in flows in the early part of the wet season (i.e. November and December) and a reduction in the latter part of the wet season (i.e. January–March). In contrast, the mean monthly dry-season flows (i.e. April–October) were almost identical to those that occurred prior to wetland cultivation. The mean annual flow decreased from 38.67 to 34.28 $hm^3$. None of the changes are statistically significant, and all the mean monthly flows after 2001 lie well within the envelope of variability of flows prior to 2000.

Water-table measurements confirm that the hydraulic gradient is generally towards the river, in both the wet and the dry season, indicating that groundwater moves from the wetland to the river. Figure 6 presents the results for the dip wells in two transects (i.e. 1 and 6), which are broadly representative of the groundwater conditions across the wetland.

For the two months of the dry season when the upstream flow was measured (July–August 2006), flow upstream of the wetland was significantly lower than at B7H013 (Fig. 7). Upstream flow varied from 0.27 to 0.41 $m^3\ s^{-1}$, but, in contrast to the flow measured at B7H013, showed no declining trend. It seems likely that any trend in the inflow is masked by inaccuracy in the discharge measurements obtained with a current meter.

Over the period of measurement, inflow averaged 0.35 $m^3\ s^{-1}$ (i.e. 1.875 $hm^3$) and the outflow averaged 0.57 $m^3\ s^{-1}$ (i.e. 3.06 $hm^3$). Thus, there was a 63% increase in flow along the river reach between the upstream and downstream end of the wetland. This is a very significant increase occurring over a very small proportion of the catchment. However, the dip well measurements indicate only a very small drop in the water table of between 3 and 7 cm between the beginning of July and the end of August. Assuming the physical soil characteristics presented in Table 1, this would equate to a volume

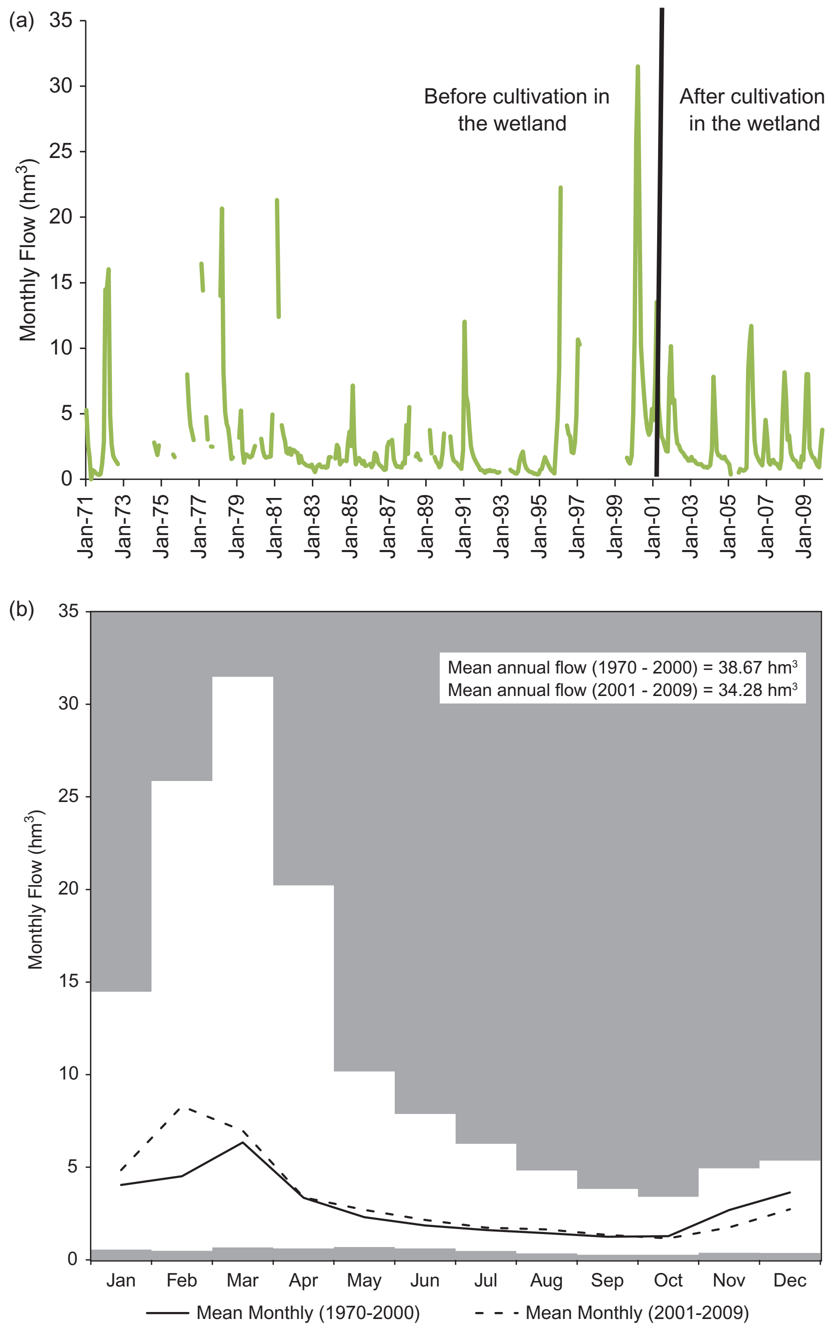


**Fig. 5** (a) Time series of Mohlapitsi flow measured at B7H013. (b) Comparison of mean monthly flow as measured at the B7H013 gauge for the periods 1970–2000 (dashed line) and 2001–2009 (solid line). The white bars indicate the monthly maximum and minimum flows measured between 1970 and 2000.

of drainage water in the range 0.003–0.140 hm$^3$ and a loss to evapotranspiration of between 0.003 and 0.007 hm$^3$. Hence, at most the wetland contributes 12% of the observed 1.18 hm$^3$ increase in flow.

Assuming a total change in storage within the wetland of between 0.006 and 0.147 hm$^3$ (i.e. accounting for drainage and evapotranspiration), the estimated wetland water fluxes over the two-month period July–August 2006 are presented in Table 3. The data indicate that, to provide both the water for evapotranspiration and the groundwater flux to the river, there must be a sizeable groundwater inflow to the wetland, of between 1.120 and 1.349 hm$^3$.

## 4.2 Livelihoods and economic valuation

The results of the livelihood analysis highlight the diversity of wetland uses and their contribution to livelihoods. Almost all households in GaMampa are engaged in one or more wetland activities. The nature

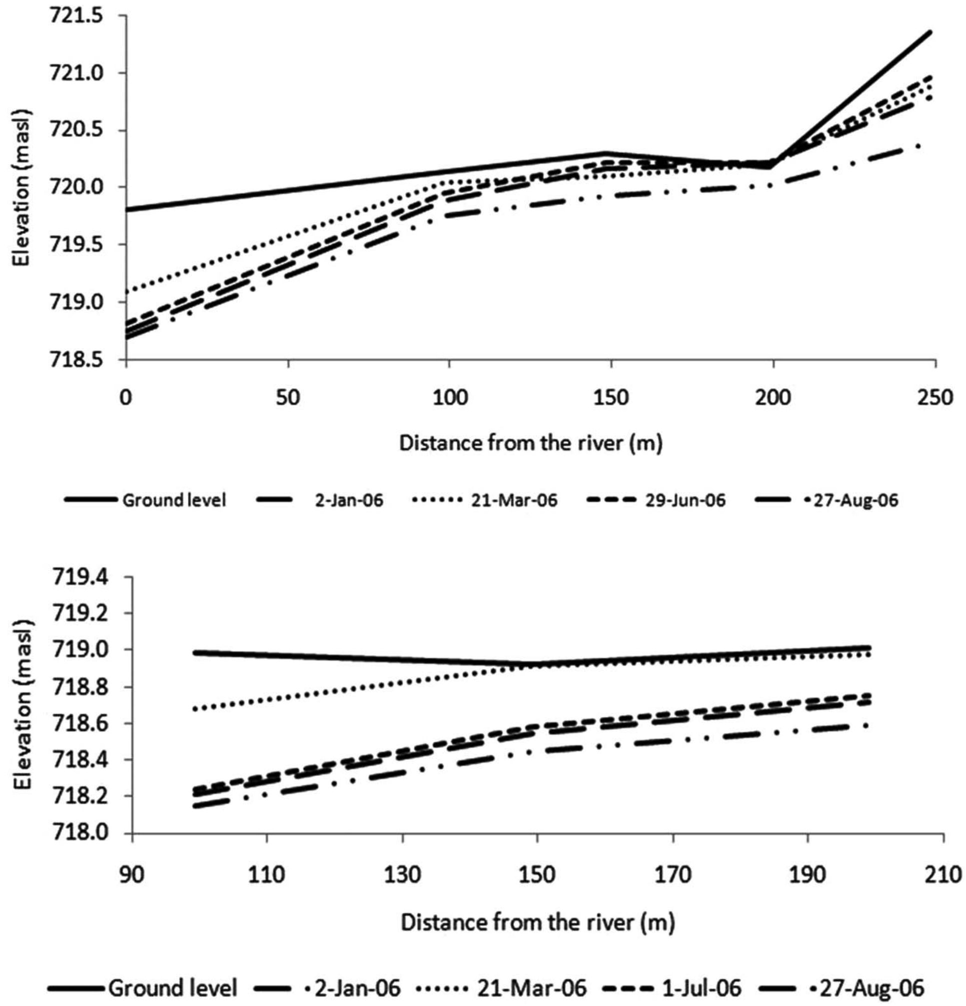


**Fig. 6** Water table elevation on different dates along: (a) transect 1 and (b) transect 6.

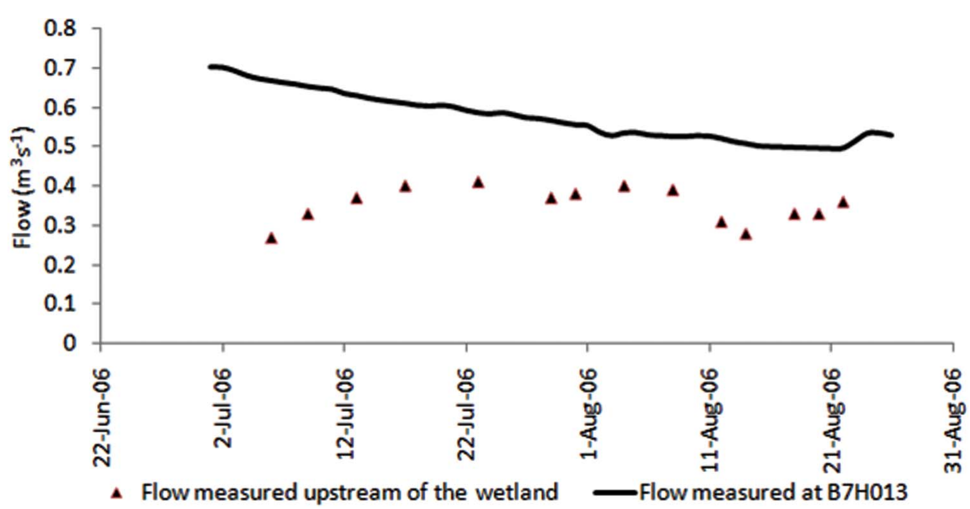


**Fig. 7** Flow measured upstream and downstream of the wetland over the period 6 July–22 August 2006.

of household use of wetlands was very different between households and appeared to be highly influenced by socio-economic factors, with the results of the Tobit model showing that the gender of the household head, education, access to off-farm income and wealth status are key variables influencing

**Table 3** Water fluxes ($hm^3$) into (+ve) and out of (–ve) the wetland area (1 $km^2$) for July and August 2006.

| Rainfall, $P$ | Evapotranspiration, $E$ | Surface water | | Groundwater | | Change in storage, $\Delta Sw$ |
|---|---|---|---|---|---|---|
| | | In ($SW_i$) | Out ($SW_o$) | Out ($GW_o$) | In ($GW_i$) | |
| 0 | −0.089 to −0.177 (89–177 mm) | 1.875 | 3.060 | −1.178 | +1.120 to +1.349 | −0.006 to −0.147 |

dependence on wetland resources. Households with large family size and female-headed households were more likely to be engaged in wetland cropping and the collection of natural products (reeds, sedges and edible plants) from the wetland. Education and access to off-farm income significantly reduced household dependence on wetland resources. Poor households were more dependent on wetland resources than wealthier households.

The range of wetland services used was found to be dependent on the wealth of the household, with wealthier households more frequently engaged in multiple uses, or grazing only. Poorer households were more frequently engaged in fewer wetland uses (grazing only or cropping and grazing). Households not using the wetland at all were most frequently among the medium-high wealth index group (Table 4). The results also showed that households with access to a plot in an irrigation scheme were less likely to engage in collection of natural products, but were more likely to engage in wetland cropping.

The results of the economic valuation show that the contribution of the wetland to the livelihoods of the local community, estimated at a total annual net financial value of US$ 83 623, far exceeded the annual cash income of US$ 13 909 (Fig. 8). Benefits derived from the wetland varied a lot across households. The net financial value ranged from US$ 17 to US$ 2625 per year, with an average of US$ 211 per household. For many households, the cash income generated from the wetland was approximately half of the average monthly cash income from all income sources. Crop production contributed the highest gross and net financial value, whereas sedge collection (for handicrafts) yielded the highest cash income.

Most of the plants harvested from the wetland were used for household subsistence, and only a small proportion were sold (Table 5). The survey showed that local households attached more importance to the in-kind contribution of wetland natural resources than to their cash contribution. The GaMampa wetland contributed to the food security (25% of maize needs, 30% of local production), diet diversity (edible plants, vegetables and fruits), buildings (50% of buildings with thatched roofs), and cash income (crops and craft materials). For some of the products (i.e. sedges and reeds), there was no alternative location where they could be harvested. In addition to their economic and livelihood value, the wetland products were also essential to sustain the social and cultural practices of giving gifts to neighbours and relatives.

## 5 DISCUSSION

The hydrological analyses substantiated the perception of the significant contribution that the Mohlapitsi catchment makes to the flow of the Olifants River. Although it varied considerably between months and years, the flow from the Mohlapitsi contributed far more to the flow of the Olifants than would be anticipated from the size of the catchment. Average annual runoff from the Mohlapitsi catchment to gauge B7H013 was 103 mm, whilst that for the Olifants catchment to B7H009 was just 20 mm. The slight increasing trend in the contribution from the Mohlapitsi over time may be attributed, in part, to increased water resource development that occurred in the Olifants catchment between 1971 and 1996. Over this time, irrigation in the Olifants catchment increased from approximately 73 500 to 128 000 ha. Although some of this increase occurred downstream of the confluence with the Mohlapitsi River, a significant proportion is upstream (McCartney *et al*. 2004).

The comparison of BFI and the flow duration curves confirmed the importance of groundwater to the flow of the Mohlapitsi River, and its role in the maintenance of dry-season flows in the Olifants River. However, the results also indicate that the contribution of the wetland to dry-season flows was small. Though there was a significant increase in dry-season flows between the upstream and downstream ends of the wetland, the observed changes in the water table

**Table 4** Distribution of households per wetland use using mutually exclusive combinations of wetland use (source: Household Survey 2006).

| Combination of wetland uses | Wealth index categories | | | | | Total | Frequency |
|---|---|---|---|---|---|---|---|
| | High | Medium high | Medium low | Low | Unknown | | |
| Cropping & grazing | 1 | 4 | 6 | 7 | 1 | 19 | 0.133 |
| Cropping & edible plants | 3 | 4 | 8 | 1 | 4 | 20 | 0.140 |
| Multiple uses, few cropping | 8 | 2 | 4 | 5 | 8 | 27 | 0.189 |
| Edible plants only | | 2 | 2 | 3 | 17 | 24 | 0.168 |
| Mostly grazing | 8 | 5 | 1 | 7 | 6 | 27 | 0.189 |
| Multiple uses, all cropping | 5 | 3 | 1 | 1 | 5 | 15 | 0.105 |
| No use | 1 | 5 | 3 | 2 | | 11 | 0.077 |
| Total | 26 | 25 | 25 | 26 | 41 | 143 | 1.000 |
| Frequency | 0.182 | 0.175 | 0.175 | 0.182 | 0.287 | 1.000 | |

Chi-square = 64.85 at 24 degrees of freedom, significant at 1% level.

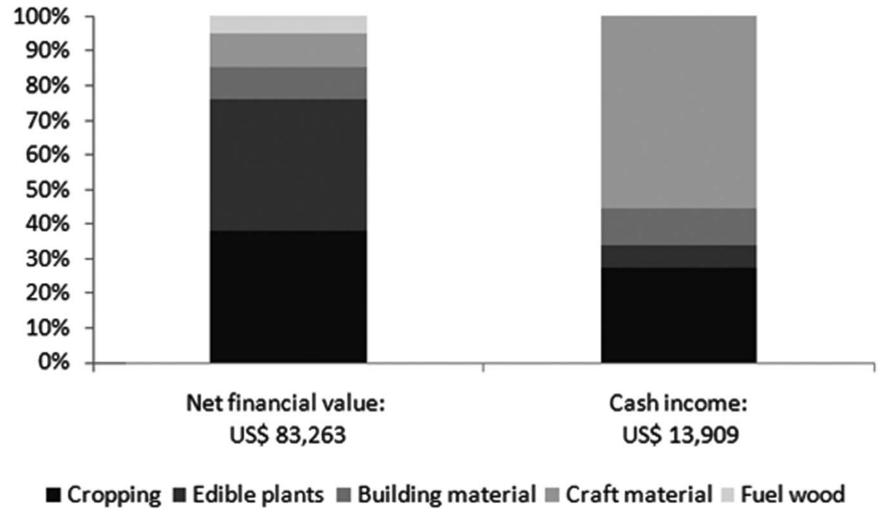


**Fig. 8** Total financial and cash income from GaMampa wetland provisioning services (source: Adekola 2007).



**Table 5** Total quantity of wetland products harvested annually and annual gross financial value (source: Adekola 2007).

| Wetland products | Total annual quantity harvested | Annual gross financial value (US$) † | Percentage sold (%) |
|---|---|---|---|
| Cultivation | 110 t of maize | 30 474 (maize)<br>36 788 (all crops) | 5 (maize) |
| Edible plants | 15.3 t | 31 523 | 3 |
| Building material | 2526 bundles * | 7 820 | 19 |
| Craft material | 756 bundles | 9 882 | 25 (bundles)<br>77 (mats) |
| Fuel wood | 1296 bundles | 4 012 | 0 |

*a bundle of reeds or sedges weighs approximately 5–10 kg, a bundle of fuel wood 10–15 kg.
†Rand prices were converted to US$ using an exchange rate of R6.46 : US$ 1 (Statistics South Africa 2006).

indicate that the changes in storage in the wetland were too minor to account for the increase.

The water budget, though based on several assumptions, and calculated for just two months of the dry season in one year, indicated that by far the largest fluxes were from groundwater into and out of the wetland (Table 3). Thus, the wetland appeared to act primarily as a conduit for groundwater flows originating in the upper catchment, rather than a significant source of water *per se*. Although located on the floodplain of the Mohlapitsi River, the river is not a major source of water within the wetland. Rather, it seems that the wetland exists primarily as a result of groundwater upwelling, which, in turn, supports the river flow downstream of the wetland. Thus the widely-held perception that the wetland supported dry-season flow in the Mohlapitsi River (Darradi *et al.* 2006) appears to be incorrect.

Findings from the livelihood and economic valuation studies confirmed that the wetland played a crucial role in the provision of basic needs required for household survival, making an appreciable contribution to food security, household income and welfare, of nearly all the nearby households. The wetland supported a wide range of livelihood activities and brought substantial financial benefits to local communities, in particular the poorest households. A considerable proportion of the value of the wetland came from agriculture. These findings are similar to other studies focused on African wetlands that have found household income generated from wetland crops ranging from US$ 19 to 640 (Turpie *et al*. 1999, McCartney and van Koppen 2004, Masiyandima *et al*. 2004, Emerton 2005, Sullivan *et al*. 2008, Lannas and Turpie 2009).

Households with a plot in the irrigation scheme were the most likely to also engage in wetland cultivation, possibly because people who get access to irrigation plots participate in a particular social network that also helps them to access plots in the wetland. It is also possible that households that already had experience of irrigated cultivation were more ready to engage in wetland cultivation. This seems likely to be the case at GaMampa, where significant cropping in the wetland was initiated only after the floods in 2000 damaged the irrigation infrastructure.

Agricultural practices have resulted in large changes to the wetland ecological character, and undermine some of the other provisioning services that the wetland provides (e.g. reeds and sedges for thatching and handicrafts). It is possible that, over the long term, agricultural productivity will decline as the organic soils are depleted as a consequence of desiccation (through drainage), active tillage and burning of desiccated soils, all of which are common practices in the cultivated areas of the wetland (Kotze 2005). However, agricultural activities currently provide the greatest direct benefit to the local communities.

Despite the high value of wetland cultivation, there has been no additional conversion of the wetland to agriculture since 2004. This is likely due to the fact that the most accessible parts of the wetland had already been converted to agriculture, with only the wettest areas remaining. In addition, due to increased interaction between the local communities and external stakeholders, and research conducted at the site, local communities have become increasingly aware of the value of the natural wetland. Consequently, the headmen are refraining from allocating new agricultural plots within the remaining areas.

There is no evidence that the conversion of approximately 50% of the wetland to agriculture has had a significant impact on the catchment hydrology. Though the mean annual flow over the years 2001–2009 was slightly lower than that prior to the start of agriculture in the wetland in 2000, this was most likely a consequence of differences in rainfall throughout the catchment rather than a consequence of the agricultural use. It is possible that the observed changes in wet season flows, though not statistically significant, are real and a consequence of the artificial drainage in the wetland. However, more rigorous hydrological investigations are needed to confirm this.

Further research is needed to fully evaluate the hydrological functioning of the wetland and its links to the regional groundwater system. Hydrochemical investigations, including the measurement of chloride, and electrical conductivity, as well as natural isotopes (e.g. deuterium), provide simple approaches for determining water sources and hydrological pathways within catchments, and have proved their value in other wetland studies in Africa (McCartney *et al*. 1998, McCartney and Neal 1999). Further research is also needed to fully understand the links between the hydrological functioning of the wetland, the variety of ecosystem services that it provides and the long-term consequences of agriculture (especially through the dynamics of organic matter). Despite the importance of agriculture within the wetland, there is currently little technical advice to support the farmers. Greater understanding of the hydrological functioning of the wetland, in conjunction with better understanding of the socio-economic factors influencing its use, would assist in better management.

## 6 CONCLUSION

In common with many wetlands in sub-Saharan Africa, agriculture contributed a significant proportion of the value of the GaMampa wetland to the communities living in the vicinity. The net financial value of the wetland, arising in a diversity of ways, far exceeded the cash income generated from it. For the poorest households, the wetland provided a vital safety net contributing significantly to both food security and their total income.

Although concern has been expressed that agricultural modification of the wetland would result in changes to downstream river flows, this study has shown that this is not the case. The Mohlapitsi catchment is important for water resources in the Olifants River, but this is not a consequence of the hydrological functioning of the wetland. Rather, it is more likely the result of the catchment geology and the fact that the upper catchment remains in a relatively natural state. Nevertheless, care needs to be taken in the management of the wetland to ensure long-term sustainability and an equitable distribution of benefits.

Modification of wetlands for agriculture inevitably results in trade-offs with other ecosystem services. However, where people are poor and constrained in their livelihood options, they have few choices. Appropriate management of wetlands where agriculture is occurring is dependent on a proper understanding of the hydro-geomorphological processes occurring within them and the links to ecosystem services. Only then can trade-offs be correctly identified and informed decisions made.

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