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Full Length Research Paper

Determination of climate parameters effect on soil carbon fluxes along the north-south moisture gradient in the kalahari ecosystem

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Abstract

Temperature and rainfall patterns have globally, regionally and locally changed. At global and regional level, temperature and rainfall are dominant factors affecting soil organic storage and that carbondioxide emissions increases with increasing rainfall and decreasing temperature. The objective of this study was to determine "in situ" the effects of temperature and rainfall on soil carbon emissions in the Kalahari, south west of Botswana. Data on temperature and rainfall for a period of 35 years were collected for trend analysis. Six sites were selected across different land use zones in the area to measure soil CO_2 emissions. Results indicated a trend towards an increase in mean annual temperatures and for rainfall, the extreme southern part of the study area is becoming wetter and in the north a moderate trend towards a decrease was observed. CO_2 emissions were significantly ($p<0.05$) higher at watering sites and declining with distance in both the wet and dry seasons. Wet season emissions were significantly higher (64.50 µmol/m^2/s) than during the dry season (4.72µmol/m^2/s). Findings showed that the region is experiencing the impact of climate change and variability. Temperature and rainfall are the major factors affecting soil carbon emissions in the Kalahari ecosystem.

Keywords: CO_2 emissions, land use, Kalahari, temperature and rainfall.

1.0 INTRODUCTION

Impact of climate change on soils is a slow complex process as soils are not only strongly affected by climate change directly, but can also act as a source of greenhouse gases emissions and therefore contribute to the gases responsible for climate change (IPCC 2018; Karmakar et al., 2016).

Despite the increasing urgency of climate change and repeated warnings from international institutions that the world is in a path of catastrophic climate change (Dooley, 2014; Hassler and Krusell, 2012), the greenhouse gases concentrations are rising. The global temperature has increased and indications are that it will continue to increase, and by so doing, simultaneously changes in global and regional rainfall patterns should be expected (Song et al., 2012). Increase in the amount of greenhouse gases in the atmosphere has intensified the greenhouse effect and consequently led to global warming (Mphale et al., 2018; McMichael et al., 2012) and ultimately climate change and variability. According to Bisai et al. (2014), mean global surface air temperature has increased by 0.3 – 6.0^{0}C over the last century. The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) also indicates that global air temperature has continued to rise at a rate of 0.08 – 0.14^{0}C per decade since 1951 (IPCC, 2013). Karmakar et al. (2016) further mentions that for the past 100 years the global mean temperature has increased by more than 15^{0}C, which is widely assumed to have not only been due to natural drivers, but also due to anthropogenic

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factors (Stips, 2016).
At regional level, climate models employed to simulate the effects of continued current emission rate of greenhouse gases into the atmosphere have indicated that, Southern Africa region will be hotter and drier by the end of the century (Willis et al., 2013; Davis, 2011). Its mean surface air temperature is projected to be 3 – 4^{0}C warmer by the 2080s (Kenabatho et al., 2012; Davis, 2011). This phenomenon of continued build-up of these greenhouse gases in the atmosphere has been closely associated with rising global or regional temperature, reduced rainfall and increased climate variability in general (Byakatonda etal., 2018). According to Kumar et al. (2014) the EL NINO Southern Oscillation (ENSO) occurrence is regarded as the primary cause for interannual climatic variability around the globe and to influence Southern Africa's climate (Edossa et al., 2014; Nicholson et al., 2001). Thus, the sea-surface temperature fluctuations in the Indian and South Atlantic Oceans influence climate change in Botswana especially the south western region (Adedoyin and Mphale, 2014). Data from four synoptic stations in Botswana used to predict temperature and rainfall trends in the country indicated that there is a trend towards an increase in maximum temperature and a tendency towards a decline in total annual rainfall (Adedoyin and Mphale, 2014).
Soil is the largest terrestrial organic carbon pool and stores two-thirds of the total terrestrial organic carbon (Zhao et al., 2017). The soil also contains three times as much carbon as the vegetation organic pool and twice as much as the atmosphere (Scharlemann et al., 2014; Batjes, 1996). As elaborated by Ciais et al. (2014) and Lal, (2004), small changes in the soil organic carbon pool will have a significant impact on the global carbon balance, which in turn has a bearing on global and regional climate change. Hence soils are intricately linked to the atmosphere-climate system through the carbon, nitrogen and hydrologic cycles (Brevik, 2012). Environmental factors controlling soil organic carbon differ according to the magnitude or intensity (Hobley et al., 2015; Longbottom et al., 2014). Follett et al. (2012) and Jobbagy and Jackson (2000) explained that at global and regional level, temperature and rainfall are dominant factors affecting soil organic storage and that the soil organic carbon increases with increasing rainfall and decreasing temperature. Furthermore (Davidson and Janssens, 2006) enlightened that the production of CO_2 in soils is almost entirely from root respiration and microbial decomposition of organic matter. Like all chemical and biochemical reactions, these processes are temperature-dependent and to some degree on precipitation (Kotroczo et al., 2014). In arid and semi-arid ecosystems soil moisture is expected to be the primary control on the exchanges of water and carbon between the land surface and atmosphere (Kurc and Small, 2007).
The Southwestern Kalahari region of Botswana known as the Kgalagadi district is considered to be environmentally fragile, highly susceptible to land degradation, drought and climate change and variability. Therefore, the objective of this study was to determine the effects of temperature and rainfall on soil carbon dioxide emissions across different land use zones along a north – south transect in Kgalagadi District. Although several studies (Dintwe et al., 2014; Thomas et al., 2011; Thomas and Hoon, 2010; Thomas et al., 2008) on CO_2 emissions in the Kalahari ecosystem have been conducted, the data or information on the link between CO_2 emissions and meteorological parameters (temperature and rainfall) remains inadequate.

2.0 MATERIALS AND METHODS

2.1 The Study Area

The study area was conducted in the Kgalagadi District of Botswana (Figure 1). The district falls on the south western part of the Kalahari ecosystem. It is a semi-arid to arid area when one transect from north to south. The rainfall is low and highly variable (coefficient of variability 43% and 48% for the northern and southern part of the study area respectively) both spatially and temporally. Annual average rainfall ranges from 350mm in the extreme north to 150mm in the extreme south (Byakotonda et al. 2018; Biotrack Botswana, 2016;Joss et al., 1986;). Ambient temperatures fluctuate widely on a daily and seasonal basis, with the mean maximum and minimum temperatures being 37.4^{0}C and 19^{0}C in summer and 22.2^{0}C and 1.2^{0}C in winter (Horn, 2008). The area is covered by deep to very deep Aeolian sands that are generally poor in terms of soil fertility for crop production.

2.2 Study Design and Data Collection

An exploratory study design, where they were no manipulation of the environmental conditions was adopted. Primary and secondary data on meteorological parameters (rainfall and temperature) were collected from the field and Department of Meteorological Services. Six sites were purposively selected considering accessibility and area representation. Two sites were located at livestock watering sites (boreholes), one in Kgalagadi North (KGN) and the other in Kgalagadi South (KGS); three sites were located in wildlife management areas (WMAs) and one in a conservation area (National Park - KTP). In this study the conservation area was treated as a control (Figure 2).
Monthly average data on temperature and rainfall trends for a period of 35 years (1980 to 2015) in the Kgalagadi district were collected from the Department of Meteorological Services. The data are from records at two synoptic weather stations located at Tshane and Tsabong villages in KGN and KGS south respectively. Some data on temperature and rainfall were also obtained from Ngwatle settlement located approximately 60km north of Tshane synoptic weather station. The weather station started operating from February 2014.

2.3 Soil CO_2 Emission Measurements

Three piosphere transects were established at each watering point located in communal grazing land zone. The direction of transects followed the most preferred livestock movements routes to and from the watering point. Along the transects, CO_2 emissions were measured within radii of 10m, 30m, 50m, 100m, 500m, and 1000m (referred to as a, b, c, d, e, and f respectively) from the watering point. Shorter sampling intervals closer to the water sources were adopted because as indicated by Totolo and Mosweu (2012) and Perkins and Thomas (1993) rapid changes in soil characteristics occur close to the watering site and remain almost constant with distance**.** Therefore, 56 CO_2 emission measurement points were established (32 at watering points in communal grazing zones, 18 in WMAs and 6 in the control (KTP). In WMAs and control a spot was randomly selected and the transects were established from the picked spot to make measurements.

Closed survey dynamic single chamber equipment was used to measure soil carbon (CO_2) emissions. The LI-8100A automated soil CO_2 instrument with a 20cm diameter chamber was used (Figure 3). Soil collars were inserted into the soil 24hrs before CO_2 emission measurements were taken. The measurements were conducted with 10 replicates of 90 seconds at each soil collar. Between replicates, there was a 20 seconds interval for the chamber to open to allow the conditions inside the chamber to revert to ambient conditions. Two sets of soil CO_2 emission measurements were taken, one set in the dry season and the other in the wet season. Data were then transferred from the LI-8100A Analyser Control Unit using the LI-8100A 4.0.0 PC software to a personnel computer for further analysis.

The effect of diurnal temperature on CO_2 emissions was also determined by selecting two sites from both KGN and KGS; one within 10m radius of livestock watering site and the other in a grazing area beyond 2.5km from the watering site. CO_2 emissions were measured at different times during the day, that is, at 0800 to 0830hrs; 1030 to 1100hrs; 1400 to 1430hrs and 1800 to 1830hrs. The 30 minutes period was to give chance to move the equipment from the watering site to the site located in grazing area or vice versa.

2.4 Statistical Analysis

Statistical analysis was performed using the SPSS (version 20) statistical software and Microsoft Excell. Analysis of variance (ANOVA) and the student t-test were used at $p<0.005$ to determine the significance differences in the means of temperature, rainfall and CO_2 emissions across different land use zones and climatic seasons. Regression and correlation analysis were also performed to determine relationships between or amongst different variables.

3.0 RESULTS AND DISCUSSION

3.1 Analysis of Temperature and Rainfall Trends in Kgalagadi District: Implications on CO_2 Emissions

Figure 4 shows the mean monthly temperature trends over a period of 35 years (1980 - 2016) recorded at Tshane and Tsabong synoptic weather stations located in KGN and KGS respectively. In KGS the mean maximum temperature ranged from 22.1^{0}C to 34.8^{0}C and the mean minimum ranged from 1.1^{0}C to 19.7^{0}C and in KGN the mean maximum temperatures ranged from 22.7^{0}C to 33.7^{0}C and the mean minimum ranged from 4.0^{0}C to 20.0^{0}C.

The t-test statistical analysis results of the temperature data indicated that there was no significant difference (at 95% confidence level) between KGN and KGS. However, for the winter season (May to August) KGS was colder than KGN although the variation was not statistically different as illustrated in figure 4.

Figure 5 below demonstrate the trend in temperature over a period of 30 years (1980 to 2016) in the Kgalagadi district (south western Kalahari region). The figure indicates that the area is becoming less cold as the mean annual minimum temperatures are significantly ($p<0.05$) positively increasing. This phenomenon is supported by New et al (2006) results who demonstrated that in the interior region of Southern Africa; mean minimum temperatures are increasing at a faster rate than mean maximum temperature. In KGN (Tsh_Min) the mean minimum temperature had positively increased from 10.8^{0}C in 1980 to 13.7^{0}C in 2016 and for KGS (Tsb_Min) it had also positively increased from 12.2^{0}C to 14.4^{0}C during the period of 1980 to 2016. The trend shows a tendency towards warming of the south western Kalahari region as reported by Adedoyin and Mphale (2014), who also indicated that the region is experiencing a trend towards an increase in maximum temperatures contrary to observations made in this study (Figure 6) in which no significant change in mean maximum temperatures was noticed. However, Davis-Reddy and Vincent (2017) concluded that over the last century Southern Africa has been warming significantly at a rate of 0.4^{0}C per decade for the period 1961 to 2014.

The mean annual maximum temperatures for both KGN and KGS do not significantly indicate any increase or decrease in temperature trend. The mean maximum temperatures had remained almost consistent throughout the past three decades; the data does not indicate any tendency towards warming. However, from the latest recordings maximum temperatures of 39^{0}Cto 41^{0}C in the area have been recorded in summer (Davis-Reddy and Vincent, 2017) in months of December to January.

The 35 years (1980 to 2016) period mean annual rainfall data for Tshane and Tsabong synoptic weather stations and also from Bokspits weather station are graphically presented in figure 7a, 7b and 7c respectively. The data from the three stations shows that there are ten years circle periods were the Kgalagadi region receives normal to above normal rainfall. These circles are intercepted by periods of drought, unreliable and erratic below normal rainfall. A similar trend was observed by Byakatonda, et al., (2016) who further explained that from the 1970s Botswana in general has slowly been experiencing droughts roughly once in 5 years (20% of the time) in the recent past. Figure 7a and 7c designates a positive significant increase ($p < 0.05$) in annual rainfall in the southern part of the study area (KGS). Over the past three decades on average the rainfall increased from 270 to 310 mm

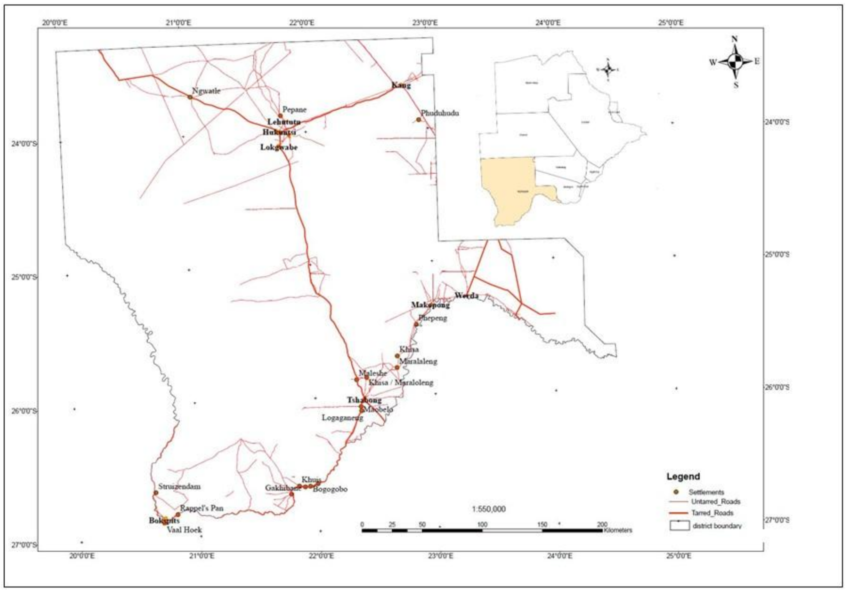


Figure 1: Location of the Study Area, Kgalagadi District, Southwest Botswana.

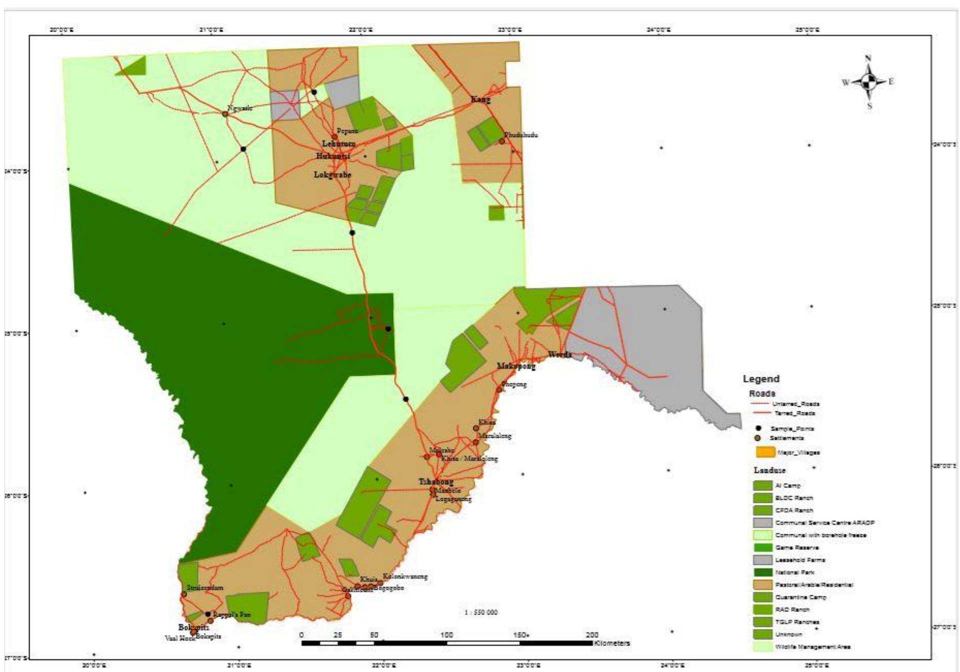


Figure 2: Location of Synoptic Weather Stations and Sampling Sites.

at Tsabong and 120 to 235 mm at Bokspits. In KGN represented by data from Tshane synoptic station (figure7b), the meteorological data shows a slightly declining rainfall pattern from an average annual rainfall of 320 mm to 310 mm over the past three decades. The results are similar to those reported by the European Commission (2015) through the Management and Policy Options for the Sustainable Development of Communal Rangelands and their Communities in Southern Africa (MAPOSDA) project conducted in the same area using data from the same synoptic station. Davis-Reddy and Vincent (2017) and Davis (2011) explained that rainfall patterns or

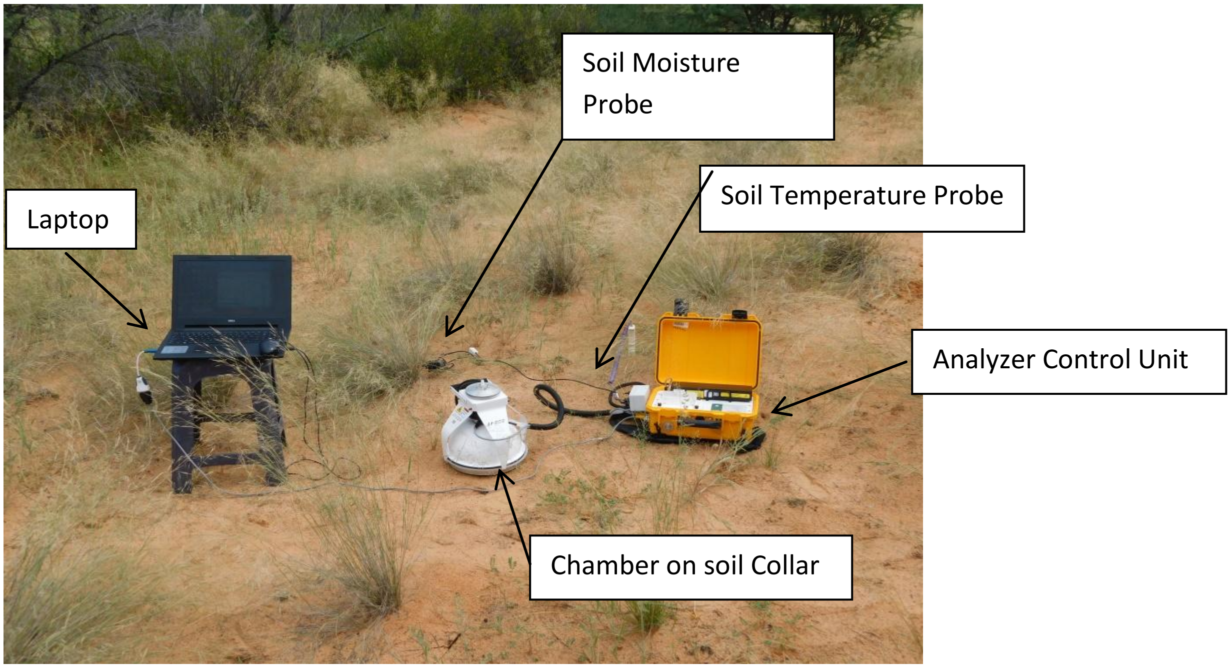


Figure 3: Taking CO_2 fluxes measurement.

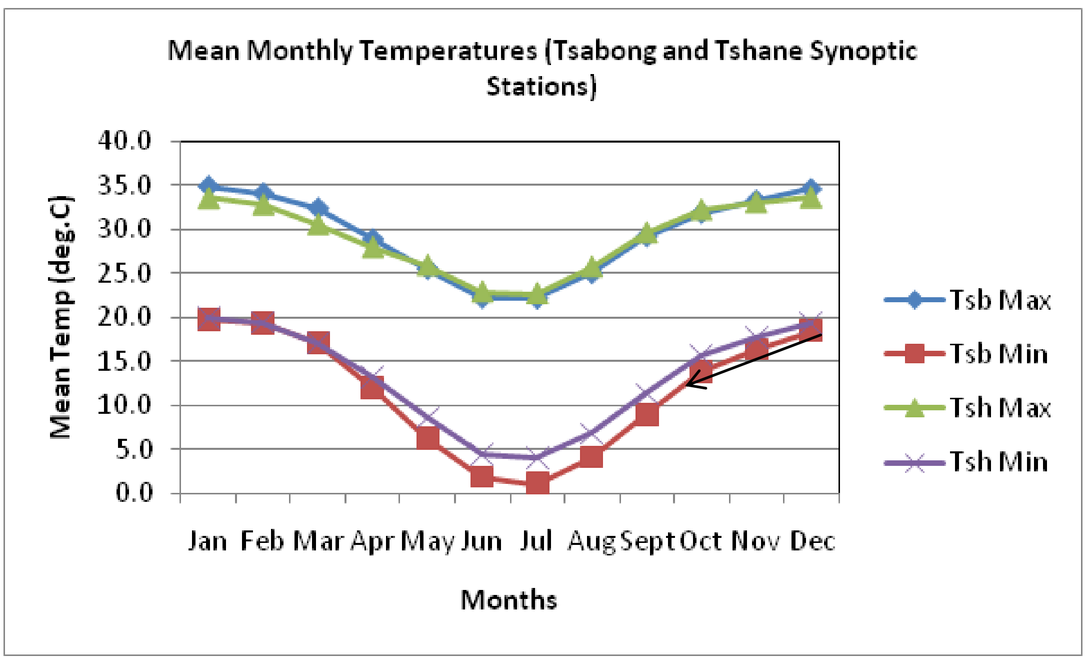


Figure 4: The mean monthly temperatures for KGN (Tshane) and KGS (Tsabong) for 1980 – 2016.

trends are difficult to detect as rainfall varies so much from place to place and year to year across the Southern Africa region.

Generally it is predicted that the Southern African region is experiencing a trend towards increasing mean annual temperatures (Mphale et al., 2018; Adedoyin and Mphale, 2014) and decrease in mean annual rainfall (Conway et al., 2015; Batisani and Yarnal, 2010). Cairns et al., (2013) and Davis (2011) mentioned that General Climate Models (GCMs), statistical downscaling and dynamical downscaling techniques

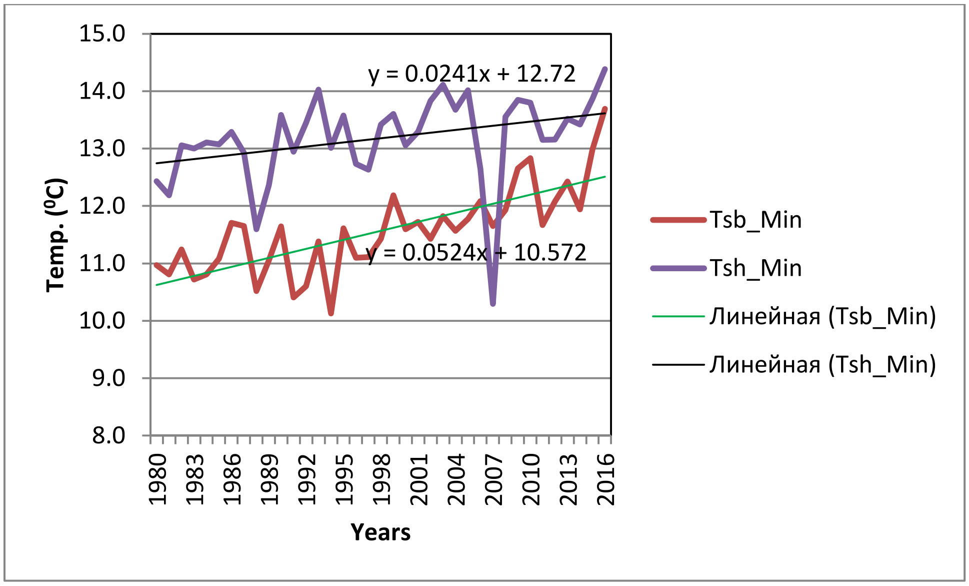


Figure 5: Trend in mean annual temperatures for Kgalagadi north (Tsh_Min) and Kgalagadi south (Tsb_Min) 1980 to 2016.

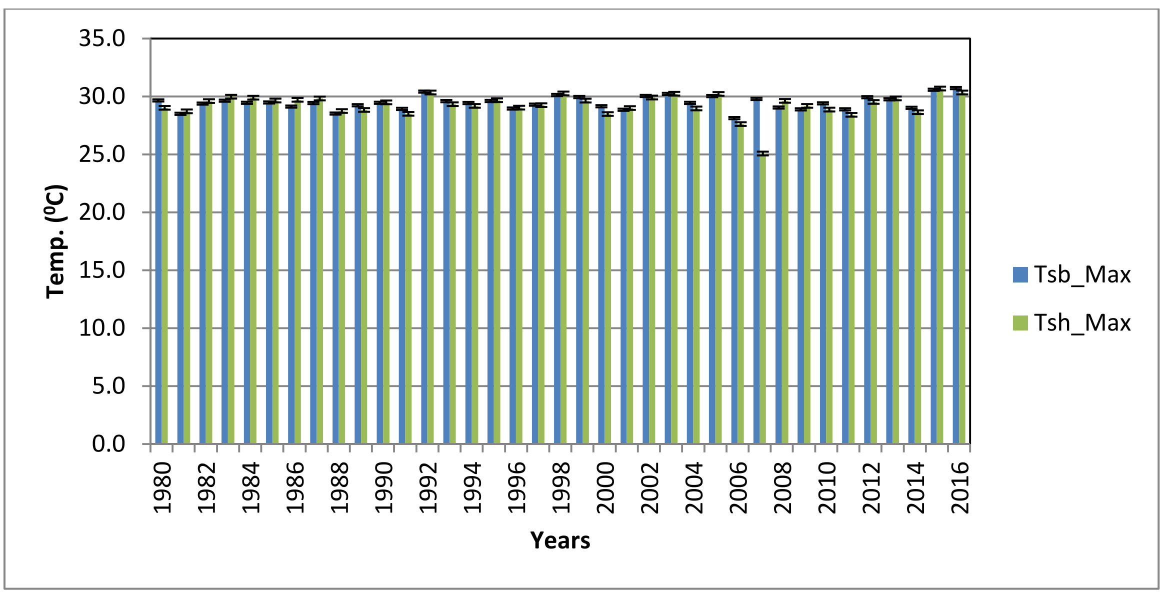
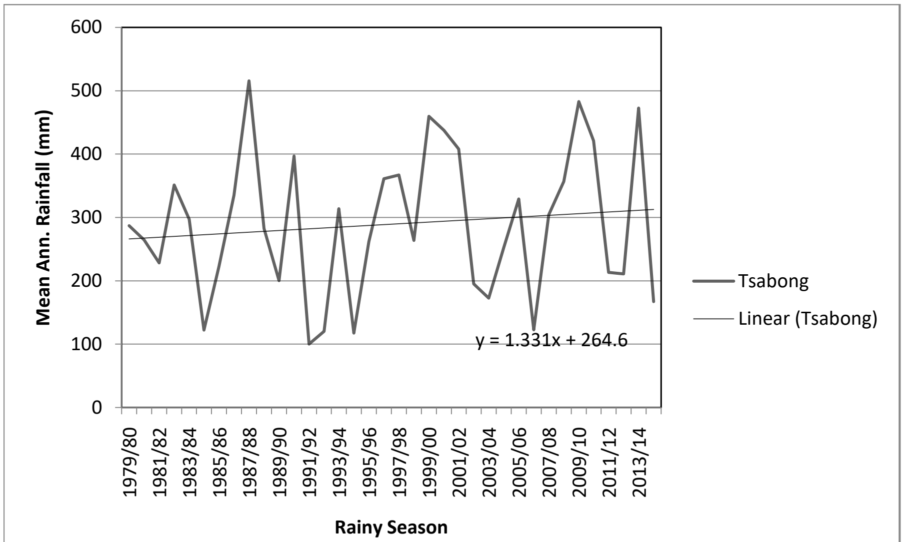
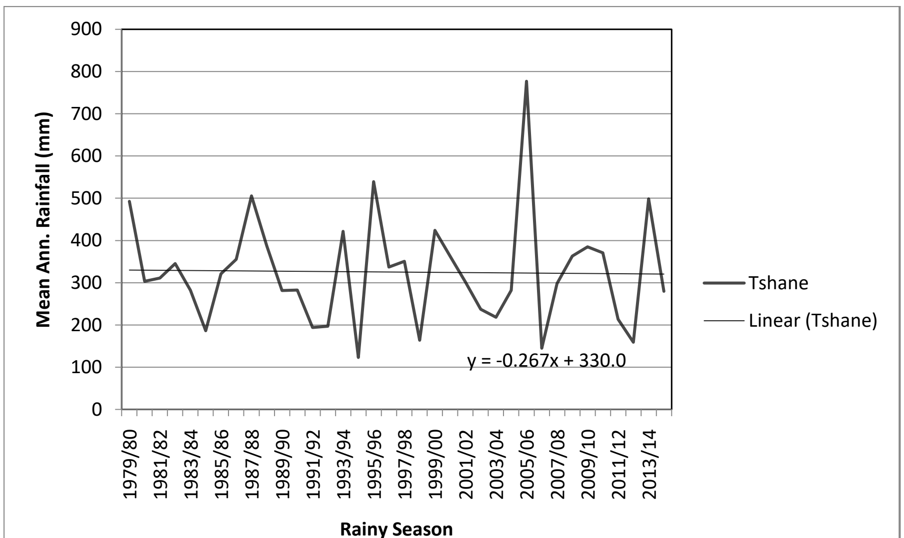


Figure 6: Mean maximum temperature trend (1980 to 2016) with standard error bars for Kgalagadi District recorded at Tsabong and Tshane synoptic stations.

all show an increase in projected temperature across Southern Africa. In contrast, other subtropical regions such as the Eastern Africa region are predicted to experience an increase in rainfall (Serdeczny et al., 2017 and Waha et al., 2013). As mentioned by Batjes (2011), drier and well-aerated soils promote more rapid decomposition and accumulation of less soil organic matter. Where soil O_2, soil moisture levels and nutrient status are sufficient, higher temperatures would accelerate biological processes such as biomass production, decomposition and mineralisation of carbon (Karmakar et al., 2016). Brevick (2013) explained that as CO_2 atmospheric enrichment increases due to increase in temperature, the soil C:N ratio, decomposing organisms in the soil need more N, which can reduce N mineralization. Hence plant-available N levels in the soil would be reduced and plant productivity negatively affected. The results of the analysis of rainfall and



7a

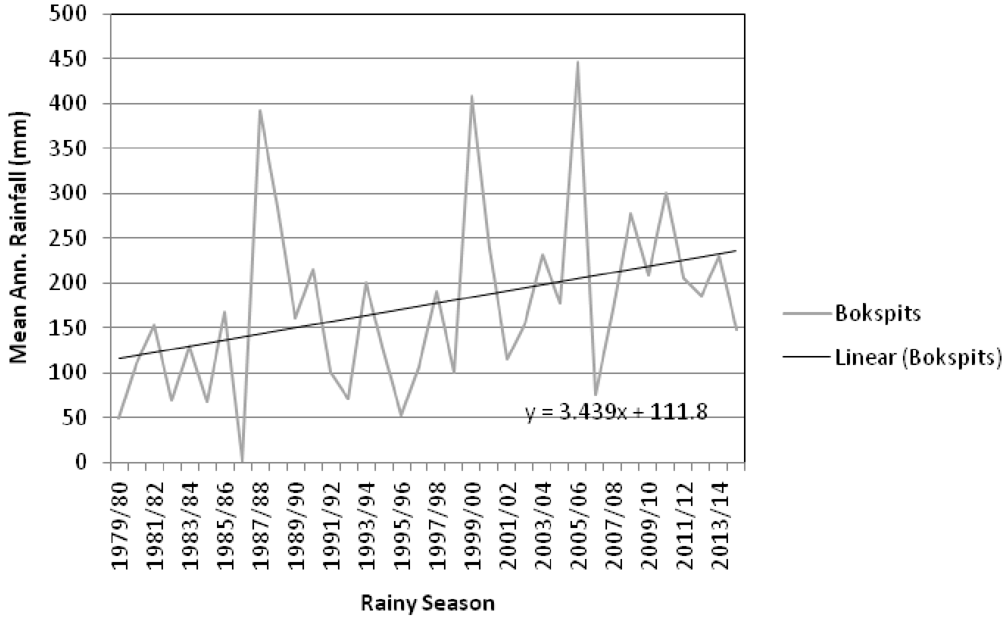


7b

temperature trends implies that with the indicated increase in temperature and increase or decrease in rainfall, soil CO_2 fluxes in the Southwestern Kalahari region would be affected. Kotroczo et al. (2014) explains that increase in temperature coupled with optimal soil moisture will enhance soil respiration.

3.2 Comparison of Wet and Dry Season Soil Carbon (CO_2) Emissions along the North-South Transect in Kgalagadi District

The data graphically presented in figure 8a and 8b designates the influence of rainfall on soil CO_2 emissions. The results indicate that soil CO_2 emissions during the wet season are significantly higher (at 95% confidence level) than in the dry season. The wet season emissions along 1 km transects radiating from livestock watering sites ranged from 64.50 to 1.25 µmol/m^2/s and 44.19 to 0.77 µmol/m^2/s in KGN and KGS respectively. In the dry season the emissions ranged from 4.72 to 0.46 µmol/m^2/s and 2.37 to 0.73 µmol/m^2/s for KGN and KGS respectively. It can also be realised that for both the wet and dry season periods the emissions dropped sharply from within the 10 m radius of the watering site to a 50 m radius and thereafter the emissions are significantly not different up to WMAs and the control (KTP). The same pattern



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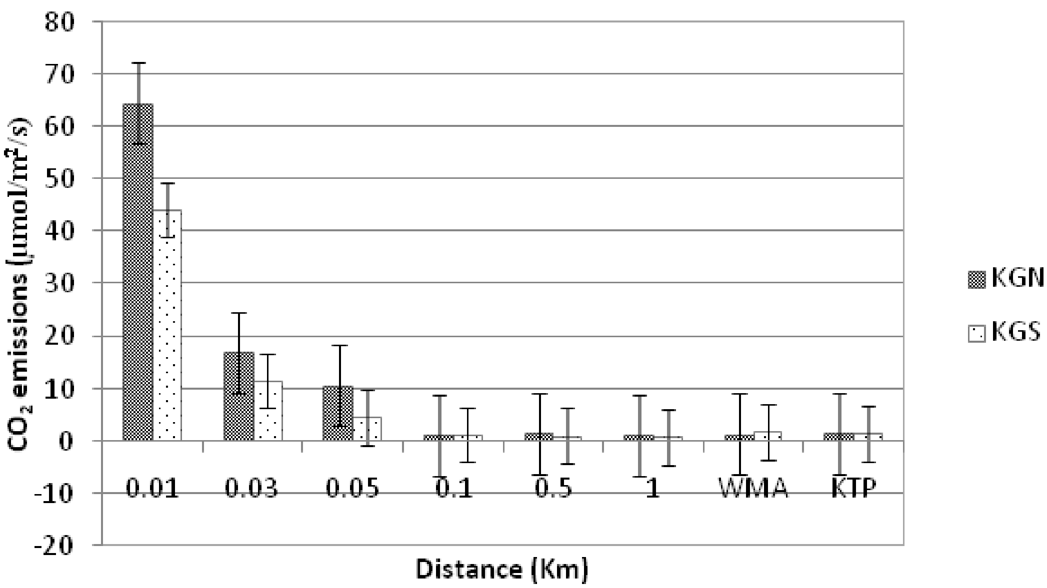


8a

was observed for both the wet and dry season soil CO_2 emissions.

Table 1 below indicates the actual rainfall, temperature and CO_2 fluxes values measured in WMAs and the control in the wet and dry season. Rainfall levels are cumulative amounts that were received in the previous ten days before CO_2 emission measurements were taken. The CO_2 emissions in the wet season are significantly high (at 95% confidence level)

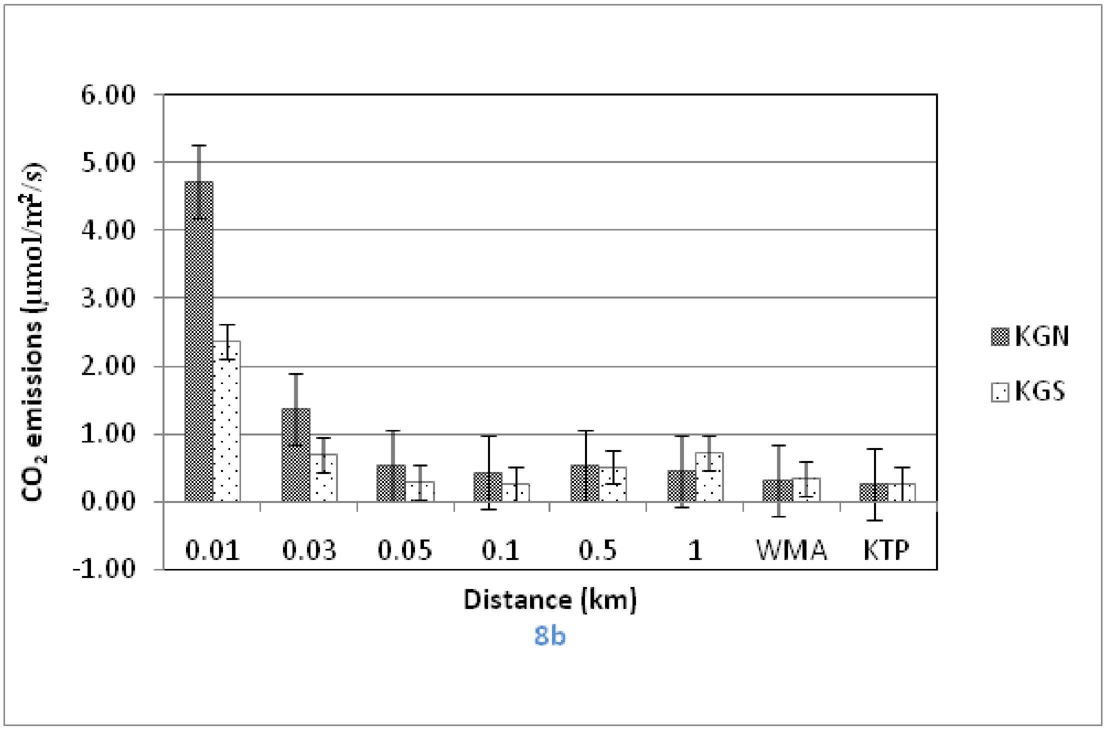


Figure 8 a and 8b: Wet (8a) and Dry (8b) CO2 emissions with standard error bars of means in WMAs, KTP and with distance from Livestock watering sites in KGN and KGS.

Table 1: Wet and dry season actual rainfall, temperature and CO_2 emission levels measured from WMAs and the control.

Sites	Wet Season			Dry Season		
	Temp. (^{0}C)	Rainfall (mm)	CO_2 flux (µmol/m^2/s)	Temp. (^{0}C)	Rainfall (mm)	CO_2 flux (µmol/m^2/s)
WMA_KGN	26.5	25.4	1.32	38.6	0.0	0.32
WMA_KGS	36.7	41.02	1.83	38.6	0.0	0.35
Control_KTP	33.9	20.0	1.49	32.5	0.0	0.26

than the dry season CO_2 emissions. The results designate that soil moisture is highly important in biogeochemical processes such as decomposition of organic matter particularly in dry areas (Haffman and Vogel, 2008) such as the southern Kalahari region. Dintwe and Okin (2018) and Wang et al., (2007) mentioned similar results that soil respiration increased with precipitation from their study of soil organic carbon in Kalahari ecosystem.

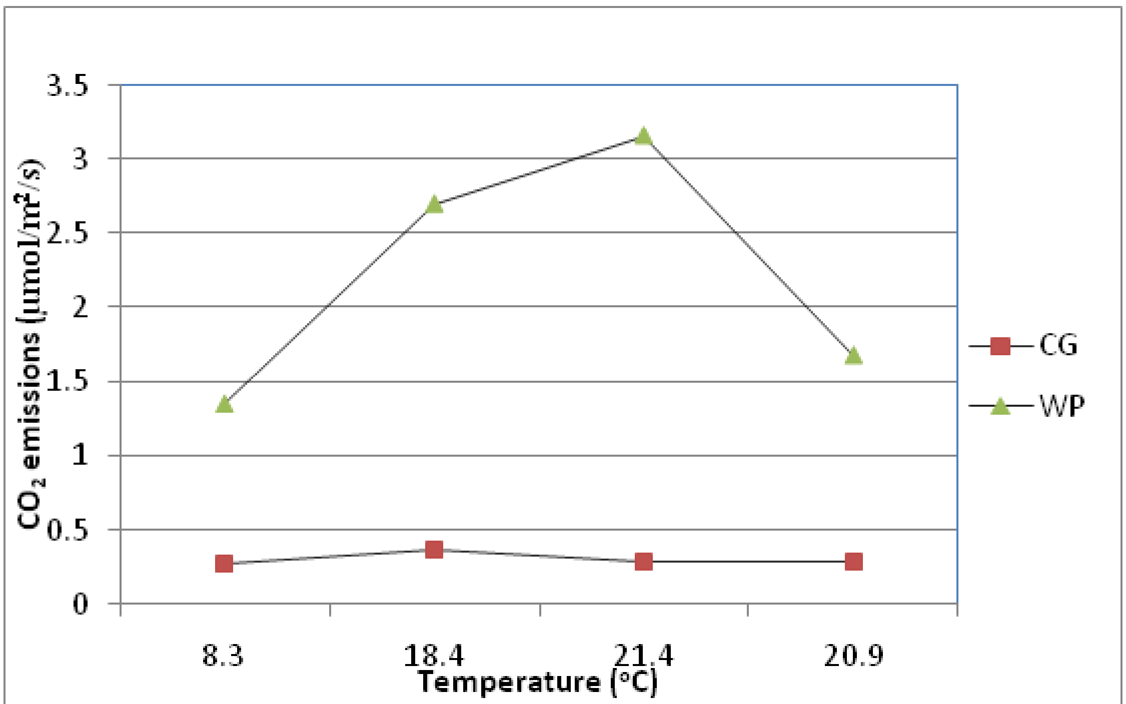
The wet and dry season results demonstrate that soil CO_2 emissions are strongly affected by soil moisture content, the drier the soil the less CO_2 emissions. This phenomenon as explained by Dilekoglu and Sakin, (2017), is due to the fact that when soil lacks moisture, carbon emissions are reduced because of lack of organic matter disintegration and decay, soil microorganisms and plant roots activities (Dintwe and Okin, 2018). Several studies (Dintwe and Okin, 2018; Dintwe et al., 2014; Thomas and Hoon, 2010; Haffman and Vogel, 2008; Thomas et al. 2008; Wang et al. 2007; Raich, 1992) on soil CO_2 emissions from the Kalahari savannas have also reported similar results that rainfall or soil moisture significantly increases CO_2 soil emissions. The scenario is further emphasised by Kurc and Small, (2007) that in arid and semi-arid ecosystems, soil moisture is expected to be the primary control on the exchanges of water and carbon between the land surface and atmosphere. They further explained that the interactions between carbon fluxes and soil moisture are fundamental characteristic of eco-hydrological processes.

Even though their study designs were constructed under simulated soil wetting and cynobacteria crusted soils environ-


9a

9b

Figure 9a and 9b: Livestock excrement accumulation in proximity to watering sites and loose eroded topsoil.



10a

ments, the results are of a similar trend as obtained in this study which was conducted under natural conditions (in situ) without manipulation of the soil environment.

Furthermore, the results indicate that land use or land management is one of the key variables in influencing soil carbon fluxes in the Kalahari. In close vicinity to the watering sites, that is within the 50 m radius there is high accumulation of cow dung and urine and also high soil erosion incident because of livestock sedentarism (Weber and Horst, 2011). This result in creation of vegetation bare areas referred to as “sacrifice zones” (Katjiua and Ward, 2012; Dougill and Thomas, 2004; Mphinyane, 2001) (Figure 9a and 9b). Large quantities of carbon accumulation in the form of cow dung and soil erosion enhances CO_2 emission as explained by Jiang et al., (2012) and Kizza and Areola, (2010). In this study the scenario can be realised by the significantly high CO_2 emissions within the 50 m radius of the watering site.

Although in this study the effect of temperature and moisture or a combination of the two is not explicitly revealed, analysed data elaborates that the two coupled with land use could be the major abiotic factors determining soil respiration in the Kalahari ecosystem (Asensio et al., 2007; Li et al., 2006). Across the Kgalagadi region temperature intensity is almost the same. This translates to suggest that soil moisture

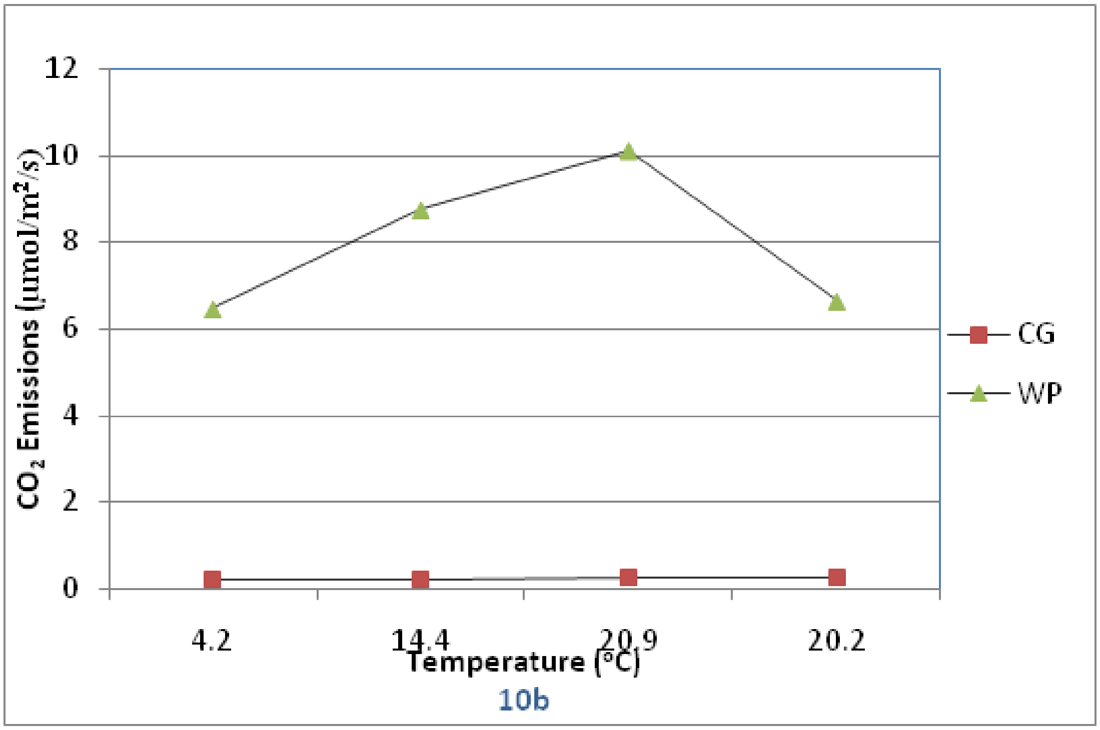


Figure10a and 10b: Effect of diurnal temperature on soil CO2 emissions from livestock concentration areas and grazing areas in KGN (10a) and KGS (10b) respectively.

and land use intensity would bring the difference in CO_2 emissions between KGN and KGS.

3.3 Analysis of Soil Carbon (CO_2) Emissions in Response to Diurnal Temperature Variations

The effect of diurnal temperature on soil carbon emissions is illustrated in figure 10a and 10b. The results indicate that emissions from livestock concentrations areas (watering points) are significantly higher than those from grazing areas. In livestock concentration areas CO_2 emissions increased significantly ($p < 0.05$) from morning (0800hrs) to afternoon (1400hrs) and then significantly declined in the evening (1800hrs). The emissions increased from 1.35 to 3.16 µmol/m^2/s (134% increase) and dropped to 1.68 µmol/m^2/s (47% decrease) in KGN and in KGS CO_2 emissions increased from 6.46 to 10.12µmol/m^2/s(56.7% increase) and dropped to 6.64 µmol/m^2/s (34.4% decrease). The results indicate that temperature increase leads to an increase in CO_2 emissions and this can be accelerated by land use activities.

The results further indicated that in both KGN and KGS communal grazing areas, temperature had little or no effect on soil carbon emissions. This could mean that with optimal land use or well managed grazing, the system allows organic manure containing carbon to re-enter the soil promoting increased plant growth and carbon sequestration (Climatenexus, 2017; Mcsherry and Ritchie, 2013). The emissions ranged from 0.27 to 0.37 µmol/m^2/s (mean 0.30 µmol/m^2/s)and 0.21 to 0.25 µmol/m^2/s(mean 0.23 µmol/m^2/s) in KGN and KGS respectively. CO_2 emissions in KGN are higher than in KGS and the variation is statistically different ($p<0.05$).

High CO_2 emissions in proximity to livestock watering sites are anticipated to be due to cow dung and urine accumulation which translates to high soil organic carbon storage (Wang et al., 2016). Soils around these areas are highly degraded, no herbaceous vegetation cover. The top soil is very loose and remains bare throughout the year due to continuous livestock sedentarism and trampling. Jiang et al., (2012) in their study on contribution of urine and dung to carbon dioxide fluxes, found that urine and dung significantly increase carbon dioxide and other greenhouse gases emissions, a phenomenon realised in this study with CO_2 emissions.

4.0 CONCLUSION

The south western part of Botswana, the Kgalagadi district is experiencing the impact of climate change and variability. The rainfall and temperature patterns are changing towards the worst scenarios even though it was not clearly expressed in this study. Like the rest of the region mean annual temperatures are rising and the rainfall especially in the extreme southern part of the study area is showing a tendency

towards an increase or the area is becoming wetter. The mean annual maximum temperatures trends from both the northern and southern parts of the Kgalagadi region do not indicate any signs of increase or decrease. However, for the whole region the mean annual minimum temperatures indicated a trend towards an increasing intensity.
Temperature and rainfall are the major factors affecting soil carbon emissions in the Kalahari ecosystem. However, it was not explicitly possible with data collected in this study to separate between the two meteorological variables, that which one is more significant than the other in affecting soil carbon fluxes. The two meteorological parameters have an effect on the decomposition of organic carbon, mineralisation of carbon and increase or decrease in microbiological activity: processes that determine CO_2 release from the soil. An important observation made from the results of this study is that land use and land management activities are very essential in influencing soil carbon fluxes. Areas inundated with livestock and degraded emit significantly high volumes of soil CO_2 compared to sparsely grazed, wildlife management areas and protected areas (virgin land).

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