CHARACTERIZATION OF AGRICULTURE-RELATED LAND DEGRADATION IN EASTERN AND WESTERN PARTS OF BOTSWANA

B. Kayombo[1], F. Meulenburg[2], B.G. Moganane[3], O. Dikinya[4], J.N. Aliwa[5], M. Nsinamwa[6], G. Gaboutloeloe[1], C. Patrick[1], M. Mzuku[1] and S. Machacha[2]

[1]Department of Agricultural Engineering & Land Planning, Botswana College of Agriculture
[2]Department of Crop Science & Production, Botswana College of Agriculture
[3]Ministry of Agriculture Headquarters, Gaborone, Botswana
[4]Department of Environmental Science, University of Botswana
[5]Botswana Technology Centre
[6]Department of Animal Science & Production, Botswana College of Agriculture
E-mail: bkayombo@bca.bw

A study was carried out during 1998-2001 with the objective of, firstly, assessing the impact of cultivation on soil quality, and secondly, evaluating the effects of human and animal activities on soil erosion and range resources. A Topical Rapid Rural Appraisal (TRRA) based on rapid appraisal approaches, was conducted in three benchmark villages in Bobirwa Sub-district. A diagonistic survey report provided similar information for Kgalagadi District. Three benchmark sites were located in Bobirwa Sub-district and two others in Kgalagadi District. Soils were characterized at benchmark sites and in the laboratory for physiochemical properties. Soil erosion was monitored using embedded nail technique. At all benchmark sites, trends show a deterioration of soil quality, both in terms of nutrient depletion and poor physical properties for cultivated soils in comparison to uncultivated soils. There is visible evidence of environmental degradation of land resources resulting partly from considerable soil trampling and loosening during the dry season by livestock. During the wet season, the loosened soil is washed down elsewhere and/or deposited at watering points. The confounding effects of drought, overgrazing, poor management and ever-increasing utilization of veld products have led to the decline of a considerable number of tree and grass species.

Keywords: Agriculture, soil quality, range resources, environmental degradation

1 INTRODUCTION

Botswana is classified into what is called the hardveld and the sandveld, with the former covering the eastern part and the sandveld the western part of the country. The hardveld soils are mostly derived from Precambrian rocks, whereas the sandveld soils are predominantly of late tertiary aeolian origin [1].
Land degradation, defined as the loss of the productive capacity of the land to sustain life, is prevalent throughout Botswana. This process results from a multitude of factors. Some are physical, especially those related to the climate, while others are socio-economic. Because the primary effect of land degradation is to reduce the productivity of land, the process fundamentally affects all those who depend on the land as a basic resource, whether for crops, livestock or fuel wood.

In Botswana, land degradation studies have concentrated in the sandveld areas of north central and northern parts of the country. A study in the mid-Boteti area using a combination of climatic / hydrological data and comparative analysis of remotely sensed data showed that the area has experienced increases in soil erosion, vegetation loss and species change during 1984-93 period [2, 3]. This resource decline was largely attributed to inappropriate land use pressure, particularly during drought periods. The data derived from satellite imagery was also used to show the extent and possible causes of land management / fenceline induced degradation problems in the Okavango area [4]. The only study conducted in the hardveld dealt with spectral assessment of indicators of range degradation [5]. The study concluded that the most suitable indicators of range condition and degrees of desertification could be obtained by directly applying spectral ranges from the red band. A country-wide potential degraded area mapping using satellite imagery for the 1984-94 period indicated that certain areas appeared to have become more degraded since the 1980s drought [6]. This included areas in the vicinity of settlements and those peripheral to the major river valleys. The country-wide mapping study was, however, on a 1:1 500 000 scale which is too small for any detailed analysis of the actual processes taking place on the ground. Furthermore, the assessment of land degradation, as above-mentioned, has relied on land cover conditions especially vegetation. There is a need to assess the impacts of agriculture-related activities such as crop cultivation and livestock herding on land degradation in the country.

The objective of this report is to characterize agriculture-related land degradation in Botswana by, firstly assessing the impact of cultivation on soil quality, and secondly, evaluating the effects of human and animal activities on soil erosion and range resources.

2 METHODOLOGY

In this study, the eastern and western parts of Botswana are represented by Bobirwa Sub-district and Kgalagadi District, respectively.

A Topical Rapid Rural Appraisal (TRRA) was conducted in November 1998 with the aim of identifying issues and constraints in crop and livestock production and other human activities related to the extent and severity of land degradation. The techniques used were based on rapid appraisal approaches, where a multi-disciplinary team consulted and discussed with local leaders, groups, individual farmers as well as support institutions promoting agricultural development in the district. The TRRA involved visits to three villages, namely Tsetsebjwe, Mathathane and Motlhabaneng in Bobonong Agricultural District of Bobirwa Sub-district. No TRRA was done for the western part of Botswana as a diagnostic survey carried out earlier provided sufficient information [7].
The benchmark sites were located at Mathathane, Motlhabaneng and Tsetsebjwe villages in Bobirwa Sub-district and at Tsabong and Hukuntsi in Kgalagadi District.

Two soil pits (of 100 x 150 cm width and 120-150 cm depth) were dug at each of the above-mentioned villages, one on cultivated and the other on uncultivated soil. The uncultivated soil was near homesteads and covered by trees interspaced with grass and bushes, and had not been ploughed for 15-20 years. The cultivated soil was, however, ploughed annually and sown with sorghum, water melons and cowpeas. The profiles were described using the FAO soil classification system [8]. Soil samples were taken from each horizon and analysed in the laboratory for Cation Exchange Capacity (CEC) and exchangeable cations (using ammonium acetate + atomic absorption method), phosphorus (Bray Kurtz or Olsen method depending on pH of soil), organic carbon (modified Black and Walkey method), total mineralisable nitrogen (Kjeldahl method) and pH (in calcium chloride). The methods used in the analysis are according to FAO [8].
At each of the soil pits, physical tests were conducted to determine the infiltration rate (using double ring method) and soil penetrometer resistance (by soil penetration method). Soil samples were also brought to the laboratory to determine bulk density (core sampler), water holding capacity (pressure plate apparatus), soil structural stability (Haines apparatus), texture (hydrometer method) and porosity (calculated empirically from bulk density) according to Klute [9]. Data were analysed statistically using SAS v6.12 for Windows.
Soil erosion by water and wind was monitored using the embedded nail technique. Steel pegs were driven into the ground at pre-determined transects of benchmark sites. Changes in the height of the pegs above the soil surface over a 9-month period, were measured using the level.

3 RESULTS AND DISCUSSION

3.1 Site and Soil Characterization

3.1.1 Bobirwa Sub-district

The benchmark sites in this area are found on an almost flat plain. The soils are reddish brown in colour and their texture ranges from loamy sand to sandy loam with basalt as the rock type of the area. The soil types are classified as Chromic Luvisol (Mathathane), Calcic Cambisol (Molthabaneng) and Ferric Luvisol (Tsetsebjwe)[8].

Although soils in Bobirwa Sub-district exhibit relatively high water holding capacities and structural stability under good management, intensive cultivation and arid conditions cause hard setting, crusting and compaction as evidenced by the high bulk densities and penetrometer resistance (Table 1).

The differences in chemical properties between cultivated and uncultivated soils in Bobirwa Sub-district are generally small, except for soil phosphorus (P). Chemical properties of soils at Motlhabaneng (Table 2a, b) illustrate this. Soil P content was conspicuously higher for the uncultivated soil

(Table 2b) compared to that of the cultivated soil (Table 2a). P is a highly immobile element in the soil, and therefore its decline in the cultivated soil is a sure sign that soil nutrients are being utilized without any replenishment. The consequence of this is the deterioration in soil quality.

Table 1. Soil physical properties of the benchmark sites

Village	Soil Penetrometer Resistance (Mpa)	Bulk Density (g/cm^3)	Structural Stability (vol%)	Infiltration Rate (mm/h)	Porosity (vol%)	Water Holding Capacity (mm/m)	Status
Mathathane	2.0	1.64	56	218	38	77	Cultivated
	3.2	1.60	49	74	40	115	Uncultivated
Motlhabaneng	3.3	1.31	45	80	51	116	Uncultivated
	0.19	1.47	44	72	45	107	Cultivated
Tsetsebjwe	>5	1.53	74	38	42	191	Uncultivated
	0.13	1.58	74	59	40	108	Cultivated
Hukuntsi	n.a.	1.62	n.a	497	39	42	Cultivated
	n.a.	1.60	n.a.	413	40	42	Uncultivated
Tsabong	n.a.	1.63	n.a.	399	37	34	Cultivated
	n.a.	1.67	n.a.	336	38	44	Uncultivated

Table 2a. Chemical properties for the soil profile at Motlhabaneng on a cultivated soil

Depth cm	pH $CaCl_2$	%Organic carbon	P ppm	CEC	Ca	Mg	K	Na
				-----------meq/100g-----------				
0-15	6.91	1.5	9	23.8	18.2	9.5	2.3	0.0
15-45	7.49	1.7	7	30.8	27.5	11.8	0.8	0.1
45-70	7.61	1.2	6	30.7	30.0	12.2	0.4	0.1
70-95	7.80	0.8	2	23.9	45.0	11.7	0.3	0.1
95-115	7.85	0.3	1	21.9	63.8	13.8	0.3	0.1
115-125	7.96	0.1	6	19.1	54.3	13.9	0.2	0.1

Table 2b. Chemical properties for the soil profile at Motlhabaneng on uncultivated soil

Depth cm	pH $CaCl_2$	%Organic carbon	P ppm	CEC	Ca	Mg	K	Na
				-----------meq/100g-----------				
0-15	6.86	1.4	23	31.0	23.0	8.1	2.1	0.0
15-50	7.30	1.7	2	26.5	24.6	7.3	0.6	0.0
50-95	7.72	0.8	1	18.9	51.1	7.5	0.3	0.0
95-120	7.79	0.2	0	17.0	51.9	10.9	0.3	0.0

3.1.2 Kgalagadi District

Two benchmark sites were selected in this area; one on an almost flat sand plain and the other on a crested sand dune. The soils are mainly fine sand with aeolian sand as the parent material. All soils in this area are classified as Arenosols [8].

Soils at Hukuntsi and Tsabong are classified as Ferric Arenosols [8]. They are typical for the sandveld, which covers about 70% of the country[10]. These soils exhibit high bulk density and low water storage capacity. They have relatively high infiltration and percolation rates (Table 1) and hence large losses of water due to vertical drainage. They, however, possess self-mulching properties during dry conditions.

The chemical properties of Ferric Arenosols are typified by those at Tsabong (Table 3a, b). Although both the cultivated and uncultivated soils are naturally unfertile, it is evident that the CEC, the basic cations as well as the pH, were higher for the uncultivated soil (Table 3b) in comparison to the cultivated one (Table 3a). A lowering of the basic cations is usually accompanied by low pH which is inductive for aluminium (Al). This is a clear sign of soil quality deterioration because Al is highly toxic to plants.

3.2 Nutrient Mining

Table 4 shows the chemical properties of benchmark sites for both cultivated and uncultivated soils. In Bobirwa Sub-district, all benchmark sites except Motlhabaneng village had higher Ca, CEC, N and P amounts for uncultivated than in cultivated soil. In Kgalagadi District, both Hukuntsi and Tsabong sites exhibited higher amounts of Ca, CEC, C and P for uncultivated compared to the cultivated soil (Table 4). A significant difference ($P>0.05$) was found between uncultivated and cultivated soils for the above-mentioned chemical properties.

At all locations except for Motlhabaneng village, Ca and CEC were consistently higher for the uncultivated soil in comparison to the cultivated soil. The CEC of a soil is an important component of its fertility. This is the capacity of the soil to exchange nutrients with the soil solution. Clay and organic matter contribute towards the CEC of a soil. A low CEC could indicate that clay and/or organic matter are in small quantities or that the clay is highly weathered. The low CEC could mean that kaolinite is the dominant clay and thus the low inherent CEC values of the soils.

Table 3a. Chemical properties for the soil profile at Tsabong on a cultivated soil

Depth cm	pH ($CaCl_2$)	%Organic carbon	P ppm	CEC	Ca	Mg	K	Na
				---------------meq/100g-----------------				
0-15	4.53	0.2	0	1.3	3.4	0.4	0.1	0.0
30-50	3.94	0.2	2	1.4	2.2	0.2	0.0	0.0
110-130	4.28	0.2	1.4	3.2	0.2	0.0	0.0	0.0

Table 3b. Chemical properties for the soil profile at Tsabong on uncultivated soil

Depth cm	pH ($CaCl_2$)	%Organic carbon	P ppm	CEC	Ca	Mg	K	Na
				---------------meq/100g--------------				
0-10	6.31	0.3	1	2.8	5.0	0.4	0.2	0.0
10-25	6.34	0.4	0	3.3	5.7	0.6	0.2	0.0
30-50	6.39	0.1	0	3.2	5.2	0.2	0.1	0.0
65-85	7.16	0.0	0	3.5	8.3	0.4	0.3	0.0
110-130	7.60	0.0	4.0	8.0	0.4	0.3	. 0.0	0.0

Table 4. Soil chemical properties studied for nutrient mining

Village	pH	K	Na	Ca	Mg	CEC	C	P	N	Status
Mathathane	5.9	0.6	0.0	4.3	5.7	6.0	0.3	18.9	364.0	Cultivated
	5.9	0.6	0.1	4.6	4.3	7.1	0.4	31.2	383.0	Uncultivated
Motlhabaneng	6.7	0.6	0.2	42.8	13.7	24.9	0.7	468.3	353.8	Uncultivated
	6.7	0.8	0.2	41.8	17.8	24.9	0.8	474.70	366.7	Cultivated
Tsetsebjwe	5.8	1.3	0.0	4.8	1.8	8.4	0.4	12.9	367.2	Uncultivated
	5.3	0.7	0.0	4.7	1.4	7.8	0.8	69.4	364.0	Cultivated
Hukuntsi	6.3	0.2	0.0	1.0	0.4	1.3	0.2	8.9	-	Cultivated
	5.6	0.1	0.0	1.3	0.3	1.5	0.3	13.6	-	Uncultivated
Tsabong	5.9	0.2	0.0	1.0	0.2	1.1	0.1	5.2	-	Cultivated
	6.8	0.2	0.0	2.0	0.3	2.0	0.2	8.1	-	Uncultivated

To improve the present fertility status of these soils, an intervention that incorporates organic matter may be needed.

Ca is an important component of the CEC which is responsible for a number of characteristics in the soil, the most important being soil structure. A good structure is associated with Ca at the exchange complex but under poor management Ca^{2+} can get replaced by other cations such as Na^{+} or Mg^{2+} which are smaller in size and therefore may result in soil compaction. For all sites except Tsabong, the cultivated soil showed higher amounts of exchangeable Mg^{2+} in comparison to the uncultivated soil (Table 4). The Mg^{2+} was also high compared to Ca^{2+}, a condition which is undesirable, and a sign of a lowering in soil quality due to cultivation.
The implication of consistently higher values of chemical properties for uncultivated compared to cultivated soils at the benchmark sites is that there is a marked reduction in soil fertility with continuous cultivation.

3.3 Soil Erosion

Soil erosion experienced in the studied areas is mainly due to wind and water.

Wind erosion is mainly caused by lack of protective cover, which in turn is due to drought and overgrazing. Even though annual rainfall is low, rainfall distribution is characterized by a few large storms of high intensity and short duration. These few storms are highly erosive, more especially when the ground is not protected by vegetation cover as is the case at the beginning of each rainy season. Dongas have developed and sediment deposition is evident on arable field boundaries and natural waterways.
Figure 1 shows profiles for Tshane watering point near Hukuntsi. This is a cattle-watering spot where animals are brought in to drink during the dry winter months. There is considerable soil trampling and loosening of the sandy soils during this period. When rain falls in summer, the loose soil is transported into the neighbouring pan by runoff. This is shown by the rise in the pan elevations, indicating a deposition. Studies in the Mid-Boteti area of north-central Botswana have shown similar results [2,3].

Figure 2 shows a set of profiles for Struizendam sand-dune/woodlot near Tsabong. It can be discerned that more sand was removed from the far end of the transect and deposited towards the beginning. Profiles for other benchmark sites showed similar trends.

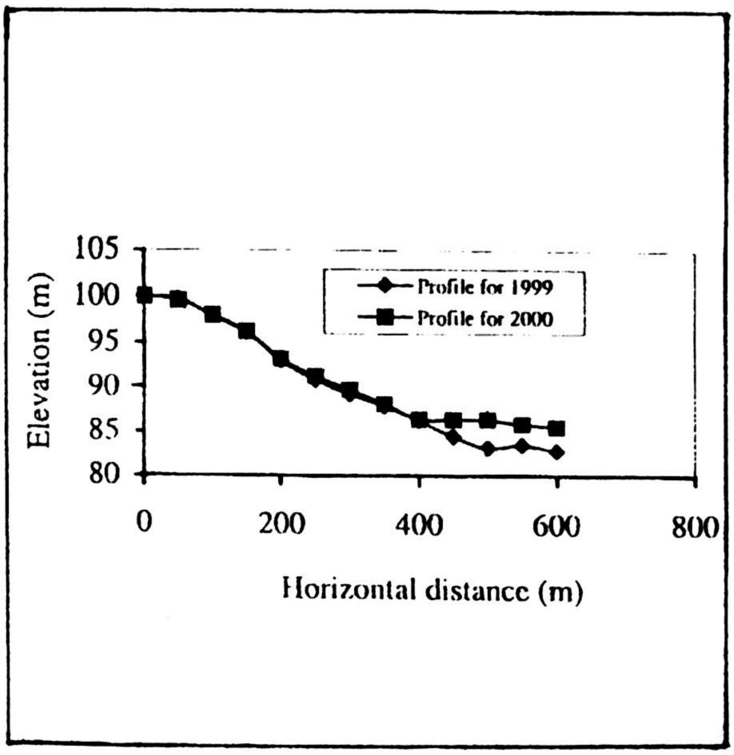

Figure 1. Soil surface profiles for Tshane watering point near Hukuntsi

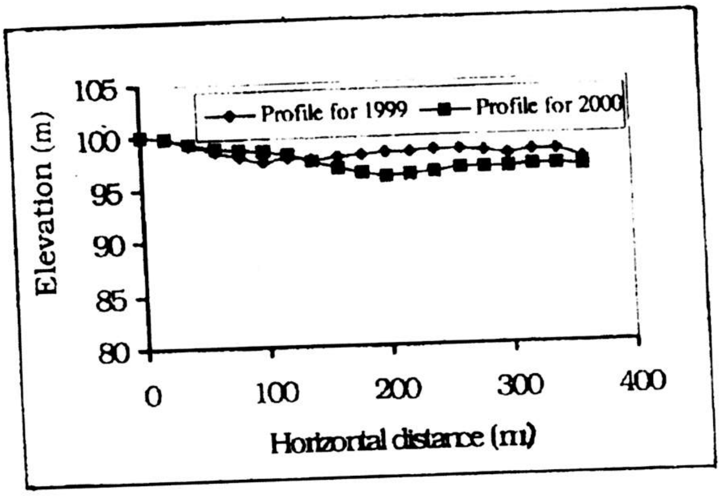

Figure 2. Soil surface profiles for Struizendan sand dune/woodlot near Tsabong

3.4 Availability of Range Resources

The vegetation for the Bobirwa Sub-district is wooded savanna with mophane (*Colophospermum mophane*) and mohudiri (*Combretum apiculatum*) as the dominant tree species. Seloka (*Aristida congesta*) grass dominates the area. The vegetation in Kgalagadi District is open savanna with mokhi (*Acacia nilotica*) as the dominant tree species with some mongana (*Acacia mellifera*) and mogwana (*Grewia bicolor*) being prevalent in both wet and dry seasons. Seloka dominates in both seasons though the quantity is markedly more during the wet season.

The results of TRRA in Bobirwa Sub-district have shown that there is an overall decline in the availability of the most important graze-and-browse species (Table 5). A similar picture is depicted in the sandveld [11]. Although drought is perceived to be the main contributor to the reduction in graze-and-browse species, resourse depletion is related to intense resourse use such as overgrazing, burning and poor management [2,12]. Graze-and-browse species reduction has serious implications for people's livelihoods. For cattle owners, loss of stock weight leads to low market prices. For small stock owners, reduction in browse species affects the condition and market value of their principal asset.

There is a marked veld product species decline in both the hardveld and sandveld. In Bobirwa Sub-district, there is broad agreement among all social strata that the majority of the most important veld species have declined (Table 6). Some of the most important veld products in the sandveld include sengaparile (*Harpagophytum procumbens*), morama (*Tylosema esculentum*), mahupu (*Terfezia pfellii*) and motshikiri (a perennial thatching grass). The depletion of sengaparile is very real due to its high market [14]. Overharvesting of veld products has tended to occur in Botswana as a result of population growth, non-sustainable harvesting and burning, and poor management. Overgrazing by livestock and wildlife also contributes to the reduction in veld product availability. Livestock browse on the young shoots of trees, bushes and thatching grass, and goats are particularly destructive in the immediate vicinity of villages [3,15].

Table 5. Graze-and-browse species availability at Tsetsebjwe, Mathathane and Motlhabaneng villages of Bobirwa Sub-district

	Uses					Depletion Status		
Tree Species	**fire wood**	**browse**	**poles**	**medicinal**	**fruits**	**ok**	**Declining**	**lost**
Mophane	✓	✓	✓			✓		
Mohudiri	✓	✓	✓				✓	
Mogonono	✓		✓					✓
Moretologa					✓		✓	
Mhatha		✓		✓			✓	
Mokomotu			✓			✓		
Motsiara	✓					✓		
Mokala	✓	✓				✓		
Moselesele	✓						✓	
Mogwana	✓	✓			✓	✓		
Monepenepe				✓			✓	
Mokabi		✓					✓	
Mokosho		✓					✓	
Moretlwa		✓			✓			✓
Morula				✓	✓		✓	
Motshijane				✓			✓	
Mhaha				✓			✓	
Mowana					✓	✓		
Sengaparile				✓			✓	

Grass Species	**grazing**	**thatching**	**ok**	**declining**	**lost**
Rathatha		✓			✓
Rantafole		✓			✓
Tshwang	✓				✓
Makurwane					✓
Sedupapula					✓
Seloka	✓		✓		
Sesadile					✓
Sesekangwetsi					✓
Tshikitshane					✓
Phoka	✓				✓
Motshikiri	✓				✓
Mogorwane	✓				✓
Pitseesule	✓				✓

Table 6. Availability of veld products by social strata at Motlhabaneng village in Bobirwa Sub-district [13]

Female-headed households

Local Name	Botanical Name	Main Use	Availability
1. Mokolwane	Hyphaene ventricessa kirk	Baskets for sale	Reduced
2. Morula	Scletocaryn caffin sand	Food	Reduced
3. Monyee	Berchemia discolor	Dye for sale	Reduced
4. Monepenepe	Cassia abbeviata	Medicine	Reduced
5. Mphuphuchi	Grewia species	Food	Reduced

Households with no livestock

1. Mokolwane	Hyphanae benguellensis	Sale	No change
5. Mphuphuchi	Grewia species	Food	Reduced
6. Mogwana	Grewia bicolor	Food	Reduced
4. Monepenepe	Cassia abbreviata	Medicine	Reduced
7. Sengaparile	Harpagophytum Procumbens	Medicine	Reduced

Households with smallstock only

1. Mokolwane	Hyphanae benguellensis	Construction	No change
4. Monepenepe	Cassia abbreviata	Medicine	Reduced
8. Rothwe	Cynadropsis gyandra	Food	Reduced
9. Thepe	Amaranthus thunbergii/moq	Food	Reduced
2. Morula	Scletocaryn caffin sand	Food	Reduced

Households owning 10+ cattle

1. Mokolwane	Hyphanae ventricessa kirk	Sale	Increased
2. Morula	Scletocarya caffin sand	Food	Reduced
6. Mogwana	Grewis bicolor jucs	Sale	Reduced
7. Sengaparile	Harpagophytum Procumbens	Medicine	No change
4. Monepenepe	Cassia abbreviata	Medicine	No change

4 FUTURE DEVELOPMENT

From the foregoing, it is clear that land degradation is taking place in various degrees of severity, caused by natural and human factors. Whilst little can be done to alter natural causes, a lot can be achieved to change the way we manage the land and its inherent resources. As communities in the affected areas derive their livelihood solely from the natural resource base, a concerted effort with full community participation is required to manage natural resources in order to minimize land degradation and prevent further loss of biodiversity. To achieve this, the following strategies need to be pursued:

1. **Improvement of community participation in natural resources management and policy formulation;**

2. **Promotion of appropriate land degradation control (for biodiversity loss reduction) technologies;**

3. Strengthening of human resources development and institutional capacities to address biodiversity management; and

4. Initiation of restoration of degraded key biodiversity systems.

These strategies will be implemented in the key degraded areas of Bobirwa Sub-district and Kgalagadi District through a 6-year Desert Margins Programme (DMP) Phase I project funded by Botswana Government and the Global Environment Facility (GEF) – a joint partnership between United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP) and the World Bank.