ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Distribution of Grazing Ungulates in Relation to Water Holes, its Consequence on Soil and Vegetation in the Serengeti Plains, Tanzania

By

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DEDICATION

This work is dedicated to:

My parents, Mr. and Mrs. Boay Hagwet, who brought me up with care and love, and made a great effort to educate me. May God bless you.

To my husband, Jason John, who took a burden of staying alone during my studies.

ABSTRACT

The distribution and abundance of grazers in relation to the water holes in the Serengeti plains were studied. Ten species of grazing ungulates were recorded in the area. Using direct and indirect count methods, high abundance of animals was found in zone 1 (areas around water holes). During the dry season, high abundance of Thomson′s gazelle was recorded in burnt areas away from the water hole. In unburnt area, they were abundant closer to the water holes. Total grass cover (percentage), species diversity and grass height were significantly lower in areas around the water holes compared to areas away from the water holes. Grazing was more intense in areas around water holes compared to areas farther. Among soil texture types, only clay fraction shows significant difference among the three zones compared. The percentage of clay in areas near the water hole was high compared to areas away. Soil organic matter, total nitrogen and potassium were significantly lower in areas closer to the water holes, whereas, ammonium, electrical conductivity and pH were significantly higher in areas close to the water holes and decrease with increased distances from the water holes. Most of the smaller grazing ungulates were abundant in burnt areas and in areas with short grasses. The study concluded that the distance from the water hole, fire and rainfall influenced the distribution and abundance of grazing ungulates. Further study should be conducted which can include the long rainy season so as to find out seasonal effects.

Key words: *Abundance, burnt areas, distribution of grazing ungulates, Serengeti plains, water holes.*

1. INTRODUCTION

1.1 General Introduction

Water is essential for the survival of all organisms. In semi-arid and arid regions, its importance increases as its availability decreases. Animals are more transient in the use of their habitat, spreading out when green fodder is available and moving on, or contracting back to the few permanent waterholes, when it is dried out (Charley and Cowling, 1968). In the tropics, availability of water is one of the major limiting factors in the distribution of wild animals. Hence, the distribution of water holes has influence on the distribution of animals (Traill, 2004). Species, whose survival depends on a regular availability of drinking water, concentrate near water holes in the dry season (Jessica *et al*., 2003), while the ones adapted to arid conditions do not. They are able to extend their ranges to inhabit even remote areas far from water source. For example, some species such as waterbuck and reedbuck require regular drinking water, whereas other species such as the gerenuk do not (Ayeni, 1975), thus resulting in uneven distribution of animals in areas of their occurrence.

Distribution of animals has impacts on plant and soil characteristics in an area. Abrahamson (1989) indicated that grazing pressure exerts a profound influence on the community structure, diversity as well as soil characteristics of the area. Grazing either affects plant growth (Moore *et al.,* 2003), or seed production through reducing the vegetative growth required to support reproduction (Robert, 1990).

Wilson (1990) pointed out that the major impact of grazing has been the removal of palatable shrubs close to water holes. There are also effects from trampling and dust associated with the movement of animals close to the water holes (Andrew and Lange, 1986). As the distance from the water source increases, the trampling effect decreases (Ntalwila, 2001). Since trampling is most obvious within 100 m of the water point, this zone is often called as the "sacrifice" zone (Andrew and Lange, 1986; Senzota and Mtahko, 1990).

Soils in arid environments are generally nitrogen and phosphorous deficient. Most nitrogen that is available to plants is held in the top 10 cm of soil as a result of breakdown of organic matter and nitrogen fixing algae (Charley and Cowling, 1968). Heavy traffic by livestock breaks up the surface cryptogam crust (Crisp, 1975). As a result, the nitrogen-fixing action of the cryptogams is disrupted. Further, the soil surface is loosened allowing wind and water erosion to remove surface layers. Denudation of vegetation and pulverisation of the soil crust under heavy stocking rates lead to soil erosion by wind and water. Denudation by removal of surface vegetation and subsequent erosion is a major problem in many countries. In the Sahelian region of Africa, drilling of bore holes at regular intervals has led to extensive land degradation. It has been noted that overgrazing in such areas during the dry season resulted in areas of denudation up to 30 km from a wells (Rapp, 1976; Glantz, 1977). This shows that the land degradation is time specific (Ayeni, 1975).

Rapp (1976) reported that grazing by cattle around artificial water sources in northern Sudan has resulted in the denudation of vegetation and in soil compaction over areas of up to 100 km diameter. Compaction appears to be restricted to heavy stock-traffic areas such as around water holes and along tracks (Crisp, 1975). Soil compaction reduces infiltration. Infiltration was lowest in areas of heavy grazing and was highest in areas of light grazing (William and Eric, 1989).

Accumulation of dung and urine of grazing animals is often inversely proportional to the distance from permanent water holes. This may have positive effect in areas close to the water point with respect to nutritive input (Andrew and Lange, 1986).

1.2 Background

The Serengeti plains comprises about 1.5 million ha of savannah habitat in the southern half of the Serengeti National Park (Sinclair, 1995). Seasonal variations in rainfall in this area are largely predictable. However, the inter-annual fluctuations are high and unpredictable.

Availability of water is the major factor limiting all life in the Serengeti ecosystem as this ecosystem is semi-arid, and mean annual rainfall is less than 600 mm (Gereta, 2004; Sinclair, 1995). Hence, water quantity is a dominant force driving the dynamics of the Serengeti ecosystem (Gereta, 2004).

As the dry season approaches, the seasonal water-holes dry up and the open savannah vegetation begins to turn to a golden colour, when wildebeests start moving northward. The annual migration of vast herds of herbivores (wildebeest, *Connochaetes taurinus;* Thomson's gazelles, *Gazella thomsoni* and zebras, *Equus burchelli*) to permanent water holes, followed by their predators, is one of the most impressive natural events in the world (Sinclair, 1995). The timing of the migration varies from year to year depending on the beginning of the rainfall indicating that this phenomenon is not driven by a biological clock (Sinclair, 1995). Most rivers are dry and water is commonly impounded with zero flushing for several months, when such impoundment forms the only source of water for wildlife. During the dry season, the resident grazers such as hartebeest (*Alcelaphus buselaphus*), warthog (*Phacochoerus aethiopicus*), impala *(Aepyceros melampus)* and Grant`s gazelle (*Gazella grantii*) concentrate near available water holes (Bernhard and Michael, 1965). Such larger animal congregations result in adverse ecological effects in the area. Further, the concentration of water holes in few areas of the Park could result in land degradation due to the damage of vegetation and loosening of the soil as a result of trampling by large herbivores (Senzota, 1997).

Several studies in Serengeti have revealed the impact of grazing. Jameson (1963) revealed the effects of defoliation with the overwhelming evidence that clipping consistently, though not universally reduces short-term root growth. This view has become ingrained in the thinking of ecologists, although field studies have also indicated that grazing might have no adverse effect (Cargill and Jeffries, 1984). More recent pot experiments have indicated that the effect of defoliation on grass root growth is complex; sometimes inhibitory, sometimes nil and sometimes stimulatory (Oesterheld and McNaughton, 1988, 1991). Other investigations in the Serengeti ecosystem indicate that grazing increases above ground net productivity for short periods (McNaughton, 1979 a, b) and full growing seasons (McNaughton, 1985). However, Coughenour *et al.,* (1984) indicated that it is impossible, for any extended time period (e.g. a full growing season), for the above ground production to remain constant or increase in response to grazing. So, there are contradictory views, but the question remains, does intense grazing at some locations in the Serengeti ecosystem lead to the change in vegetation composition and diversity? Water holes may influence the distribution of grazing ungulates and thus influence the grazing intensity in accordance with the distribution gradient of the animals.

Wild animals form a major part of natural habitat and hence have a significant role in the control and maintenance of the ecosystem. Thus, management of animals forms a major component of protected area management system. Since the main objective of protected area management is managing the animal populations, it becomes important to know how the animal populations are distributed in landscapes in relation to water holes.

Earlier studies (Charley and Cowling, 1968; Ayeni, 1975; Rapp, 1976; Andrew and Lange, 1986; Senzota, 1997; Ntalwila, 2001; Traill, 2004) have documented the influence of water holes on the distribution of ungulates and its impact around those water holes in different areas. However, no such study has been carried out in Serengeti, especially in the Serengeti plains. Hence, the present investigation was conceived to examine the distribution of grazers and their impact on the vegetation and soil in the Serengeti plains.

1.3 Objectives and hypotheses

1.3.1. Objectives

The general objective of the present study is to know the importance of water holes on the distribution pattern of grazers, and its consequences on vegetation and edaphic characteristics in the Serengeti plains, Tanzania.

The specific objectives of the present investigation are:

i. To know the distribution and species composition of grazers in the Serengeti plains, in relation to water holes,

ii. To establish the impact of grazers on vegetation around water holes in the Serengeti plains, and

iii. To know the impact of grazers on edaphic characteristics around water holes in the Serengeti plains.

1.3.2. Hypotheses

This study aimed at testing the following hypotheses:

i. There is high abundance of grazers in areas around the water holes than in areas away from the water holes.

ii. There is overgrazing effect in areas around water holes than in areas away from the water holes.

iii. There is trampling effect and high levels of soil erosion in areas around water holes than in areas away from the water holes.

2. STUDY AREA AND METHODS

2.1. The study area

Serengeti National Park is located in the northern part of Tanzania, at coordinates between 1º 30′ - 3º 20′ S and 34º 00′ - 35º 15′ E. It covers an area of about 14,763 km². It is part of the high interior plateau of eastern Africa with altitude varying from 920 m in the west to 1850 m in the east. Part of the Park has been under protection since 1929, but the current extent of the park was not gazetted until 1959, with a few minor additions in the mid-1960s (Sinclair, 1995). In 1981, the Park was granted the status of both a World Heritage Site and an International Biosphere Reserve. Serengeti National Park is bordered by the Maswa Game Reserve to the south; the Ngorongoro Conservation Area to the southeast, Loliondo Game Controlled Area to the northeast, Masai Mara National Reserve in the north and Ikorongo-Grumeti Game Controlled Area in the west (WCMC, 2000). The present study was conducted in the Serengeti plains, around the central part of the Park near Seronera (Fig. 1).

2.1.1 Climate

Temperature is relatively constant with mean monthly maximum ranging from 27ºC to 28ºC. The minimum temperature varies from 13 ºC to 16ºC in the colder months (May to August) and hot months (October to March), respectively. Annual rainfall is bimodal with heavy rains during March to May and short rains during November to December. Rainfall varies from 1200 mm in the north to less than 400 mm in the southeastern plains and in the Rift Valley (Sinclair, 1995).

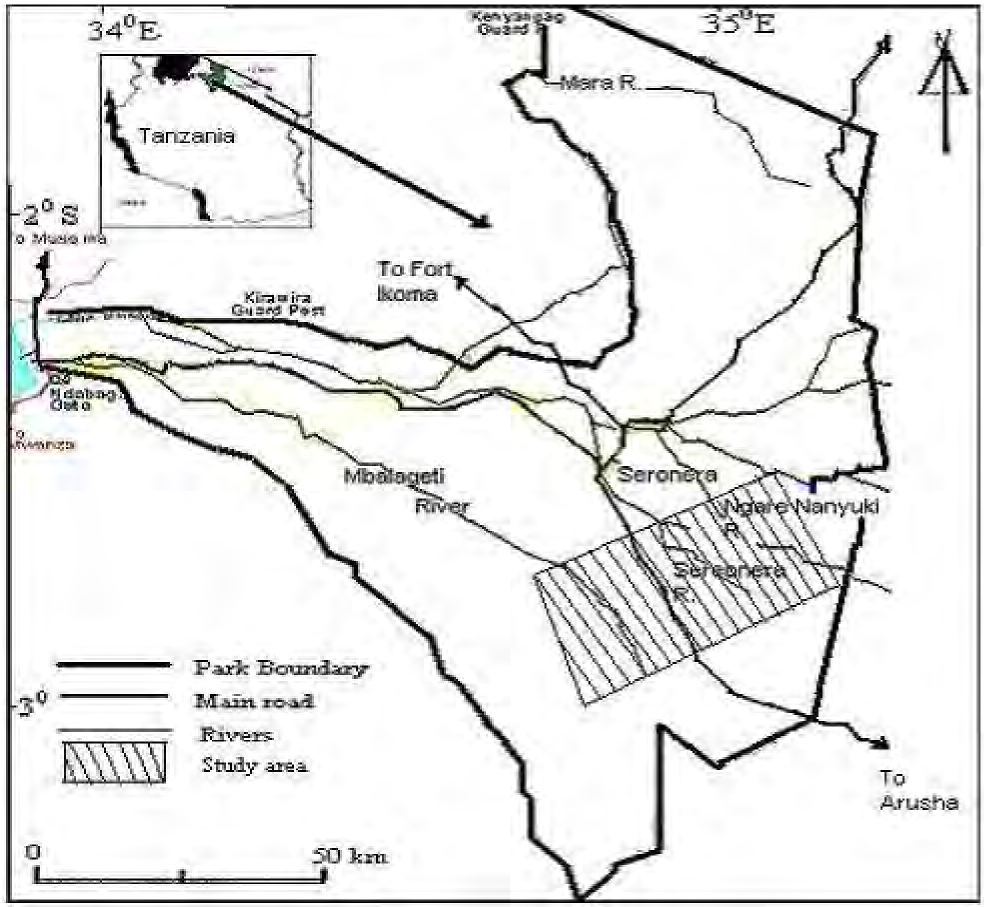

Figure 1. Map of the Serengeti National Park, Tanzania, showing the study area (Modified from Sinclair and Arcese, 1995).

2.1.2 Water sources

Serengeti National Park is drained by the Mbalageti, Grumeti and Mara rivers, all flowing westward to Lake Victoria. The Mbalageti River drains 2680 km^2 of the southern open, treeless grassland and hills (Gereta, 2004). The Seronera River is a small tributary of the Grumeti River, which drains the central woodland area of the Park (Gereta, 2004).

2.1.3 Vegetation and soil

Vegetation of the Serengeti National Park is predominantly treeless grassland within the south eastern plains and woodland in the north western part of the Park. The dominant grass species are *Themeda triandra, Pennisetum mezianum* and *Cynodon dactylon*. The woodland is dominated by *Acacia* sp. (Bernhard and Michael, 1965; McNaughton and Banyikwa, 1995). A detailed description of the Serengeti vegetation is given in Herlocker (1976). The grassland plains are categorized into three types depending on the grass height. These are the short grassland plains in the south eastern part of the Park, where the grass grows up to 5 cm high, intermediate grassland where grass grows to about 25 cm high and long grassland plains where grass grows to about 1 metre high around the border with woodland and in the western corridor of the Park (Wit, 1977).

Soils of the Park are highly saline and shallow in the eastern plains due to volcanic origin, but progressively deeper and less alkaline towards the northwestern plains (McNaughton and Banyikwa, 1995).

2.1.4 Fauna

The Serengeti National Park supports the largest herds of migrating ungulates in the world (Sinclair and Arcese, 1995). It is estimated that there are migratory species of 1.6 million wildebeest (*Connochaetes taurinus*), 200,000 zebra (*Equus burchelli*) and 440,000 Thomson's gazelle (*Gazella thomsoni*) (TWCM, 1994; Campbell and Borner, 1995). Non-migratory species of the Park include buffalo (*Synceros caffer*), elephant (*Loxodonta africana*), hartbeest (*Alcelaphus buselaphus*), topi (*Damaliscus korrigum*) impala (*Aepyceros melampus*) and giraffe (*Giraffa camelopardalis*). This Park is also famous for the highest concentration of predators in the world (Sinclair, 1995). The most numerous large canivores in the area are hyaena (*Crocuta crocuta*) (7500), lion (*Panthera leo*) (2800) and cheetah (*Acinonyx jubatus*) (300) (TWCM, 1994). There are 62 species of reptiles (Kreulen, 1979) and more than 517 species of birds recorded in the Park (Schmidl, 1982).

2.2. Methods

2.2.1 Selection of the study sites

The present study was conducted during the dry season (September and October) and during the short rainy season (December), 2004. Before the actual fieldwork, a reconnaissance survey was conducted in the Serengeti National Park for four days. Three study sites were selected in the Serengeti plains with the help of a map of the Park. The major considerations were the water holes in the plains of the Park. The first site was on the tributary of Seronera River, the second on the Ngare Nanyuki River and the third on the tributary of the Mbalageti River. These sites were then named Seronera River (site A), Ndiakarta River (site B) and Loyangalani River (site C) (Fig. 2).

Transects

A total of six transects, each of 4 km long were established during the study, two in each of the study site. The starting points of all transects were from the water holes as shown in the Figure 2. The transect width was 400 m, measured by a range finder.

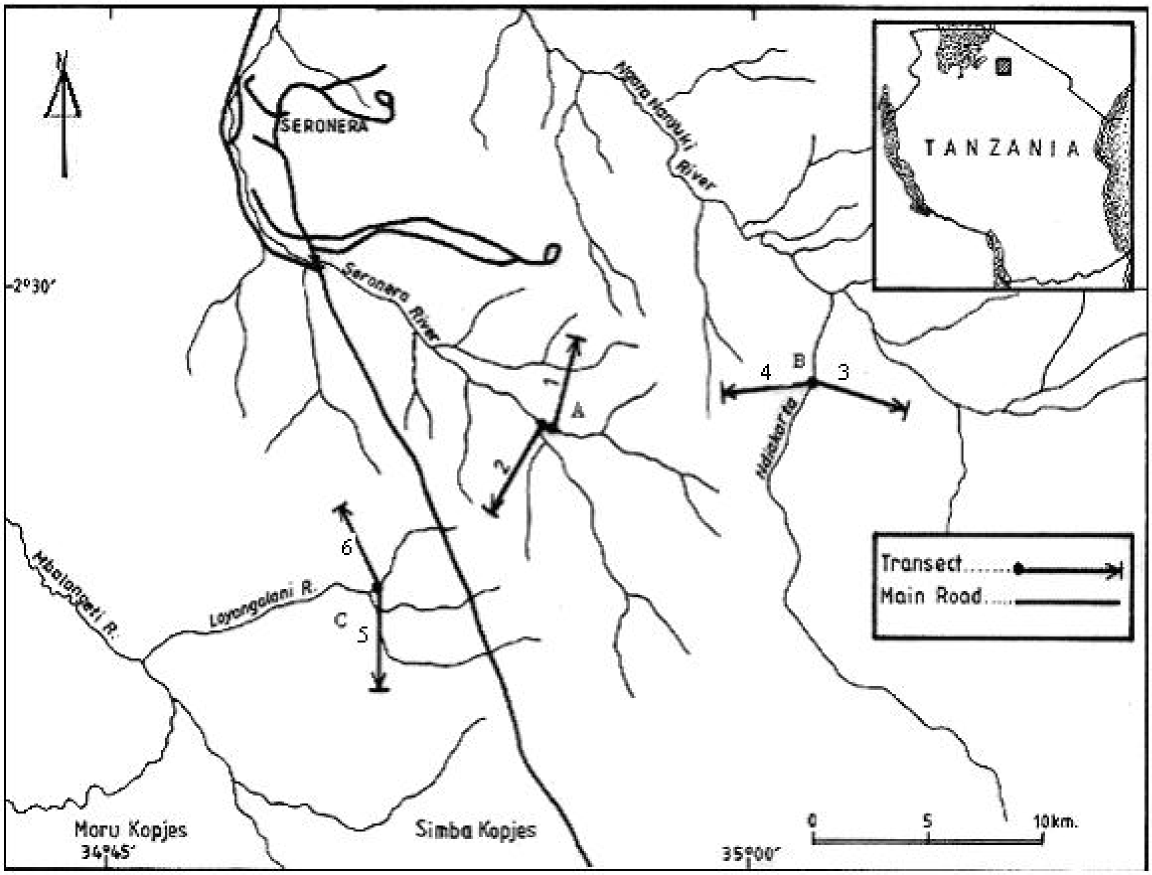

Figure 2. Map of the study area in the Serengeti plains, showing transects in sites A, B and C. (Source: GIS Unit, University of Dar es Salaam).

2.2.2 Direct count

Following transects, the grazers were counted in an area of 200 m on each side of the transect using an open vehicle. Speed of the vehicle during counting was 20 km/hour. As a first step, the three study sites were observed for any time specificity of the visits of grazers to the water hole. This revealed that animals come to drink during 09.00 - 17.00 hours. Based on this observation, during the present study, counting was conducted during the day time starting from 07.30 - 17.30 hours. To avoid bias, counting was carried out alternately among the sites. All the six transects were covered daily and the counting order was rotated for equal time coverage of 7 hours for each transect. For comparison, the transects were divided into two zones. A distance of 0-2 km from the water hole was assigned as zone 1 and the distance of 2-4 km was assigned as zone 2. Species seen, distance from the water hole, total number in a herd, approximate age composition of the herd, sex and habitat type where the animals were observed were recorded at each sighting of animal(s) during the study. Animals seen were grouped in to distance of 0-500, 500-1000, 1000-2000, 2000-3000 and 3000-4000 m from the water hole to see their distribution along the transects. Data on burned transects and the days on which there were rains were recorded to find out whether these factors have any relationship with the distribution of grazing ungulates in the area.

2.2.3 Indirect count

Along the transects, a total of 48 plots, each of 10 x 10 m^2 were marked for counting animal fecal droppings. Among these plots, 24 were located in areas around the water holes (zone 1) and the other 24 in areas away from the water holes (zone 2).

Density of animal droppings was calculated as number of droppings divided by area in m^2. These were then compared for areas around the water holes and areas away from the water holes.

2.2.4 Vegetation sampling

The area was divided into three zones; zone 1 in areas around the water holes, zone 2 in mid area and zone 3 in areas away from the water hole to analyze vegetation comparison. A total of 36 plots, each of 1×1 m^2 were marked; 12 plots in each zone. The measurements taken in these zones were compared to determine the impact of grazers on the vegetation on the basis of the assumption that grazing intensity deferred between zones. Grass cover in each plot was measured using pin frame method as described by Mulleer-Dombois (1974) Kent and Coker (1992). The grazing intensity was visually estimated and the measurements were recorded as percentages. Grass height was measured using a tape and recorded in centimetres. Plant specimens were collected and identified with the help of herbarium collection at the Serengeti Wildlife Research Institute (SWRI) and at the University of Dar es Salaam.

2.2.5 Soil sampling and analyses

Those plots used for vegetation analyses were also used for soil analyses. Soil samples were collected at the depth of 0-20 cm using a soil auger, kept in polythene bags, sealed to prevent contamination and moisture loss and brought to the Laboratory of the University of Dar es Salaam for determination of soil physical and chemical properties. Soil physical and chemical properties were analyzed for each sample as indicated below.

(a) Soil bulk density

Determination of the bulk density was done using a known volume following the core method (Blake and Hartge, 1986). Bulk density was expressed in SI unit as g/cm^3

(b) Soil texture

The soil texture was determined using the pipette method as described by Gee and Bauder (1986). Separation of sand sized particles was done by pouring the treated soil through a 270 mesh sieve (53 μ m) followed by washing the sand. Determinations of silt (2-20 μm) and clay (< 2 μm) were also done using the pipette method as described by Gee and Bauder (1986). Data were presented as percent sand, silt and clay and the texture was determined using the International Soil Science Society System (ISSS) textural classification system (Gee and Bauder, 1986).

(c) Soil water content

Water content was determined using the gravimetric method as described by Gardner (1986). The measurement was taken as percentage of water content.

(d) Soil pH

Soil pH was measured electrometrically using a Metrohm E510 pH meter. This was done using a ratio of 1:1 soil and water mixture, which was allowed to equilibrate in a beaker for 30 minutes (McLean, 1982). The pH of a stirred suspension was read from the pH metre and recorded.

(e) Electrical conductivity (EC)

Soil EC was analysed electrometrically as described by Juo (1978). The readings were taken as ms/cm.

(f) Soil organic matter

Soil organic matter was determined using the Walkley-Black Potassium Dichromate method as described by Olsen and Sommers (1982). Readings were taken as percentage organic matter.

(g) Available soil phosphorus

Available soil phosphorus was extracted by using the Olsen extraction method as described by Olsen and Sommers (1982) and Emteryd (1989). Readings were taken as meq/100g.

(h) Total soil Nitrogen

Total soil nitrogen was determined using a semi-micro Kjeldahl digestion (Allen, 1989) and calorimetric determination of the resultant ammonium by colour reaction (Endo-phenol blue method). Readings were taken as percentage nitrogen.

(i) Exchangeable base (K^+)

Potassium (K^+) was analyzed using Atomic Absorption Spectrophotometer (AAS) Perkin Elmer 3100 (Allen, 1989). Readings were taken as meq/100g.

2.2.6 Data analyses

The statistics employed in this study were either parametric or non-parametric depending on the nature of the data following Zar (1999). All probabilities were two tailed and the results were recorded as significant at $p \leq 0.05$.

(a) Abundance

The abundance of grazing ungulates was calculated as total number of individuals recorded divided by total number of counting days. However, variation in individual abundance and dropping density between the two zones were tested using t-test for samples with normal distribution and Mann-Whitney U-test for samples that do not pass the normality test (Kent and Coker, 1992).

(b) Species diversity

Shannon-Weaver Index of Diversity, (H') was used to calculate the species diversity (Kent and Coker, 1992), as follows:

$$H' = -\sum (pi \ln pi)$$

Where, H'= Diversity Index,

Pi =Proportion of the individuals of the i^{th} species

ln = log base $_n$

Species evenness were calculated using the Shannon's evenness index E,

$$E = H'/H\ max,$$

Where, E = Evenness, H max = ln S, S= Number of species in that plot, H' = Shannon's Diversity Index.

Variation in plant species diversity between the two seasons was tested using t-test, and among the three zones was tested using Analysis of Variance (ANOVA) with Least Significant Difference (LSD) as a post-test.

(c) Soil samples

Soil parameters in three zones were tested using One-Way ANOVA with Least Significant Difference (LSD) as a post-test.

3. RESULTS

3.1 Species composition of grazing ungulates

A total of ten species of grazing ungulates were recorded in the present study. These were Thomson gazelle (*Gazella thomsoni*), Grant gazelle (*Gazella grantii*), Hartebeest (*Alcelaphus buselaphus*), Topi (*Damaliscus korrigum*), Bufallo (*Synceros caffer*), Zebra (*Equus burchelli*), Wildebeest (*Connochaetes taurinus*), Warthog (*Phacochoerus aethiopicus*), Reedbuck (*Redunca redunca*) and Hippo (*Hippopotamus amphibious*).

Site A had the highest number of species (nine species), followed by site C (eight species) and site B (seven species) (Fig. 3).

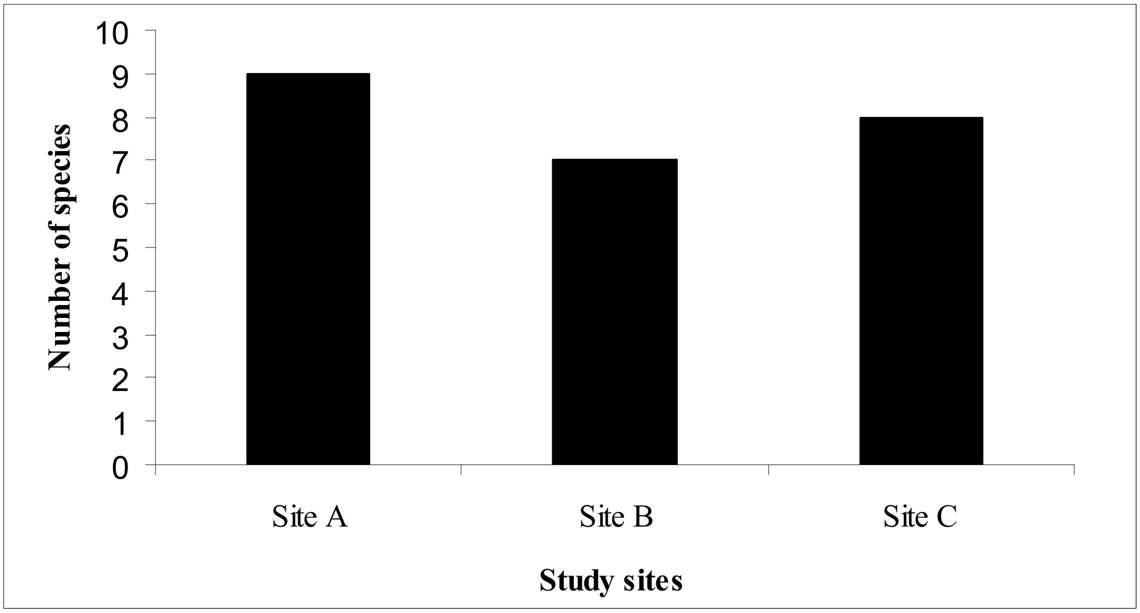

Figure 3. Species abundance of grazing ungulates recorded in the Serengeti plains.

During the present study period, species other than grazing ungulates were also recorded. These were Lion *(Panthera leo), Hyaena (Crocuta crocuta),* Cheetah *(Acinonyx jubatus),* Golden backed jackal (*Canis capensis*), Banded mongoose (*Mungos mungo*), Elephant (*Loxodonta africana*), Ostrich (*Struthio camelus*), Rabbit (*Oryctagus cuniculus*) and Honey badger (*Mellivora capensis*).

3.2 Distribution of grazing ungulates at different distances from the water hole

The distribution of grazing ungulates in relation to water holes is shown in Figure 4. The distribution pattern of species in relation to distance from the water hole shows a negative correlation, i.e. there was a decline in the number of species of grazing ungulates with reference to increased distance from the water hole (Fig. 4).

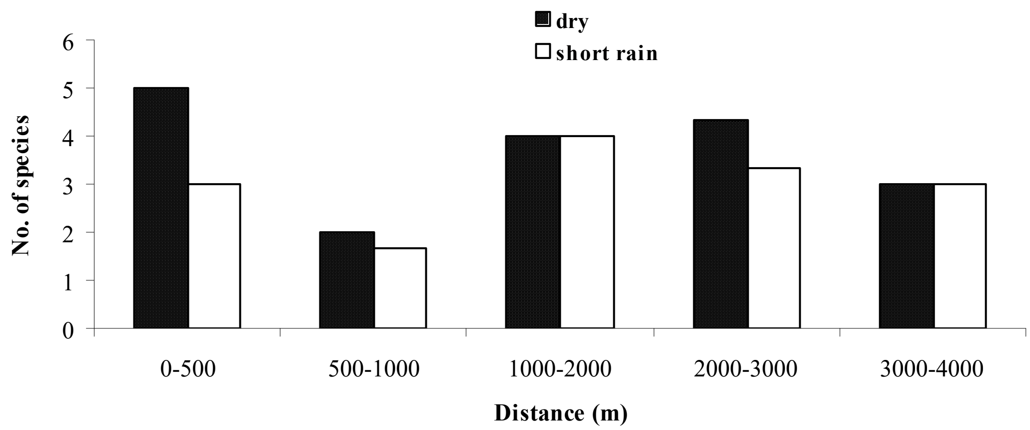

Figure 4. Distribution of grazing ungulates with respect to distance from the water hole during different seasons.

During the dry season, there was a high number of species recorded at distances between 0 to 500 m from the water hole. However, during the short rainy season the number of species was almost the same at all distances except at 500- 1000 m from the water hole, where the number of species was low both during the dry and short rainy seasons (Fig. 4). Overall, there was no significant variation between seasons (dry and short rainy seasons) in the distribution of grazing ungulates in the study area ($p = 0.33$, $t = 1.03$, $df = 8$).

3.3 Animal abundance

3.3.1 Direct count

Overall comparison of animal abundance between zones showed no significant difference ($p>0.05$). However, data on fire and days when it rained showed the differences (a & b below).

(a) Comparison of species observed between zones in unburnt and burnt areas

In unburnt areas, there were significantly more animals in zone 1 than in zone 2 ($p< 0.0046$, $t = 3.637$, $df=10$). In burnt areas, the abundance of animals did not differ between two zones ($p = 0.0845$, $t = 1.915$, $df=10$; Table 1; Fig. 5). However, because of rains, observation 4 had higher number of animals in areas away from the water hole even in the unburnt areas (Table 1).

Table 1. Abundance of animals between zones in unburnt and burnt areas

Observations	Unburnt area		Burnt area	
	Zone 1	Zone 2	Zone 1	Zone 2
1	259	6	300	434
2	141	2	134	250
3	138	1	143	137
4	17	70	27	259

5	326	0	50	212
6	297	21	161	184

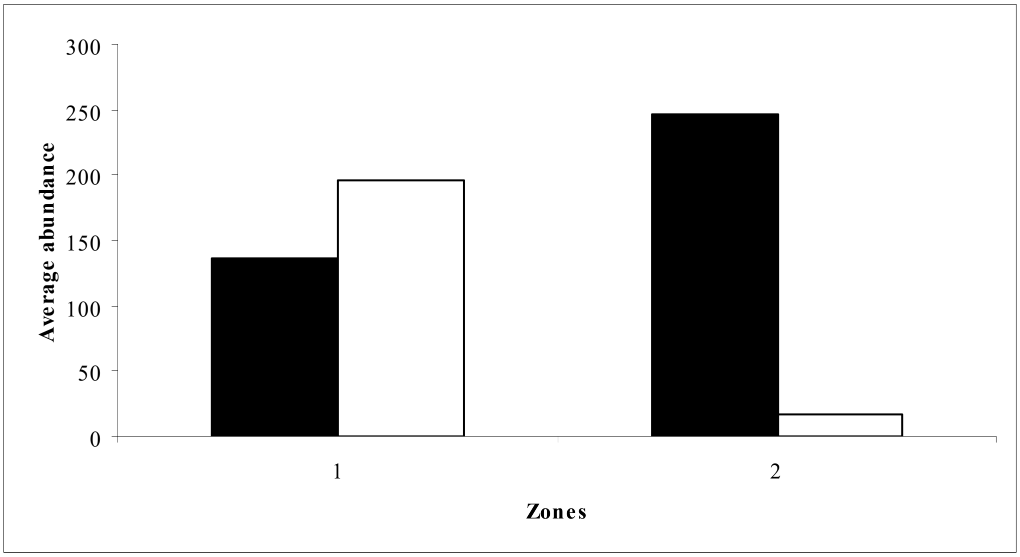

Figure 5. Average abundance of grazing ungulates recorded in burned and unburned areas in zones 1 and 2 (Closed bar = burnt areas, open bar = unburnt areas).

During the dry season, Thomson's gazelle was the most abundant species in the study area. Its abundance was high closer to the water holes in unburnt areas (p=0.0224, t=2.697, df=10). On the other hand, in burnt areas, its abundance was higher in areas away from the water holes than in areas near to the water holes (p=0.0188, t=2.801, df=10). However, wildebeest, zebra, buffalo, hippo and reedbuck were recorded only in areas around the water holes (zone 1), (Fig. 6). The t-test showed that the abundance of other species such as Grant's gazelle, warthog, topi and hartebeest was not statistically different (p>0.05) between the areas close and areas away from the water hole.

During the short rainy season, there was no significant difference between the areas close and areas away from the water holes for all species (p>0.05).

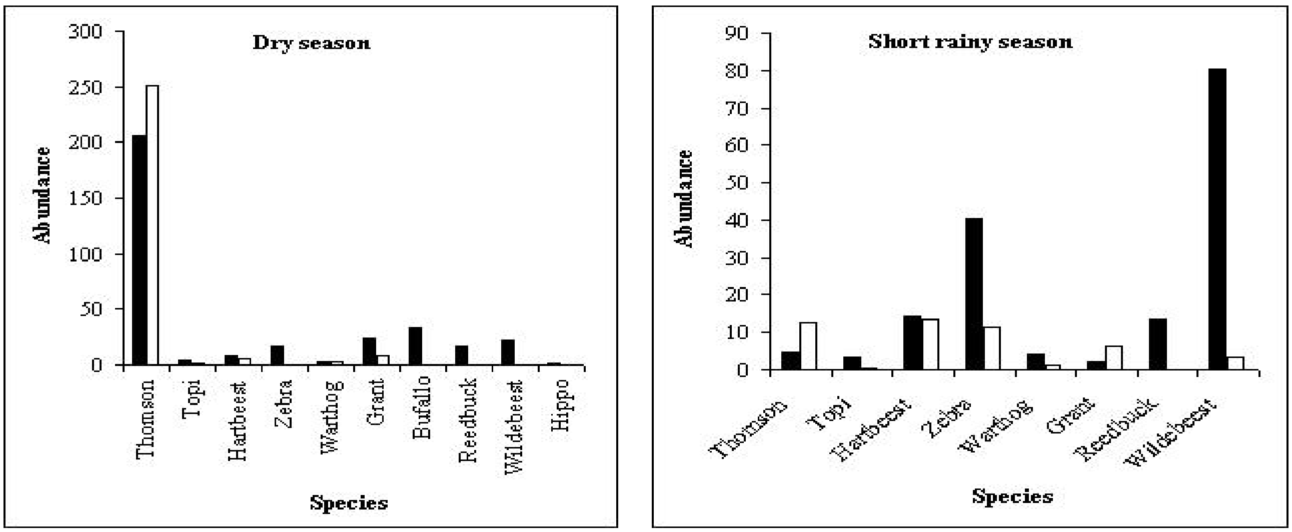

Figure 6. Comparison of species observed during different seasons in different zones (Closed bar = zone 1; open bar = zone 2).

(b) Abundance with respect to weather conditions

During the dry season, t-test showed that the abundance of grazing ungulates did not differ significantly between zones neither in the dry days nor in the rainy days (p= 0.5877, t = 0.5602, df=10 (for dry days) and p=0.1346, t = 1.628, df=10 (for rainy days); Table 2). However, during the short rainy season, the Mann-Whitney U-test showed that the abundance of grazing ungulates on the dry days was significantly higher in zone 1 (nearer the water holes) than in zone 2 (away from the water holes) (U' = 34.5, P < 0.0104; Table 2). However, t-test showed that the abundance of animals was not significantly different between zones during the rainy days (p = 0.3843, t = 0.909, df=10).

Table 2. Individual abundance of grazers in different zones during different weather conditions

Seasons / *Transect*	*ARDS*		*ADDS*		*ARSS*		*ADSS*	
	Zone 1	Zone 2	Zone 1	Zone 2	Zone 1	Zone 2	Zone 1	Zone 2
T1	4	4	584	1	23	0	533	7
T2	1	64	12	633	92	45	19	1
T3	4	66	525	20	16	2	21	1
T4	0	3	22	3	0	257	7	1
T5	4	1	32	6	2	21	19	3
T6	27	171	775	608	36	74	105	17

ARDS= Abundance in rain days in dry season, **ADDS=** Abundance in dry days in dry season, **ARSS=** Abundance in rain days in short rain season, **ADSS=** Abundance in dry days in short rain season

3.3.2 Indirect count

During the dry season, most of the animal faeces were recorded in bare areas around water holes (Fig. 7). The faecal density was significantly higher near the water holes in unburnt transects i.e. T1 (p=0.0178, t=3.236, df=6), T3 (p=0.0354, t=2.704, df=6), T4 (U'=15.6, $n_1=n_2=4$, p=0.0427), and T5 (p=0.043, $n_1=n_2=4$, U'=15.5). Comparison between zones in burnt transects, T2 and T6 showed no significant difference (p=0.2419, t=1.298, df=6 and p=0.2174, t=1.378, df=6, respectively). The comparison of faecal density between zones during the short rainy season showed no significant difference for all transects ($p>0.05$).

Figure 7. Animal droppings in bare area close to the water hole at site A

3.3 Animal species diversity (H') and evenness (E)

T-test showed that animal species diversity was not significantly different between zones either in dry season or in short rain season ($p=0.75$, $t=0.33$, $df=10$; $p=0.68$, $t=0.42$, $df=10$) respectively. However, the evenness between zones was significantly different during the short rain season ($p=0.01$, $t=2.92$, $df=10$). The mean evenness was higher in zone 2 than in zone 1 (0.28 ± 0.06, 0.15 ± 0.09) respectively. But during the dry season the evenness was not significantly different ($p>0.05$).

3.4 Vegetation

3.4.1 Species composition

A total of 31 species of grass and herbs were recorded in the study area (Table 3).

Table 3. Grass and herb species recorded at the study sites in Serengeti plains

No.	Species	Family
1	*Aristida adoensis*	Poaceae

2	*Bothriochloa radicans*	Poaceae
3	*Chrysochloa orientalis*	Poaceae
4	*Cida ovata*	Malvaceae
5	*Cloris gayana*	Poaceae
6	*Commelina africana*	Commelinaceae
7	*Cymbopogon escavetus*	Poaceae
8	*Cynodon dactylon*	Poaceae
9	*Dicanthium annulatum*	Poaceae
10	*Digitaria macroblephara*	Poaceae
11	*Digitaria sclarum*	Poaceae
12	*Eragrostis tenufolia*	Poaceae
13	*Eustachys paspaloides*	Poaceae
15	*Hapachne schimperi*	Poaceae
16	*Heliotropium subulatum*	Boraginaceae
17	*Hibiscus micranthus*	Malvaceae
18	*Hyparrhenia filipendula*	Poaceae
19	*Indigofera basiflora*	Papilionaceae
20	*Microcloa kunthii*	Poaceae
21	*Panicum coloratum*	Poaceae
22	*Pennisetum mezianum*	Poaceae
23	*Pennisetum straminium*	Poaceae
24	*Setaria sphacelata*	Poaceae
25	*Solanum incanum*	Solanaceae
26	*Sporobolus fimbriatus*	Poaceae
27	*Sporobolus ioclados*	Poaceae
28	*Sporobolus spicatus*	Poaceae
29	*Sporobolus vestivus*	Poaceae
30	*Tephrosia pumila*	Papilionaceae
31	*Themeda triandra*	Poaceae

3.4.2 Grass cover, height and grazing intensity

The ANOVA showed that there were significant differences in total grass cover, grass height and grazing intensity between areas nearer the water holes and those away from water holes. The grass cover and grass height were significantly lower in areas nearer to the water hole (Fig. 8) than areas away ($p=0.01$, $F=5.32$, $df=35$ and $p=0.05$, $F=3.42$, $df=35$ respectively). Grazing intensity was significantly higher nearer to the water holes than areas away from the water hole ($p=0.001$, $F=8.44$, $df=35$).

During the short rainy season, the ANOVA shows that, the total cover and grass height were significantly different between zones ($p= 0.002$, $F=7.95$, $df=35$ and $p=0.04$, $F=3.45$, $df=35$ respectively), being lower in zone 1 and higher in zone 3. The grazing intensity was not significantly different between zones ($p=0.1$, $F=2.43$, $df=35$).

The Least Significant Difference (LSD) test revealed that, during the dry season, the total cover for zone 1 was significantly different from that of zone 2 and zone 3. Grazing intensity was different between zone 1 and 3 and between 2 and 3. The grass height in zones 1 and 2 was the same while zone 1 and 3 was significantly different (Table 4).

Figure 8. Low grass cover and animal trails at 20 m from the water hole at site A.

Table 4. The Least Significant Difference (LSD) test for the three zones during the dry season

Dependent Variable	(I) ZONE	(J) ZONE	Mean Difference (I-J)	Std. Error	Sig.
COVER	1	2	-19.17*	8.020	.023
		3	-25.00*	8.020	.004
	2	1	19.17*	8.020	.023
		3	-5.83	8.020	.472
	3	1	25.00*	8.020	.004
		2	5.83	8.020	.472
GRAZING	1	2	7.92	8.591	.363
		3	33.75*	8.591	.000
	2	1	-7.92	8.591	.363
		3	25.83*	8.591	.005
	3	1	-33.75*	8.591	.000
		2	-25.83*	8.591	.005
HEIGHT	1	2	-7.00	5.548	.216
		3	-14.50*	5.548	.013
	2	1	7.00	5.548	.216
		3	-7.50	5.548	.186
	3	1	14.50*	5.548	.013
		2	7.50	5.548	.186

*. The mean difference is significant at p=0.05.

During the short rainy season, all variables (total cover, grass height and grazing intensity) differed significantly between zone 1 and zone 3. Total grass cover also differed between zones 1 and 2 (Table 5).

Table 5. Least Significant Difference (LSD) test for the three zones during the short rainy season

Dependent Variable	(I) ZONE	(J) ZONE	Mean Difference (I-J)	Std. Error	Sig.
COVER	1	2	-22.58*	6.957	.003
		3	-25.25*	6.957	.001
	2	1	22.58*	6.957	.003
		3	-2.67	6.957	.704
	3	1	25.25*	6.957	.001
		2	2.67	6.957	.704
GRAZING	1	2	5.67	10.446	.591
		3	22.17*	10.446	.041
	2	1	-5.67	10.446	.591
		3	16.50	10.446	.124
	3	1	-22.17*	10.446	.041
		2	-16.50	10.446	.124
HEIGHT	1	2	-6.42	5.794	.276
		3	-15.17*	5.794	.013
	2	1	6.42	5.794	.276
		3	-8.75	5.794	.141
	3	1	15.17*	5.794	.013
		2	8.75	5.794	.141

*. The mean difference is significant at $p<0.05$.

3.4.3 Plant species diversity and evenness

Plant species diversity and evenness were presented in table 6. Mean diversity shows that zone 1 was the least diverse in both seasons, and zone 2 was the most diverse (Table 7).

Table 6. Plant species diversity Index (H') and Evenness (E) for dry and short rainy seasons.

Plots	Dry season		Short rain season	
	H'	E	H'	E
1	1.38	0.77	1.47	0.76
2	0.82	0.74	0.92	0.66
3	1.18	0.85	1.20	0.87
4	1.42	0.88	1.35	0.84
5	0.00	0.00	0.00	0.00
6	0.66	0.95	0.67	0.97
7	0.52	0.47	0.55	0.50
8	0.33	0.47	0.45	0.65
9	1.17	0.60	1.23	0.63
10	1.38	0.86	1.37	0.85
11	0.66	0.95	0.67	0.97
12	1.04	0.95	1.02	0.92
13	1.87	0.85	1.83	0.83
14	1.51	0.84	1.49	0.83
15	0.98	0.61	1.07	0.66
16	1.74	0.79	1.90	0.83
17	1.24	0.69	1.33	0.75
18	1.12	0.81	1.06	0.66
19	1.51	0.84	1.58	0.81
20	1.54	0.79	1.59	0.82
21	1.57	0.76	1.56	0.75

22	1.20	0.67	1.19	0.66
23	1.38	0.77	1.66	0.76
24	1.49	0.93	1.56	0.87
25	1.32	0.82	1.30	0.81
26	1.67	0.93	1.61	0.90
27	1.28	0.71	1.26	0.70
28	1.57	0.87	1.56	0.87
29	1.56	0.68	1.56	0.68
30	1.81	0.87	1.83	0.88
31	1.44	0.74	1.42	0.73
32	1.21	0.75	1.19	0.74
33	1.52	0.78	1.45	0.75
34	0.74	0.46	0.70	0.43
35	1.64	0.79	1.65	0.79
36	1.26	0.78	1.54	0.79

Table 7. Mean diversity for plant species among the three zones for both dry and short rainy seasons

Seasons	Zones	Mean	Std. Error
Dry season	1	.880	.131
	2	1.429	.074
	3	1.418	.081
Short rainy season	1	.908	.129
	2	1.485	.078
	3	1.422	.083

The ANOVA showed that the species diversity in zone 1 was significantly different from that of zones 2 and 3 ($p<0.0001$, $F=10.00$, $df=35$ and $p=0.001$, respectively), whereas diversity in zone 2 was the same as that of zone 3 ($p>0.05$). The Least Significant Difference (LSD) test for diversity among zones is presented in Table 8.

Mean for species evenness (E) was lowest for zone 1 (Fig. 9), but on overall ANOVA showed the means of species evenness did not differ significantly among three zones for either the dry or short rainy seasons ($p> 0.05$).

Table 8. Least Significant Difference (LSD) for dry and short rainy seasons

Dependent Variable	(I) zone	(J) zone	Mean Difference (I-J)	SE	Sig.
Dry season diversity	1	2	-.5492*	.14040	.000
		3	-.5383*	.14040	.001
	2	1	.5492*	.14040	.000
		3	.0108	.14040	.939
	3	1	.5383*	.14040	.001
		2	-.0108	.14040	.939
Short rain season diversity	1	2	-.5767*	.14110	.000
		3	-.5142*	.14110	.001
	2	1	.5767*	.14110	.000
		3	.0625	.14110	.661
	3	1	.5142*	.14110	.001
		2	-.0625	.14110	.661

*. The mean difference is significant at the p<0 .05 level.

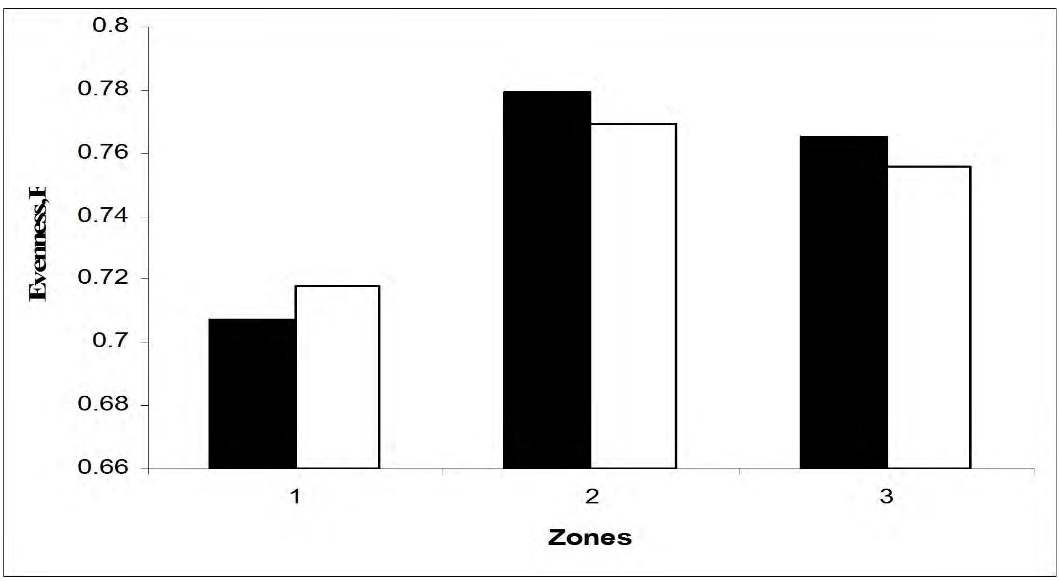

Figure 9. Species evenness (E) between zones, Closed bar = dry season; Open bar = short rain season.

3.5 Soil physical and chemical parameters

3.5.1 Physical parameters

(a) Soil bulk density

There was a decline in soil bulk density away from the water hole in the study area (Fig. 10). However, ANOVA showed that the decline was not significantly different ($p>0.05$) (Table 9).

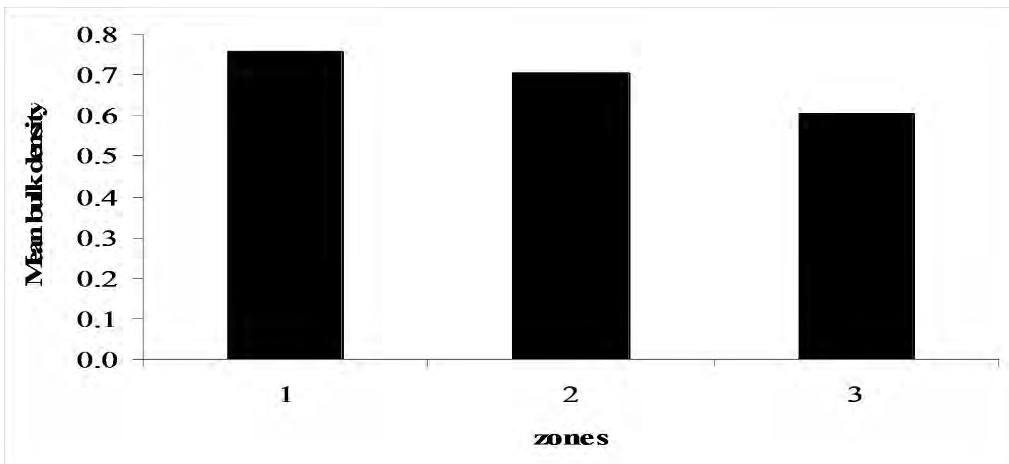

Figure 10. Trend of soil bulk density among zones 1, 2 and 3.

(b) Soil texture

The soil texture among zones is given in Figure 11. Among the soil texture types, only clay showed a significant difference. The percentage of clay was significantly higher in areas around the water hole; it decreased away from the water hole, i.e. towards zone 3. The percentage of silt and sand increased with distance from the water hole; however, the difference was not significant (Fig. 11; Table 9).

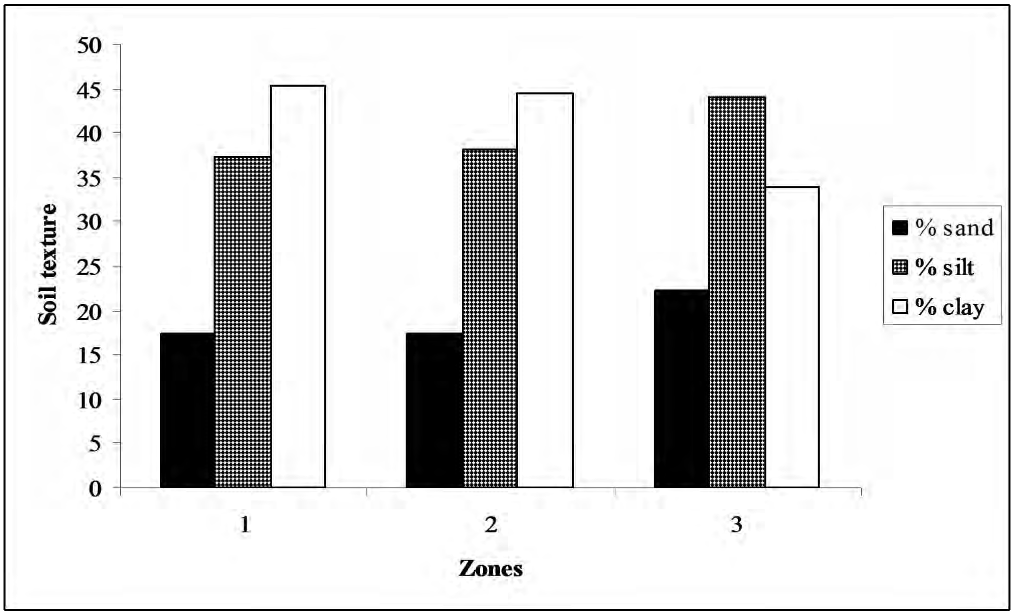

Figure 11. Trend of soil texture among zones 1, 2 and 3.

(c)Soil moisture content

The moisture content in the study area was higher in areas close to water holes (Fig. 12). However, the statistical comparison for percentage of moisture content showed no significant difference among three zones ($p>0.05$; Table 9).

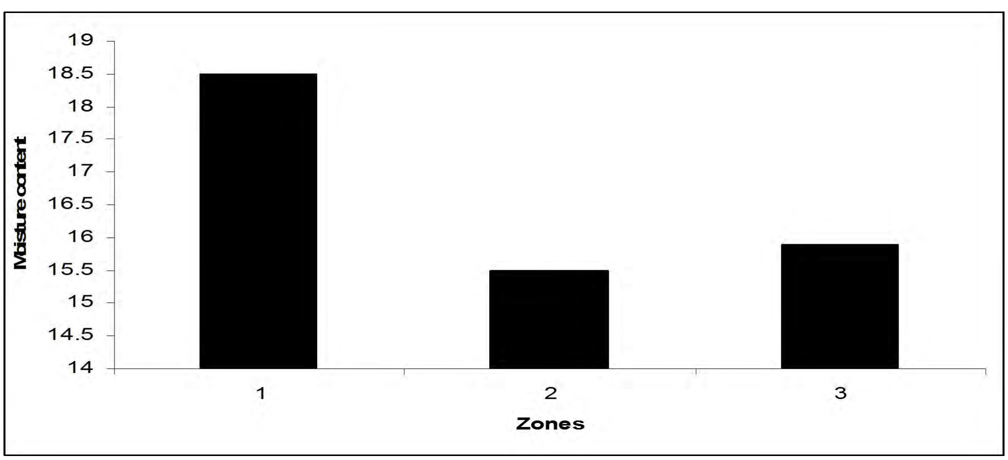

Figure 12. Trend of moisture content among zones

Table 9. Analysis of Variance (ANOVA) for soil physical parameters.

Variables	Sum of Squares	df	F	Sig.
Bd	2.26	35	1.13	0.33
Sand	2033.77	35	1.66	0.21
Silt	3017.39	35	1.92	0.16
Clay	4338.54	35	4.85	0.01
M/C	1290.526	35	0.829	0.44

Bd= Bulk density**, M/C**= Moisture content

The Least Significant Difference (LSD) test showed that the percentage of clay in zone 1 was significantly lower than that of zone 3 (p=0.009), and in zone 2 was significantly lower than in zone 3 (p=0.014).

(c) Soil erosion and trampling effects

Most of the areas near water holes (< 20 m) were observed to be almost bare with animal dung and droppings found spread all over the area (Fig. 7). Trampling by animals was also observed in areas near the water holes that resulted in formation of some cliffs along the rivers (Fig. 13). The most upper soil of the areas around the water hole was eroded (Fig. 14).

Figure 13. Cliff along the animal path towards waterhole at site C.

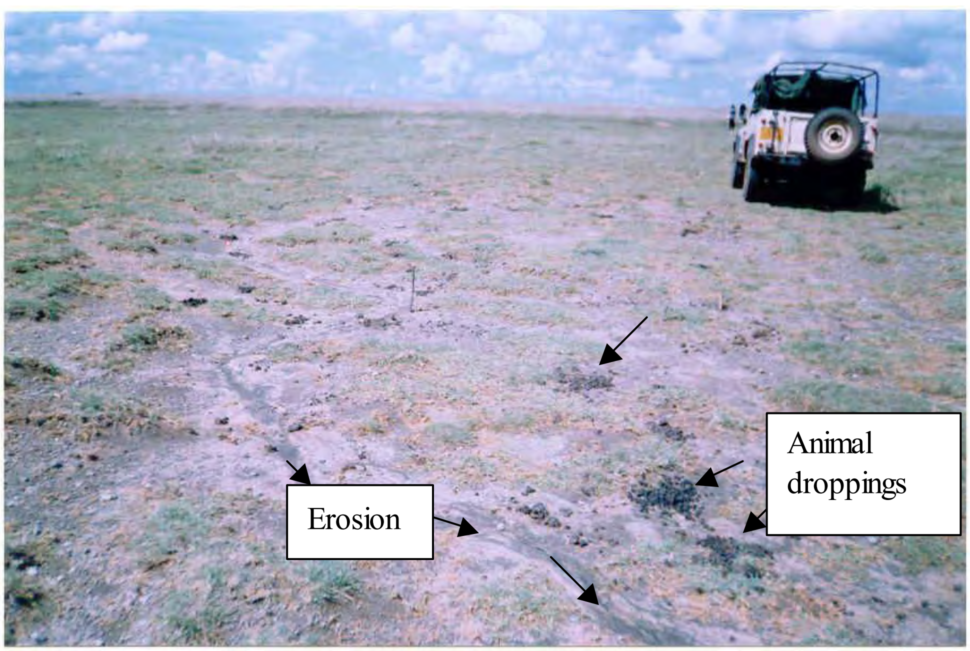

Figure 14. Soil erosion in areas close to the water hole at site B.

3.5.2 Chemical parameters

The mean for organic matter content, potassium (K) and total nitrogen (TN) increased as the distance from the water hole increased whereas, pH, electro conductivity (EC) and ammonium nitrogen (NH_4-N) decreased as distance from the water hole increased. PO_4^- did not show any change with distance (Table 10).

The analysis of variance (ANOVA) showed that all variables were significantly different between zones except phosphorus (Table 11).

Table 10. Soil chemical properties in the different zones in the study area.

Variables	Zone	Mean	Sd
OM	1	4.82	2.81
	2	6.06	2.33
	3	7.55	1.98
K	1	5.05	2.92
	2	12.80	4.73
	3	16.60	1.59
pH	1	9.28	.90
	2	8.25	1.13
	3	7.25	.29
EC	1	1318.33	1299.26
	2	745.83	1393.52
	3	45.83	21.51
TN	1	.29	.07
	2	.46	.10
	3	.52	.04
NH_4	1	.88	.64
	2	.26	.15
	3	.17	.09
PO_4	1	.83	.24
	2	.68	.23
	3	.75	.37

Table 11. Analysis of Variance (ANOVA) for soil chemical characteristics.

Variables	Sum of square	F	Sig.
OM	235.135	3.89	.030
K	1199.86	37.34	.000
pH	48.80	17.05	.000
EC	49683200	4.02	.027
TN	.54	26.91	.000
NH_4	8.58	12.05	.000
PO_4	2.94	.88	.424

The differences between zones for all variables were summarized in Table 12. Most differences were between zone 1 and 3.

Table 12. Least Significant Difference test for soil chemical characteristics

Dependent Variable	(I) ZONE	(J) ZONE	Mean Difference (I-J)	Std. Error	Sig.
OM	1	2	-1.2417	.98014	.214
		3	-2.7325*	.98014	.009
	2	1	1.2417	.98014	.214
		3	-1.4908	.98014	.138
	3	1	2.7325*	.98014	.009
		2	1.4908	.98014	.138
K	1	2	-7.7525*	1.36266	.000
		3	-11.5542*	1.36266	.000
	2	1	7.7525*	1.36266	.000
		3	-3.8017*	1.36266	.009
	3	1	11.5542*	1.36266	.000
		2	3.8017*	1.36266	.009
PH	1	2	1.0333*	.34813	.006
		3	2.0333*	.34813	.000
	2	1	-1.0333*	.34813	.006
		3	1.0000*	.34813	.007
	3	1	-2.0333*	.34813	.000
		2	-1.0000*	.34813	.007
EC	1	2	572.5000	449.10208	.211
		3	1272.5000*	449.10208	.008
	2	1	-572.5000	449.10208	.211
		3	700.0000	449.10208	.129
	3	1	-1272.5000*	449.10208	.008
		2	-700.0000	449.10208	.129
TN	1	2	-.1642*	.03229	.000
		3	-.2300*	.03229	.000
	2	1	.1642*	.03229	.000
		3	-.0658*	.03229	.050
	3	1	.2300*	.03229	.000
		2	.0658*	.03229	.050
NH4	1	2	.6258*	.15824	.000
		3	.7117*	.15824	.000
	2	1	-.6258*	.15824	.000
		3	.0858	.15824	.591
	3	1	-.7117*	.15824	.000
		2	-.0858	.15824	.591

*. The mean difference is significant at p=0.05 level.

4. DISCUSSION

Serengeti is famous for its annual migration of vast herds of herbivores (wildebeest, gazelles and zebras). They constitute the largest component of grazing ungulates in the Serengeti plains. The present study was conducted during the period from September to December 2004 while the migratory species were in Masai Mara Game Reserve. Therefore, only resident species of grazing ungulates were encountered in the Serengeti plains during the present study; except at the end of December when some of the migrants had started to go back to the plains. Ten species of grazing ungulates were recorded during the study period. There were also other nine additional species recorded besides grazing ungulates. Among these, 60% were carnivores. Lions were found wandering near water holes. Hyena and jackals were also found in the vicinity of gazelles, mostly in burnt areas where Thomson's gazelle was more abundant.

In the present study, animal distribution pattern and abundance were observed to change with distance from the water hole. During the dry season, the number of species of grazing ungulates was higher in areas around the water holes and less in areas away from the water holes. The results suggest that water holes were the spheres of attraction although the strength of the attraction varies among species. It was suggested that herds of water-independent species should be distributed randomly with respect to distance to water, whereas herds of water-dependent species should occur close to water sources (Jessica *et al.,* 2003). During the present study, reedbuck (*Redunca redunca*) was not observed beyond 800 m from the water hole. This suggests that it is among the water- dependent species as stated by Jessica *et al.* (2003).

Animals were found to be more abundant in zone 1 (areas close to the water hole). This proves the hypothesis that there is high abundance of grazing ungulates around the water holes than areas away from water holes. The studies (Bernhard and Michael, 1965; Charley and Cowling, 1968; Dora and Balakrishnan, 1991; Senzota, 1997 and Traill, 2004) documented that during the dry season, animals congregate around water holes. However, on the overall, there was no significant difference in the abundance of animals between zones. It is suspected that burnt portions in some of the transects, attracted animals, thus obscuring the influence of water holes on the distribution of animals during the present study. This can be explained by the fact that the new flushes after burning has high nutrient content required by the small sized ones, thus attracting them to congregate in burnt areas as stated by Wilsey (1996). At the same time, in burnt areas, the grasses were short and hence animals, especially small sized ones prefer those areas because of easy visibility to locate their predators (Wilsey, 1996).

Thomson's gazelles were more in areas away (zone 2) from the water hole compared to areas near water hole during the dry season, contrary to the expectation. This is due to the fact that they were mostly attracted by the new flushes after burning. This observation is in line with Wilsey (1996), who noted that small-sized ungulates show a stronger preference for post-fire flushes because they require foods with higher digestibility and nutrient content. Therefore, it can be concluded that their distribution is mainly influenced by the availability of quality food irrespective of the distance from the water hole. The study on herbivore distribution constraints by Jessica *et al*. (2003) suggested that, the smaller species opt for the quality rather than the quantity of food.

In addition to the higher level of protein content, post-burn flushes are also higher in water content, thus providing some metabolic and other free water to the animals. For the un-burnt transects, places closer to the water holes (zone 1) had significantly higher abundance of animals, suggesting that areas where post-burns flushes were absent, water holes had a major role in attracting herbivores.

It was also observed that smaller-sized ungulates, particularly Thomson's gazelle, concentrated in areas with short grass and in areas that were burnt. The smaller ungulate species are vulnerable to a greater range of predators more often when they are in areas of tall grasses compared to when they are in areas of short grasses. As pointed out by Wilsey (1996), they also require food items with high digestibility and nutrient contents that are more available in short burnt grassy areas.

An even distribution of animals in zone 2 also suggests that the animal species were not confined in one area such as close to water hole. Further, the present results showed that during the days when it rained, zones did not differ significantly in the abundance of animals, suggesting that, when it rained, animals could obtain water even in areas away from the water holes (Fig. 15). This agrees with the findings of Senzota (1997) in Mikumi National Park, that grazing ungulates were not dependent on the water hole during the rainy season, when they utilize the areas away from water holes that had small pot holes which harboured water for a few days (Fig. 15).

Animal droppings were assumed to be a measure of presence or absence of certain species in a particular area or habitat. Therefore, droppings can be used in estimating population abundance in an area (Riney, 1982). During the present study, the faecal density provided supportive data to the direct counting of animals. Faecal density was high in areas close to water holes during the dry season indicating that the grazing ungulates were more concentrated and grazed more in areas around water holes (Fig. 7). The findings are consistent with that of Andrew and Lange (1986), who documented that accumulation of dung and urine of grazing animals were higher in areas close to the water holes and less as distance from the water hole increased.

Figure 15. Surface water in small pot holes away from the water hole at site A.

In general, animal density was low during the study period due to the fact that most of the grazing ungulates of Serengeti were in the Masai Mara in Kenya (Sinclair, 1995). The study by Gereta (2004) showed that during the peak of the dry season (August to October), the densities of grazing ungulates, particularly the migratory species in the Serengeti plains were lower compared to that of other months of the year.

Species richness and evenness are combined in the diversity index. The higher the values of evenness or sometimes-called J (Equitability), the more even the species are in their distribution and more diverse are within the area (Kent and Coker, 1992). In the present study, the areas close to water holes (zone 1) were found to have low diversity of plant species. The intermediate areas, zone 2 were found to be more diverse than areas near the water hole (zone 1) and areas away from water holes. This can be explained by the extent of disturbances exerted in these areas. Highly disturbed areas and completely undisturbed areas tend to have low species diversity compared to moderately disturbed area. Humphrey and Patterson (2000) in their study in Upland conifer forest, revealed that, the species richness declined in ungrazed plots and remained unchanged in grazing plots for ten years. On the other hand, Crawley (1997) stated that moderate level of disturbance prevents dominance of one or few species in a particular habitat. The least disturbed (grazed) area farthest from water hole during the dry season has high species richness (Jill *et al.,* 1997). However, in my study area, zone 2 had more diversity of species probably due to moderate level of grazing disturbance.

The present study has revealed that areas around water holes were highly overgrazed and this high grazing intensity by grazing ungulates contributes to the high trampling effect. As a result, most of such areas were left bare. These observations also agree with the findings of Ntalwila (2001) on the study of the pattern of plant species diversity around Lake Manyara in Northern Tanzania, and that of Senzota (1997) in Mikumi National Park, Tanzania. The high grazing effect around the water holes is associated with high number of animals (grazers) that frequently visit the area for drinking purposes (Senzota, 1997).

The highly overgrazed and highly trampled areas around water holes, probably contributes to low diversity of plants. The areas around zone 2 were only moderately grazed hence more diverse. It has been argued that the ground cover diminishes and species richness decreases as a consequence of increasing grazing pressure (Zerihun Woldu, 1985).

Not only that, but also salt tolerance by plant species is probably another factor contributing to the low diversity in areas close to water holes. In the present study, the soil in areas close to water holes was found to be affected by salt, the probable reason could be because of lack of exchangeable bases such as potassium in those areas. Thus, only salt tolerant species were favoured (Wit, 1977), which further affects the herb species diversity in the area. During the present study, the dominant species of grass found in areas around water holes were *Sporobolus spicatus, Sporobolus ioclados and Cynodon dactylon.* These were the species those are either salt tolerant or those that have higher ability to withstand grazing pressure. It was documented that in the salt affected soil e.g. along the Seronera River, Mbalageti River, Magungu River and the Olduvai Gorge, short grasses form the main component of the vegetation. *Sporobolus homblei, Sporobolus spicatus* and *Odyssea jaegeri were* the characteristic species. *S. spicatus* and *O. jaegeri* dominate at the salt encrusted spots (Wit, 1977). As a result, the plant species diversity in areas close to water holes becomes low compared to the areas away from the water holes.

Further, the grazing intensity contributes to the low grass cover and height in areas around water hole. In this study, it was observed that the total cover and grass height were low at quadrats located around the water holes and animal trails dominate the area closer to water holes forming network of paths (Fig. 14). The grass cover was high in areas away from the water holes for all transects except in burnt transects. The low grass height in areas closer to water holes could be a result of constant clipping effect that affects the plant growth (Moore *et al.,* 2003).

Most of the soils were clay near the water holes and silt clay in areas away from water holes. The percentage of clay in some plots was above 70 indicating clay accumulation horizons. However, in most areas away from water holes, the silt fractions tended to dominate over other fractions. The presence of high percentage of silt in those plots indicates the possibilities of alluviation (Brady and Weil, 1999). Accumulation of clay on surface soil and lower coarser fractions (sand) in areas closer to the water hole can be explained by the fact that soil is constantly eroded leaving the subsurface horizons in which the accumulation of material by illuviation has taken place (Brady and Weil, 1999).

In this study, though not to the extent that restrict the root penetration (Arshad *et al..,* 1996), the soil bulk density was higher in areas around the water holes and tended to be lower in areas away from water holes. In principle, the soil bulk density is higher when the soil is dominated by coarser texture (sand) and it is lower when fine particles dominate (clay) because the fine-textured soils are normally organized. This condition assures high total pore space and low bulk density (Brady and Weil, 1999).

According to Brady and Weil (1999), the solid particles of the fine textured soil tend to be organized in porous granular, especially if adequate organic matter is present, favouring low bulk density. However, the higher bulk density around the water hole, where fine particles dominate, suggests soil compaction, probably brought about by animal trampling, or due to low soil organic matter caused by erosion as an impact of animal trampling.

The soils exhibited two features in relation to soil organic matter content. First, the soils around or near the water holes (zone 1) had low organic matter and are classified as mineral soil, i.e. 0.1% - 2% (Allen, 1989). The second feature is that when moving away from the water hole (in zones 2 and 3), the soil organic matter tends to be higher and are classified as organic soil (2 - 30%) (Allen, 1989). Possible explanations for these two different features accruing on the same site is that lower organic matter around the water hole resulted from loss of surface A-horizons, primarily caused by erosion during the rainy season. The erosion of top-soil (A-horizon) around the water hole is enhanced by animal trampling that may have occurred during the dry season. The soil clay content indicates that erosion is high and has exposed the deeper sub-soil.

The high percentage of organic matter found in locations away from the water hole is attributed to the nature of vegetation and surface litter accumulation. It is well documented that high percentage of organic matter on subsoil is caused by grass roots, which in combination with both grass and trees accounts for tremendous increase in soil organic matter (Allen, 1989; Brady and Weil, 1999). The high organic matter content improves soil texture and water holding capacity in zone 3 by increasing pore space in the A- horizon (Brady and Weil, 1999). As plant roots are concentrated in this layer of soil, the presence of organic matter has an impact on productivity in that zone. The distribution and nature of vegetation in the study area seems to influence the soil organic matter. Any activity which leads to the decline of vegetation, eventually lead to lower soil organic matter (Allen, 1989). The frequency and the total number of animals visiting the areas around water holes have resulted in depletion of vegetation, resulting in deficiency of soil organic matter components.

Even though there is accumulation of animal dung in areas near water holes (Fig. 7), which would enhance availability of organic manure (Andrew and Lange, 1986); the present study revealed sparce distribution of organic matter in areas close to water hole. This may be due to the high rate of erosion in bare areas around the water holes.

Soil total Nitrogen tended to increase with increase in distance from the water hole (Table 10). Total nitrogen was highly correlated to percentage of organic matter. One can expect to have higher percentage of total nitrogen in areas close to water holes because of addition through animal urine as ammonium, but in the present study the result was contrary to that. This descrepancy could possibly be due to the influence of low organic matter in those areas close to the water hole and not inorganic ammonium. The ammonium compound in areas close to the water holes might be removed through natural process of denitrification and evaporation. The soils of the area close to water hole (zone 1) was found to be light in colour that is poor in regulating soil temperature (Brady and Weil, 1999), and therefore, the evaporation process in such areas may be fast.

In this study, Electro-conductivity (EC) was found to be very high in areas near the water hole than in areas away from the water hole. The high EC in such areas may have resulted from erosion that exposes the lower horizon (probably B-horizon), where there is always accumulation of salt (Brady and Weil, 1999).

The high pH suggests that the soil was saline and it has resulted from salt accumulation (Wit, 1977) and loss of organic matter near the water hole.

The results suggest that the exchangeable K^+ was lower near the water hole compared to areas away from the water hole. It has been demonstrated that organic matters are reservoirs of K^+ minerals (Brady and Weil, 1999). Hence, the lack of organic matter led to low K^+ in areas near water holes.

Clay, silt and sand (primary particles) generally do not occur as discrete particles, but are frequently combined together to form secondary particles known as aggregates. The soil aggregates stability is influenced by several factors; including the amount of organic matter, wetting and drying, biological activity and electrolytes affecting colloidal dispersion. Soils near the water holes were generally low in soil organic matter content compared to soils in areas away from the water hole. It was observed that water stability aggregates are improved or influenced by organic matter content. The aggregates of soil with high levels of organic matter are more stable than those with low levels of organic matter (Brady and Weil, 1999). Almost all soils collected from zone 1 were granular without consistence; whereas those soils collected from zone 3 were sub-angular block structures. Again the soil structures are favoured by high percentage of organic matter and low electrolytes (Allen, 1989).

The highest values of ammonium were found in areas near the water holes and the lowest values in areas away from the water holes. The possible reason is the ability of the sub-soil to fix ammonium ion. According to the following equation ammonium tends to be in equilibrium with Ammonia gas:

$NH_4 + OH \leftrightarrow H_2O + NH_3\uparrow$ (Brady and Weil, 1999).

As mentioned earlier, one of the sources of ammonia gas is animal manure. From the reaction above we can draw three conclusions: (i) ammonia volatilisation will be pronounced at high pH level (i.e. OH ions drive the reaction to the right), (ii) ammonia gas-producing amendments will drive the reaction to the left raising the pH of the solution in which they are dissolved and (iii) as most soil dries, water is removed from the right–hand side of the equation, again driving the equation to the right.

However, other soil conditions suggest that the values obtained might have been underestimated because most of the ammonia added is lost through volatilization. The soil characteristics which supports this idea, are the high pH, alkaline soil and calcareous soil. High temperatures favour the volatilization of ammonia (Brady and Weil, 1999).

Available phosphorus (PO_4^-) mean values showed no much variation among the three zones. Animal manures and other decomposable organic wastes might have increased the available phosphorus, but this was not the case, may be because of the soluble phosphorus added to soil quickly fixed into insoluble forms that become unavailable to growing plants (Allen 1989; Brady and Weil, 1999). According to Brady and Weil (1999), the greatest degree of phosphorus fixation occurs at the extremes of pH range (i.e. in very low pH and very high soil pH) and in soils with higher clay release contents. But in this study the available phosphorus (PO_4^-) was higher in a higher pH i.e. pH of 10 compared to optimum pH of 6 – 7 and higher in clay dominated soil as well. This can however be explained by fire practice. These plots showing uniqueness were burnt before sampling so that all phosphorus in litter and standing vegetation were ashed.

5. CONCLUSION AND RECOMMENDATIONS

Animals form a major resource for management in protected area management system. As the main objective of protected area management is managing the wildlife populations, it becomes important to know how the animal populations are distributed in landscapes in relation to water holes. The animal species composition and abundance observed during this study matched with similar studies in the Serengeti plains. The species recorded in this study represented almost all the major grazing ungulates in the Serengeti plains, and suffice to give a rough ideas/picture on their impact around water holes and away from the water holes.

The abundance of grazing ungulates was high in areas close to the water holes than in areas away from water holes. This study also revealed that to some extent the distribution and abundance of grazing ungulates was influenced by fire. The transects which were burnt had high abundance of grazing ungulates in areas away from the water holes. Unexpected rainfall during the dry season brought an effect on the distribution and abundance of grazing ungulates also. There was no difference in the abundance of grazing ungulates between areas near to water holes and away from the water hole during the rainy days. Since reedbucks' distribution was restricted to areas near water holes, monitoring of its population calls for concern.

Low grass cover and grass height, high grazing intensity and low species diversity revealed the negative impact of grazers on vegetation in areas around the water holes in both dry and short rainy seasons. Although it was argued that habitat degradation around the water holes is time specific (Ayeni, 1975), in this study, it was difficult to give a clear conclusion on seasonal difference in respect to impacts of grazing ungulates in the Serengeti plains. Hence, further study is recommended which can go round the year to accommodate both the dry season and the wet seasons.

The three zones showed a significant difference in plant species diversity. The areas around the water holes were devoid of grass cover and highly affected by erosion. High species diversity in areas away from water holes could be attributed to low disturbance and availability of essential requirements such as organic matter and other soil nutrients that are lacking in the areas around the water holes. The study on the rate and intensity of the disappearance of plant species around the water holes is recommended.

Water source is an important asset in arid ecosystems. Animals move large distances in search of water in the dry season and are forced to move to the regions with open water resources. It is, therefore, important for management to have a clear picture of water availability in Protected Areas (PAs), so that animals can be discouraged from moving outside the boundary of the PAs, where they become prone to poaching and other threats. This study revealed that the animal species abundance and diversity was low suggesting they might have moved to other areas such as Western Serengeti due to the availability of water. Therefore, water resource management should form a priority management programme in the Serengeti plains and any other PAs in arid habitats.

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8. APPENDICES

Appendix 1. Raw data for soil parameters recorded in the Serengeti plains.

Variables	OM (%)	BD(g/cm3)	% sand	% silt	%clay	K meq/100g	pH	EC	Total N	NH4-N meq/100g	PO4 meq/100g
zone 1	2.1	0.63	4.5	18.06	77.44	3.14	10.1	3500	0.26	1.2	0.87
	6.49	0.34	9.4	35.8	55.12	4.22	8.9	2400	0.31	1.1	0.92
	0.499	1.05	14.28	32.1	53.62	2.214	10	2400	0.25	0.42	0.88
	2.497	0.94	16.62	40.52	43.06	3.14	10	3500	0.22	0.52	0.97
	1.99	0.95	24.28	39.02	36.7	3.14	8.2	210	0.26	1.2	1.26
	2.798	0.99	33.2	28	38.8	6.21	8.5	70	0.51	1.6	0.54
	8.495	0.86	32	30.4	37.6	4.26	9.8	530	0.24	2.4	0.81
	8.495	0.62	7.02	37.2	55.78	3.97	10	320	0.28	0.83	1.26
	6.49	0.59	22.2	42	35.8	10.6	9.1	430	0.35	0.53	0.62
	7.496	0.82	11.9	57.58	30.52	5.12	10	1260	0.27	0.21	0.66
	3.992	0.80	12.56	52.5	34.94	3.4	9.5	1090	0.26	0.32	0.62
	6.49	0.50	20.82	35	44.18	11.17	7.3	110	0.35	0.34	0.64

zone 2	6.49	0.60	8.5	47.44	44.06	10.8	8	660	0.51	0.4	0.87
	6.49	0.65	7.64	43.48	48.88	17.26	9.8	410	0.52	0.4	0.32
	2.497	1.44	28.1	25.06	46.84	3.1	10.3	3600	0.21	0.46	1.21
	2.497	1.31	17.07	39.36	43.62	4.56	10	3800	0.56	0.11	0.56
	2.798	0.85	14.94	24.2	60.86	15.16	7.9	40	0.53	0.1	0.53
	5.998	0.64	25.6	42	32.4	15.55	7.2	90	0.52	0.12	0.56
	8.495	0.72	24	45.6	30.4	11.12	8.2	70	0.37	0.52	0.62
	8.999	0.55	10	48.52	41.48	16.31	7.9	90	0.52	0.31	0.67
	6.49	0.41	15.8	46	38.2	12.1	7.9	40	0.34	0.24	0.83
	8.999	0.52	21.2	32.8	46	15.25	7.4	50	0.45	0.22	0.61
	6.49	0.38	15.3	22.44	62.26	15.14	7.2	70	0.48	0.17	0.51
	6.49	0.38	19.14	40.92	39.94	17.26	7.2	30	0.52	0.11	0.87
zone 3	3.44	0.73	14.26	40.92	44.82	17.55	7.3	40	0.53	0.3	0.46
	6.49	0.51	17.94	52.7	29.36	17.97	7.1	30	0.55	0.4	0.31
	6.49	0.79	21.78	37.6	40.62	12.17	7.1	70	0.54	0.1	0.54

6.596	0.48	16.34	54.22	29.44	15.63	7.1	30	0.51	0.12	0.54
6.49	0.74	25.8	49.2	25	16.34	7.2	20	0.51	0.11	0.82
7.496	0.26	30.42	40	29.58	15.97	6.9	40	0.55	0.11	0.84
8.395	0.57	26.84	46.2	26.96	16.51	7.9	30	0.54	0.22	0.63
8.395	0.64	23.2	40.8	36	16.92	7	50	0.53	0.11	0.84
8.99	0.54	18.2	44	37.8	17.11	7.4	40	0.46	0.24	0.59
9.27	0.64	25.6	34.2	40.2	17.61	7.2	50	0.44	0.22	0.6
11.474	0.51	13.56	50.94	35.5	17.51	7.7	100	0.55	0.11	1.16
7.096	0.84	31.94	37.06	31	17.94	7.1	50	0.61	0.09	1.72

Appendix 2. Data sheet for animal counting

Date:…………… Site:………………… Transect:…………… Weather…………

Habitat……….. Time: Start……………. End………………..

	Species	No.	Sex			Age			Dist. From the water	Dist. From the transect	Other Information
			M	F	Unk.	Adu.	Juv.	Calf			
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
n											

Appendix 3. Data sheet for vegetation sampling

Date:…………… Site:………………… Transect:…………… Weather…………

Habitat………… Time: Start……………. End……………

Name of the participants: 1)…………….. 2)…………………

Plot	Species	Cover (%)	Grass height (cm)	Grazing intensity (%)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
n				

Appendix 4. Data sheet for dung counting

Plot	No. of dung boli	Species	Fresh dung	Recent dung	Old dung

1					
2					
3					
4					
5					
6					
7					
8					
n					

DECLARATION

I, Martina B. Hagwet, declare that this is my original work and has not been presented for a degree in any other university and that all sources of materials used for the thesis have been acknowledged.

_________________________	_________________	_____________
Name	Signature	Date