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Resource use conflicts: the future of the Kalahari ecosystem

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The Kalahari ecosystem is characterized by natural resource conflicts and land-use pressure resulting from intensification of human activities. This paper addresses three issues of concern associated with the Kalahari ecosystem resource management: (i) the major land-use/land cover shifts in the Kalahari ecosystem since 1970 and the resulting pattern in vegetation species composition, cover and density; (ii) the possible explanations for the observed shifts; and (iii) the possible resource conflicts likely to arise.

Data collection involved the comparison of two sets of panchromatic photographs along two transects (Hukunsti–Ngwatle and Tshane–Tsabong) to study land-use/cover shifts that have occurred in the Kalahari ecosystem between 1971 and 1986. Secondly, the nature of possible conflicts resulting from population pressure and associated patterns of land-use was investigated by making observations on selected environmental variables along a 300 km transect with diverse environments comprising different-sized settlements, vegetation communities and land-uses.

Land-use/land cover shifts have occurred within the Kalahari ecosystem as evidenced by the two transects analysed in this paper. The main changes are the retreat of grass cover up to 18 kms from settlements and the increase in thorny and non-thorny woody encroachers closer to the settlements. In the Matsheng area, land-use/land cover gradients reflect marked differences in human pressure. For instance, while settlements (kraals/households) and fields around Tshane (smaller and dwindling settlement) have declined to 5% at the 4 km distance in 1986, these land-uses account for 22·3% of land cover at 4 km around Hukuntsi (bigger and expanding village).

Five major vegetation communities were identified using key plant species during the dry season. However, these communities do not have distinct land-use activities associated with them. Cattle densities were higher in communities found far away from settlements and water points where the grass cover was abundant. Cattle graze far from settlements to obtain quality fodder and trek to the water points around village pans or at cattle posts.

There are no definite boundaries between vegetation communities and land-use activities, hence a lot of interaction between activities of these zones depends on the dispersion of resources. Shifts in land-use/cover changes can be accounted for by anthropogenic activities (arable agriculture, livestock

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grazing and human settlements) enhanced by natural factors like seasonal variations and prolonged droughts of the mid-1980s. It is argued in this paper that potential remedial measures include biosphere conservation areas, resource zoning and resource modeling plans to determine land suitability.

Keywords: Kalahari ecosystem; land-use/cover; resource use conflict; Matsheng; anthropogenic activities; biosphere conservation areas; resource zoning.

Introduction

The Kalahari ecosystem has evolved under conditions of edaphic drought, prior to the introduction of heavy livestock grazing and intense human settlements (Cooke, 1985). With the drilling of boreholes early last century (Perkins & Thomas, 1993) livestock and human populations increased and became sedentarised (Arntzen, 1998), consequently pushing the Kalahari ecosystem into resource use pressure and conflicts. This has tended to cause complications for the sustainable management of the livestock and wildlife sub-sectors in relation to other Kalahari ecosystem resources. The difference between the past and the present in ecosystem changes is emphasised by local people (International Union for the Conservation of Nature—IUCN, 1990).

Changing patterns in the ecosystem can be understood by studying the land-use/cover dynamics. It is important to study the pattern of change in land-use and cover over time for specific regions because the eastern and western parts of Botswana have been utilized differently at least in the past 100 years (Campbell & Child, 1971). Early last century significant wildlife ungulates and cattle co-existed in the eastern hardveld of the country. This situation, however, has long changed and cattle husbandry now dominates in these areas, with very negligible numbers and diversity of wildlife species (Williamson *et al*., 1988). The sandveld areas to the west of Botswana were initially used by wildlife species that could survive for long periods without being dependent on surface water. This has changed since the early 1930s, when borehole technology was introduced (Cooke, 1985). Ringrose *et al*. (1997) observed that resource conflicts can result in degradation and to abate such widespread environmental deterioration, processes have to be devised to resolve such resource use conflicts.

The increase in the human and livestock populations in the Matsheng area, which is probably associated with intensification of human activities, resulted in land use/cover changes and conflicts. It is argued in this paper that unregulated changes in land use/cover ultimately leads to some land uses/covers being driven to the margins or rather being displaced. The study investigates both the past and present land use/cover shifts, and therefore adopts two approaches: interpretation of panchromatic air photographs from different time points; and measurement of carefully selected environmental variables along transects over different land uses/covers. This paper addresses the following questions.

(1) What major land-use/land cover shifts have occurred in the Kalahari ecosystem since 1970?
(2) What are the possible explanations for the observed shifts?
(3) What possible resource conflicts are likely to arise in view of the pattern of shifts that have occurred?

Study area

This study focuses on the Matsheng villages in the Kgalagadi North sub-district (Fig. 1) of Botswana. The Matsheng area is located approximately 24°S and 22°E, and it is among the driest in the country. Major land-use activities in the area include: grazing, crop production, settlement and collection of veld products.

The area has semi-arid climate with erratic rainfall, and a long-term mean rainfall of about 350 mm (Bhalotra, 1987). Most of the rain falls between the months of October and April. On average, the study area receives 95% of its total rainfall during the summer season. Temperatures are relatively high with a minimum diurnal average of 12°C (May–August) and maximum of 41°C (September–April). During the winter season (June–August) ground frost incidences are common (Bhalotra, 1987). As a result of high temperatures experienced during the months with highest rainfall, evapo-transpiration is high exceeding the amount of precipitation. This implies that there is relatively little moisture retained within the soil for the vegetation. Vegetation is therefore always under acute moisture stress making the study area less conducive for vegetation establishment. It is this arid nature of the study area, which makes it more sensitive and vulnerable to increased natural resource conflicts.

The Matsheng villages cover approximately 3500 km^2, the population density was 1 person km^{-2} in 1971, 2·5 person km^{-2} in 1981 and 1·6 person km^{-2} in 1991 (Arntzen *et al.*, 1998). The population for the five major settlements of Matsheng villages grew from 5772 in 1981 to 6379 in 1991, which implies an average annual growth rate of 1% in the 1980s (Van der Maas *et al.*, 1994 as quoted by Arntzen *et al.*, 1998). Like the rest of the country, Matsheng villages show a steady increase in population.

The study area is an important cattle grazing and sensitive wildlife management area with scattered arable farming fields. The increase in human population in Kgalagadi North sub-district (mainly Matsheng villages) has been accompanied by a steady increase in livestock numbers (Fig. 2). While there were fluctuations in cattle numbers in the sub-district attributed to the impact of drought that decimated the cattle populations during the 1980s, declines in small stock population occurred during the 1990s probably due to high mortality rates. Most of the cattle in the sub-district occur around the Hukuntsi/Lokgwabe/Lehututu/Tshane area, Kang and Phuduhudu. They are also found at Ukwi, Ncaang, Hunkukwe and Zutshwa. Apart from the support, which the livestock sector receives from the government, the major factor that has led to the expansion of the industry in this district is the introduction and advancement of borehole technology.

As a result, livestock production has taken over from wildlife as the dominant type of rangeland use in this district, as is the case in most parts of the country. Cattle encroachment into the Kalahari region has deprived the wildlife industry firstly of their resorts in the driest of drought years, and better watered land to the east of the Kalahari, and secondly, of access to many of the pans and areas of dead river-bed in the Kalahari that are now heavily grazed by stock (Campbell & Child, 1971). Wildlife is a very valuable resource in western and particularly northern Botswana. Following the 75% decline in animal numbers during the 1980s (Adams *et al.*, 1990), wildlife in the Kalahari is at a crossroad.

The Matsheng area lies between two major animal wildlife sanctuaries, the Kalahari Transfrontier National Park and the Central Kalahari Game Reserve. Expansion of the human population has meant an interference with migratory routes of wild animals between these reserves. This has therefore alienated and driven the wildlife further from their habitats. Common wildlife species in the Kalahari environment are eland, gemsbok, duiker, kudu, hartebeest, springbok, steenbok, wildebeest, ostrich

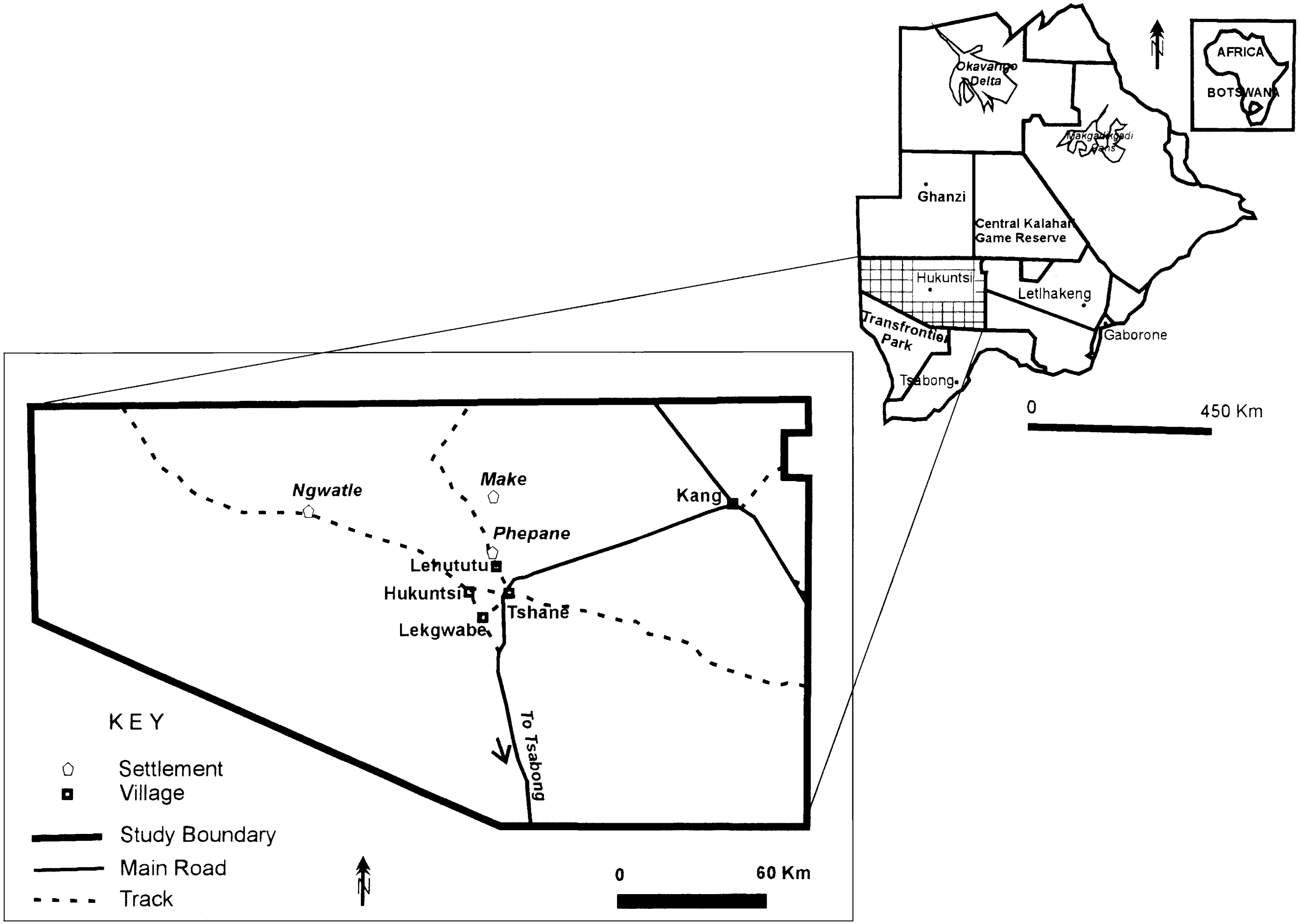
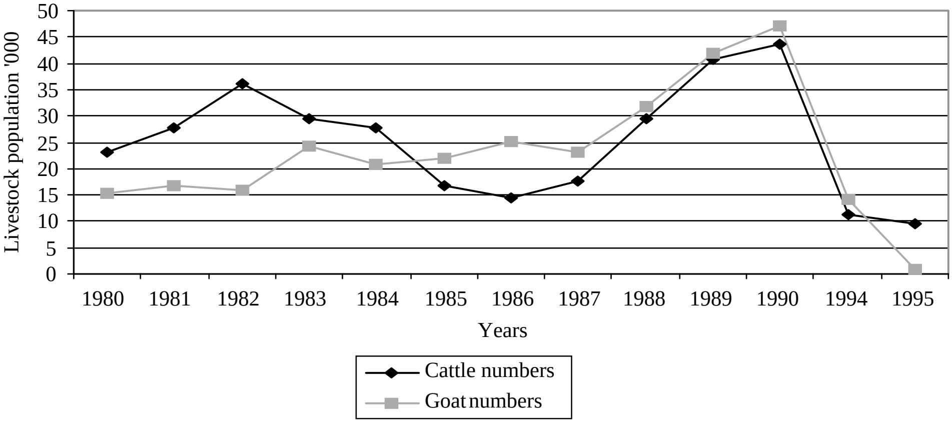


Figure 1. Location map showing the Matsheng villages in the Kgalagadi North Sub-district of Botswana. (prepared by Mr. G. Koorutwe, Department of Environmental Sciences.)



Source: Botswana Agricultural Survey Reports (1980-1995). Livestock figures after 1990 are based on estimates due to the unavailability of data

Figure 2. Trends in livestock numbers in Kgalagadi North Sub-district.

and warthog (Arntzen & Veenendaal, 1986; Michelsen Institute, 1996). It is, however, very evident that the quantity and variety of animals available for hunting has declined over the years (Table 1).

The likely causes of decline in wildlife numbers in the Kgalagadi region have included the expansion of the livestock sector, increasing hunting pressure, drought, declining surface water and the erection of cordon fences which interfere with the migratory patterns of wildlife from the Kalahari to the Okavango delta with far reaching reduction effect on wildlife (Pearce, 1995; Arntzen *et al.*, 1998; Kgabung, 1999; Mbututu, 2000; and Table 1). This decline in wildlife numbers in the district has resulted in (1) reduction in wildlife products for subsistence and commercial use; (2) reduction in wildlife processing activities; (3) increased hunting efforts and opportunity costs (Arntzen *et al.*, 1998) and (4) decline in subsistence income levels.

Table 1. *Wildlife decline in the western region (Kalahari and Ghanzi Districts)*

Species	Scientific name	% Change between 1978 and 1986
Hartebeest	*Alcelaphus baselaphus*	−76·1
Wildebeest	*Connochaetes taurinus*	−94·2
Springbok	*Antidorcas marsupialis*	−7·0
Ostrich	*Struthio camalus*	−63·3
Gemsbok	*Oryx gazella*	+35·9
Eland	*Taurotragus oryx*	−46·6
Kudu	*Tragelaphus strepsicerus*	−15·1

Note: This period largely includes the drought period of 1982/87.
Source: Van der Maas *et al.* (1994) (quoted by Arntzen *et al.*, 1998).

Methods

Two approaches were adopted to investigate the objectives of the study. The first approach considered the land-use/cover shifts that have occurred in the Kalahari ecosystem since 1971, while the second focused on (land-use/cover) conflicts likely to arise. The discussions about the two approaches follow below.

Land-use/cover shifts

The Matsheng villages are nucleated and the sampling design took advantage of the differential gradual decline in resource use intensity with distance from the major villages (Fig. 1). Two transects, each stretching out for 40 km, were identified from Hukuntsi towards Ngwatle (the Hukuntsi–Ngwatle transect) and Tshane towards Tsabong (the Tshane–Tsabong transect). Assessment of patterns of land-use/cover were done at 4, 18 and 40 km along each transect. Two sets of panchromatic aerial photographs per transect were acquired from the Surveys and Mapping Department and used in the analysis. For the Hukuntsi–Ngwatle transect, the two sets used were for the years 1971 and 1986, while for the Tshane–Tsabong transect the years 1976 and 1986 were acquired.

At each sampling distance (i.e. 4, 18 and 40 km) along the transect on the photographs, a quadrat of $10 \times 10\,km^2$ was placed. The hectare coverage of different land-uses/covers was estimated within these quadrats using a dot planimeter. The following land-uses/covers were defined: grassland; woody–thorny; shrubland; bare ground; active fields; abandoned fields; pan areas and kraals/homesteads (Table 2). This method allowed three types of comparisons of change in land-use/cover: changes in distance (along each transect); changes in direction (between transects) and changes in time (for the same transect).

Land-use/cover conflicts

To have an insight of the nature of conflicts likely to arise in the Kalahari in view of the pressures resulting from population increase and its associated patterns of land-use, a

Table 2. *Land use/cover classes characterized/defined at 4, 18 and 40 km along the two transects (Hukuntsi-Ngwatle and Tshane-Tsabong) on the panchromatic photographs*

Land uses/covers	Description
Grassland	The herbaceous cover dominates and less than 5% woody cover
Woody–thorny	Mainly bush encroachment species dominating (e.g. *Acacia mellifera*, *Dichrostachys cinerea*). Very low grass cover (< 15%)
Shrubland	Shrub species mainly *Terminalia sericea*, *Grewia flava*, i.e. non-thorny woody species
Bare ground	Almost 0% herbaceous cover, with minimal or no woody species
Active fields	These are arable fields that were actively being used (ploughed in the last growing season)
Abandoned fields	Fields that have stayed fallow for probably more than one year, and are starting to get invaded by grasses and shrubs
Pans	Depressions on land surface with or without water
Kraals/ Homesteads	This is the village itself, composed of built structures (huts and houses) and kraals for livestock

much longer transect (stretching beyond the defined study area) traversing across different Kalahari vegetation types, land-uses/covers and different-sized settlements was assessed. The 300 km transect stretched from Kang to Letlhakeng through vegetation patches comprising of shrub savanna, thorny bush savanna and grassland savanna with multiple land-uses (e.g. wildlife management areas (WMAs), cattle grazing areas, settlements and fields). Sampling was done in August and September of 1999 and the transect followed an existing rough gravel road that connects Letlhakeng to the Trans-Kalahari highway at Kang. Dry season sampling was considered appropriate due to acute shortages and enormous demand (competition) for resources experienced around this time by animals (both livestock and wild).

Seventy-eight plots each measuring $30 \times 30\,m^2$ were placed between Kang and Letlhakeng. Sixty of these plots were placed systematically at every 5 km, while 18 plots were randomly placed on land cover patches that were missed during the systematic sampling. All the plots were at least 1 km away from the existing gravel road. Within these plots, environmental variables that could characterize vegetation types, densities of domestic and wild animals, utilization pressure, fire frequency and soil texture were assessed.

Vegetation characteristics were considered at two levels: both the woody layer and herbaceous cover. Woody vegetation composition and density were determined from the $30 \times 30\,m^2$ plots, while grass cover and composition was recorded in five randomly placed $0{\cdot}5 \times 0{\cdot}5\,m^2$ quadrats within the $30 \times 30\,m^2$ plots. Problems of grass species identification (especially the herbaceous layer found with no inflorescence) were experienced for plots with acute utilization pressure.

Other environmental variables: wildlife density; cattle density; donkey density; grazing pressure; fire frequency; water; land use and soil texture were also assessed within the $30 \times 30\,m^2$ plots. The densities of wild herbivores, cattle and donkeys were estimated by counting the amounts of pellets or dung present in any particular plot (see Table 3). It was assumed that plots placed in areas with less animal (cattle, donkeys or wild animals) populations would have less dung or pellet densities per unit area and vice versa. The grazing pressure was subjectively determined by observing the magnitude to which the herbaceous layer within the $30 \times 30\,m^2$ plots was damaged (0 = no signs; 1 = low; 2 = moderate; 3 = high and 4 = very high). Plots were assessed for fire by characterizing them according to the relative age of fire occurrences (0 = no signs of fire; 1 = old signs of fire on trees; 2 = few months (6–12) signs of fire on trees and grasses; and 4 = freshly burnt evident on the herbaceous layer). Water resources were categorized according to whether they were a borehole, pan or none of the two, while land-use categories were: arable fields;

Table 3. *A summary of three environmental variables and their magnitude rating used in the field*

Environmental variables	0·0	1·0	2·0
Wildlife density	None (no pellets)	Moderate (1–3 piles of pellets)	High (>3 piles of pellets)
Cattle density	None (no dung puddings)	Moderate (1–3 dung puddings)	High (>3 dung puddings)
Donkey density	None (no pellets)	Moderate (1–3 piles of pellets)	High (>3 piles of donkey pellets)

settlements for remote area dwellers (RADS); villages and others (e.g. wildlife management areas). Soil texture was assessed in the field using four categories (0 = sandy; 1 = sandy loam; 2 = sandy clay; 3 = clay).

Vegetation communities were determined from the collected vegetation data using two way indicator species analysis (TWINSPAN) (Hill, 1979). To examine/determine the influence of environmental variables on species data, both the plant species data and environmental variables were subjected to direct canonical correspondence analysis (CCA) gradient techniques using canonical community ordination (CANOCO) programme (ter Braak, 1988). Through a combination of ordination and multiple regressions, CCA directly relates variations in floristic composition to supplied environmental variables. Forward stepwise selection of environmental variables was performed to retain only variables that account for most of the variance in the species data set (Van Rooyen *et al.*, 1994). The Monte Carlo test was performed to show significance of the first canonical axis (ter Braak, 1988).

Results

Land-use/cover shifts

Land-use/cover changes for the Tshane-Tsabong transect indicate that the 'grassland' cover decreased from 12% and 5·6% (in 1976) to 7·5% and 2·6% (in 1986) at 4 km and 18 km, respectively. The 'grassland' cover increased to 13·7% and 17·4% at 40 km in 1976 and 1986, respectively. Over the years 1976 and 1986, 'shrubland' cover decreased with increasing distance from the village. 'Woody–thorny' cover evidently increased at 4 km from 46·7% (1976) to 50·7% (1986). Field covers (both active and abandoned) and class 'kraals/homesteads' were only found at 4 km. The area extent of 'active fields' declined by almost half (from 5·4% in 1976 to 3·8% in 1986) and the class 'abandoned fields' slightly increased in coverage extent from 0·7% in 1976 to 0·8% in 1986. The class 'kraals/households' decreased in size from 1·8% in 1976 to 0·4% in 1986. The details of the Tshane–Tsabong transect land-use/cover changes are illustrated in Table 4.

In the Hukuntsi-Ngwatle transect, the 'grassland' class declined from 2·1% and 21·9% (1971) to 0% and 15% (1986) at 4 and 18 km, respectively (Table 5). At 40 km, 'grassland' cover increased from 7·4% (1971) to 22·9% (1986). On the other

Table 4. *Land-use/cover changes along Tshane-Tsabong transect (1976 and 1986)*

Year	1976			1986		
Distance from the village (km)	4	18	40	4	18	40
Land-use/cover changes						
Grassland cover (%)	12·0	5·6	13·7	7·5	2·6	17·4
Woody–thorny (%)	46·7	65·9	61·0	50·7	66·7	55·8
Shrubland	31·9	26·6	25·3	31·2	29·9	26·8
Bare ground	1·1	0·0	0·0	3·0	0·0	0·0
Active fields (%)	5·4	0·0	0·0	3·8	0·0	0·0
Abandoned fields (%)	0·7	0·0	0·0	0·8	0·0	0·0
Kraals and households (%)	1·8	0·0	0·0	0·4	0·0	0·0
Pan areas	0·4	1·9	0·0	2·6	0·8	0·0
Total	100·0	100·0	100·0	100·0	100·0	100·0

Table 5. *Land-use/cover changes along Hukuntsi-Ngwatle transect (1971 and 1986)*

Year	1971			1986		
Distance from the village (km)	4	18	40	4	18	40
Land-use/cover changes						
Grassland cover (%)	2·1	21·9	7·4	0·0	15·0	22·9
Woody–thorny (%)	59·0	47·3	53·7	67·7	56·2	52·6
Shrubland (%)	11·0	30·0	37·6	2·8	26·8	24·2
Bare ground	0·7	0·0	0·0	3·2	0·0	0·3
Active fields (%)	14·3	0·4	0·0	12·8	0·4	0·0
Abandoned fields (%)	6·5	0·0	0·0	6·7	0·0	0·0
Kraals and households (%)	4·6	0·4	0·0	2·8	0·8	0·0
Pan areas	1·8	0·4	1·1	3·9	0·8	0·0
Total	100·0	100·0	100·0	100·0	100·0	100·0

hand, 'woody–thorny' increased from 59% (1971) to 67·7% (1986) at 4 km. At 18 km, the extent of 'woody–thorny' increased from 47·3% (1971) to 56·2% (1986), whilst in both years, negligible changes were noted at 40 km. While the 'woody-thorny' class increased in extent at 4 and 18 km, both the 'grassland' and 'shrubland' classes declined. 'Active fields' decreased in extent from 14·3% in 1971 to 12·8% in 1986, while 'abandoned' fields' slightly increased from 6·5% in 1971 to 6·7% in 1986. At 18 km there was no change in area extent of 'active fields' between 1971 and 1986. Details of the Hukuntsi–Ngwatle transect land-use/cover changes are illustrated in Table 5.

Interpretation

Generally, there has been an increase in the 'grassland' class with increasing distance from the villages along both transects between the years (1971 and 1986) especially along the Hukuntsi–Ngwatle transect from 7·4% in 1971 to 22·9% at 40 km. The 'grassland' cover trend is inversely related to the 'thorny-woody' class at Hukuntsi. The disappearance of the 'grassland' class at 4 km in 1986 can be explained by the increase in the extent of the 'woody–thorny' vegetation, 'bare-ground' and 'abandoned fields'. The 'pan areas' seem to have increased in size or extent, but in reality this implies more bare spaces in 1986 compared to 1971 at 4 km as most pans are devoid of vegetation. It can therefore be concluded that a former grass dominated plant community in the vicinity of the Hukuntsi and Tshane pans has been gradually replaced by thorny vegetation (woody–thorny class) and bare ground. The 'woody–thorny' class is composed mainly of thorny species that are known encroachers in highly disturbed areas. Brundin and Karlsson (1999) working in the same area found that the main encroacher species were *Acacia mellifera*, *A. luederitzii*, *Ehretia rigida*, *Grewia flava* and *Terminalia sericea* communities (Table 6). These species often increase and form thickets or communities in areas where grazing has destroyed the field layer (Skarpe, 1986 and Table 6).

The influence of human pressure is evident from the presented results. While the classes 'kraals/homesteads' and 'fields (both abandoned and active)' around Tshane have declined to 5% at 4 km distance in 1986, these land-uses account for 22·3% of land cover at 4 km along the Hukuntsi–Ngwatle transect. This merely implies more human pressure on land cover/uses at Hukuntsi than Tshane. This is further evidenced by the 1·2% of land cover being used for 'kraals/homesteads' and 'fields' at

Table 6. *Woody species distribution at selected distances along four transects radiating from Hukunsti and Tshane villages (percent of total trees at each transect)*

Species	Distance (km) from the village			
	4	10	18	50
A. erioloba	9·9	13·6	18·0	12·2
A. hebeclada	5·4	0·4	6·2	0·0
A. luederitzii	2·5	3·1	2·3	3·6
A. mellifera	26·5	6·3	11·3	14·3
Boscia albitrunca	4·5	5·1	5·3	10·1
Ehretia rigida	7·3	2·0	5·7	8·4
Grewia flava	25·6	45·1	27·2	21·8
Grewia retinervis	1·7	0·7	2·7	5·7
Lycium retinervis	0·0	0·0	0·5	0·0
Lycium hiusutum	3·4	5·3	7·4	6·9
Rhygosum brevispinosum	0·3	9·9	0·0	1·8
Rhus tenuinervis	0·0	4·8	13·3	14·0
Terminalia sericea	11·8	3·4	0·0	1·2
Ziziphus mucronata	1·1	0·3	0·2	0·0

Source: Brundin and Karlsson (1999).

18 km compared to 0% at 18 km along the Tshane–Tsabong transect. The observed differences can partially be explained by a high population density at Hukuntsi compared to Tshane and the anthropological differences of the people living in settlements surrounding the two villages (Arntzen *et al.*, 1998). Hukuntsi has the highest population among the Matsheng settlements with approximately 2700 inhabitants. Most of the settlements along the Tshane–Tsabong transect are considered RADS where households are predominantly Basarwa (also known as the San) with wildlife utilization as the most important income earning activity to more than 90% of households. RADS are groups of disadvantaged people (e.g. Basarwa), whom the Government is trying to assist in different ways so that they could settle down in village-like settlements, and they are discouraged from leading nomadic lifestyles. Silberbauer (1973) observed that remote area dwellers (RADS) do not have alternative income generating sources hence exert less pressure on land covers.

The 'active' fields were lower in coverage in 1986 compared to 1971/76 for both transects, while the 'abandoned' fields slightly increased in coverage in 1986 compared to 1971/76. This can probably be explained by good rainfall conditions in 1971/76 and the drought that plagued the whole country in the mid-1980s.

Land-use/cover conflicts

TWINSPAN technique classified species composition by site and abundance into community clusters 1–5 (Fig. 3). At the third level of the sub-division, community clusters were clearly defined while the composition of clusters became less specific with further sub-divisions. Community cluster 1 is characterized by abundant *A. mellifera, Terminalia sericea* and *Aristida congesta,* which are the indicator/key species for that community. Many sample sites are represented in this community cluster showing that it is well established in the study area. The community represents about 30% of the sample sites studied though they do not form a distinct cluster in the CCA biplot diagram (Fig. 4). The second community cluster comprises of sites with

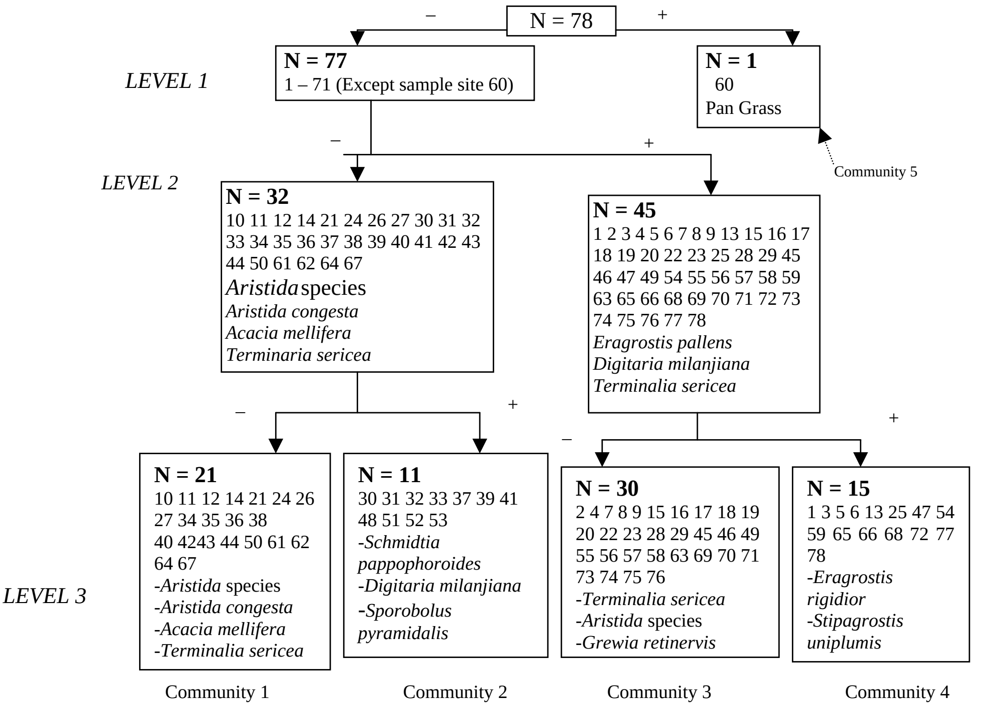


Figure 3. Dendrogram showing TWINSPAN classification of major community clusters in the study area. Positive and negative signs indicate a particular dichotomy preferred by sites and species while indicator species dominant in each community cluster are shown (N = number of sample sites in each community cluster).

indicator species dominated by grass species such as *Schmidtia pappophoroides*, *Digitaria milanjiana* and *Sporobolus pyramidalis*. The community cluster has few representative sample sites (14%), which generally lack affinity and are thus dispersed from each other when assessed by the CCA technique. However, the major activities taking place in this zone are mainly wildlife dispersion and water resource abstraction as illustrated in Fig. 4.

Community cluster 3 was the most common and comprises of *T. sericea*, *Aristida* species and *Grewia retinervis*, with about 38% representative sample sites. The community represents a large part of the study area as shown by the large number of sample sites and species. The resource conflicts in the community emanate mainly from activities that occur in the settlements or villages. The community is also associated with wildlife activities, as the general direction of the influence is along the *Y*-axis (Fig. 4).

The fourth community cluster consists of *Eragrostis rigidior* and *Stipagrostis uniplumis* with about 19% representative sample sites in the study area. The major human activity in this community is livestock grazing closer to the settlements (by orthogonal projection) as illustrated in Fig. 4. Pan vegetation community represented as cluster 5 was omitted from the final analysis as sampling failed to pick up enough samples from the pans, hence it is represented as a minor component of the environment (in reality it is an important aspect of the ecosystem).

When the species data were interpreted in relation to the ten measured environmental variables, the result was a CCA biplot with eigenvalues of the first and second axes of 0·40 and 0·27 respectively. This suggests that the supplied

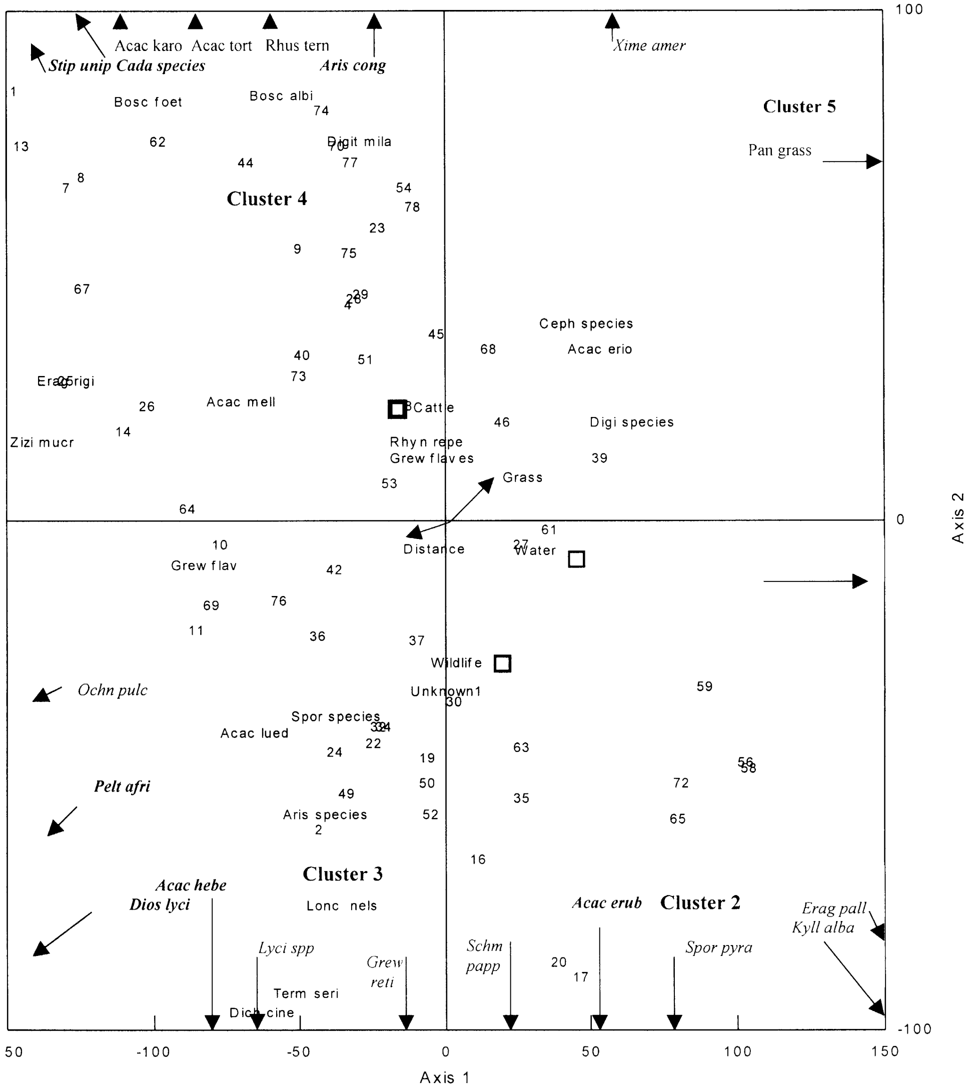


Figure 4. Ordination diagram based on CCA species abundance data with respect to five environmental variables (wildlife density, cattle density, grass cover, water resources and distance from the settlement). Acac karo (*A. karoo*), Acac tort (*A. tortilis*), Rhus tern (*Rhus ternuinervis*), Spit unip (*Stipagrostis uniplumis*), Cada species (*Cadaba* species), Aris cong (*Aristida congesta*), Bosc foet (*Boscia foetida*), Bocs albi (*Boscia albtrunca*), Digi mila (*Digitaria milanjiana*), Erag rigi (*Eragrostis rigidior*), Zizi mucr (*Ziziphus mucronata*), Acac mell (*Acacia mellifera*), Rhyn repe (*Rhynchelytrum repens*), Grew flaves (*Grewia flavescens*), Grew flav (*Grewia flava*), Ochn pulc (*Ochna pulchra*), Acac lued (*Acacia luederitzii*), Spor species (*Sporobolus* species), Aris species (*Aristida* species), Acac hebe (*Acacia heberclada*), Dios lyci (*Diospyros lycioides*), Lonc nels (*Lonchocarpus nelsii*), Lyci species (*Lycium* species), Term seri (*Terminalia sericea*), Dich cine (*Dichrostachys cinerea*), Grew reti (*Grewia retinervis*), Xime amer (*Ximenia americana*), Ceph species (*Cephalocarpus* species), Acac erio (*Acacia erioloba*), Digi species (*Digitaria* species), Acac erub (*Acacia erubescens*), Schm papp (*Schmidtia pappophoroides*), Spor pyra (*Sporobolus pyramidalis*), Erag pall (*Eragrostis pallens*), and Kyll alba (*Kyllinga alba*).

Table 7. *T-values and variable inflation factors for the nine environmental variables*

Environmental variables	*t*-values	Variables inflation factors
Wildlife density	−0·26	1·13
Grazing pressure	−1·89	3·48
Cattle density	0·82	1·68
Donkey density	0·87	2·31
Fire frequency	−1·70	1·23
Water resources	5·54	1·32
Land-use type	−1·26	1·64
Grass cover	3·62	1·81
Distance from the village	−2·27	1·28

environmental variables accounted for a large amount of variance in axis 1 of species by site data matrix. The environmental variable; soil texture, was omitted by the programme (CCA) implying negligible variance. On the basis of *t*-values for the first axis on the environmental variables, only five of the ten environmental variables were retained as they accounted for a large portion of the variance within the data set. Variables with *t*-values $<2{\cdot}1$ and those which showed multi-collinearity (with high variable inflation factors) were omitted (Table 7) from further analysis (ter Braak, 1988). The five retained environmental variables were: 'distance from the village'; 'water resources'; 'wildlife density'; 'cattle density' and 'grass cover'.

Interpretation

Five definite plant communities identified in the study area are derived from plant species association and composition. The five communities are presented in Table 8 together with summary of associated conflicts. There are several lessons that can be learned from the magnitude of activities that occur in the various plant community clusters identified in Figs 3 and 4, and Table 8. During the dry season, cattle disperse for 15–20 km from the water sources in search of suitable forage (White, 1993). This explains why the environmental variable 'cattle density' is located relatively far from the point that represents the 'water resources' variable. Therefore, during the study period (dry season), cattle densities were higher further away from water points, where the grass cover was abundant (consider the straight distance between cattle and grass and between cattle and water). However, at a certain point during the day, livestock congregate around boreholes for watering, causing further stress on vegetation. Thus, areas closer to the villages and water resources have very little vegetation (grass cover) associated with them, similar to Perkins (1991) sacrifice zones in eastern Kalahari. Conflicts near water resources and settlements are thus exemplified by the sheer absence of abundant herbaceous cover resulting in such areas being less favourable for livestock, wildlife or other activities.

Secondly, lack of suitable forage and water at a certain period of the year determines the behaviour of wild herbivores and livestock and the nature of conflict with other human activities. Highest wild herbivore densities occur at the sites that are opposite areas associated with high cattle density, partially implying that the two do not coexist where either is controlled (Fig. 4). Wild herbivore species are located away from the point representing increasing grass cover but relatively closer to the water points and villages. This can be explained by a number of factors. First, wild herbivore species are

Table 8. *The major plant communities and summary of associated conflicts*

Plant community	Key species	Implications for conflicts
1. *A. mellifera*/ *T. sericea* community (Bush encroached)	*Aristida* spp., *Aristida congesta, A. mellifera, Terminalia sericea*	This community is not well defined in the CCA diagram, but probably could be the transition zones between communities. The magnitude of resource conflicts within these transitional zones will probably vary or be influenced by the status/ condition of the other communities
2. *A. erubescens*/ *S. pyramidalis* community	*Schmidtia pappophoroides, Digitaria milanjiana, Sporobolous pyramidalis*	Conflicts within this community emerge from the integration of wildlife activities, water abstraction and human settlement as shown in the CCA diagram
3. *L. nelsii*/*T. sericea* community	*Grewia retinervis, Terminalia sericea, Aristida* spp.	Resource conflicts arise as the settlements lie along the wildlife dispersal and migration area. Wildlife species come into conflict with other activities even for those species whose hunting licences are not issued. Such situations may allow unlicensed hunting
4. *B. albitrunca*/ *S. uniplumis* community	*Eragrostis rigidior Stipagrostis uniplumis*	Conflicts arise from the fact that the zone is fundamentally used for livestock grazing closer to the settlements in addition to water resources in the form of pans and boreholes
5. Pan community	Pan grasses	This community has abundant pan grass with cattle, water abstraction and wildlife activities being prevalent

known to congregate around empty dry pans (in social groups) for resting (Bergstrom & Skarpe, 1999) during their local dispersions in search of food or minerals (Williamson *et al.*, 1988) during dry season migration and dispersion, which at times traverse through villages (e.g. Tsetseng and Tshwaane). This phenomenon is little understood especially that wild herbivore species prefer to rest in bare pans with no trees to provide for shade. However, most of these wild herbivore species are water independent and therefore their association with water points can only be accounted for by dispersal patterns during search for food or minerals rather than water for drinking. Large herbivores such as zebras (*Equus burchelli*), buffalo (*Syncerus caffer*), giraffe (*Giraffa camelopardalis*) and elephant (*Loxondata africana*) are absent in this region mainly due to the relative absence of sufficient water quantities to sustain them. Second, during the dry season, cattle move far afield (into clusters 1 and 4) from the settlements than normal. This movement probably overlaps with wild herbivore habitats, and in response wild herbivore species disperse (move out) through the villages (e.g. Tsetseng and Tshwaane) towards community clusters 2 and 3. These two clusters are found relatively close to high-density wildlife areas and although they have low grass cover, key woody species (evergreens or those that take long to loose their leaves) are found within the clusters: *Lonchorcarpus nelsii; Ochna pulchra; T. sericea; Lycium* spp; *A. erubescens.* These clusters are therefore valuable to the wild herbivore of the study area, since browsers and mixed-feeder wildlife species dominate them.

Past studies have demonstrated that some activities are not fully compatible. For example, Verlinden (1997) demonstrated differences in distribution between wildlife and livestock areas with some species clearly avoiding cattle areas while others were least affected. Parris & Child (1973) have argued that the effect of livestock keeping on the vegetation in southern Kalahari could be noticed after several decades of protection with likely negative effects on wildlife. Such sources of conflicts ultimately determine the nature and the degree of the establishment of other conflicting activities.

Summary discussion

The study area can broadly be divided into three management areas: the wildlife management areas (WMAs); grazing areas for cattle and the settlement/fields areas. There are no definite boundaries between these management zones and hence a lot of interaction between activities of these zones depending on the dispersion of resources at any point in time. A resource in this context refers to forage, rainfall, water resources/water points and settlements. It is however evident that land-use/cover change is occurring e.g.:

- 'grassland' communities are disappearing closer to settlements;
- bare ground is increasing around pans and settlements;
- bush encroachment species are increasing towards settlements;
- 'active' fields have been reduced.

These changes are driven by human pressure through activities such as grazing, and the expansion of settlements, arable fields and artificial water sources (Williamson *et al.*, 1988; Perkins & Thomas, 1993). It is however also evident and possible that climatic factors have the upper hand in determining the rate of such changes (Arntzen *et al.*, 1998). For instance, the observed reduction in cover of active fields between 1971/76 and 1986 can be explained by the drought conditions of the mid-1980s.

If human activities and climatic factors were to remain constant, there would be no need to talk about conflicts in resource use, since land-uses or land covers would remain fixed. However, this is not the case in the study area, as cattle grazing and settlements have intensified in the Kalahari and some traditional uses such as wildlife grazing are being pushed to the fringes (Fig. 4). It is also apparent (Fig. 4) that co-existence in the status quo will prove very difficult. Cattle and some wildlife herbivore species do not co-exist (Fig. 4) as it has been found elsewhere (e.g. Maasailand in Kenya) where agricultural expansion forces wild animals and Maasai herdsman into increasing conflicts with agricultural systems (Pearce, 1995).

What therefore is the future of the Kalahari ecosystem? Land-use/cover pressures will increase with increasing population and some land-uses/covers (e.g. wildlife species that do not co-exist with cattle and other human activities) will be gradually driven to the fringes. Unless the present arrangement of activities within the study area is modified (suggested later), it is very likely that this trend in land-use will continue intensifying until cattle husbandry replaces all other environmental-friendly uses such as wildlife management in the Kalahari ecosystem. This could be particularly so where wildlife utilization is not restricted (Verlinden, 1997). The present analysis further indicates that land-use/cover is slowly shifting from a more environmental friendly (wildlife use, subsistence hunting and gathering) to a less conservation-oriented land-use practice (e.g. intensive grazing and monocropping). This is attributed to more people investing in agriculture especially along the Hukuntsi–Ngwatle transect.

However, borehole drilling is not likely to alleviate the current pressure within the study area nor will agricultural subsidies sustain Kalahari resources.

The shift in land-use is considered environmental unfriendly because the soils are characteristically dystrophic with low agronomic value (Chanda & Totolo, 2001). The soils are thus less suitable for arable farming and poor cattle husbandry methods could result in further soil deterioration.

Way forward

The Kalahari is very fragile and haphazard land-use and reactive (reacting to arising problems) planning will not minimize the changes and the resource conflicts evident in the study area. To mitigate problems of land-use/cover changes and the ensuing resource conflicts, it is important that the underlying dynamics driving land-use/cover changes be understood from various dimensions including historical (how has land cover and usage changed over time) and spatial (e.g. the local processes driving such changes). The paper therefore argues for a long-term land use planning of the Kalahari ecosystem where parcels of land are designated to specific suitable uses. Proposed measures to determine land use suitability as a way of resolving resource use conflicts are suggested in Fig. 5 as a working tool. Among the salient issues to be included in the resource use model include *inter alia:*

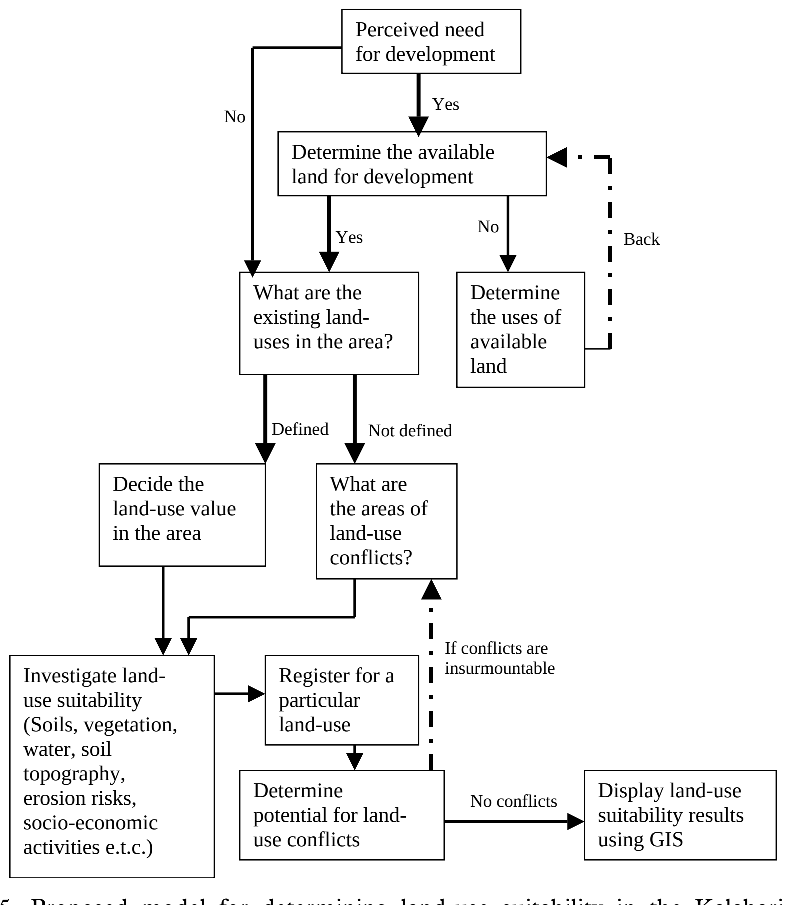


Figure 5. Proposed model for determining land-use suitability in the Kalahari to resolve resource use conflicts.

- Land Boards are the custodian of communal land in Botswana, and they are responsible for allocation of land for different purposes to individuals or groups of people. It is proposed in this paper that Land Boards should set aside areas for specific activities depending on prior known suitability (see Fig. 5). Some zones could be used for wildlife *per se*, others for cultivation, settlement and so forth with strict adherence to the plans. As biodiversity is known to be the key to all the primary activities taking place in the area, biosphere conservation programmes in some of these zones should be established to ensure that flora and fauna are sustained.
- A more efficient and intensive use of the Kalahari environment could reduce resource pressure and conflicts (see Tables 4–6 and Fig. 4) if potential for land-use conflicts are well known (see Fig. 5). Many resources are exploited on an extensive scale with low levels of efficiency demanding more land (e.g. for livestock grazing, arable farming, etc.), which is insufficient. Areas of resource integration should be identified (Dikobe, 1990) and the contribution of each sector to conflicts defined. Conflicts arise along the interface of different land-use sectors that may appear to be incompatible as in the emotional debate on wildlife and livestock industry.

The success of the future resource planning in the Kalahari ecosystem lies in a rational modelling that integrates socio-economic development and natural resources thereupon. The suggested model (Fig. 5) typically helps in the determination of the optimal productivity on any piece of land based on the application of Geographic Information System (GIS) procedure where land suitability analysis and decision-making are integrated. Land demand to meet various developments in agriculture, settlement, transport, leisure and aesthetic beauty continue to rise. The perception that all land and the encompassing resources could be used for all types of land-use leads to misallocation of land to some non-deserving land uses whilst barring the most appropriate cases. Determination and establishment of the current land use database and the land available for various land uses is the first step in this respect. Such data will clearly demonstrate what a piece of land is currently used for and optimal potential and best utilization. Key questions to answer at this stage are whether the land already under certain use(s) is being used productively for that purpose. If the land-use is not defined, conflicts could be investigated with regard to resources there in.

Resources available could be optimally utilized if prior investigation on land use is launched to determine the suitability of any piece of land for a given purpose. Physical, socio and economic variables have to be investigated as the basis of understanding the best use value for every piece of land. Parcels of land are thereafter registered for particular uses on condition that no serious resource use conflicts are to arise thereafter. Once all potential conflicts have been addressed, then the land could be added into a GIS database accessible to all stakeholders in land-use allocation and resource users. In case potential conflicts still persist, sources of conflicts can be addressed through fresh resource use and land suitability investigations. Networking of such data between different stakeholders will eventually attenuate the magnitude of natural resource-use conflicts. Attributes attached to parcels of land will thus optimize productivity where land-use problems are minimal than under the current laissez-faire system that exhibits little coordination among various land-use demands and available resources.

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